GEM TN-92-123
Rev. A

Studies of LSDT's in a Magnetic Field

A. Korytov, G. D. Ross, J. Sears, F. E. Taylor
Massachusetts Institute of Technology

September 30, 1992

Abstract:

We performed a series of experiments upon a model drift chamber to study the sensitivities of observed electron drift times to the magnitude and direction of an externally applied, homogenous magnetic field, and to the strength of the electric field within the chamber. These experiments were conducted for the separate chamber gas mixtures Argon:Isobutane::1:3, Argon:Carbon Dioxide:Isobutane:: 2.5%:88.0%:9.5%, and Carbon Tetrafluoride:Carbon Dioxide:Isobutane:: 69%:20%:11%. We found the spatial resolution within the chamber to be degraded by the Lorentz Angle Effect to between 5 and 15 μm for each of these mixtures. Only the Argon:Carbon Dioxide:Isobutane mixture displayed a significant response to a change in the strength of the electric field within the chamber.

GEM Muon Note
TN-92-123

Studies of LSDT's in a Magnetic Field

J. Sears, A. Korytov, G.D. Ross, F. E. Taylor
Massachusetts Institute of Technology

September 30, 1992

Abstract

We performed a series of experiments upon a model drift chamber to study the sensitivities of observed electron drift times to the magnitude and direction of an externally applied, homogenous magnetic field, and to the strength of the electric field within the chamber. These experiments were conducted for the separate chamber gas mixtures Argon:Isobutane::1:3, Argon:Carbon Dioxide:Isobutane::2.5%:88.0%:9.5%, and Carbon Tetrafluoride:Carbon Dioxide:Isobutane::69%:20%:11%. We found the spatial resolution within the chamber to be degraded by the Lorentz Angle Effect to between 5 and 15 μm for each of these mixtures. Only the Argon:Carbon Dioxide:Isobutane mixture displayed a significant response to a change in the strength of the electric field within the chamber.

I. Introduction

The objectives of these experiments were to investigate the behaviors of the electron drift times observed in our model drift chamber under the influence of various conditions. Our principal concern was to evaluate quantitatively the influence of the Lorentz Angle Effect upon the chamber resolution in the presence of an external magnetic field. We also determined the sensitivity of the resolution to the strength of the electric field within the chamber. These experiments were conducted for three different chamber gas mixtures, as listed in Table 1, in an attempt to find a satisfactory, non-flammable alternative to the standard mixture Argon:Isobutane::1:3.

The primary resolution of each gas mixture was manifested by the spatial resolution R within the chamber and the changes ΔT_{drift} in the electron drift times observed under alternating field conditions.

II. Experimental Procedure and Analysis

Our basic experimental arrangement consisted of a near-diffraction, 337 nm wavelength nitrogen laser aligned with a rectangular, aluminum, single 100 μm copper-beryllium wire drift chamber (placed between the poles of a cyclotron), and an organic scintillator. Under this configuration, laser photons incident upon the chamber gas mixture induced electron avalanches which drifted towards the chamber's anode as the laser photon traveled to the scintillator. We were able to obtain a measure of the avalanche's drift time to the anode by analyzing the pulses from the anode and the scintillator in a simple NIM circuit, illustrated in Figure X1.

The magnetic field in these experiments was generated in the gap between the pole pieces of the MIT cyclotron. The chamber anode wire was aligned alternately parallel and perpendicular to the direction of the field to study the TPC effect.

The concentrations of the chamber gases were regulated by a mass flow meter.

In order to improve the statistics of true ionization of the gas mixture by successive laser pulses (resulting in unphysical drift times), we characterized our sets of observed drift times by the means and standard deviations of Gaussian curve fits. We defined the ΔT_{drift} time as the difference between the Gaussian mean drift times observed under alternate field conditions, e.g. drift time under magnetic field less drift time in absence of field. We determined the spatial

resolution R as the product of the drift velocity (derived from the Gaussian means) and the Gaussian standard deviations. However, we determined the random error in the Gaussian mean drift times in the usual manner, as the standard deviation divided by the square root of the number of events. For a more thorough discussion of the error inherent in the resolution due to measurement uncertainty in the magnitude of the applied magnetic field, refer to Appendix I.

III. Response of the Chamber Gas Mixtures to the Magnitude of Anode High Voltage

A. As expressed by Sauli [1], the electron drift velocity in the absence of an externally applied magnetic field is directly proportional to the product of the electric field strength and the mean time between collisions with the molecules in the gas mixture. Figure X2 displays a typical plot of the drift velocities derived for our chamber under a gas mixture of Argon:Isobutane::1:3 at a variety of anode high voltage settings. At the relatively weak electric field strengths corresponding to the laser-anode separations of $\pm$ 4mm, the drift velocity increased with increasing electric field, indicating that these separations were beyond the region of saturation. At smaller laser-wire separations, however, the drift velocity remained approximately constant, which is characteristic of a saturated gas mixture. Given that each of our gas mixtures' derived drift velocity curves varied in this typical manner, we expected the observed ΔT_{drift} as functions of the anode high voltage setting to be relatively constant within the saturation region close to the wire, and to increase in a uniform manner beyond the region of saturation, to the edge of the chamber wall.

B. Observations

(1) Argon:Isobutane::1:3 (Figures X3 to X5)

The drift times T_{drift} at 5.20 and 5.56 kV varied linearly with laser-wire separation and were symmetric about the position of the anode wire, a consequence of the physical symmetry of the chamber about this axis.

The ΔT_{drift} times were generally constant within the region of saturation, and increased parabolically to between 6 and 8 ns at the edges of the chamber.

The spatial resolution R varied in the expected manner, increasing

uniformly to between 90 and 100 μm at the chamber walls.

(2) Argon:Carbon Dioxide:Isobutane::2.5%:88%:9.5% (Figures X6 and X7)
The difference in the ΔT_{drift} times observed for 5.30 and 5.50 kV ranged from 5 ns near the wire to as much as 25 ns at the wall.

The spatial resolution did not follow the predicted behavior, remaining a level 40 μm over the interior of the chamber, with only a slight increase at large separations. The unusually poor resolutions close to the wire were direct consequences of the ohmic nature of this gas.

(3) Carbon Tetrafluoride:Carbon Dioxide:Isobutane::69%:20%11% (Figures X8 and X9)
The ΔT_{drift} times varied in the familiar manner to between 2.0 ns at 5.40 kV and 5.5 ns at 5.30 kV.

The spatial resolution at 5.40 kV was erratic and inconsistent near the wire.

IV. Response of the Gas Mixtures to the Lorentz Angle Effect

A. A primary objective of these experiments was to evaluate the magnitude of the Lorentz Angle Effect upon the spatial resolution within our chamber under an applied magnetic field. In the absence of a magnetic field, an electron in a typical drift chamber drifts toward the anode along the direction of the electric field's lines of force. This trajectory is significantly altered in the presence of a magnetic field, however, due to the influence of the Lorentz ExB deflection force. As explained by Sauli [2], this deflecting force causes the electrons to drift at an angle α to the electric field lines, where α is dependent upon parameters describing the gas mixture and the electric field. We studied the influence of this effect upon the spatial resolution observed within each of our three gas mixtures.

B. Observations

(1) Argon:Isobutane::1:3 (Figures X10 and X11)
The ΔT_{drift} times and the spatial resolution varied in the predicted manner and were symmetric about the axis of the wire.

The resolution for B = 0.8 T increased to between 105 and 115 μm at the chamber walls.

(2) Argon:Carbon Dioxide:Isobutane::2.5%:88.0%:9.5% (Figures X12 to X14)
The spatial resolution at 0.8 T remained a level 40 μm over most of the width of the chamber, excepting a small increase to 60 μm at the wall and the wire.

The resolution (at a fixed laser-wire separation) varied in a gradually linear manner with increasing strength of the magnetic field, increasing only 6 μm over a field range of 1.0 T.

(3) Carbon Tetrafluoride:Carbon Dioxide:Isobutane::69%:20%:11% (Figures X15 and X16)
The inconsistent spatial resolution for B = 0.8 T at small laser wire separations exhibited the limitations of the experiment's electronics.

V. Conclusions

We conducted these experiments in order to determine if either of our three gas mixtures could become a suitable alternative to the standard Argon:Isobutane::1:3 drift chamber mixture. Toward this end, we investigated the responses of the electron drift times observed for each of our alternative mixtures to the strength of the electric field within our model drift chamber, and to the magnitude and direction of an applied magnetic field. In summary, then, we concluded the following.

(1) Neither Argon:Isobutane::1:3 nor CF_4:CO_2:C_4H_{10}::69%:20%:11% showed a significant sensitivity to the magnitude of the anode high voltage setting. However, Ar:CO_2:C_4H_{10}::2.5%:88.0%:9.5% did show a marked response to even a small (0.10 kV) change in the high voltage setting. The difference in the ΔT_{drift} times at the edge of the chamber was 25 ns.

(2) The Lorentz Angle Effect degraded the spatial resolution to between 5 and15 μm, at the chamber wall, for a magnetic field of 0.8 T, independent of the gas mixture.

(3) The spatial resolution varied in a gradually linear fashion with increasing magnetic field for Ar:CO_2:C_4H_{10}::2.5%:88.0%:9.5%. The slope of the increase was approximately 6 μm/ 1.0 T .

We conclude upon this basis that perfluoroalkane mixtures in general, like CF_4:CO_2:C_4H_{10}::69%:20%:11%, will provide the most promising sources for future investigations. Our perfluoroalkane mixture, although much less flammable than the standard Argon:Isobutane::1:3, had a satisfactory resolution as well as drift

times adequate to trigger effectively other components of the GEM muondetector system. We therefore propose further experimentation upon our carbon tetrafluoride mixture, as well as upon other mixtures using heavier perfluroalkanes.

Appendix I
Evaluation of the Resolution Error due to Uncertainty in the Magnetic Field

An important evaluation of error is the determination of the sensitivity of the spatial resolution within the chamber to the magnitude and direction of the applied magnetic field. Standard manipulation of the kinematic description of electron drift, $d = v(B) \times T$, under the assumption of a linear relationship between the strength of the applied magnetic field and the Lorentz Angle Effect, results in an expression for the accuracy of the spatial resolution δd given by $\delta d = v(B)\ [\Delta T\ (\delta B/B) + \delta T]$. With respect to the two contributions to δd, the uncertainty δT in the measurement of the drift times is negligible in comparison to the uncertainty δB in the measurement of the magnetic field strength. In the worst case scenario when the electron drift is far from the anode wire, the ΔT drift time was found to be on the order of 10 ns. Taking the drift velocity to be 50 μm/ns, and keeping the Lorentz Angle Effect to be less than10 μm requires a measurement of the magnetic field strength to better than 2 % accuracy. This accuracy in the magnetic field measurement is not difficult to obtain.

Appendix II
Investigation of the TPC Effect in Argon:Isobutane::1:3

In a final set of investigations upon the standard Argon:Isobutane mixture, we measured the chamber's spatial resolution as a function of the strength and direction of the external magnetic field. According to the TPC effect, an electron drifting in a chamber in which the electric field and magnetic field are approximately parallel follows a tight, spiral trajectory about the magnetic field lines, into the conducting wire. The character of this trajectory would reduce effectively the usual dispersion in the paths followed by electrons drifting either in the presence of an external magnetic field perpendicular to the chamber's electric field, or in the complete absence of any magnetic field. We thus expected the spatial resolution observed with the applied magnetic field parallel to the wire, and perpendicular to the drift, to improve quantitatively after rotating the chamber to make the field perpendicular to the wire, and parallel to the drift.

This prediction was fulfilled as can be seen in Figure X17, a plot of the spatial resolution recorded at a fixed laser-wire separation as a function of the magnetic field strength for the field lines alternately parallel to the wire and parallel to the electron drift. The resolution with the field lines parallel to the wire increased from nearly 35 μm in the absence of the field, to almost 45 μm at a field strength of 1.0 T. However, the resolution observed with the field parallel to the drift decreased from approximately 38 μm to 25 μm over the same range of field strengths, providing quantitative support for our prediction. The magnitude of the TPC effect, then, appeared to be an average of 10 μm over a range of 1.0 Teslas.

References

[1] F. Sauli, Principles of Operation of Multiwire Proportional and Drift Chambers, Cern 77-09, 3 May 1977, p. 22.

[2] *Ibid.*, p. 31.

Figures

Table 1. Compositions of the chamber mixtures
Figure X1. Schematic of NIM circuit used to record drift times.
Figure X2. Drift velocity versus the strength of the electric field inside the chamber, Argon:Isobutane.
Figure X3. Gaussian mean drift times versus laser-wire separation distance, Argon:Isobutane, 5.56 and 5.20 kV.
Figure X4. Effect of anode high voltage, Argon:Isobutane.
Figure X5. Spatial resolution, Argon:Isobutane, 5.56 kV.
Figure X6. Effect of anode high voltage, Argon:Carbon Dioxide:Isobutane.
Figure X7. Spatial resolution, Argon:Carbon Dioxide:Isobutane, 5.50 kV.
Figure X8. Effect of anode high voltage, Carbon Tetrafluoride:Carbon Dioxide:Isobutane.
Figure X9. Spatial resolution, Carbon Tetrafluoride:Carbon Dioxide:Isobutane, 5.40 kV.
Figure X10. Lorentz Angle Effect, Argon:Isobutane, 0.8 T, 5.56 kV.
Figure X11. Spatial resolution, Argon:Isobutane, 0.8 T, 5.56 kV.
Figure X12. Lorentz Angle Effect, Argon:Carbon Dioxide:Isobutane, 0.8 T, 5.30 kV.
Figure X13. Spatial resolution, Argon:Carbon Dioxide:Isobutane, 0.8 T, 5.30 kV.
Figure X14. Spatial resolution, Argon:Carbon Dioxide:Isobutane, 5.30 kV, as a function of the strength of the applied magnetic field.
Figure X15. Lorentz Angle Effect, Carbon Tetrafluoride:Carbon Dioxide:Isobutane, 0.8 T, 5.40 kV.
Figure X16. Spatial resolution, Carbon Tetrafluoride:Carbon Dioxide:Isobutane, 0.8 T, 5.40 kV.
Figure X17. Spatial resolution, Argon:Isobutane, 5.40 kV, as a function of both the strength and direction of the applied magnetic field.

Table 1. Compositions of the chamber mixtures.

(1) Argon:Isobutane::1:3
(2) Argon:Carbon Dioxide:Isobutane::2.5%::88.0%:9.5%
(3) Carbon Tetrafluoride:Carbon Dioxide:Isobutane::69%:20%:11%

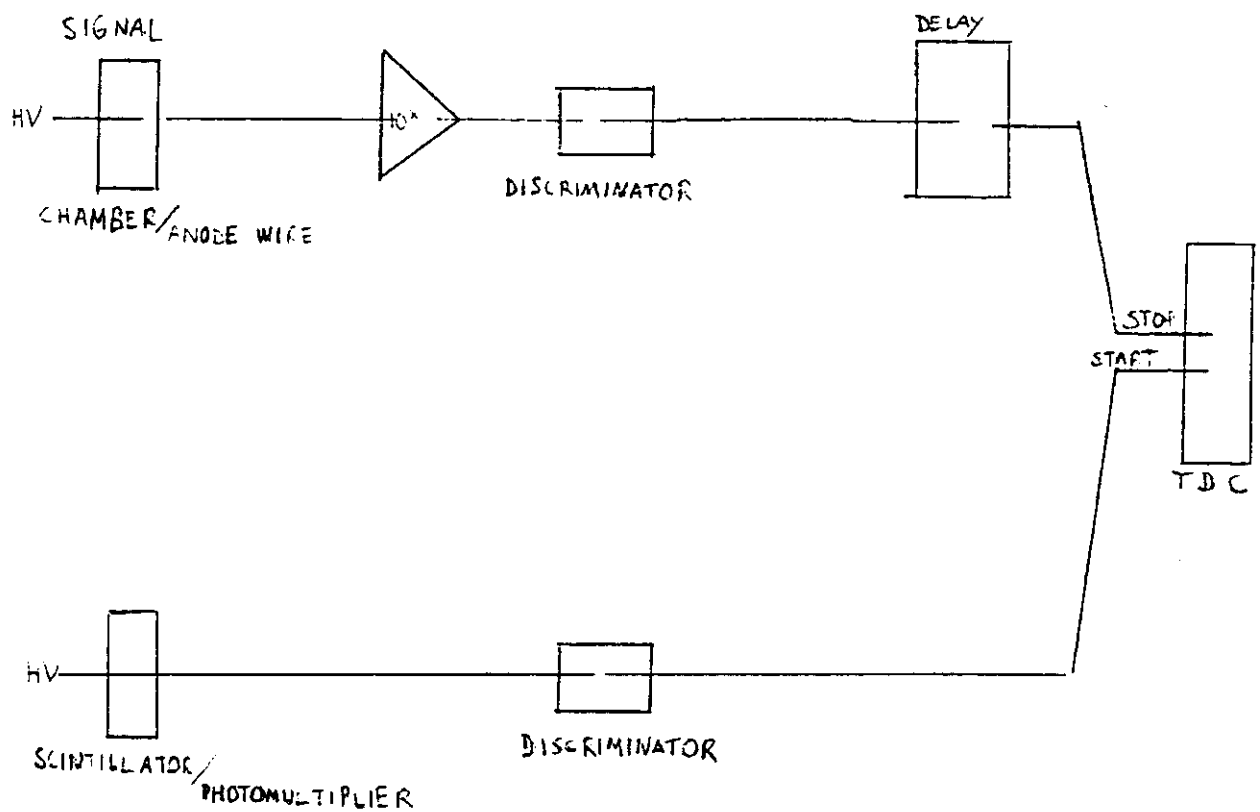

Figure X1. Schematic of NIM circuit used to record drift times.

Figure X2. Plot of the drift velocity in μm/ns versus the strength of the electric field inside the chamber in kV/cm.

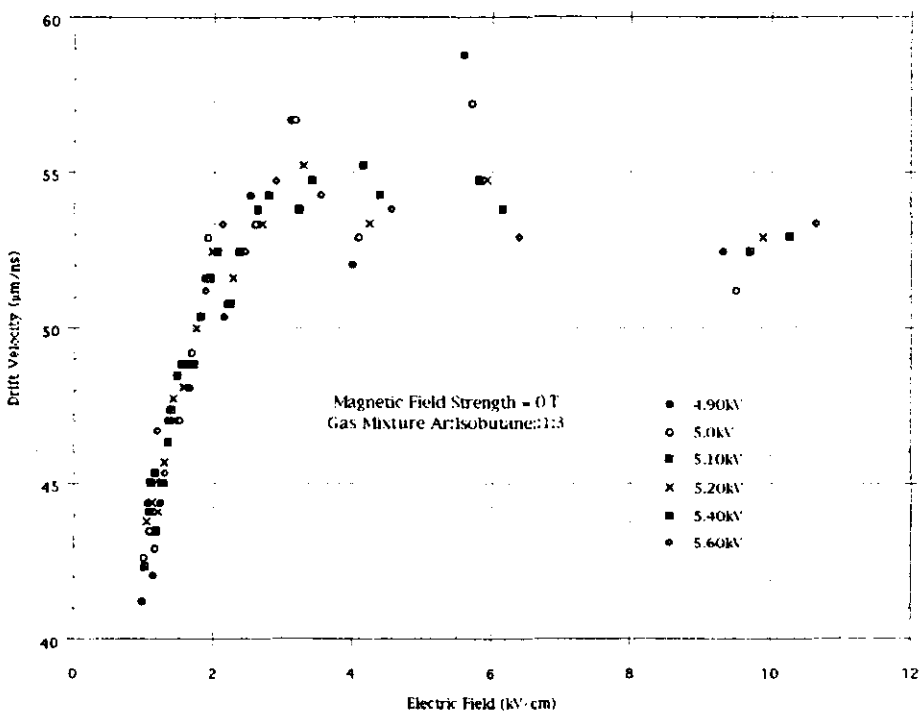

Figure X3. Plot of Gaussian Mean Drift Times (ns) versus the distance between the laser beam and the wire (mm).
Magnetic Field Strength = 0 T
Gas Mixture Argon:Isobutane::1:3

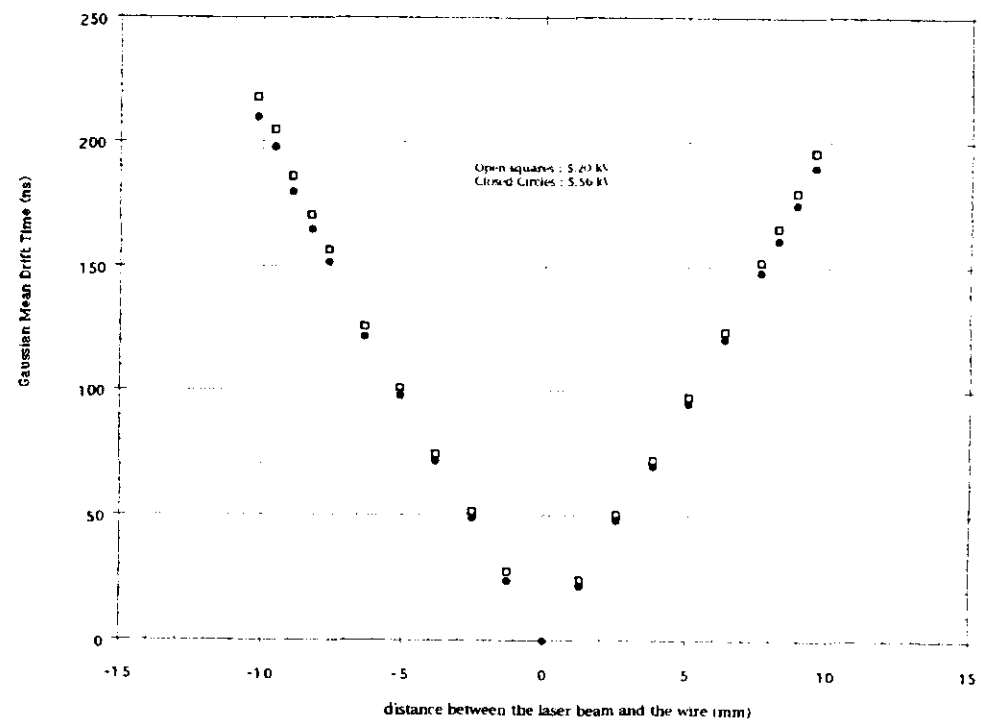

Figure X4. Plot of the Δ drift time (ns) versus the distance between the laser beam and the wire (mm).
Δ drift time = Gaussian Mean drift time (5.20kV) - Gaussian Mean drift time (5.56kV).

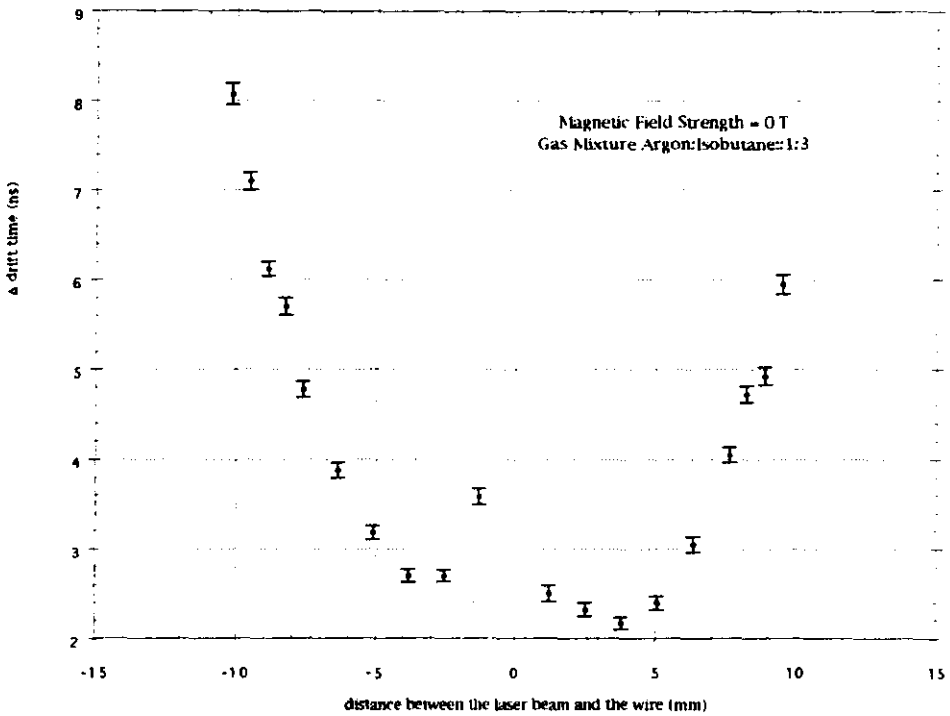

Figure X5. Plot of the spatial resolution in microns versus the distance between the laser beam and the wire.

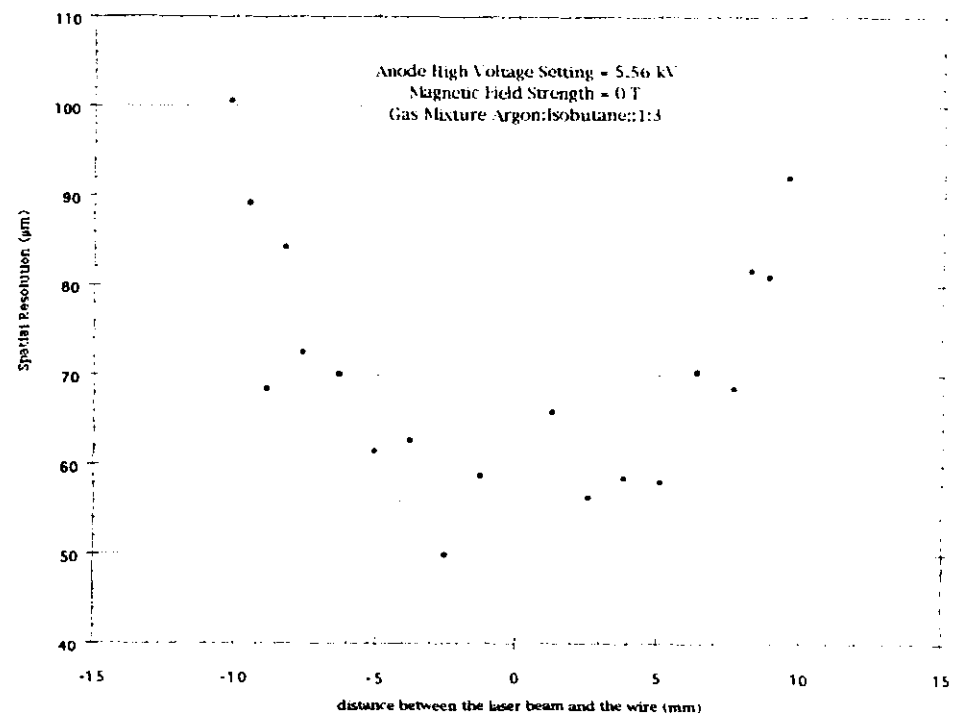

Figure X6. Plot of the Δdrift time (ns) versus the distance between the laser beam and the wire (mm).
Reference Anode High Voltage 5.70kV
Test Anode High Voltages 5.30 and 5.50kV

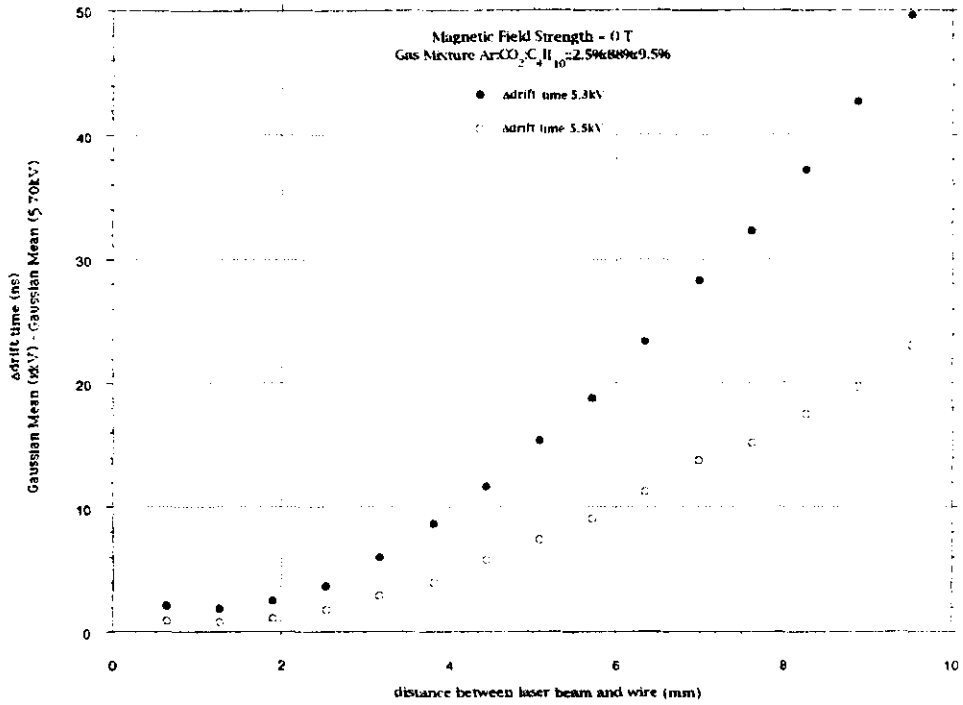

Figure X7. Plot of the spatial resolution in μm versus the distance between the laser beam and the wire.

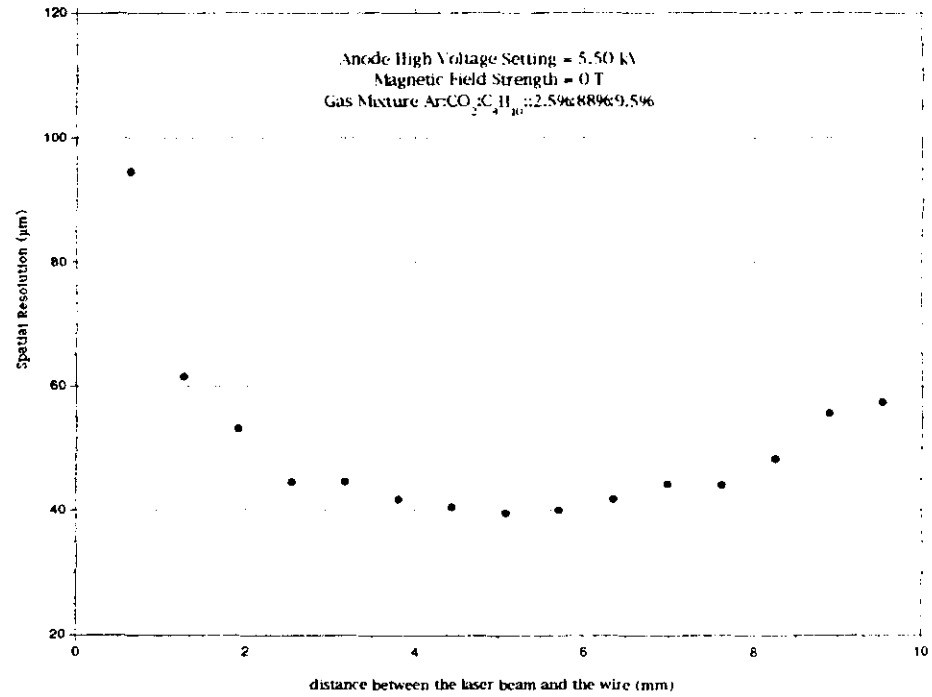

Figure X8. Plot of Δ drift time (ns) versus the distance between the laser beam and the wire (mm)
Reference Anode High Voltage 5.50kV
Test Anode High Voltages 5.30 and 5.40kV

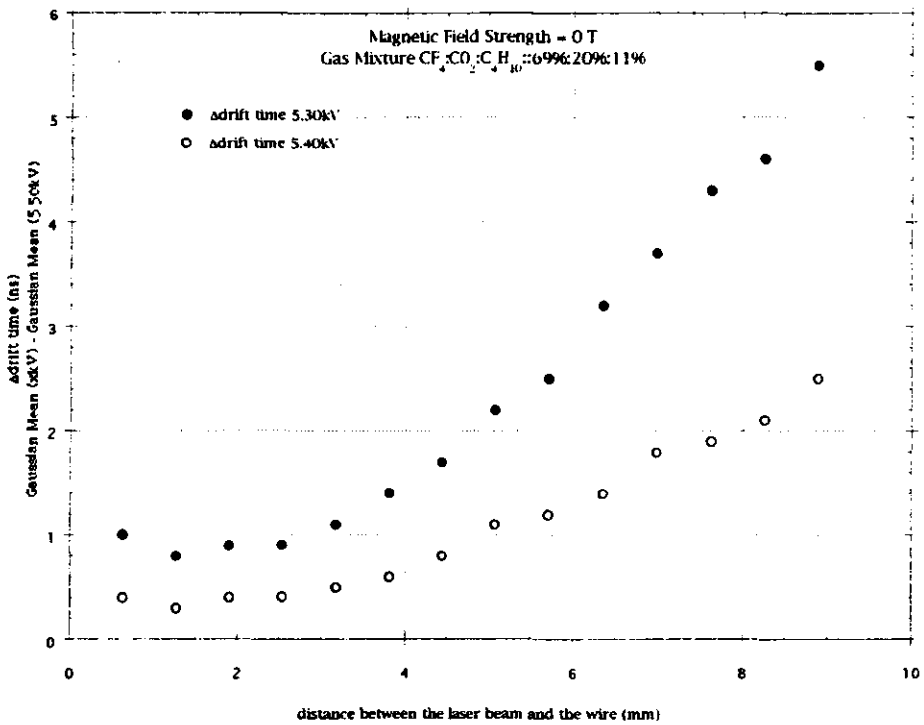

Figure X9. Plot of the spatial resolution in μm versus the distance between the laser beam and the wire.
Anode High Voltage Setting = 5.40 kV
Magnetic Field Strength = 0 T

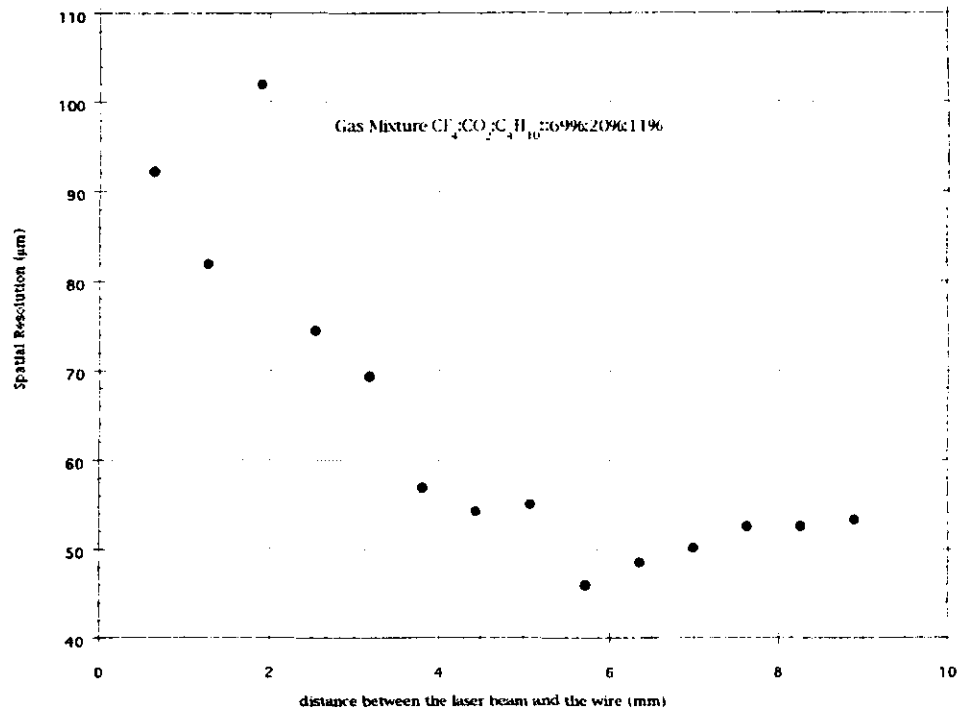

Figure X10. Plot of the Δ drift time in nanoseconds versus the distance between the laser beam and the wire.
Δ drift time = Gaussian mean drift time (B=0.8T) - Gaussian mean drift time (B=0T).

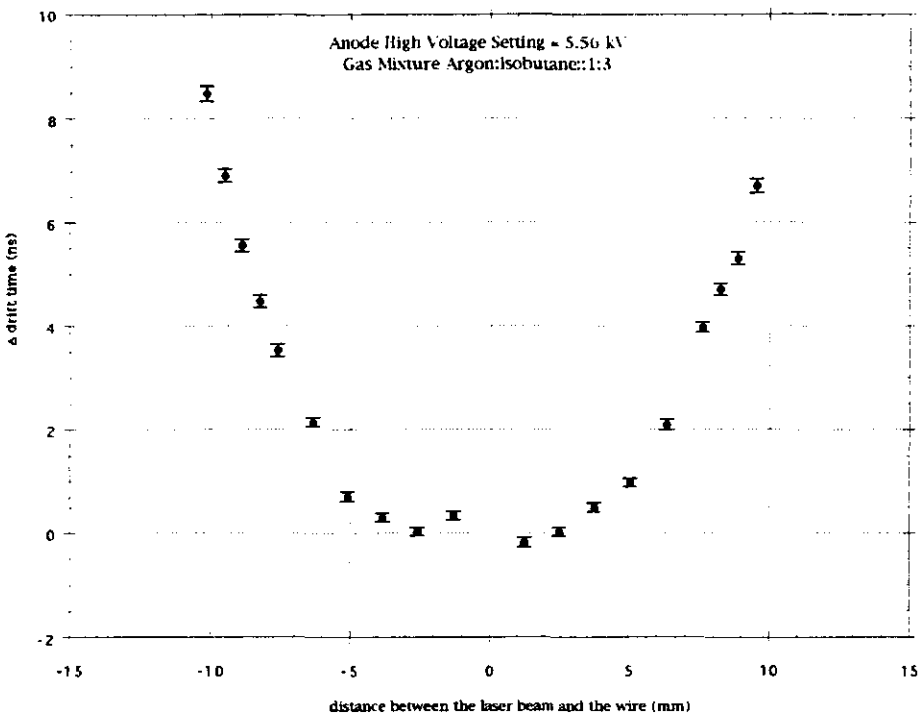

Figure X11. Plot of the spatial resolution in μm versus the distance between the laser beam and the wire.
Anode High Voltage Setting = 5.56 kV
Magnetic Field Strength = 0.8 T

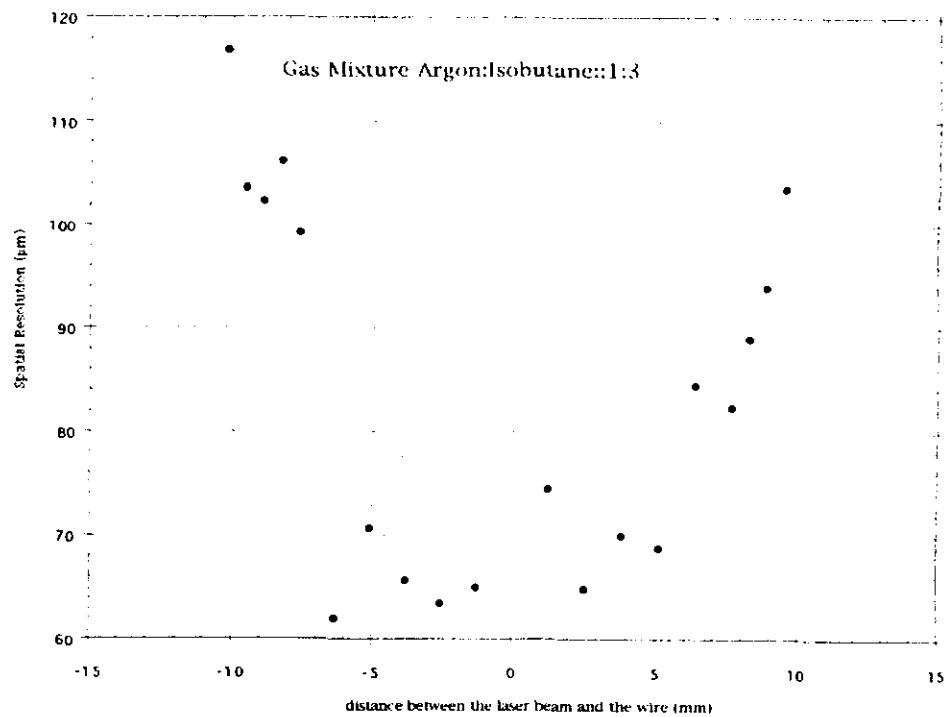

Figure X12. Plot of the Δ drift time in nanoseconds versus the distance between the laser beam and the wire. Δ drift time = Gaussian mean drift time (B=0.8T) - Gaussian Mean Drift Time (B=0T).

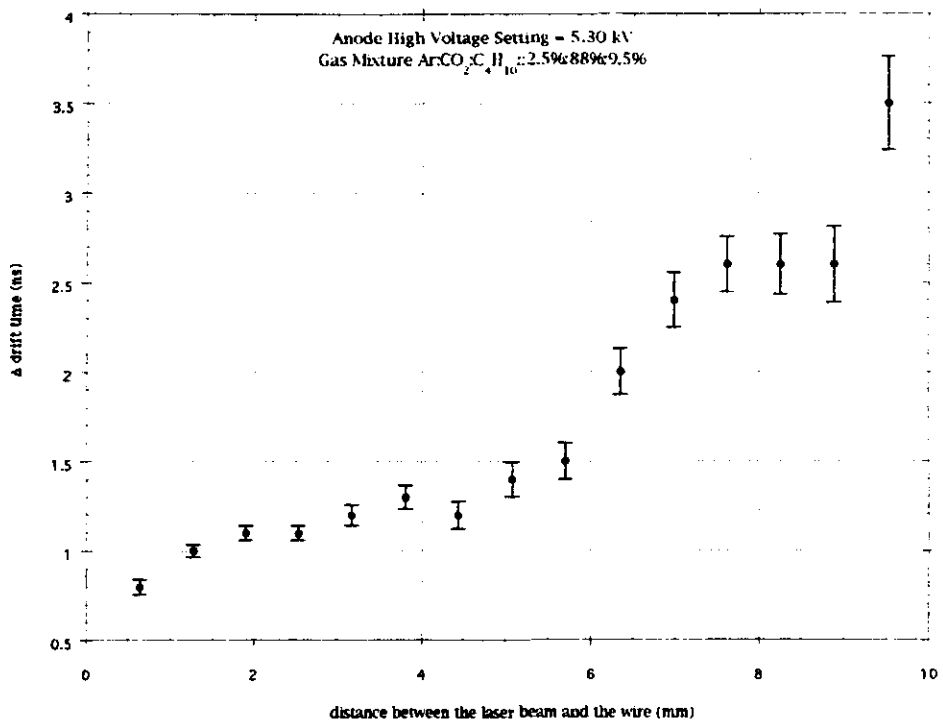

Figure X13. Plot of the spatial resolution in microns versus the distance between the laser beam and the wire.
Anode High Voltage Setting = 5.30 kV
Magnetic Field Strength = 0.8 T

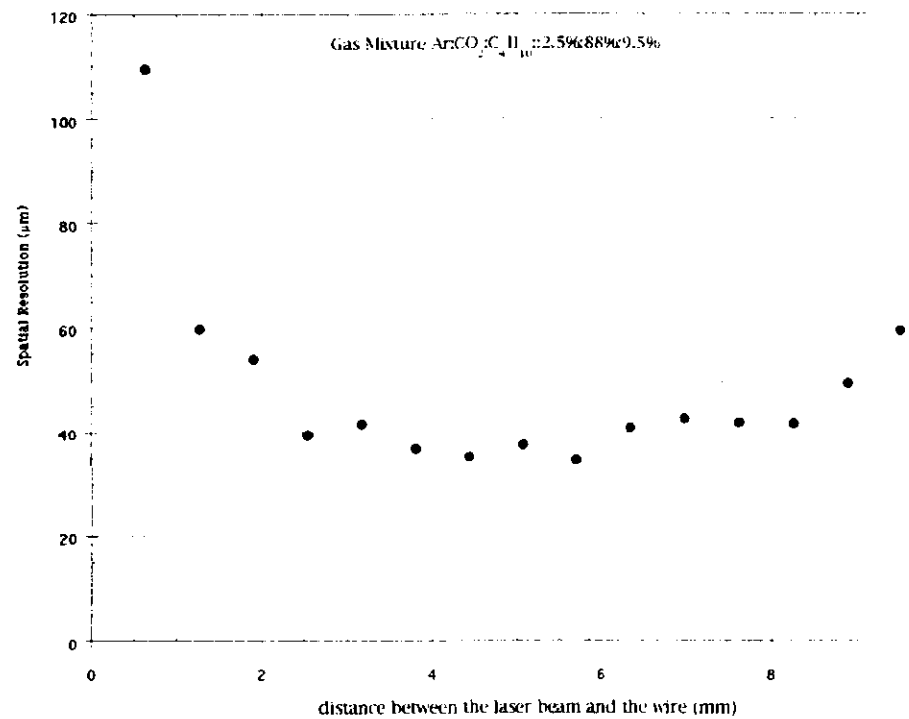

Figure X14. Plot of the spatial resolution in μm versus the strength of the applied, external magnetic field; field lines parallel to anode wire. Anode High Voltage Setting = 5.30 kV

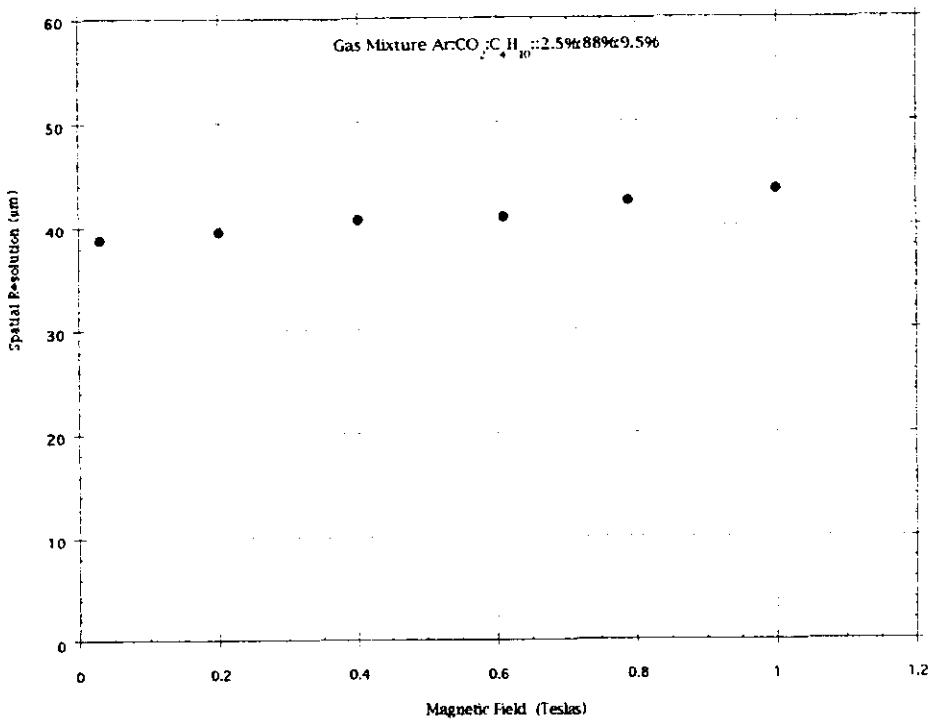

Figure X15. Plot of the Δ drift time in nanoseconds versus the distance between the laser beam and the wire. Δ drift time = Gaussian mean drift time (B=0.8T) - Gaussian Mean drift time (B=0T)

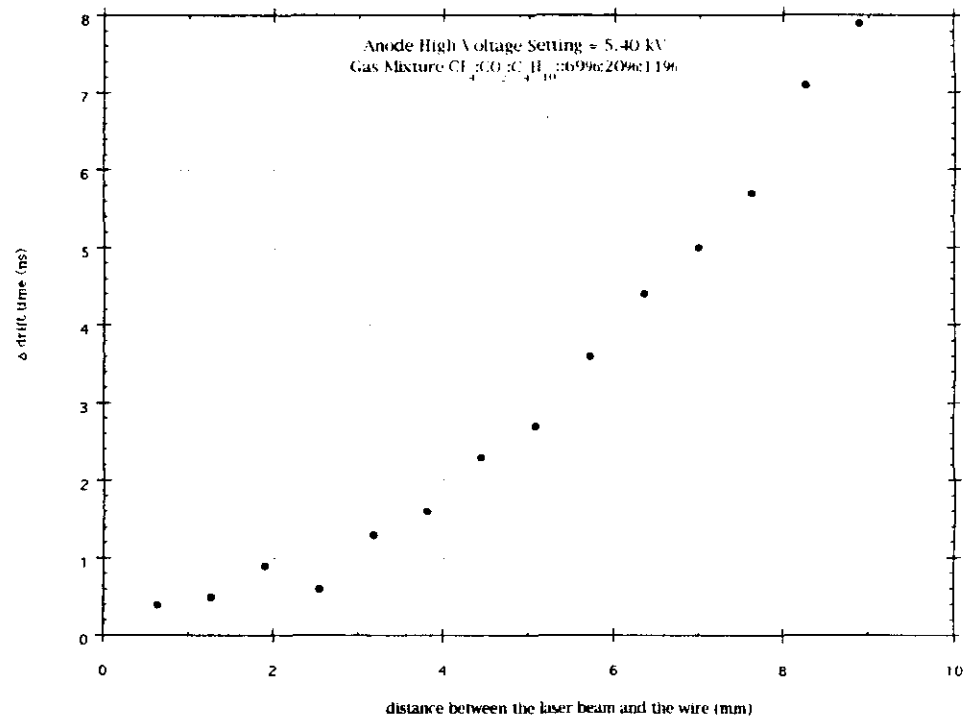

Figure X16. Plot of the spatial resolution in microns versus the distance between the laser beam and the wire.
Anode High Voltage Setting = 5.30 kV
Magnetic Field Strength = 0.8 T

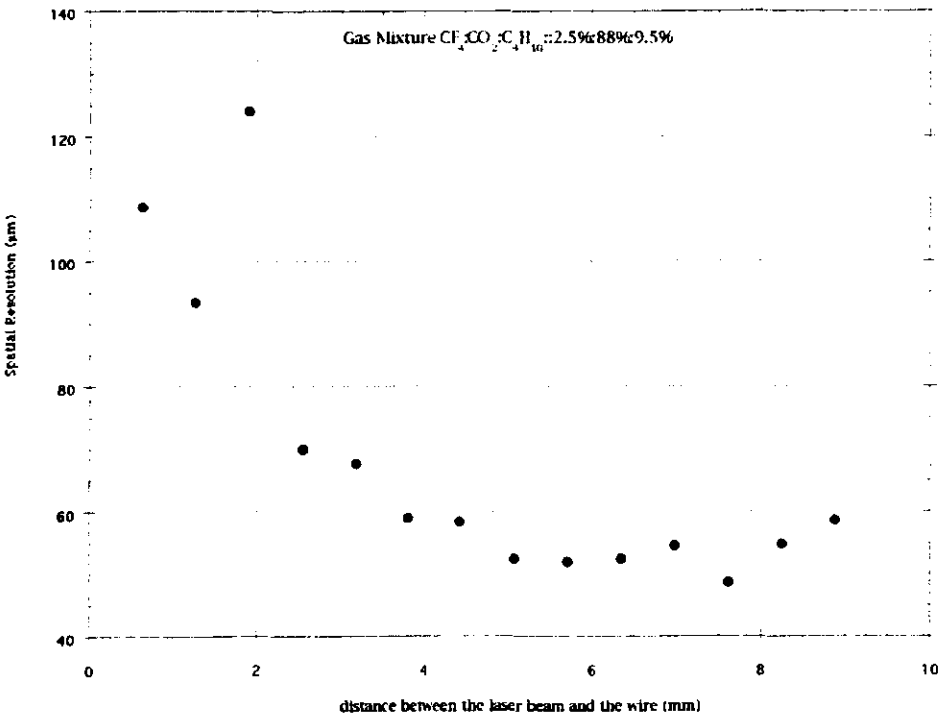
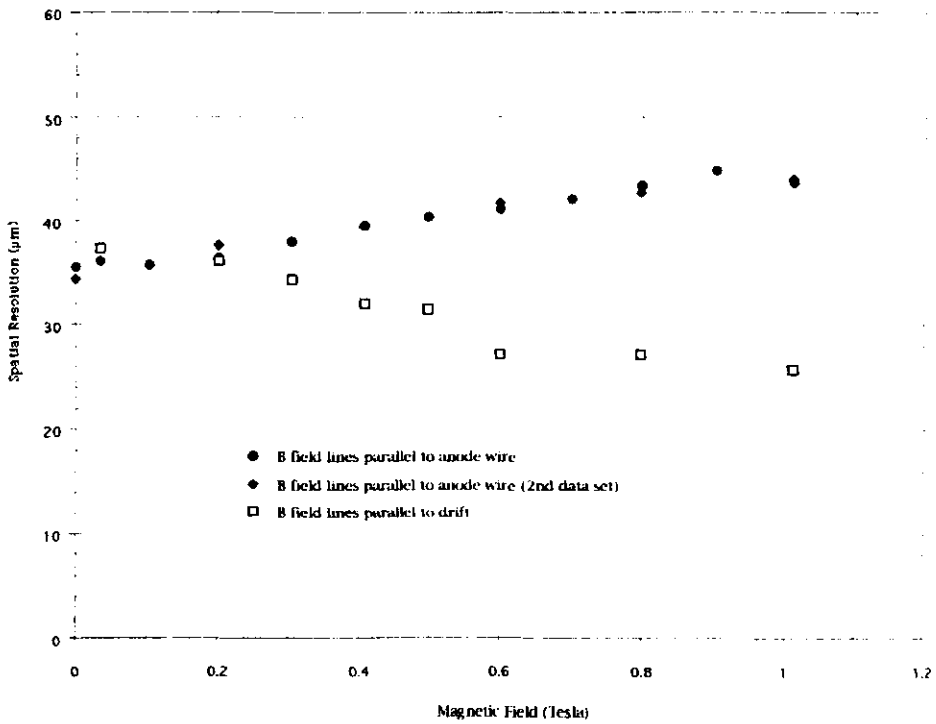
Figure X17. Plot of the spatial resolution in μm as a function of the strength and direction of the applied, external magnetic field, in Teslas.
Anode High Voltage Setting = 5.40 kV
Gas Mixture Argon:Isobutane::1:3