*IMA Journal of Mathematical Control and Information* Page 1 of 10
doi:10.1093/imamci/dri000

# MWPC Gas Gain with Argon-$CO_2$ 80:20 Gas Mixture

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## 1. Principles of Operation

A multi-wire proportional chamber (MWPC) is a type of particle detector which is useful for measuring the position of charged particles and photons. It consists of two conducting plates with a row of parallel wires in between. Inside the chamber is an ionizing gas. A high voltage is applied between the wires and the plates. A typical setting is to have the sense wires at +2000V relative to the plates which are held at ground. When a charged particle passes through the detector, it ionizes the gas, and the freed electrons are attracted to the sense wires. This current on the wires is amplified and processed electronically. By placing two detectors perpendicular to each other the two-dimensional position of an incident particle is measured.

The behavior of the detector is dependent on the choice of ionizing gas used. In this study, the gas mixture was 80% argon, 20% $CO_2$. The argon is the ionizing agent. The $CO_2$ is used to quench the gas to ensure that breakdown doesn't occur.

When an argon atom is ionized by a charged particle or photon, the freed electron is attracted to the positive voltage sense wire. The electron gains energy as it approaches the wire and eventually acquires enough energy to ionize another argon atom. This process continues and a chain reaction occurs in which a shower of electrons is produced. This gives a current on the sense wire large enough to be amplified and measured. The ratio of the total number of electrons detected on the wire to the number of primary ionizations produced by the incident particle is the **gas gain** of the detector. The gain can typically be of order $10^4$ - $10^5$, and increases with voltage.

The signal is electronically amplified with a transimpedence amplifier. The detector used in this study uses a transimpedence amplifier with a gain of $10^4$.

## 2. Measuring the Gain Using an x-ray Source

The gas gain was measured using an $^{55}$Fe source placed on top of the detector directly above the middle sense wire. The signal was output to an oscilloscope.

The $^{55}$Fe source produces monoenergetic x-rays at 5.9keV. An x-ray will undergo a single absorption in the argon gas, giving a single well-defined signal on the oscilloscope.

The oscilloscope displays voltage against time. Integrating this signal and using Ohms Law, the charge on the wire can be calculated:

$$\int V \mathrm{d}t = R \int I \mathrm{d}t = RQ \tag{2.1}$$

where the resistance R is the $10k\Omega$ resistor of the transimpedence amplifier. Thus $Q = \int V \mathrm{d}t / R$.

The average ionization energy for argon is 26eV. Then, for a 5.9keV photon which gives up all its energy to the detector, 5900/26 = 227 electrons are produced on average.

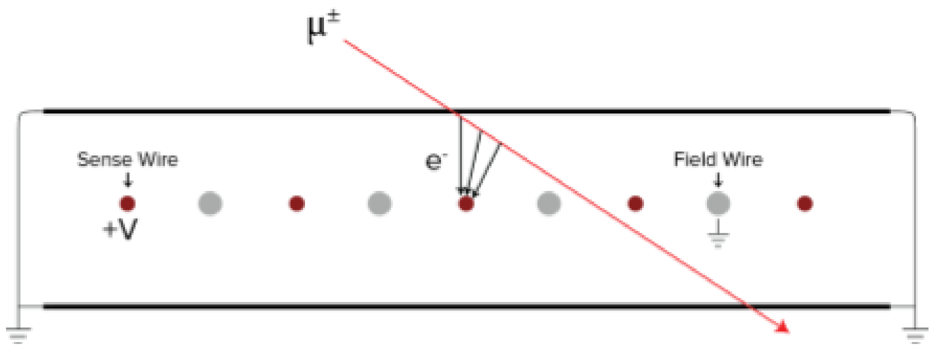


FIG. 1. Cross section of the MWPC. One cell is defined as the region between two sense wires. The sense wires are 1cm apart.

Using the measured charge Q and the primary charge produced by the photon, $227 \times \mathrm{e}$ with $\mathrm{e} = 1.6 \times 10^{-19}$C the charge of an electron, the gas gain is

$$G = \frac{Q}{227 \times \mathrm{e}} \tag{2.2}$$

The actual charge deposited during an event will vary. There is statistical fluctuation, as well as different modes of ionization. Through these different processes, some of the photon energy may escape the detector. This leaves a signature escape peak on the argon spectrum. A detailed analysis is carried out in the appendix.

In order to integrate the signals and produce a histogram, the Amptek DP5-G ADC was used. The ADC digitizes the x-ray signal, and using an MCA plots a histogram of the charge collected by the sense wire. An argon spectrum for an x-ray source typically has two distinguished peaks. The escape peak at lower energy, and the absorption peak at higher energy. The energy deposited by a photon correlates with the charge deposited, so a similar set of peaks is seen on the charge distribution.

The peak value is taken to be the charge Q used in equation (2.2) to determine the gain. The gain was measured for different voltages between 1800V and 2200V. The results are summarized in the table below for three different mixtures of gases.

The desired operating voltage of the detector is in the $10^5$ range. This data shows that the high voltage should be between 2000-2050 V for the 80:20 mixture of $Ar/CO2_2$.

### 3. Fitting the data

An accurate model for the gain G as a function of the high voltage V is the Diethorn formula.

$$\ln G = \frac{\ln 2}{\Delta V} \frac{\lambda}{2\pi\varepsilon_0} \ln \frac{\lambda}{2\pi\varepsilon_0 a E_{min}} \tag{3.1}$$

Here, $\lambda$ is the charge per unit length on the sense wire. This relates to the voltage by $\lambda = CV$ with capacitance in Farads per meter. $a$ is the wire radius, $\Delta V$ is the average potential required to produce

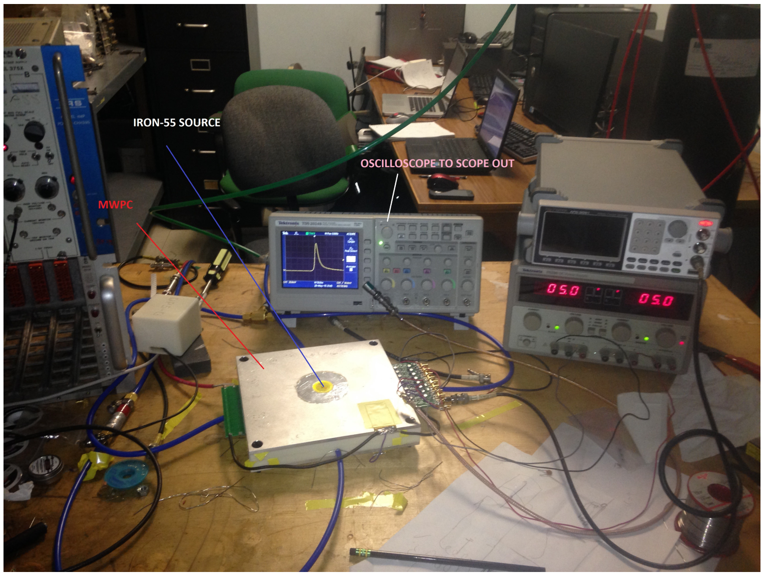


FIG. 2. The $^{55}$Fe source is placed on top of the MWPC. The signal is recorded on the oscilloscope.

an ion pair, and the minimum electric field $E_{min}$ required to ionized the gas is given by the ionization energy of the atoms divided by the mean free path. $\Delta V$ and $E_{min}$ are parameters that can be determined by the gas gain curve. These determine the properties of the gas.

For the designed detector, the values were $\Delta V = 32.57$ V, and $E_{min} = 20,525$ kV/cm, using a capacitance of 7.7814 pF/m, found using Garfield.

The gas gain data was compared with the existing Kowalski data. The Kowalski detector is a long rectangular tube of cross section $11\times16\text{mm}^2$ with a single anode wire of diameter $50\mu m$. The capacitance of this detector was determined using Garfield to be 9.9449 pF/m. Fitting the Kowalski data yields $\Delta V = 32.26$ V and $E_{min} = 33.39$ kV/cm.

In order to directly compare the gain data from Kowalski, the differences in the detector geometry must be compensated. To do this, we compare the gain when the charge on the sense wires of our detector is equal to the charge on the Kowalski sense wire. This occurs when $C_{Ours}V = C_{Kowalski}V_{eff}$,

TABLE 1 *Gas Gain for multiple gas mixtures*

| Voltage | Ar/$CO_2$ (80:20) | Ar/$CO_2$ (90:10) | Ar/Freon/$CO_2$ |
|---|---|---|---|
| 1800 | - | 88391 | - |
| 1850 | - | 185022 | - |
| 1900 | 34691 | 221916 | 4130 |
| 1950 | 55616 | 338656 | 10187 |
| 2000 | 87555 | 444383 | 21200 |
| 2050 | 135737 | - | 34691 |
| 2100 | 191905 | - | 54515 |
| 2150 | 245955 | - | 86453 |
| 2200 | 330947 | - | 138216 |

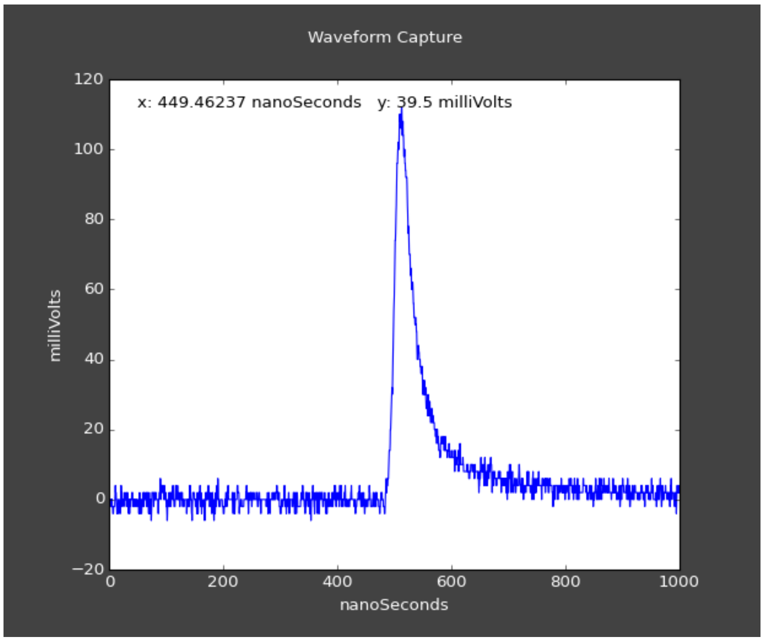


FIG. 3. The signal from an $^{55}$Fe source captured on an oscilloscope.

where

$$V_{eff} = \frac{C_{Ours}}{C_{Kowalski}} V \tag{3.2}$$

is the effective voltage which the Kowalski detector must be set at in order to match the charge on both detectors. Thus, we should plot the Kowalski gain versus $V_{eff}$. Secondly, since the wire radii are different, we must compensate for that as well. The Kowalski radius is $25\mu m$, and for our detector is $10\mu m$. Therefore, an electron traveling towards the sense wire in our detector has a further $15\mu m$ in which to travel and produce more secondary ionizations.

The additional gain factor as determined by the Diethorn formula is

$$\left(\frac{25}{10}\right)^{\ln 2 \frac{\lambda}{2\pi\varepsilon_0} \frac{1}{\Delta V}} \tag{3.3}$$

Factoring in the calibrations, the resulting comparison is shown below.

## 4. Appendix

### 4.1 *Argon x-ray absorption spectrum*

When a 5.9keV photon is absorbed by an argon atom, there are two common modes of ionization: an electron from the innermost K-shell is freed, or an L-shell electron is freed. The binding energy of the

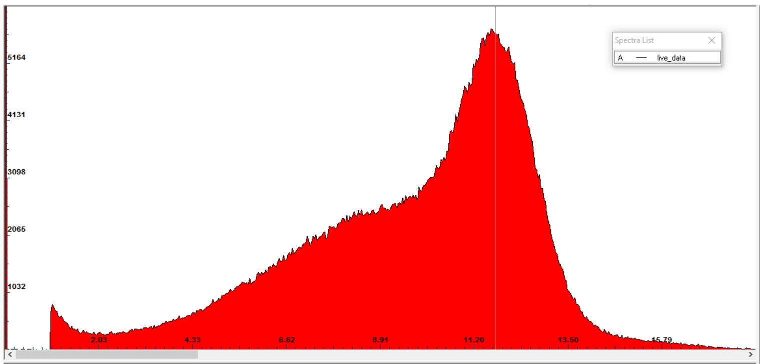


FIG. 4. Argon spectrum at 2200V. The horizontal scale is charge in $10^{-12}$C.

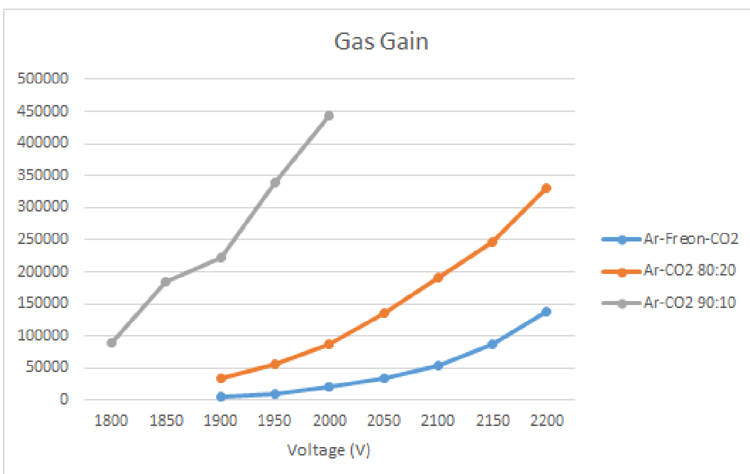


FIG. 5. Gas Gain for multiple gases.

L-shell electron is .3keV. Thus, if the L-shell is ionized, the emitted electron carries 5.6keV, most of the energy of the photon.

The K-shell has a binding energy of 3.2keV and so if the K-shell is ionized, the electron only carries away 2.7keV. The probability of an L-shell absorption is 10.5%, and K-shell is 89.5%.

The vacant K-shell can be filled by the Auger process in which the electrons of the argon atom rearrange resulting in the emission of a 3.2keV electron. This electron plus the initial K-shell electron carry the entire energy of the photon into the detector, yielding full absorption of the photon energy. There is an 85% probability of filling the K-shell by the Auger process.

The K-shell can also be filled by fluorescence with a 15% probability, in which an L electron drops into the K-shell, emitting a photon with $E_K - E_L$ = 2.9keV. This photon can escape the detector, or it can be reabsorbed. The probability of being reabsorbed depends on the size and geometry of the detector.

A Monte Carlo simulation was run to determine the relative rates for each of the above processes. The detector geometry used was a cell of cross sectional area 1cm $\times$ 2cm and infinite in depth. The

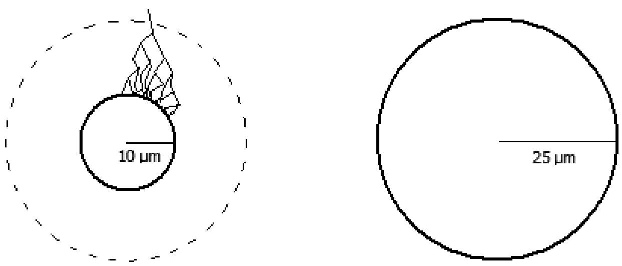


FIG. 6. Wire comparison between our detector and the Kowalski detector.

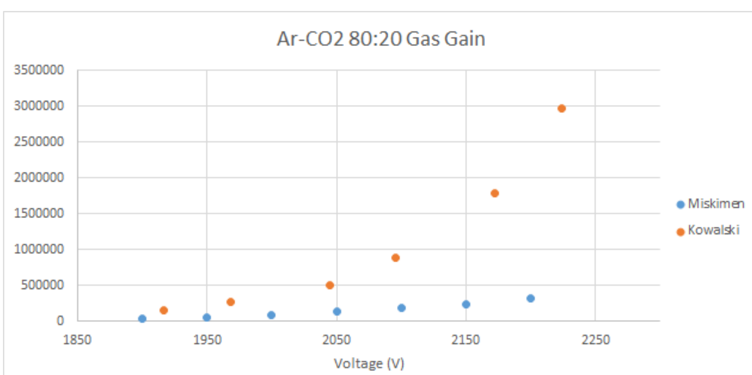


FIG. 7. Gas Gain comparison between our detector and the Kowalski data.

MWPC of this experiment is 2cm between grounding plates and has a 1cm spacing between sense wires. This cell used in the simulation represents the effective area around a single sense wire.

### 4.2 *Calibrating the Amptek DP5-G ADC*

The Amptek ADC generates a histogram of charge, however, the horizontal scale must be calibrated to ensure correct results. This was achieved using a signal generator. The signal generator was passed through a 22pF capacitor with a 50Ω terminating resistor. The capacitor was in series with the ADC and decouples any DC offset.

A short square wave pulse was sent into the ADC. The capacitor allows this voltage signal to be converted to a charge using Q = CV. This charge shows up as a clear spike in the Amptek histogram. Four voltages were used to generate four points of calibration.

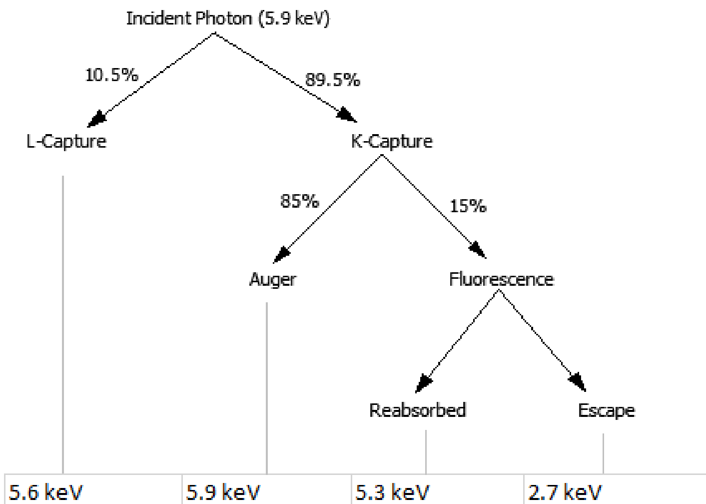


FIG. 8. Flow chart of dominant argon-x-ray interactions in MWPC.

Amptek then has an option to calibrate the MCA channels to the desired scale and units. The MCA collected data in 2048 channels. The figure below shows the Amptek calibration screen and the values used for calibrating.

## REFERENCES

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T. KOWALSKI, A. STOPCZYNSKI (1992) The gas gain process in Ar/$CO_2$ filled proportional tubes, *Nuclear Instruments and Methods in Physics Research*, A323, 289.

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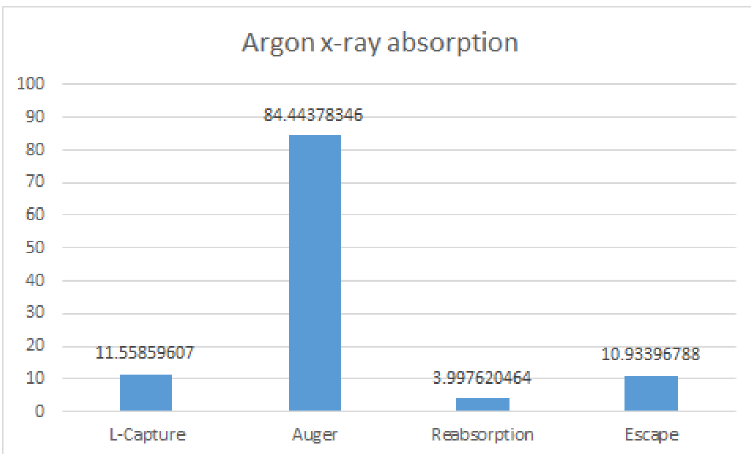



FIG. 9. Results of Monte Carlo simulation for x-ray absorption in argon

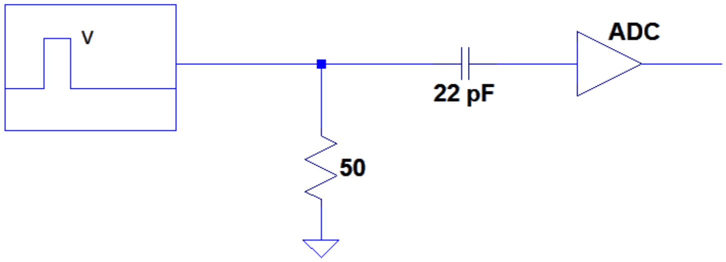



FIG. 10. Amptek calibration circuit

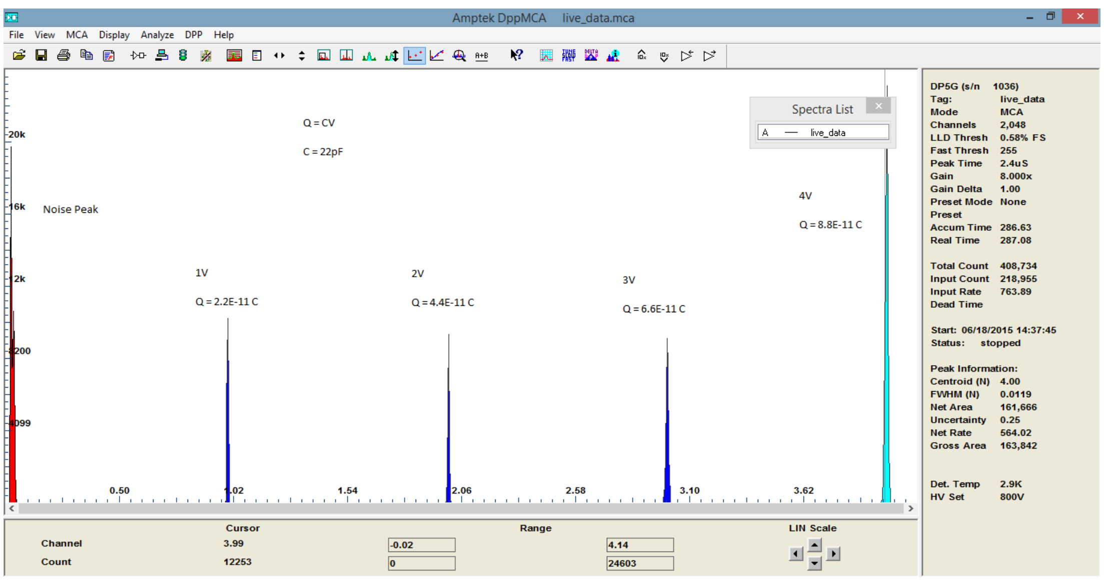



FIG. 11. Square wave signals on Amptek histogram

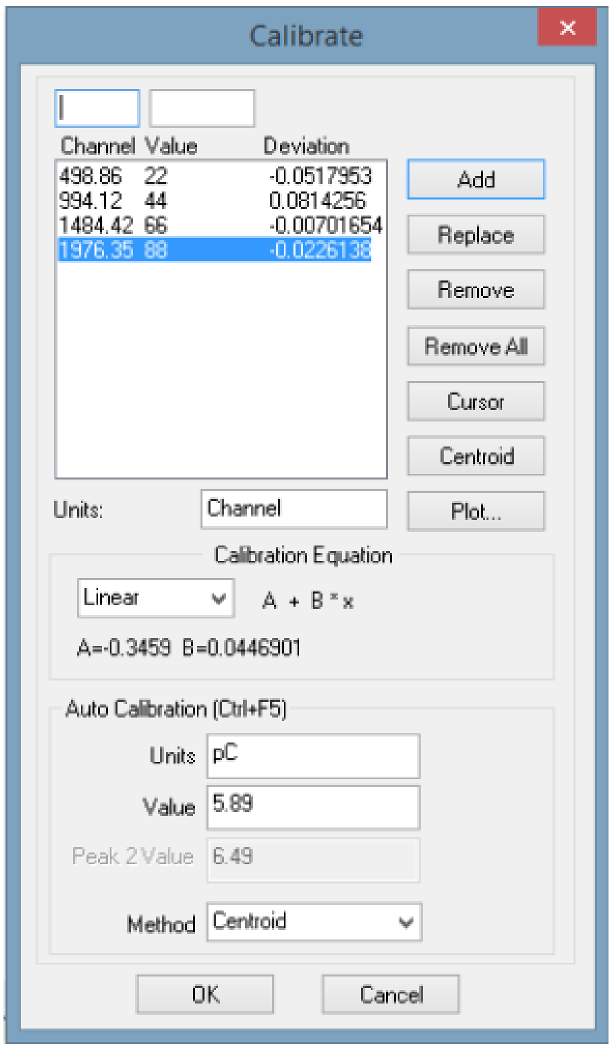
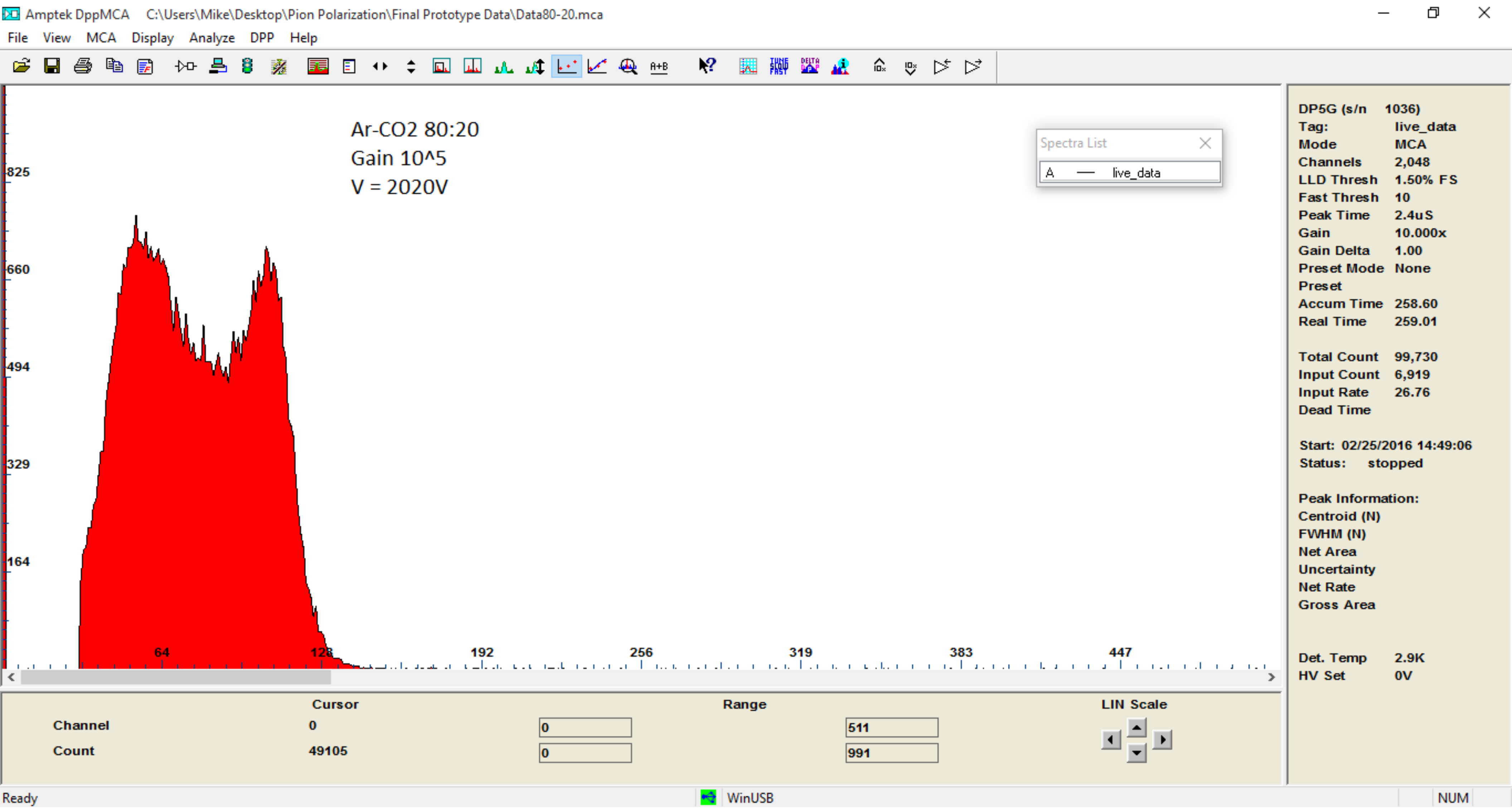



FIG. 12. Amptek calibration settins used in measuring the gas gain.



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660
494
329
164
64
128
192
256
319
383
447
DP5G (s/n 1036)
Tag: live_data
Mode MCA
Channels 2,048
LLD Thresh 1.50% FS
Fast Thresh 10
Peak Time 2.4uS
Gain 10.000x
Gain Delta 1.00
Preset Mode None
Preset
Accum Time 258.60
Real Time 259.01
Total Count 99,730
Input Count 6,919
Input Rate 26.76
Dead Time
Start: 02/25/2016 14:49:06
Status: stopped
Peak Information:
Centroid (N)
FWHM (N)
Net Area
Uncertainty
Net Rate
Gross Area
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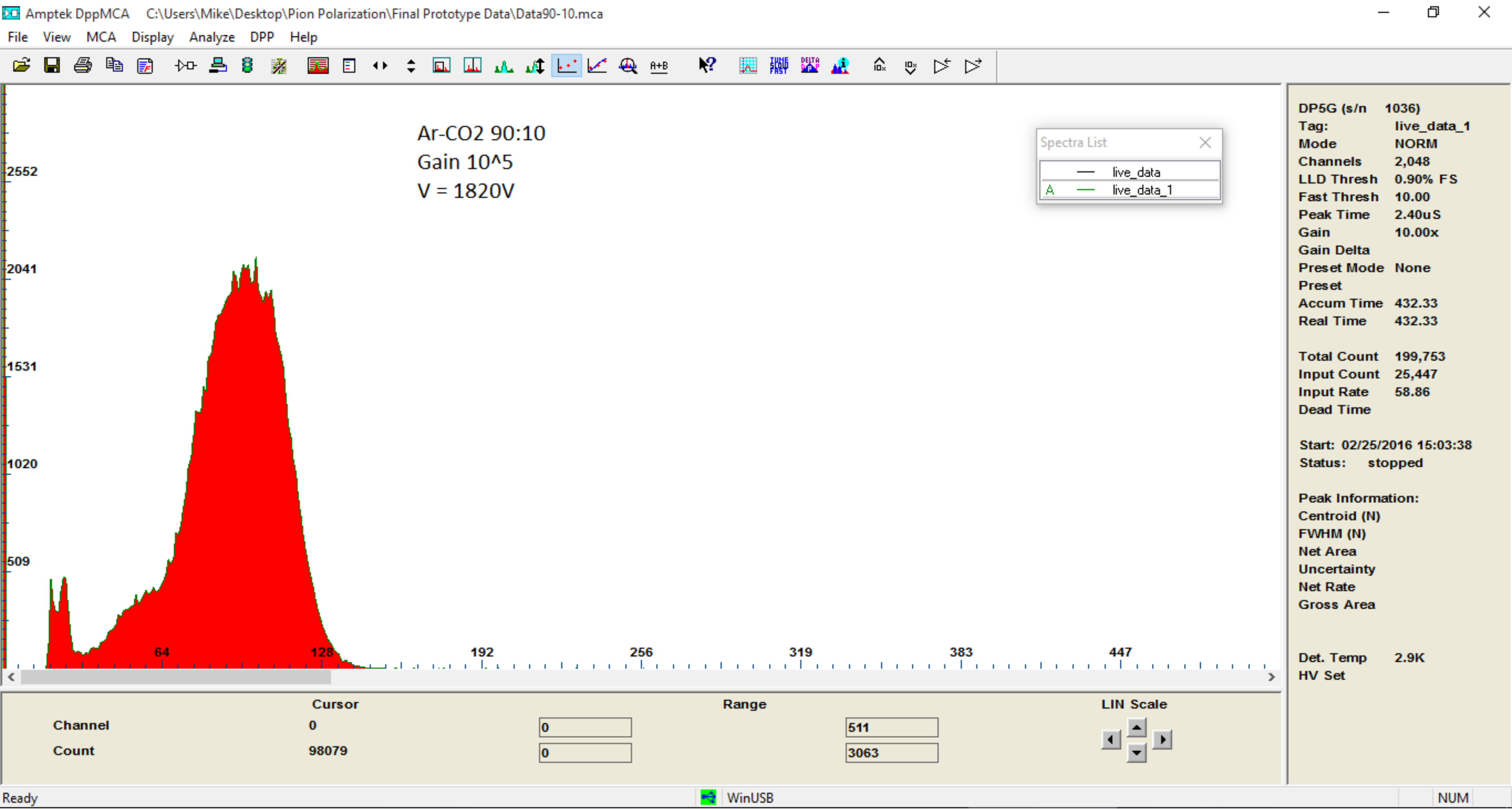
WinUSB
NUM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Gain 10^5
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Spectra List
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2552
2041
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1020
509
64
128
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256
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447
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Mode NORM
Channels 2,048
LLD Thresh 0.90% FS
Fast Thresh 10.00
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Gain 10.00x
Gain Delta
Preset Mode None
Preset
Accum Time 432.33
Real Time 432.33
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Input Count 25,447
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Peak Information:
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FWHM (N)
Net Area
Uncertainty
Net Rate
Gross Area
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511
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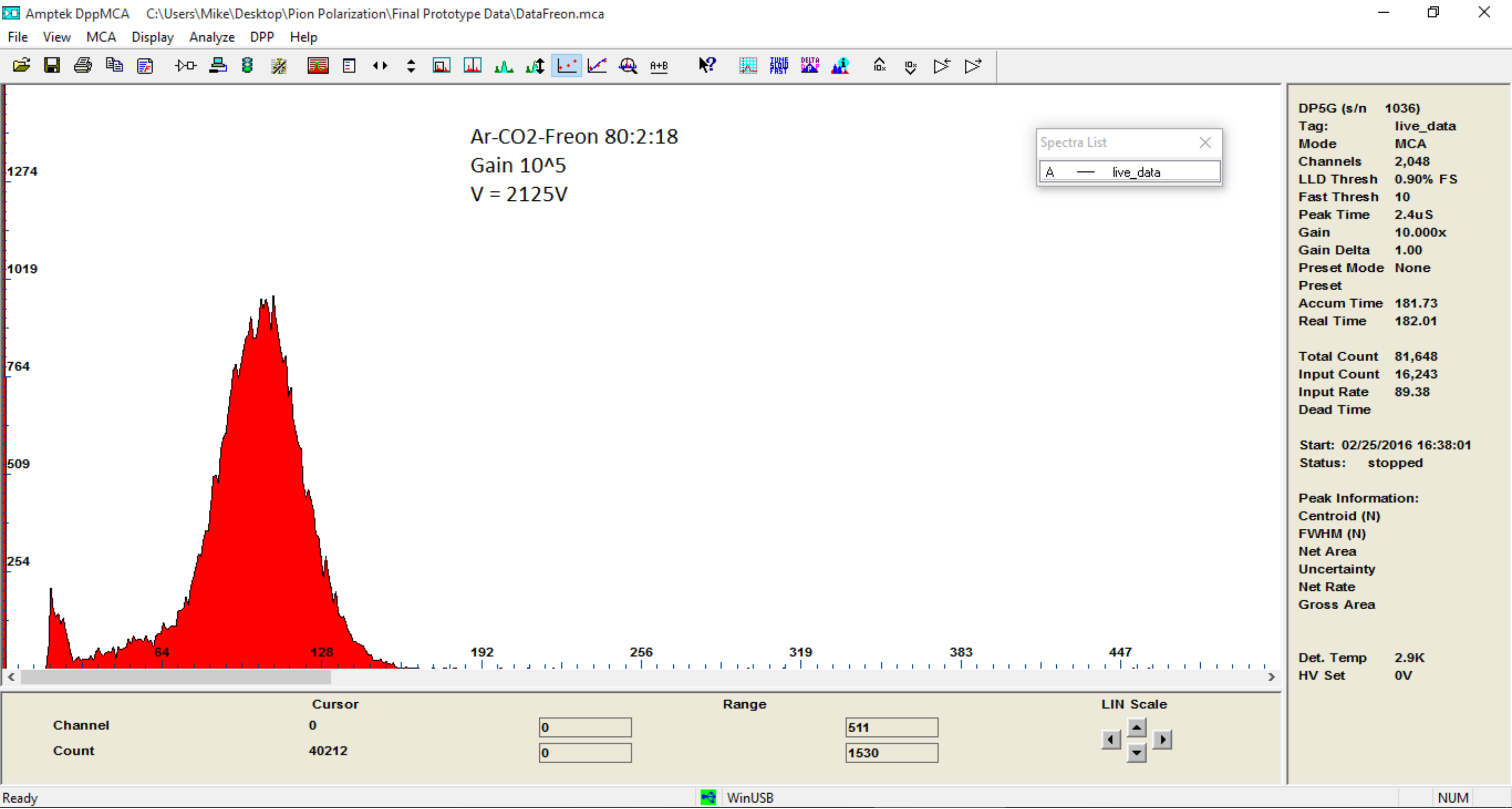
Ready
WinUSB
NUM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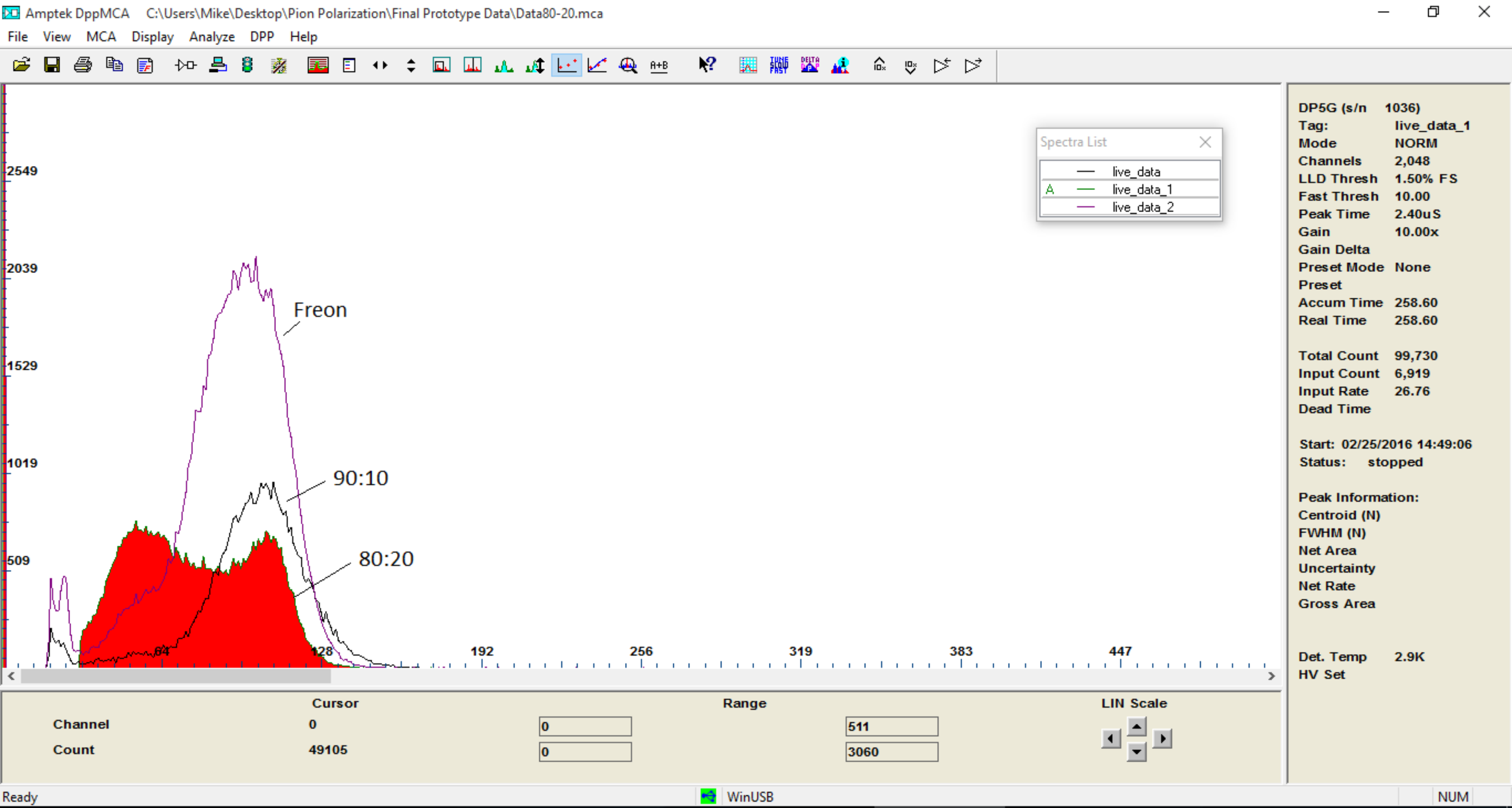
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Real Time 258.60
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Input Count 6,919
Input Rate 26.76
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FWHM (N)
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