10-9-2021

Embedded Charge Distributions in Electron Irradiated Polymers – Pulsed Electroacoustic Method Reproducibility and Calibration

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Recommended Citation

Zachary Gibson, JR Dennison, and Ryan Hoffmann, "Embedded Charge Distributions in Electron Irradiated Polymers – Pulsed Electroacoustic Method Reproducibility and Calibration" American Physical Society Four Corners Meeting, The University of Colorado Boulder, Boulder, CO, October 8-9, 2021.

Embedded Charge Distributions in Electron Irradiated Polymers – Pulsed Electroacoustic Method Reproducibility and Calibration

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APS 4CS Virtual Meeting

October 9th, 2021

Outline

- Motivation
- Pulsed Electroacoustic (PEA) Method
  - Signal Processing
- The Experiment
- Uncertainties
  - Relative
  - Absolute
- Conclusions

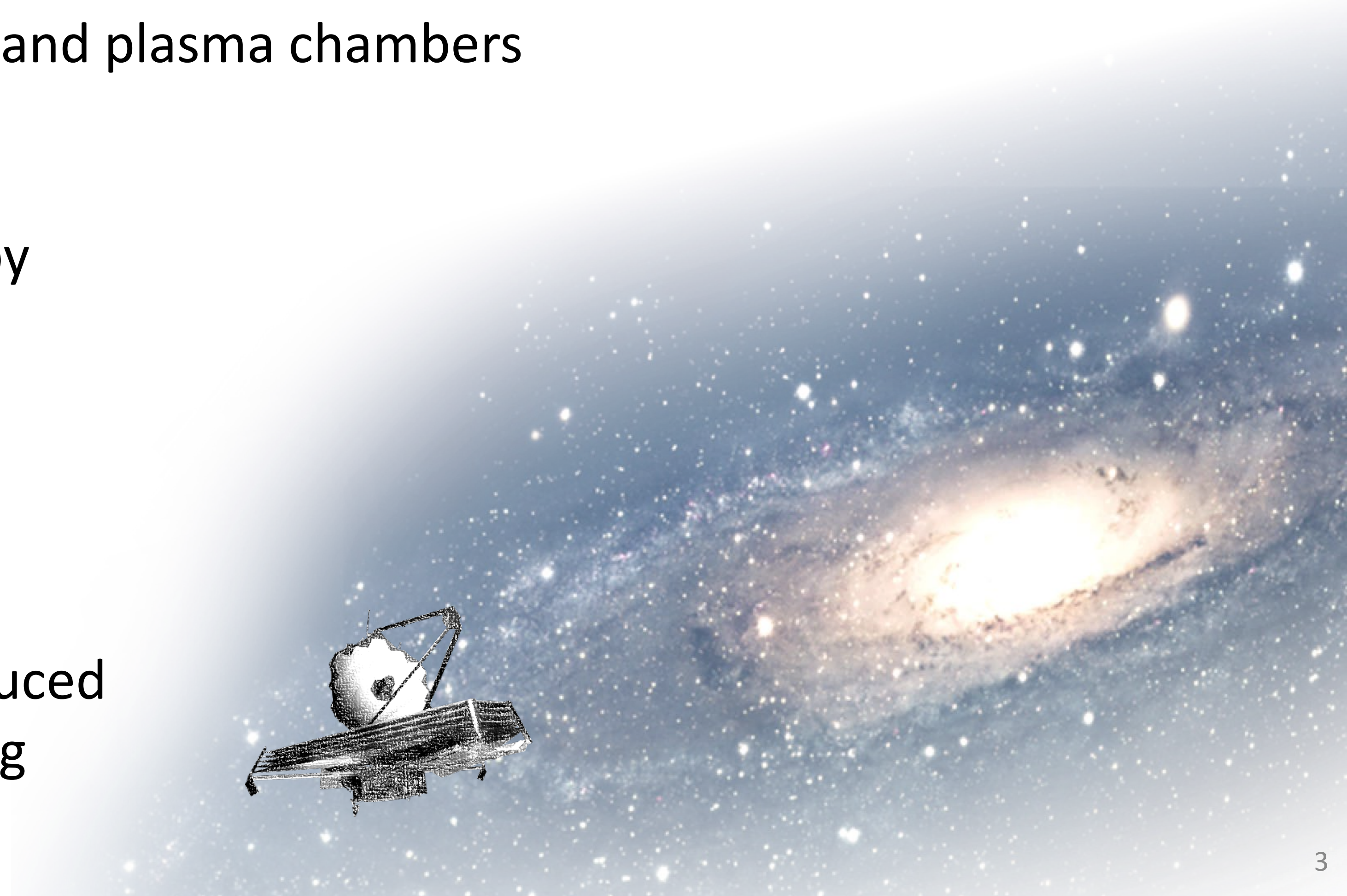
Defining the Problem – Charging of Insulators

Charge accumulation is a problem in many areas

- HV power cabling insulation
- HV devices and switches
- Electrostatic charging in accelerators and plasma chambers
- Plasma deposition
- Thin film dielectrics
- Electron microscopy and spectroscopy
- Photoconductive devices/sensors
- Inferring defect states in materials
- **Spacecraft charging**

Spacecraft Charging

- A majority of space environment-induced failures are due to spacecraft charging
- Length scales from 1-100’s of µm



The Experimental Set-up: What is PEA?

How it works:

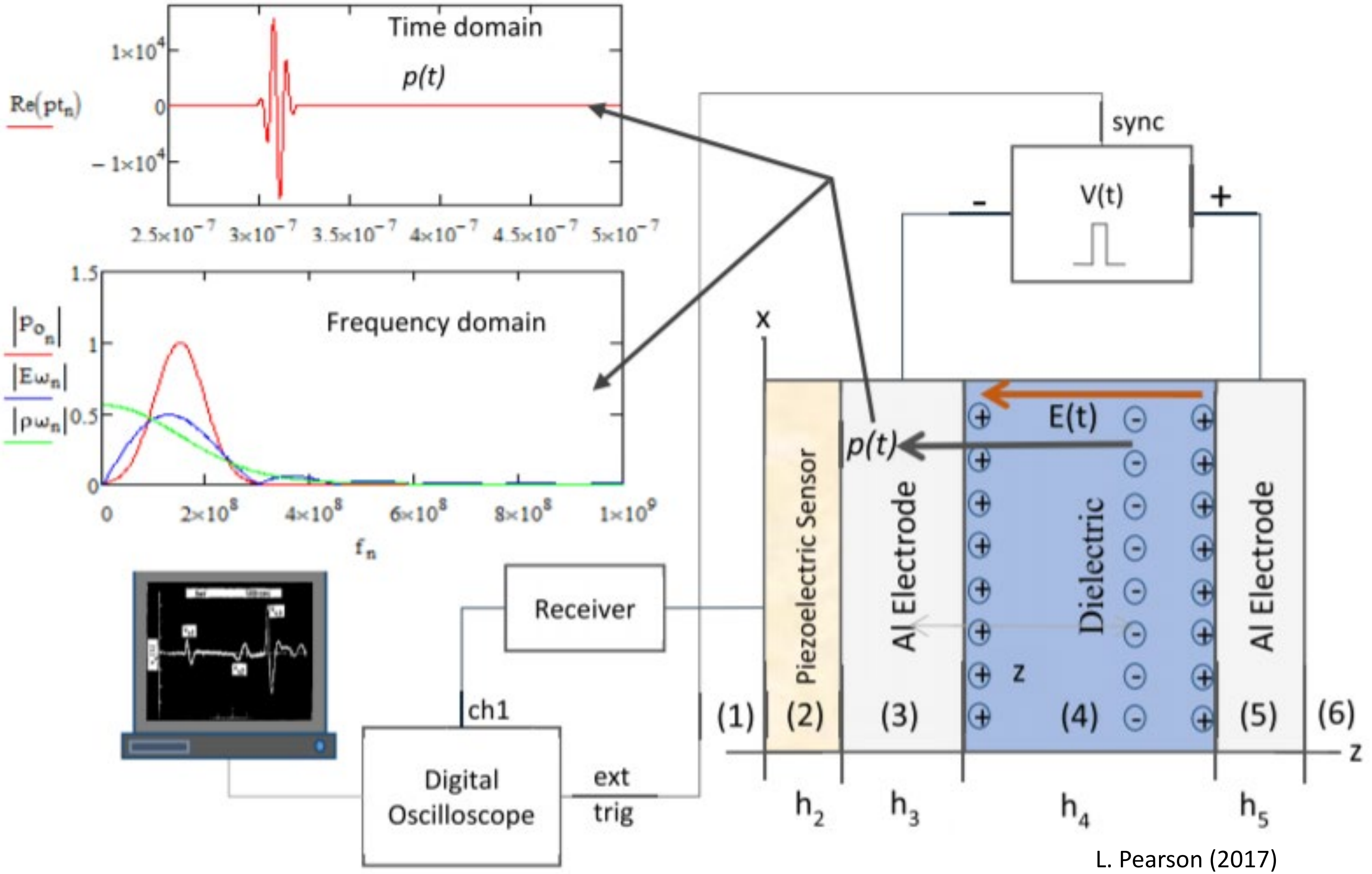
- Pulsed voltage probes embedded charge
- Time of flight indicates position of charge

Benefits:

- Nondestructive measurement
- Low cost

Limitations:

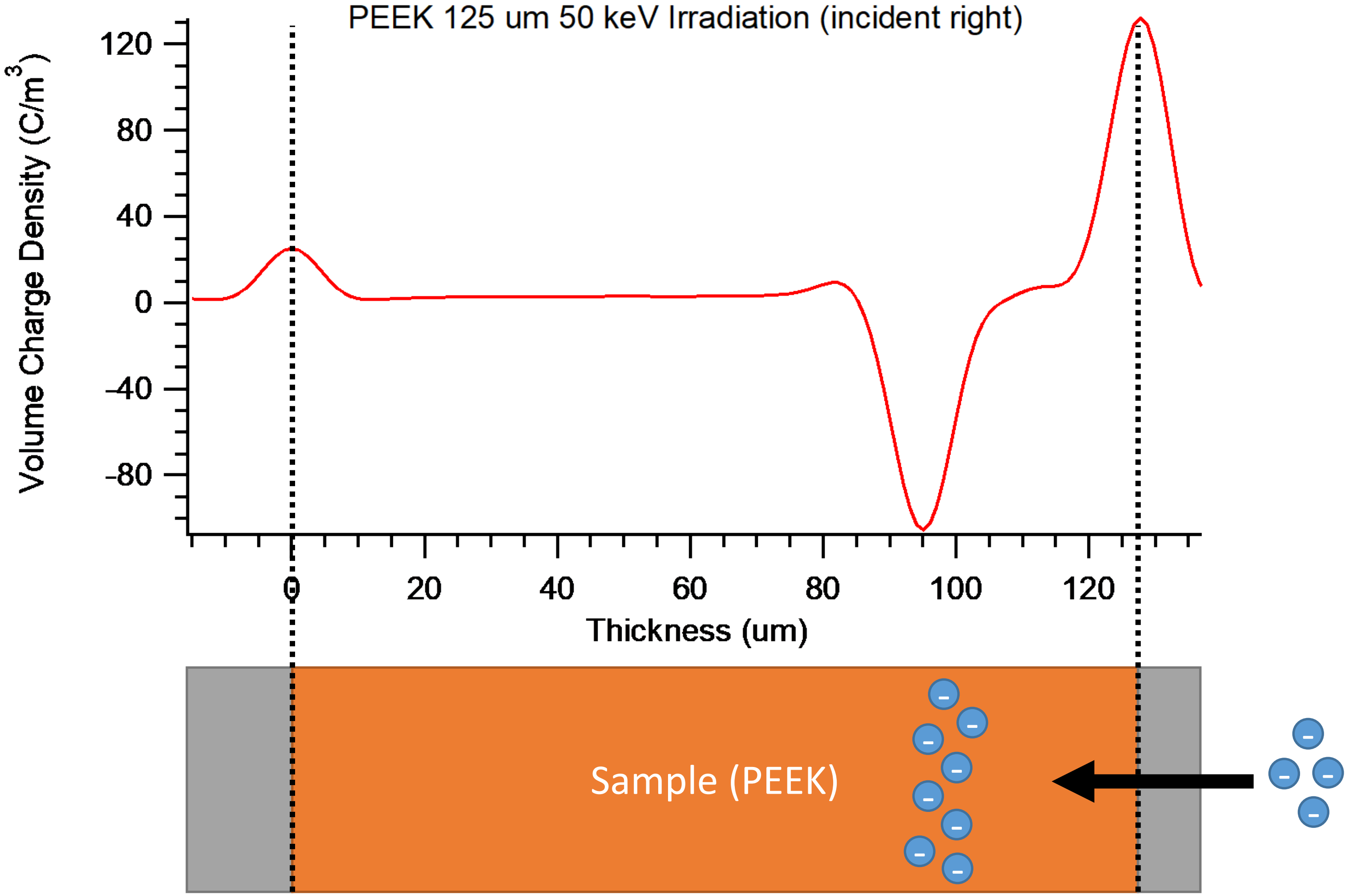
- Hard to increase resolution
  - High cost electronics
  - Difficult sensor fabrication



L. Pearson (2017)

Measuring Charge Distributions – An Example

Preliminary Data



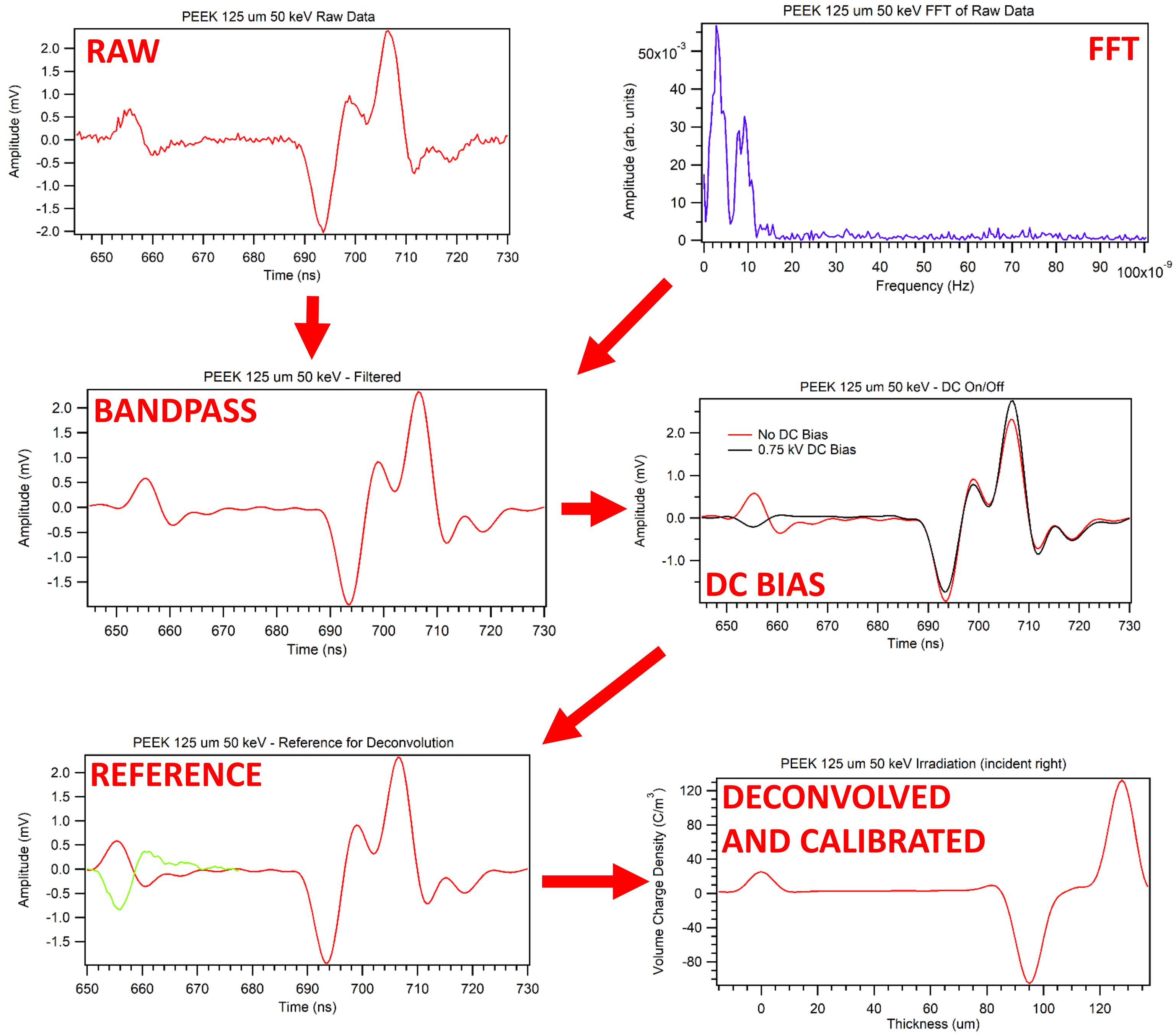
Signal Processing

Processing Steps:

- Compute FFT to determine filter
- Bandpass filter data
- Take difference of DC on – DC off
- Use system response to perform deconvolution

Calibration

- Multiply by calibration factor
  - Determined by amplitude of response to DC bias
- Convert time to distance using thickness of material
  - x axis = thickness / time

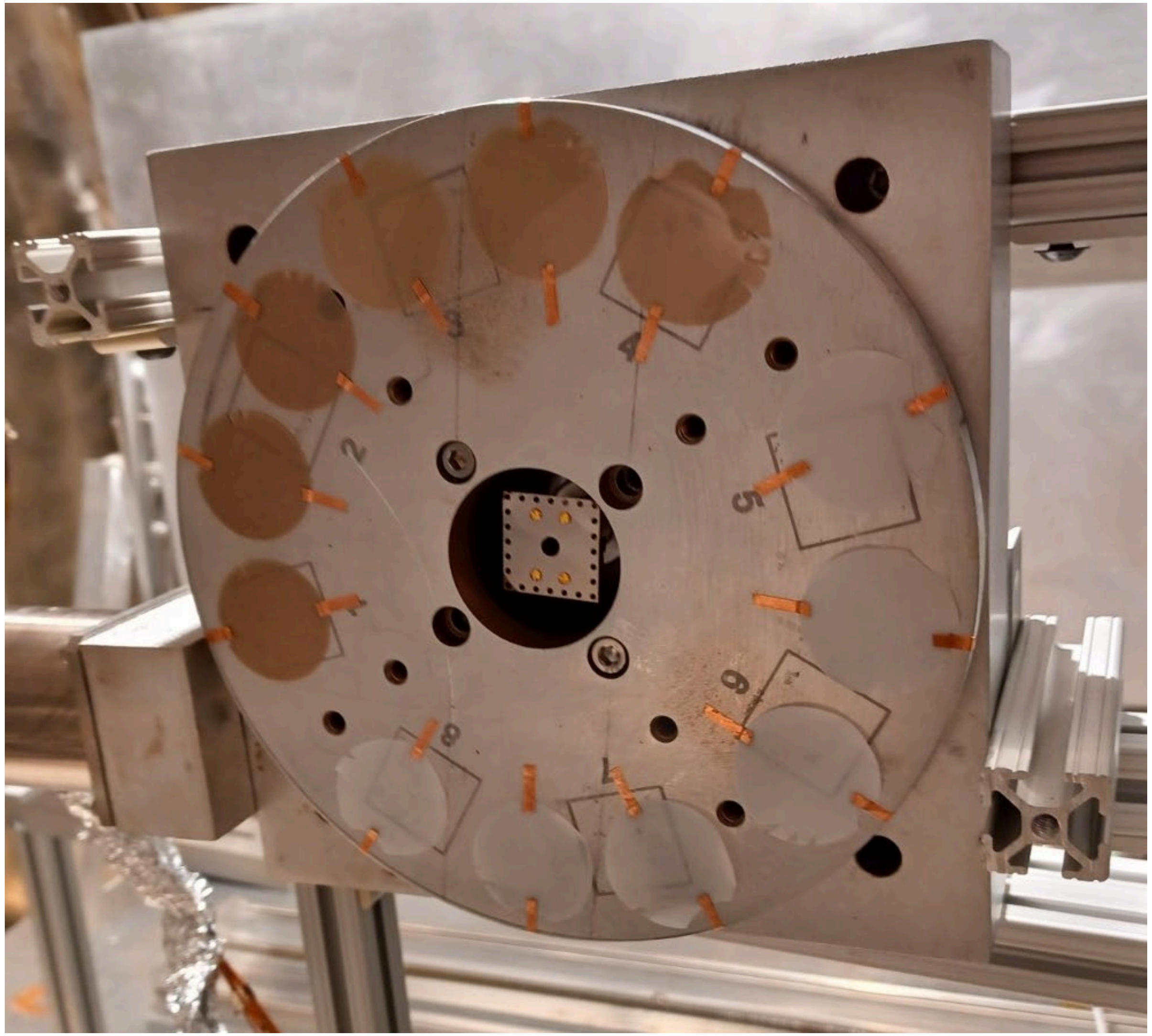


The Experiment – Electron Irradiation of Polymers

Samples
- Polyether-etherketone (PEEK)
- Polytetrafluoroethylene (PTFE)

Thicknesses
- 125 µm
- 250 µm

Irradiation Energy
- 50 keV
- 80 keV



The Experiment – Details

Average Flux

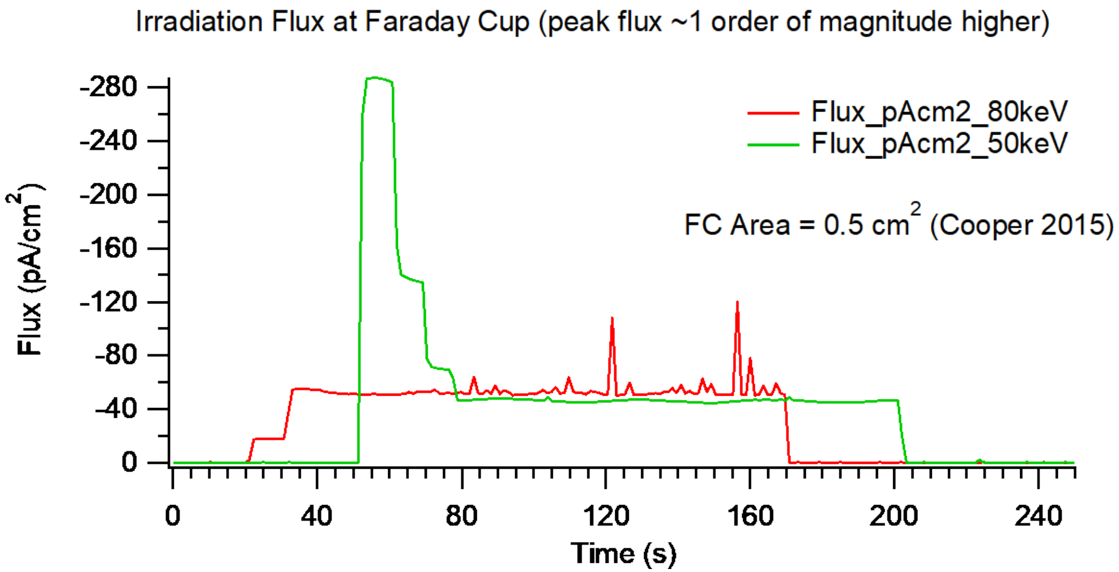
- For 80 keV, 210 pA/cm^2
- For 50 keV, 220 pA/cm^2

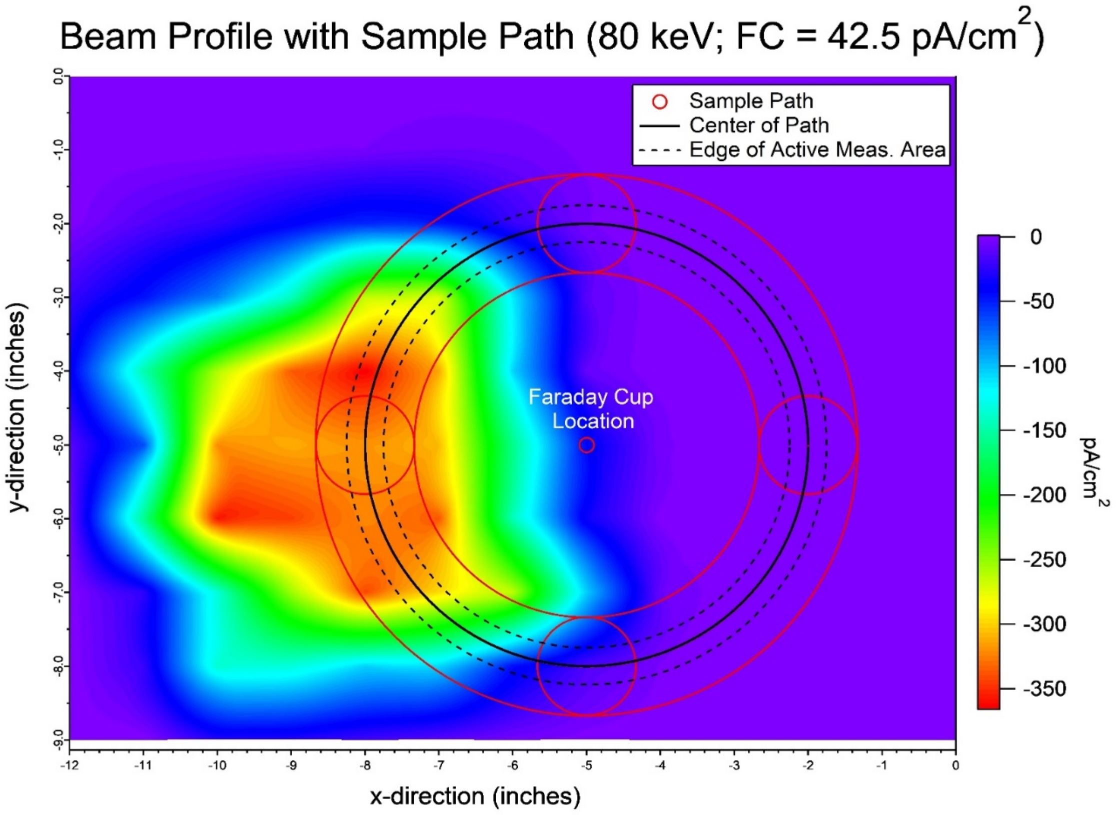
Irradiation time

- 150 s
- 75 s in beam
- 75 s out of beam
- 30 s per rotation (2 RPM)

High spike of flux

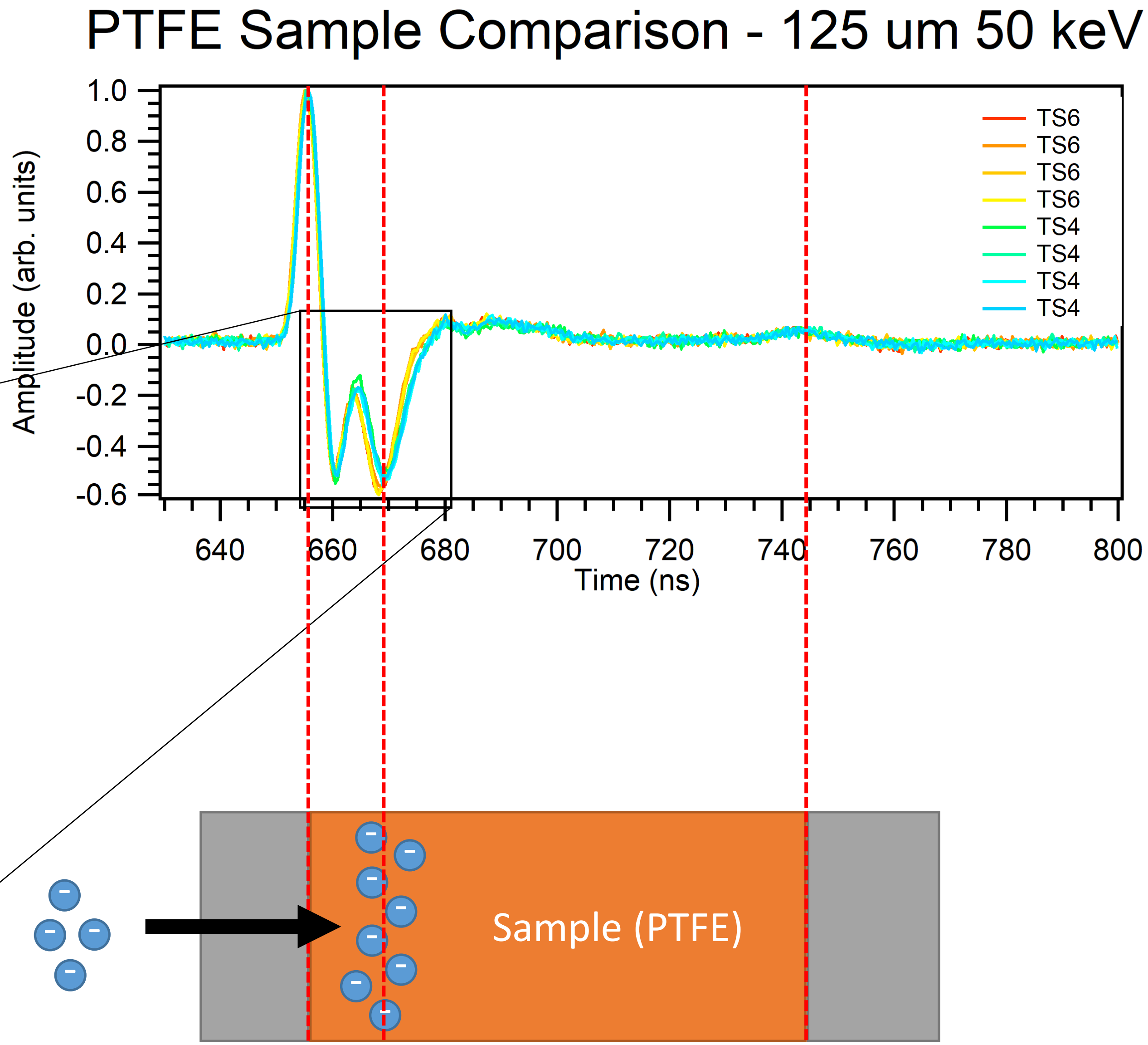
- Higher than baseline for ~15 s
- Highest flux for ~5 s
- ~1/2 of samples received higher than baseline irradiation (6 samples)
- ~1/6 of samples received highest flux (2 samples)

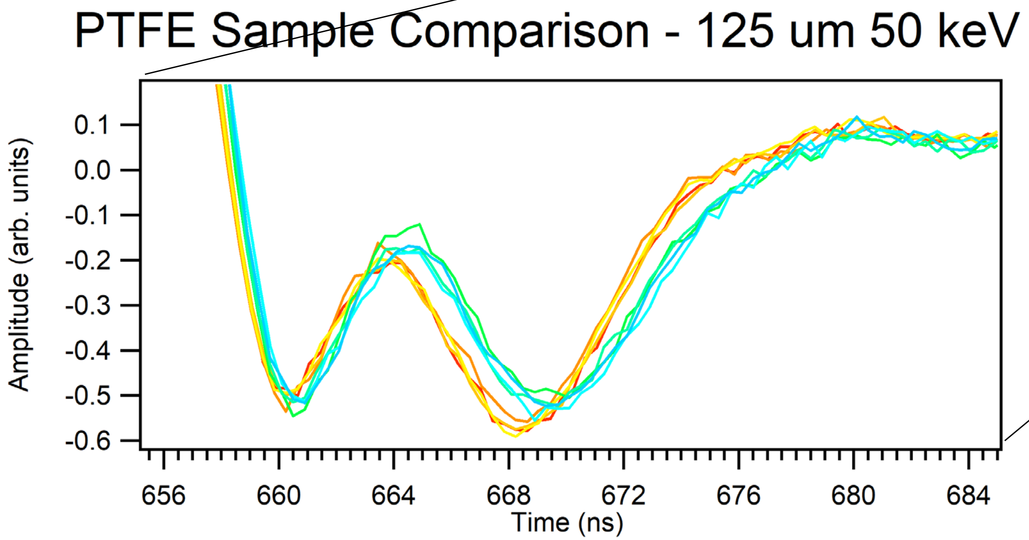




The Mystery – Is there a difference?

Can you tell the difference between the two dose rates?





Uncertainty from PEA System – Relative Error

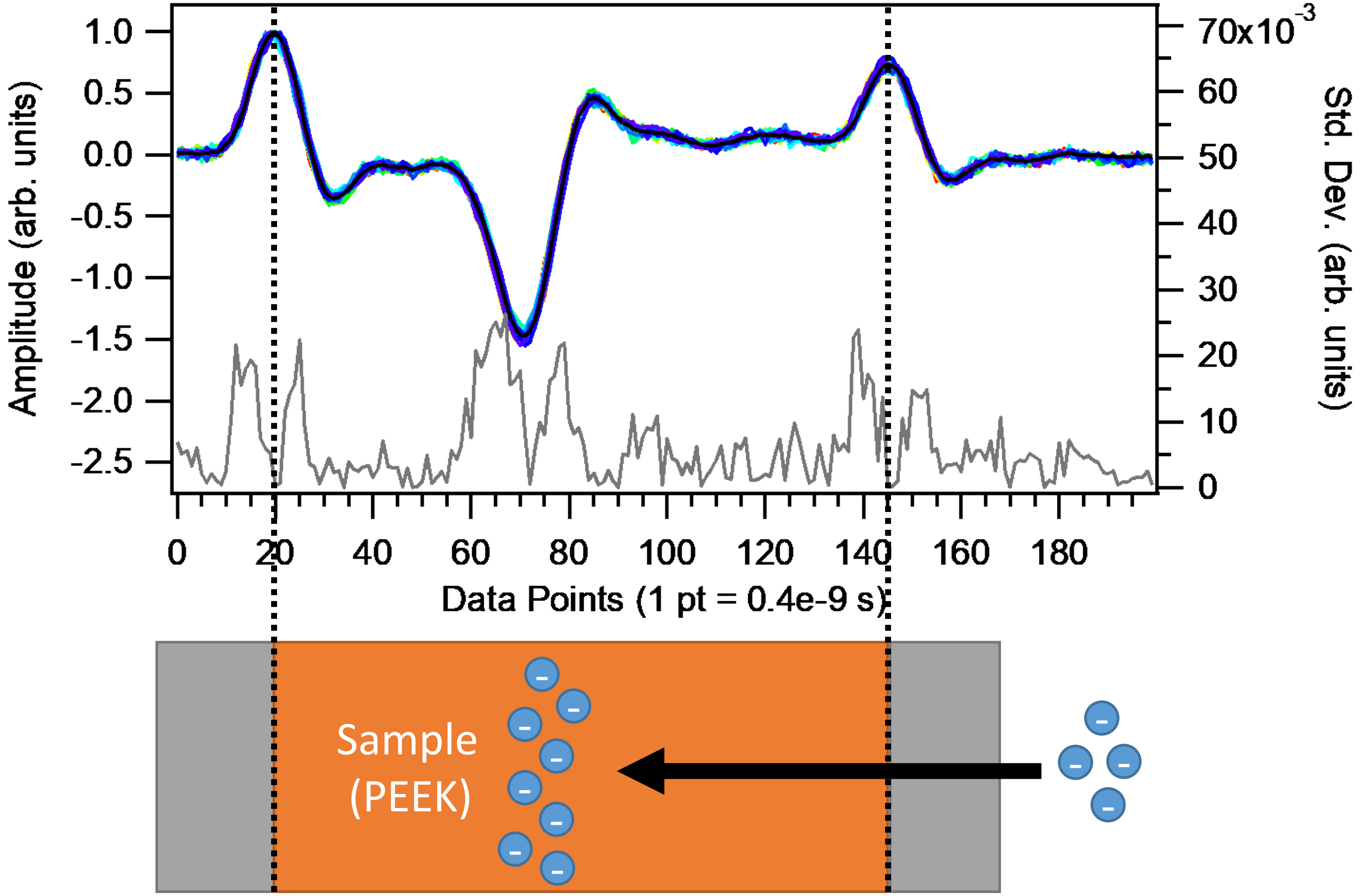
Reproducibility Measurements

- “No touching”
- Removing and replacing sample
- Pulse width and amplitude
- # of measurements averaged

Relative error $\pm$ 1-3% of the peak amplitude

- For typical settings
  - 0.5 ns 1 kV pulse
  - 1000 waves averaged

Normalized Remove/Replace Measurements
PEEK 125 um – 0.5 ns 1 kV Pulse – 1000 waves averaged

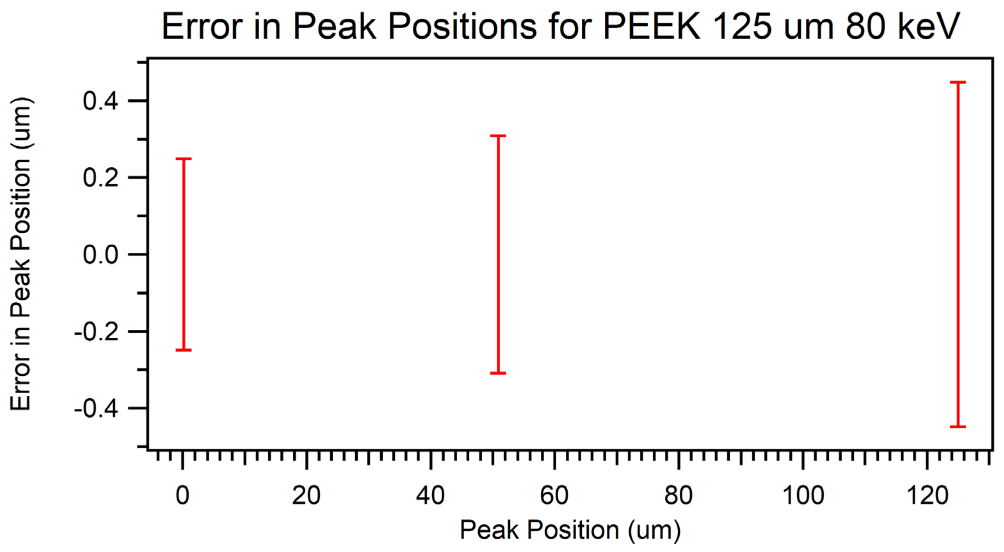


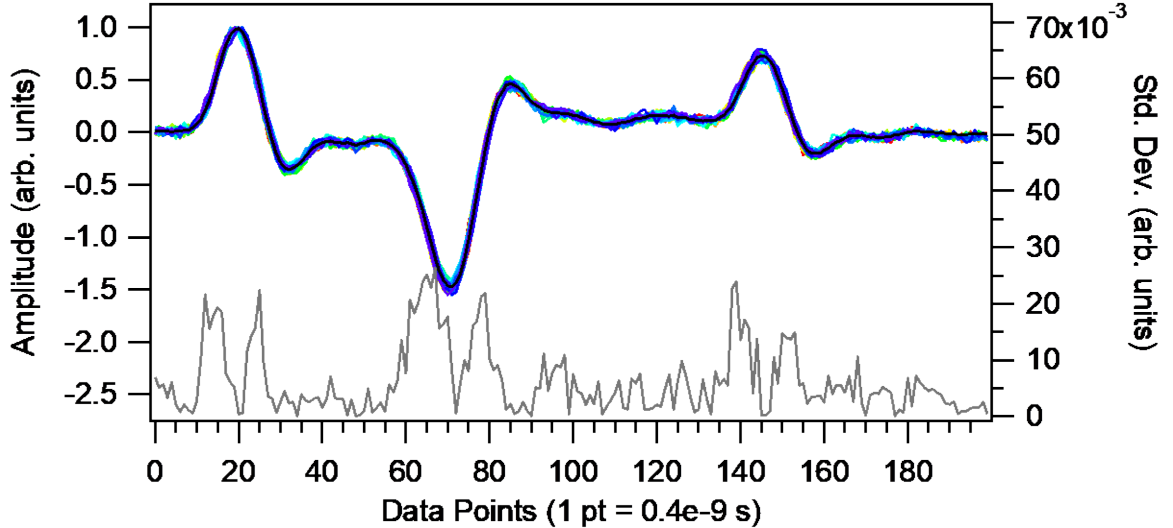
Uncertainty from PEA System – Relative Error

3 Peak Positions found
- Interfaces (2)
- Deposited charge

Calculations
- Compute average
- Compute standard deviation

Relative error ± 0.5 μm for peak position





Uncertainty from Calculations - Absolute Error

Uncertainties in the calibration are introduced from errors in:

- Sample thickness
  - For each sample $\pm$ 0.5-1 µm
  - Sample uniformity $\pm$ 1-3 µm
- Speed of sound $\pm$ 5-10% ?
- Resistance of sample
- Resistance of acoustic coupling layers
- Thickness of acoustic coupling layers $\pm$ 1-3 ? µm
- HVDC Source
- Reflections of pulsed voltage (electrical impedance mismatches)
- Pulse shape

Determination of uncertainty from these sources is still in progress

$$\text{Calibrated Signal} = \text{IFFT}[\text{R(f)}]$$

$$\text{R(f)} = \frac{V_{DC}\, \varepsilon_r\, \varepsilon_o}{d\, v_{sample}\, \tau}\left(\frac{V_{meas}(f)}{V_{response}(f)}\right)$$

R(f) is FFT of space charge distribution, V_{DC} is DC bias, ε_r is relative permittivity of sample, ε_o is permittivity of free space, v_{sample} is speed of sound in sample, d is thickness, τ is sampling rate, V_{meas} is the PEA measurement, and $V_{response}$ is the response function of the PEA system. First term is calibration factor and second term is deconvolution.

Calibrate (DC On – DC off) and use that to calibrate the original signal.

Conclusions

- With settings of 0.5 ns 1 kV pulse and 1000 waves averaged, the relative error is
  - $\pm$ 1-3% of peak amplitude
  - $\pm$ 0.5 um in spatial dimension
- Uncertainty in calibration (absolute error) still needs to be determined
- More work needs to be done to determine if difference in deposition depth is significant

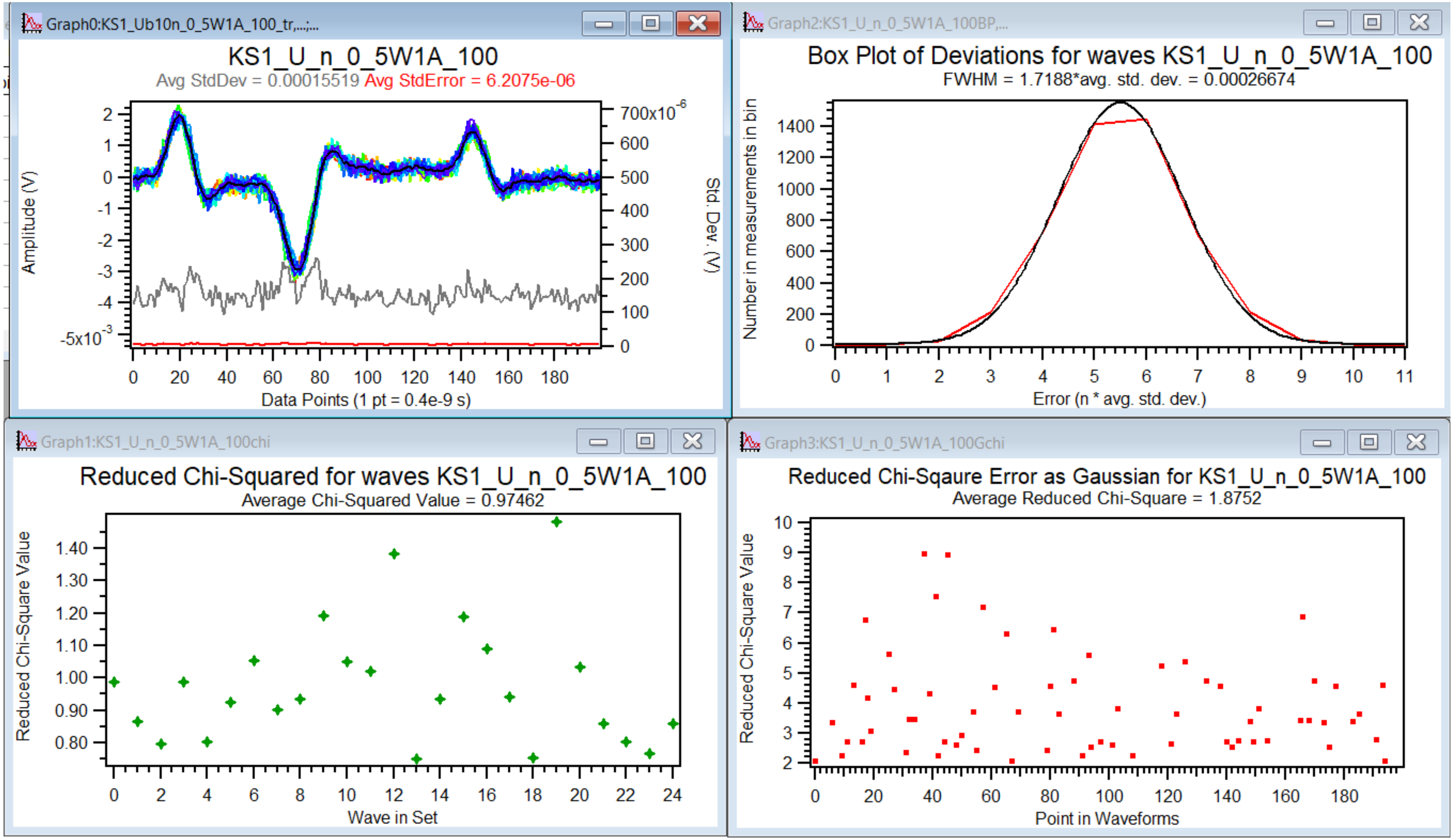
Future Work

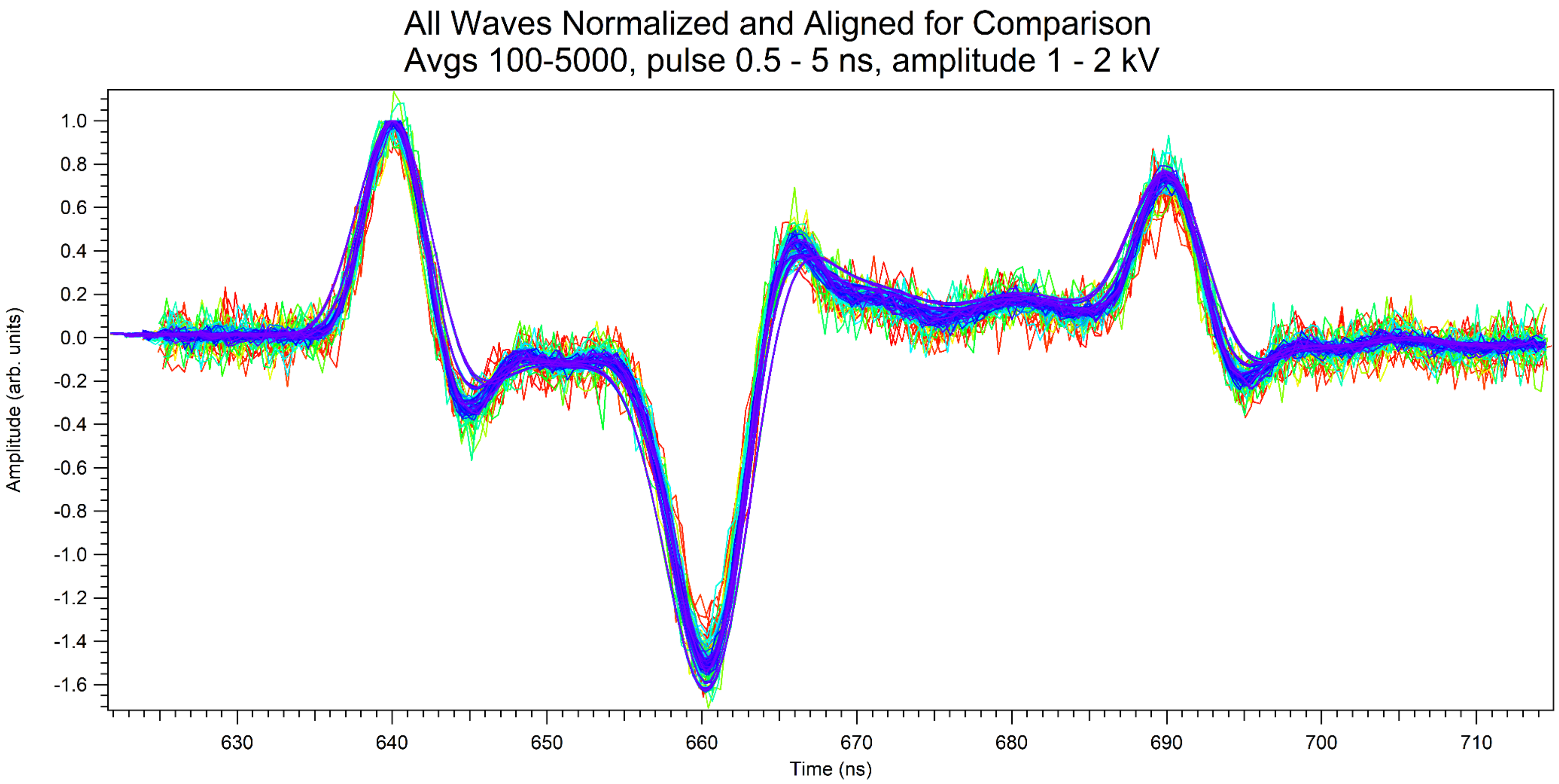
- Identify and quantify errors from
  - Sample thickness
  - Resistance of sample
  - Resistance of acoustic coupling layers
  - Thickness of acoustic coupling layers
  - HVDC Source
  - Reflections of pulsed voltage (electrical impedance mismatches)
- Solve the mystery!

References

- Pearson, L. H., Dennison, J. R., Griffiths, E. W., & Pearson, A. C. (2017). PEA System Modeling and Signal Processing for Measurement of Volume Charge Distributions in Thin Dielectric Films. *IEEE Transactions on Plasma Science, 45*(8), 1955-1964. doi:10.1109/tps.2016.2632627

Back up slides


Graph0:KS1_Ub10n_0_5W1A_100_tr,...;...
KS1_U_n_0_5W1A_100
Avg StdDev = 0.00015519 Avg StdError = 6.2075e-06
Amplitude (V)
Std. Dev. (V)
Data Points (1 pt = 0.4e-9 s)
Graph2:KS1_U_n_0_5W1A_100BP,...
Box Plot of Deviations for waves KS1_U_n_0_5W1A_100
FWHM = 1.7188*avg. std. dev. = 0.00026674
Number in measurements in bin
Error (n * avg. std. dev.)
Graph1:KS1_U_n_0_5W1A_100chi
Reduced Chi-Squared for waves KS1_U_n_0_5W1A_100
Average Chi-Squared Value = 0.97462
Reduced Chi-Square Value
Wave in Set
Graph3:KS1_U_n_0_5W1A_100Gchi
Reduced Chi-Sqaure Error as Gaussian for KS1_U_n_0_5W1A_100
Average Reduced Chi-Square = 1.8752
Reduced Chi-Square Value
Point in Waveforms



All Waves Normalized and Aligned for Comparison
Avgs 100-5000, pulse 0.5 - 5 ns, amplitude 1 - 2 kV
Amplitude (arb. units)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
630
640
650
660
670
680
690
700
710
Time (ns)