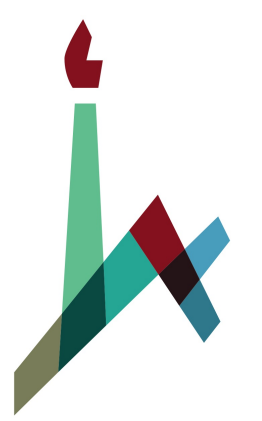


Dark Current Fluctuations in Pre-Breakdown Conditions

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Introduction

- Cathodic Breakdown (BD) is a main failure mode of systems relying on maintaining high fields under vacuum.
- We report on observations of non-Gaussian fluctuations in FE currents measured in CERN DC Spark setups and analyzed using a moving average filter.
- Such behavior is consistent with suggested surface fluctuations leading to pre-BD dynamic surface evolution.
- Initial results are reported and future experiments validating these results are proposed.

Measurements

Analysis was done on data provided by Dr. Tomoko Muranaka from the CERN DC-Spark System. The system consists of a disk cathode and hemispheric end capped cylinder anode held apart at a fixed gap. A diagram of the system is shown in figure 1. Dark currents were measured at specific sub-BD fields for fixed times. Data was initially checked for mean and variance evolution.

A running histogram window of 75 samples (ns) was applied to the measurements, normalized to have a mean value of zero, and analyzed. The resulting histograms were one of two types (figure 2):

- A single Gaussian

$$p(I) = a \cdot e^{-(x-b)^2/c}$$

- distinct splitting to a sum of two Gaussians separated by a parameter:

$$\sigma = \frac{a_1 b_1 + a_2 b_2}{a_1 + a_2}$$

There appears to be a small increase of the mean current, resulting from the splitting, and a decrease in its (figure 3). For histogram windows larger than 150(ns) the splitting vanished. The splitting of the histogram seems to behave stochastically - in a fashion similar to the behavior of mobile dislocations.

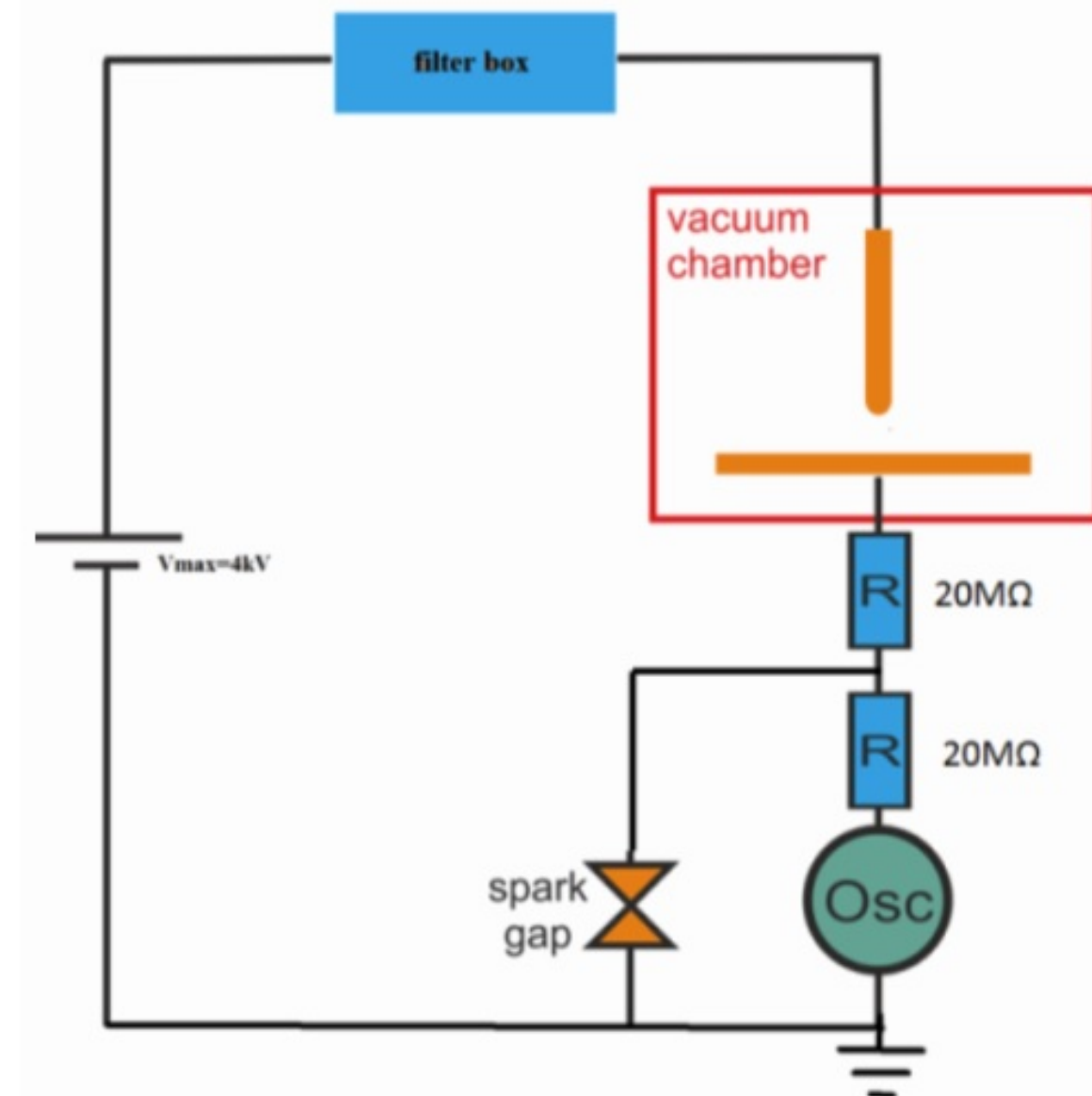


Figure 1: Schematic diagram of the DC-Spark system.

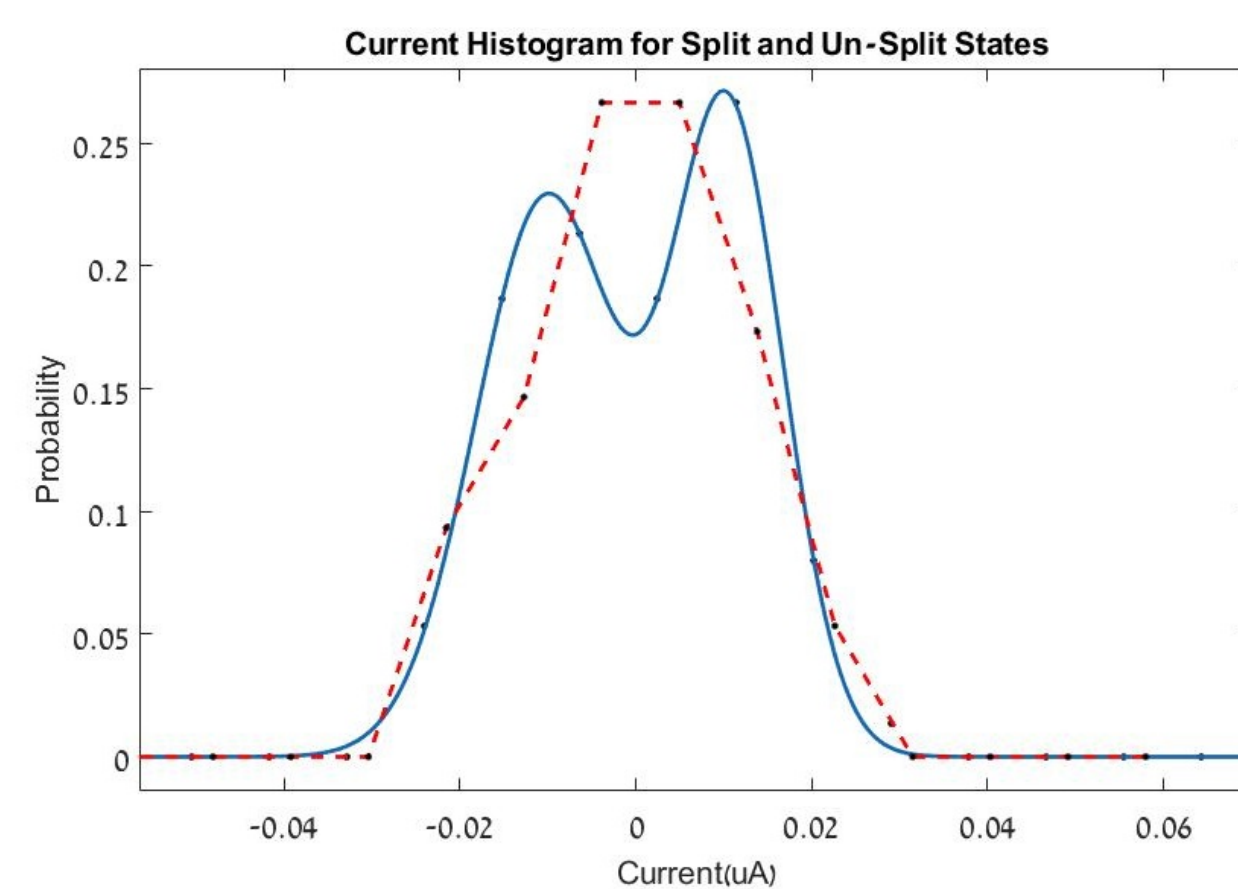


Figure 2: Current histogram for the split and non-split cases (blue and dashed red respectively).

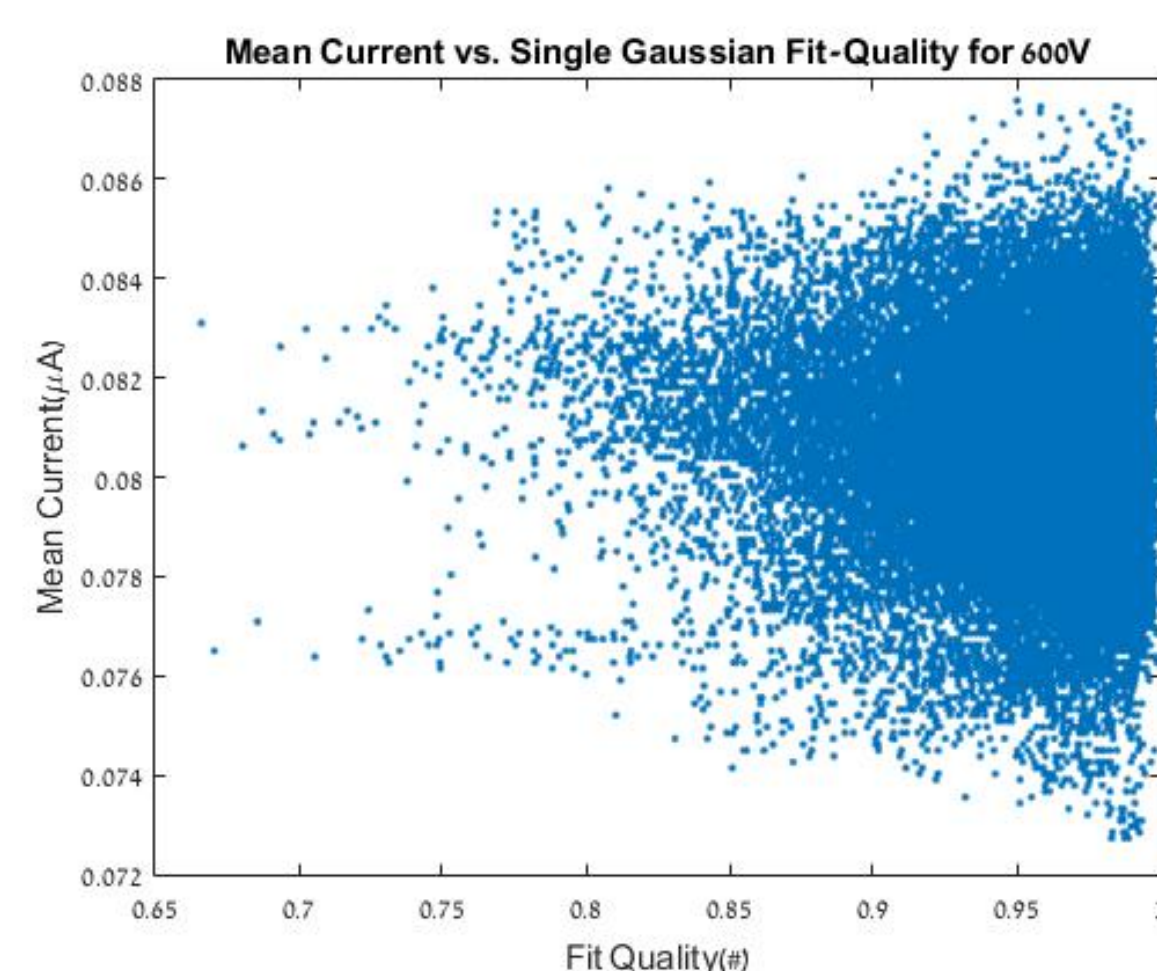


Figure 3: Mean current vs. fit quality to a single Gaussian.

Fowler Nordheim Current Histogram

The tunneling probability for a particle arriving at a barrier of height C under an external field F with an incoming energy of W is^a

$$D(W) = \frac{4(W\Delta)^{1/2}}{C} \exp\left[-3\kappa\Delta^{3/2}/3F\right], \quad \kappa^2 = 8\pi m/\hbar^2,$$

with $\Delta \equiv C - W$. The total current is given by integrating over the single energy currents $N(W)$

$$I = \int_0^\mu D(W)N(W)dW = \frac{e}{2\pi\hbar} \frac{\mu^{1/2}}{(\chi + \mu)\chi^{1/2}} F^2 \exp\left[\frac{-4\kappa\chi^{\pi/2}}{3F}\right].$$

The current probability distribution function (PDF) of a single particle energy range W is a Gaussian of the form

$$P(I) = A \binom{N(W)}{I/e} D(W)^{I/e} (1 - D(W))^{N(W) - I/e} \cong A \cdot \exp\left(\frac{(I/e - D(W)N(W))^2}{2(D(W) - D^2(W))^2 N(W)^2}\right).$$

If $D(W)N(W)$ is sufficiently sharp as a function of W around W^* , we can expect the total PDF to be similar to the single W PDF - a Gaussian with a mean $D(W^*)N(W^*)$ and a standard deviation of $D(W^*)(1 - D(W^*))N(W^*)$.

Results

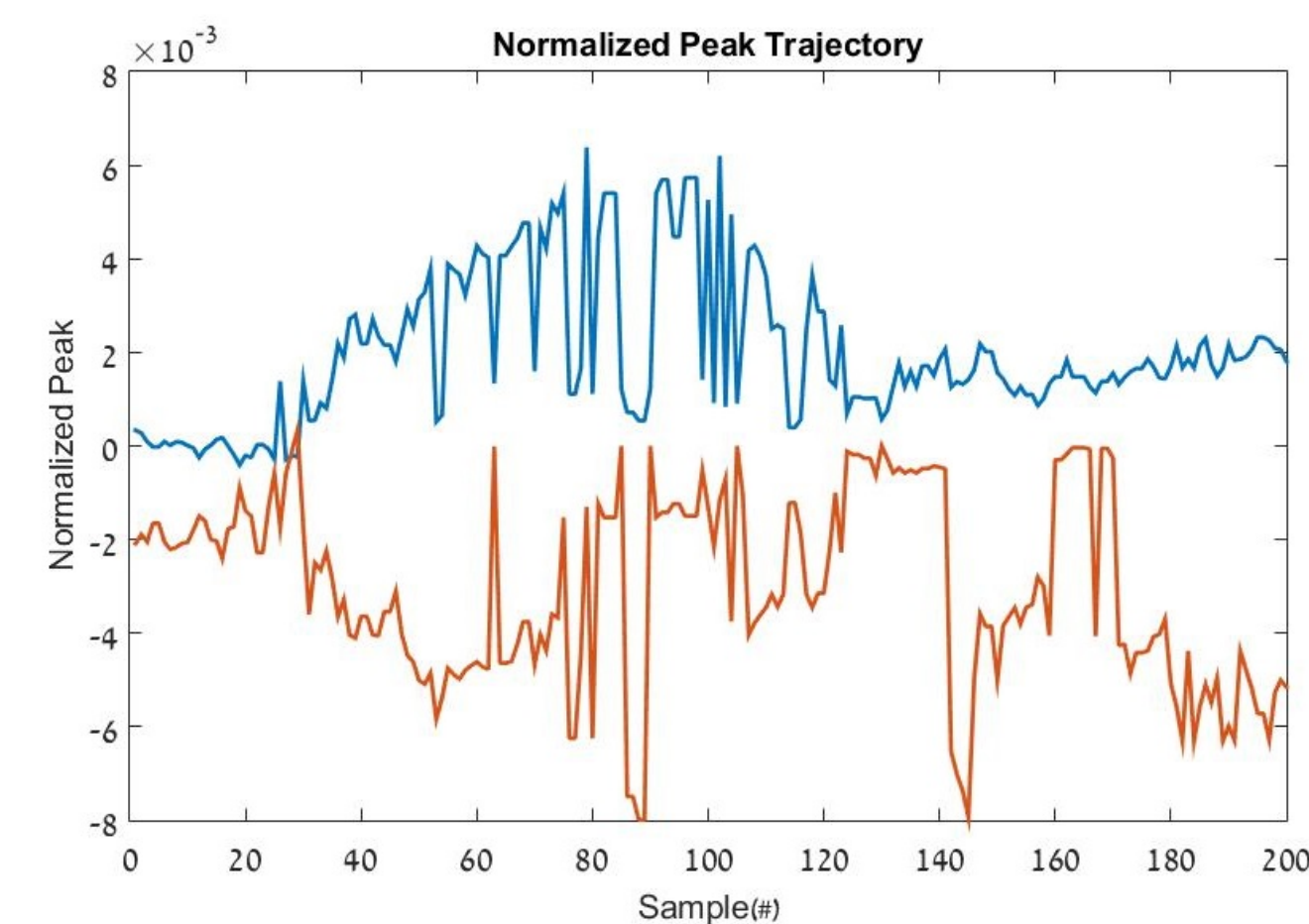


Figure 4: Trajectories of normalized histogram peak positions versus time (given by sample #) from a sample data set.

- Simulations were done for various splitting sizes.

- Apparent splitting period of 100(ns), as observed in the experiment, is reproduced for a real split period of 30(ns)

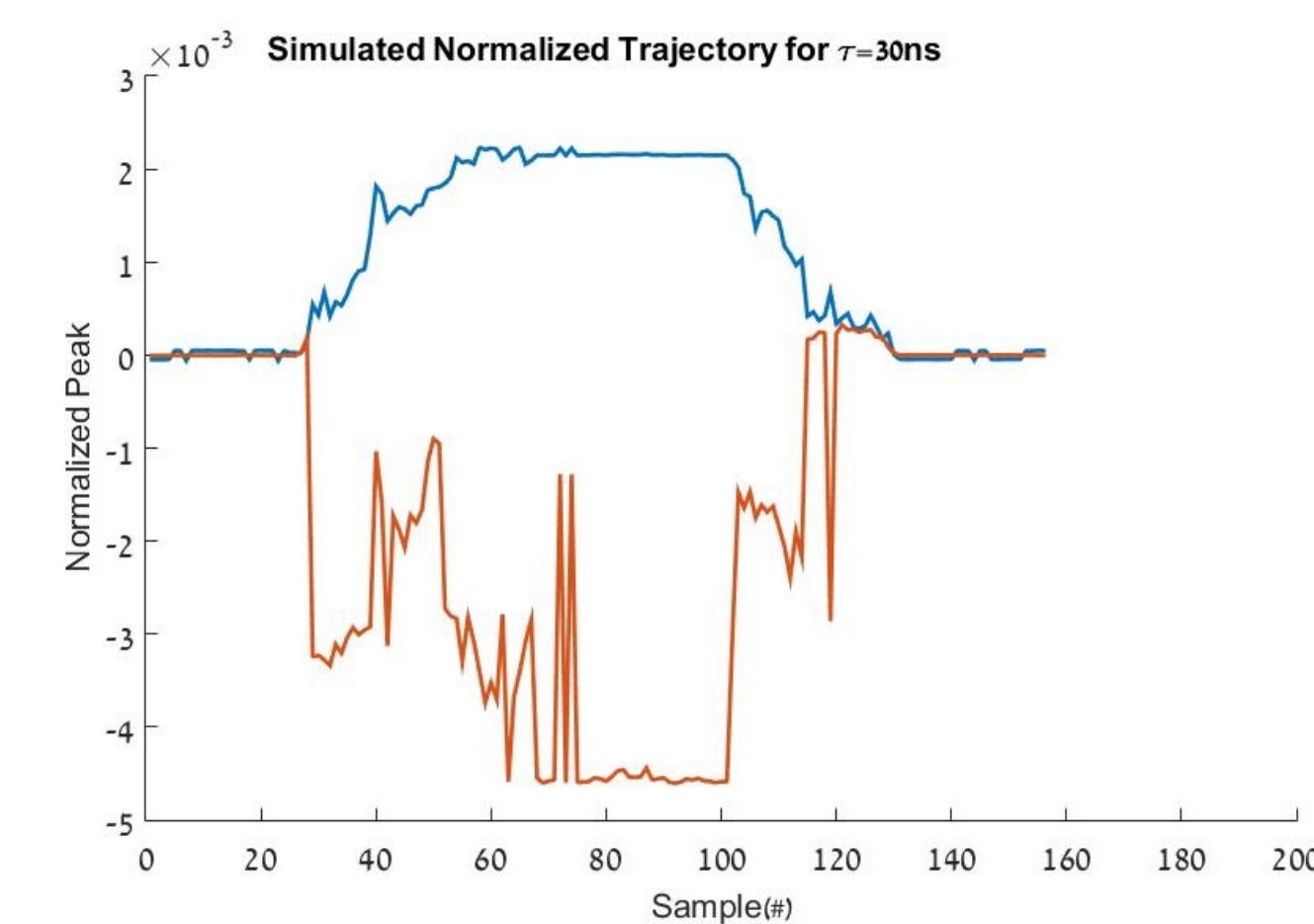


Figure 5: Trajectories of normalized histogram peak positions versus time from a simulated signal with imposed splitting of 30(ns).

- Splitting of the current histogram is a short time scale process.
- Apparent splitting period is $\approx 100(ns)$ (using a 100(ns) moving average integrator).
- To reproduce apparent measured signal, we simulated current trajectories including fixed splitting and applied a 75(ns) moving average integrator.

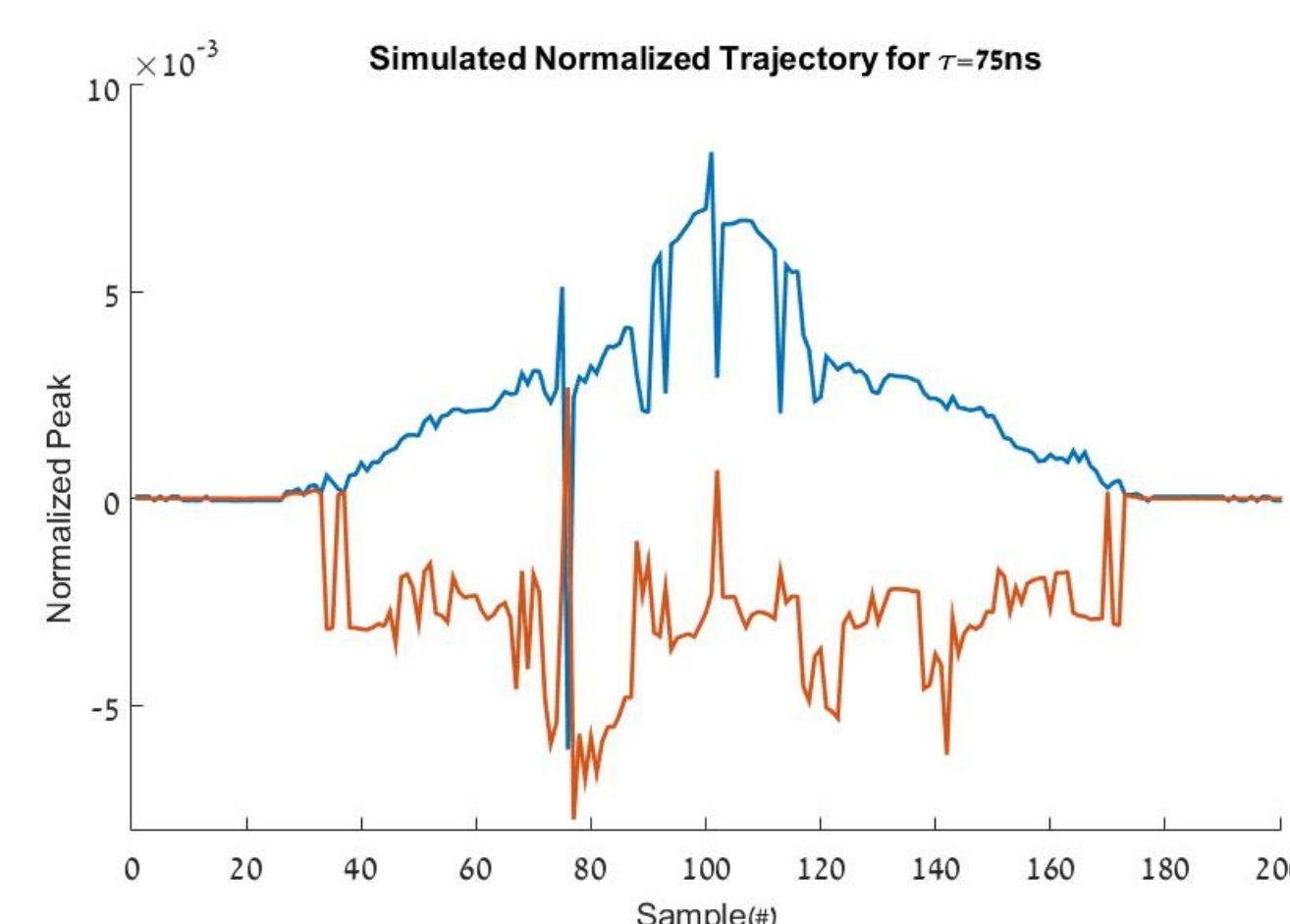


Figure 6: Same as figure 5, for simulated signal with a fixed split time of 75(ns).

Future Plans

The main difficulty of the analysis is the limited set of data: the small upper time scale of the phenomenon (10^{-7} sec) means that most available measurements were irrelevant since they were done with a time resolution of 10^{-5} sec that averaged over the phenomenon. In order to get a statistically meaningful results, further data is required.

The main vectors of analysis at this point are the peak divergence and the standard deviation of the Gaussians.

- For the peak divergence, the mean current was calculated to be^a

$$I = \frac{e}{2\pi\hbar} \frac{\mu^{1/2}}{(\chi + \mu)\chi^{1/2}} F^2 \exp\left[\frac{-4\kappa\chi^{\pi/2}}{3F}\right],$$

and so for a change of field F' , the mean current will change as

$$\frac{I'}{I} = \left(\frac{F'}{F}\right)^2 \exp\left[\frac{-4\kappa\chi^{\pi/2}}{3} \left(\frac{F - F'}{F'F}\right)\right],$$

meaning that the peak divergence should be correlated to the field enhancement factors due to surface features $F' = \beta F$.

- Increase in standard deviation may be due to increase in fluctuations of surface features leading to wider distribution of β values. By studying quantitative values of observed splitting we may be able to produce estimates to the sizes of expected surface features.
- In addition to the above data, application of an acoustic sensor array should give further indication to dislocation motion and may allow for further correlation between current splitting and measured plastic activity in the cathode.

Conclusions

- We have found experimental indications to irregular dark current fluctuations in time.
- These fluctuations are consistent with cathode surface fluctuations leading to variations in the current histogram.
- We have found a good fit of the results to a simulated splitting time of 30ns.
- This time scale is consistent with the time scale of highly driven dislocation dynamics.
- Additional high frequency high resolution of dark currents from driven cathodes is essential in order to validate these results and allow for further more conclusive interpretation.



^aElectron emission in intense electric fields - R.H. Fowler and L. Nordheim 1928