The Harvey M. Krueger Family Center for Nanoscience and Nanotechnology

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Analysis of pre-breakdown dark-currents

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Background

- We analyzed dark current measurements done by Tomoko Muranaka (from 2014) and Iaroslava Profatilova (from 2017).
- The system used was a DC setup with a needle point-plate and plate-plate gap configuration.

- The study goal is to test whether local current emitters can be identified through fluctuations in dark current.

Mathematical Basis

- Fauler and Nordheim[1] described the mean current from a single current emitter.
- Assuming an incident current of electrons, each with a probability D of tunneling the current probability should be a Binomial distribution.
- For large enough current density N, the probability becomes Gaussian of the form:

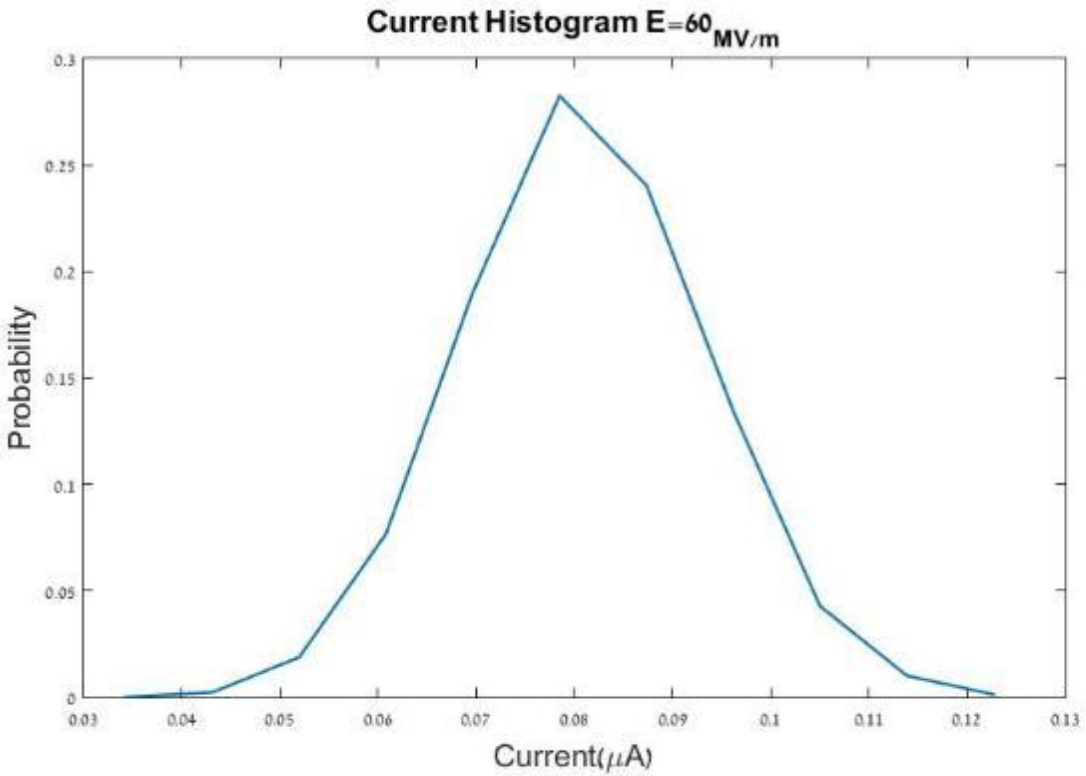
$$P(I) \cong exp\left(\frac{(I/e - D(W)N(W))^2}{2(D(W) - D^2(W))^2 N(W)^2}\right)$$

- This current is for a single incident energy W.
- While summing over W should change the result, qualitatively it should remain the same current histogram.

1 R.H. Fowler and L. Nordheim, "Electron emission in intense electric fields" (1928)

Initial Results

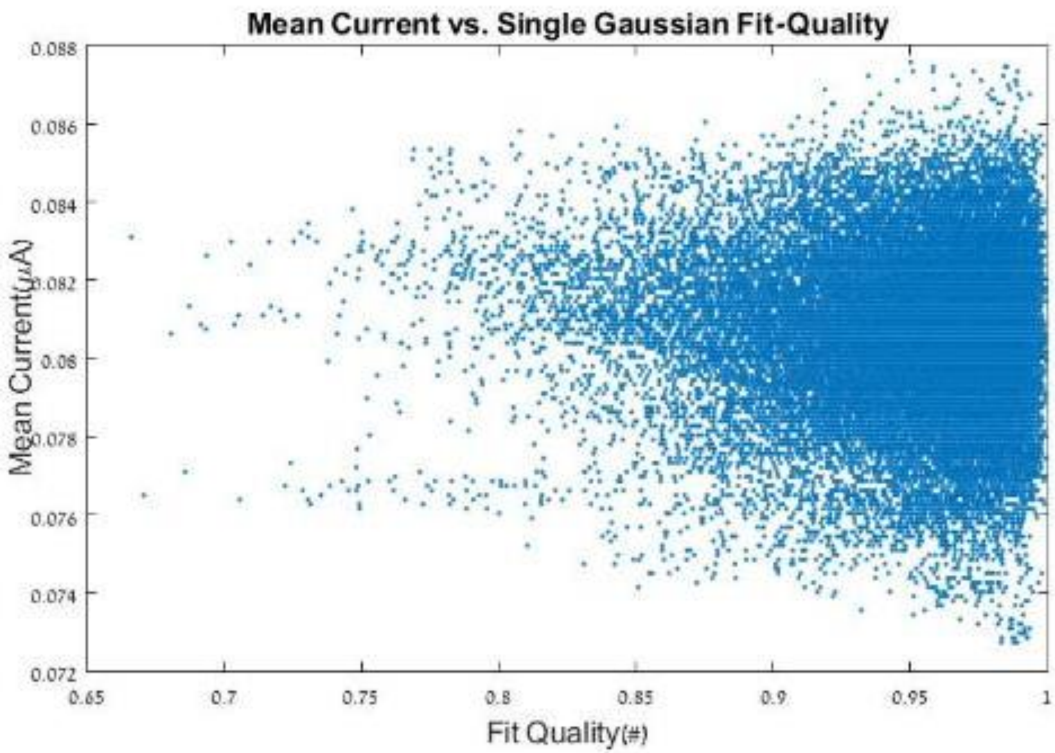
- Looking at the current histogram of an entire measurement we saw a Gaussian current distribution as expected.



Analysis Method

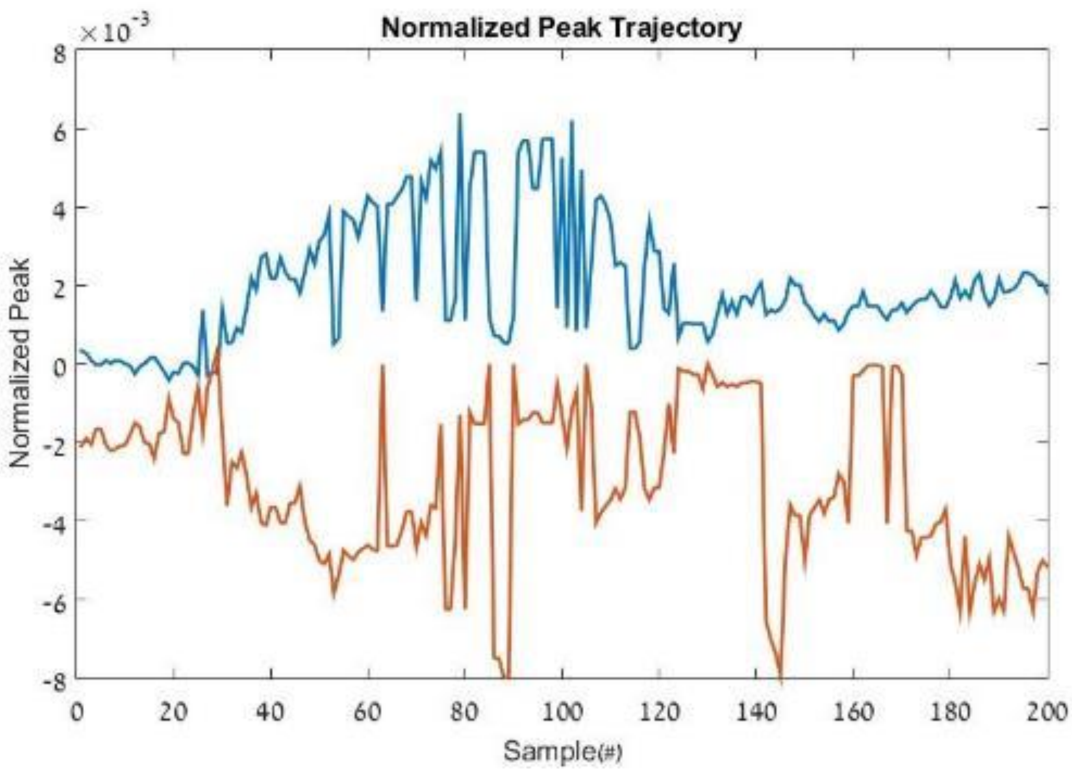
Needle-Plate Time Dynamics

- The observed splits appear and disappear sporadically without affecting the mean current significantly.
- In this graph we see the mean current vs. the fit quality to a single Gaussian.
  - The left side is the mean in a split state.
  - The right side is the mean in a single Gaussian state.



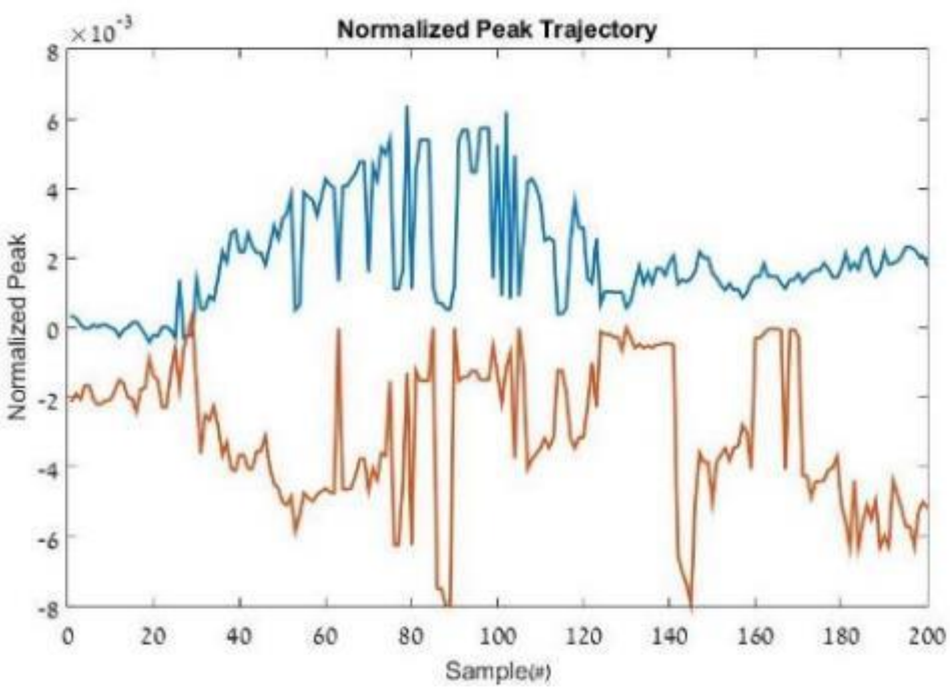
Needle-Plate Time Dynamics

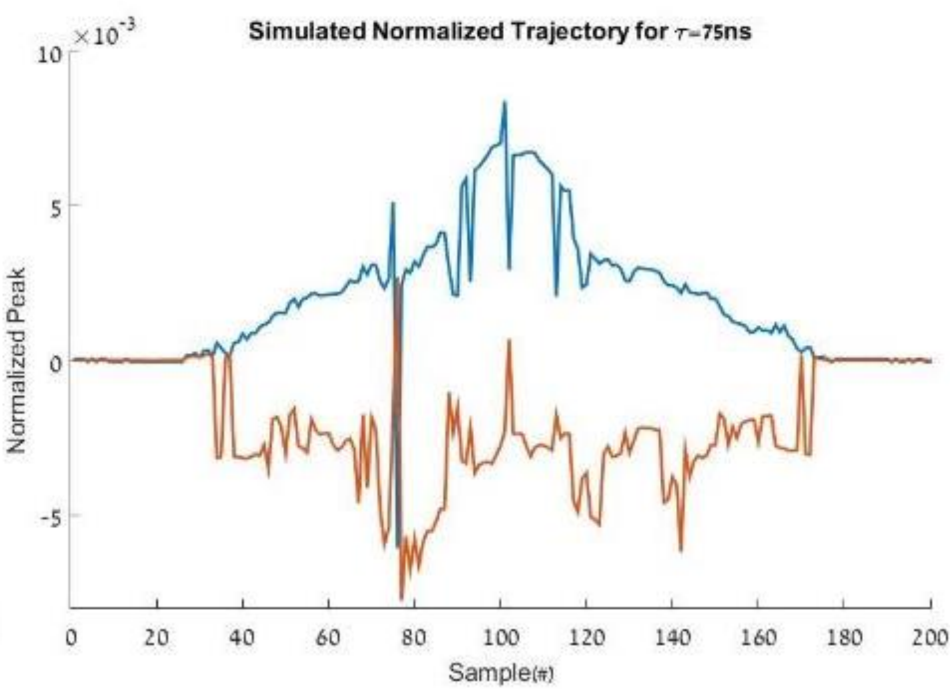
- Looking at the position of the peaks relative to one another we can observe the time evolution of the split.
- These splits range from a few tens of $nsec$ to more than $100nsec$, indicating the dynamic time range for emitter modification.



Time Dynamics Symulation

- A simulation of a split was done.
- A single Gaussian emitter was assumed at first, with a second appearing 60nsec later and disappearing after a set time.
- The behavior observed was similar to that of the measurements.





Needle-Plate Time Dynamics

- Until now we looked at the normalized current histogram, ignoring their mean value, the following was obtained by analyzing the absolute values of the histogram.
- F-N theory indicates that for a single incident energy, the STD divided by the absolute mean value of the Gaussian is related to the tunneling probability:

$$P(I) \cong exp\left(\frac{(I/e - D(W)N(W))^2}{2(D(W) - D^2(W))^2 N(W)^2}\right)$$

- The quantity $1 - \frac{\sigma}{\mu}$ should be correlated to the local field:

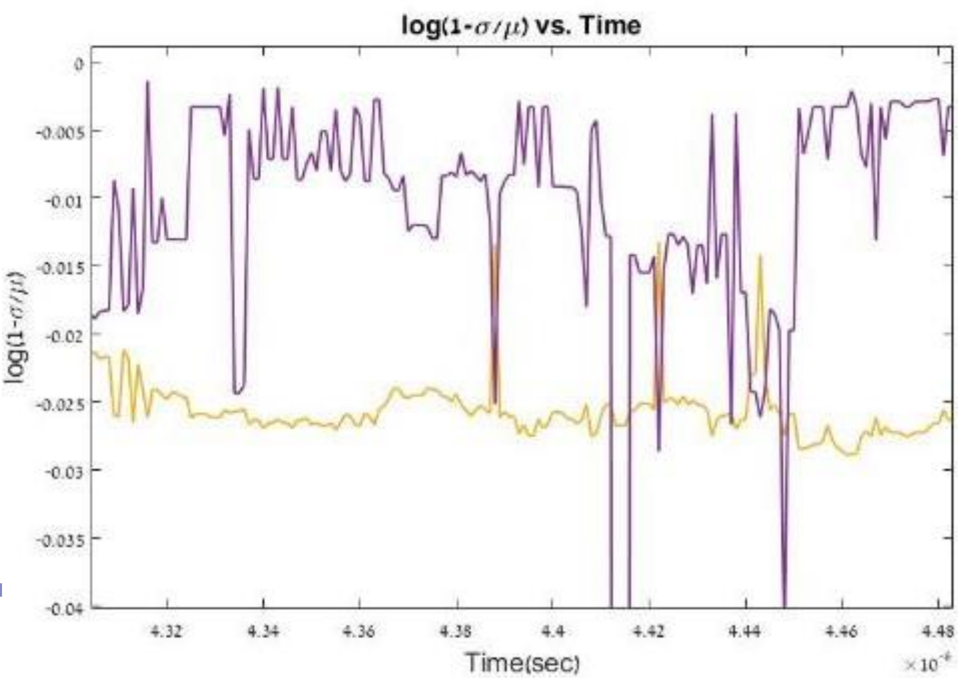
$$\sigma = \big(1 - D(W)\big)D(W)N(W)$$

$$\mu = D(W)N(W)$$

$$1 - \frac{\sigma}{\mu} = 1 - \frac{\big(1 - D(W)\big)D(W)N(W)}{D(W)N(W)} = D(W)$$

Needle-Plate Time Dynamics

- Not split (yellow and purple).
- The yellow peak is stable.
- The purple is more noisy and is a result of forcing a 2-Gaussian fit on a single Gaussian.
- Split (red and blue).
- The split peaks are highly correlated.
- Close to the split there is a weak correlation between the peaks.



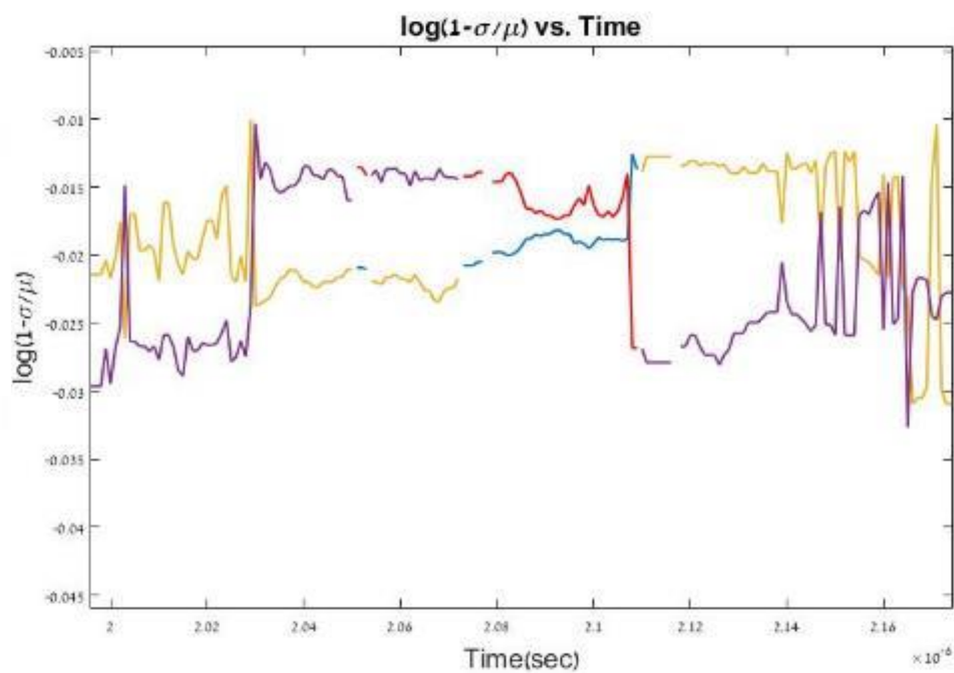
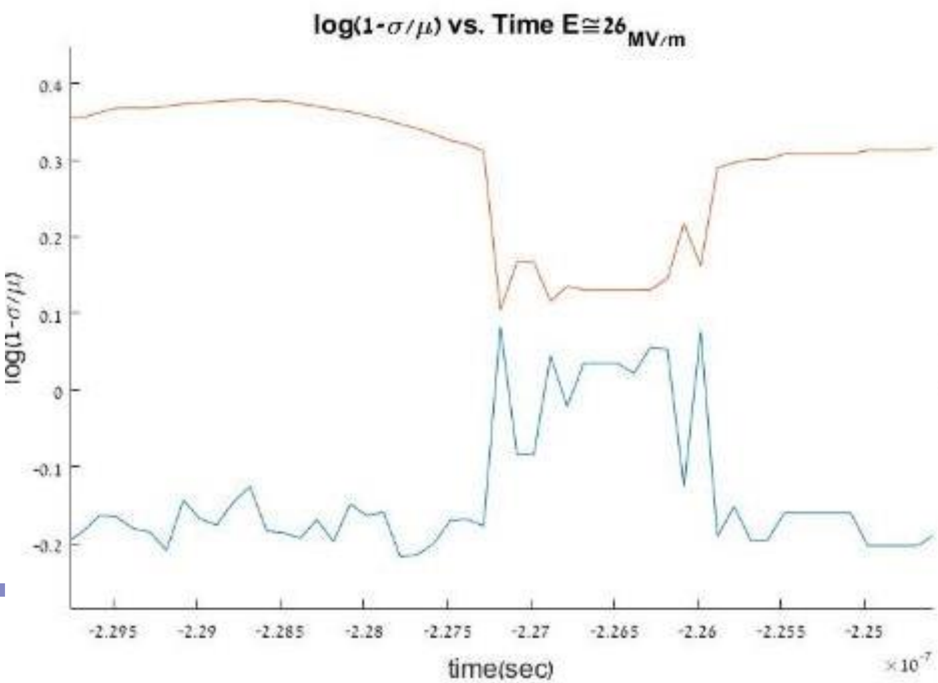


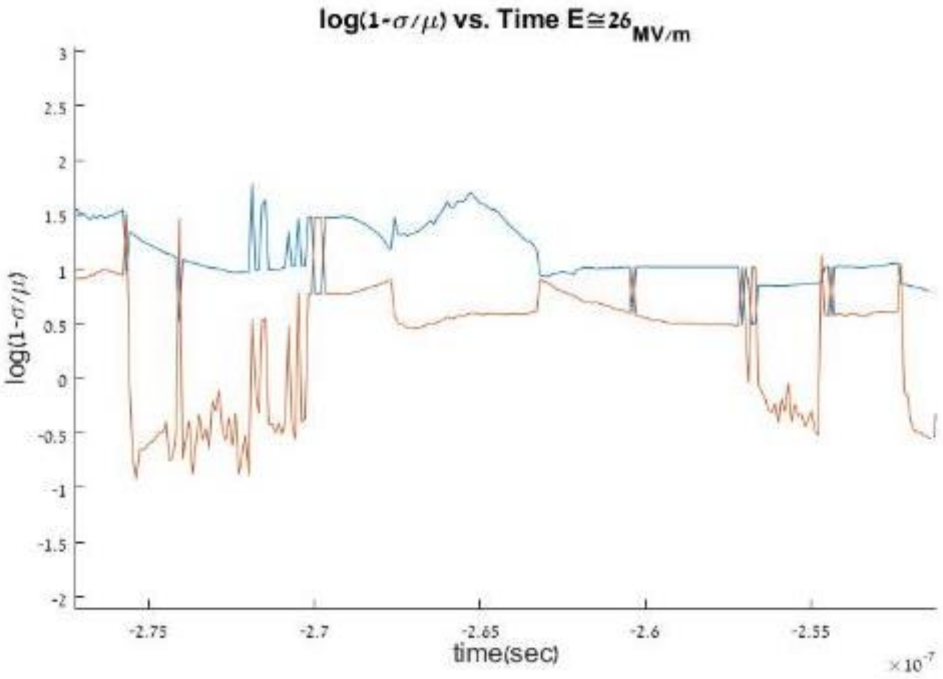
Plate-Plate Time Dynamics

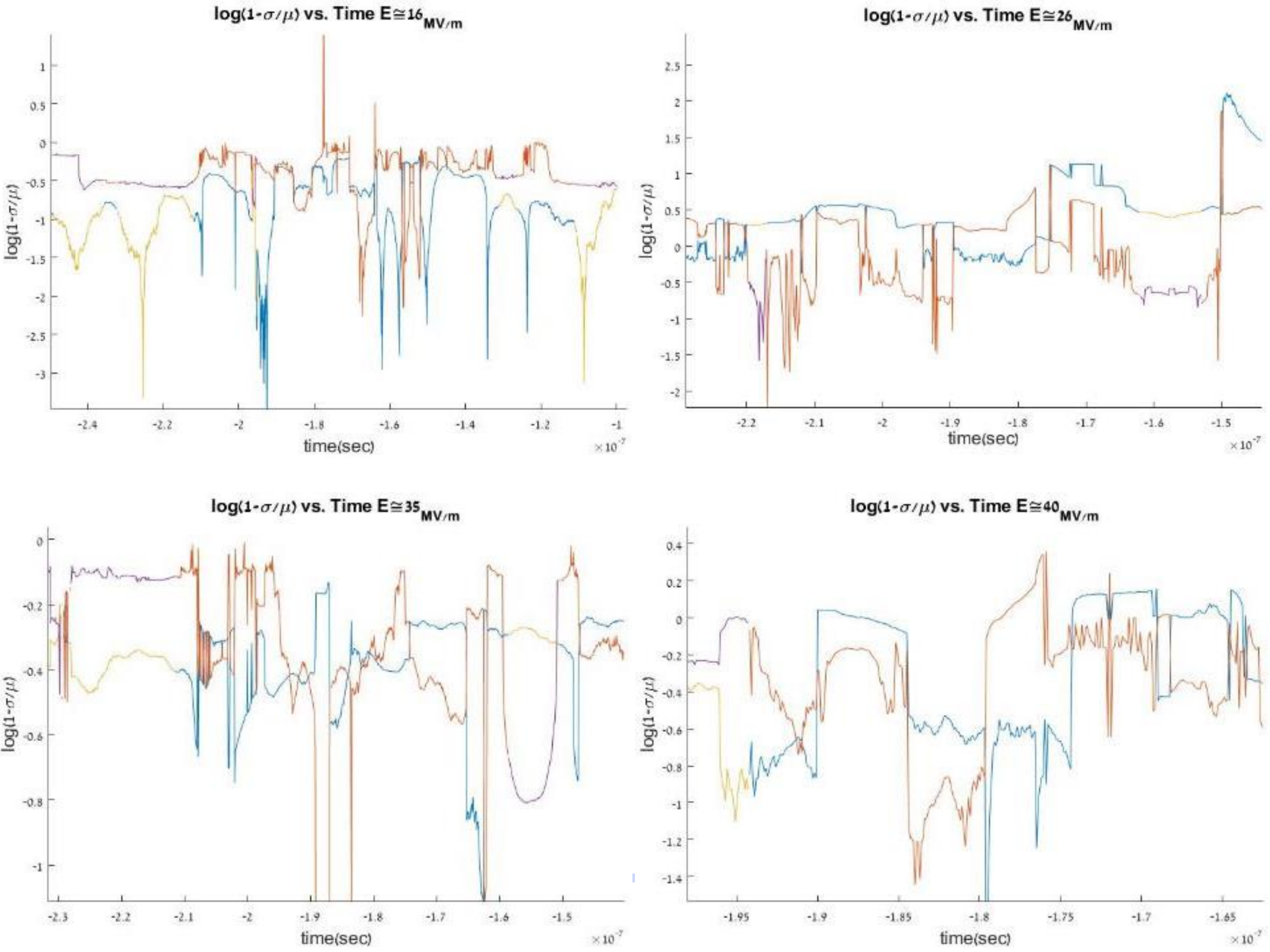
- In this data we saw the same phenomenon but also something new: low-correlation in a split state.

- High correlation as was previously observed.



- Low correlation.
- While some correlation can be seen, it is not as strong or widespread as before.

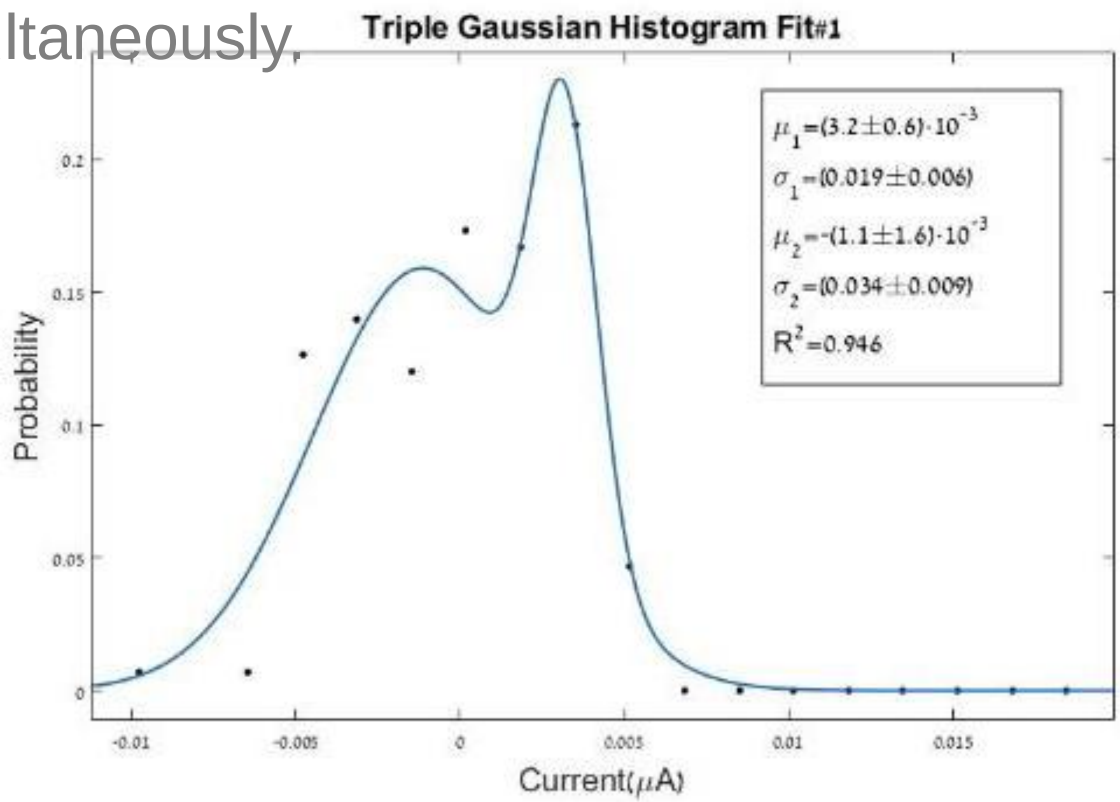




log(1-σ/μ) vs. Time E≅16 MV/m
log(1-σ/μ)
time(sec)
×10^-7
log(1-σ/μ) vs. Time E≅26 MV/m
log(1-σ/μ)
time(sec)
×10^-7
log(1-σ/μ) vs. Time E≅35 MV/m
log(1-σ/μ)
time(sec)
×10^-7
log(1-σ/μ) vs. Time E≅40 MV/m
log(1-σ/μ)
time(sec)
×10^-7

Plate-Plate Time Dynamics

- More careful inspection shows a difference in the current histograms:
- Low-correlated histograms where not as good a fit for two Gaussians.
- This may indicates that more than one type of field emitter appears simultaneously.
- Two Gaussians have 5 degrees of freedom after normalization.
- The measurement has 7-8 non-zero values.
- The data is over-fit.



Gaussian Split

- High correlation between emitters indicates a correlation between their fields.
- Since in the larger tunneling area of the plate-plate configuration there was a lower correlation, we can speculate that it is a short distance correlation.
- Two possible explanations for the local correlation are:
  1. A larger surface area means that there is a higher chance of two simultaneous emitters.
  2. The three observed emitters are the current emitter, the close area that is correlated due to local effects and the far away, un-correlated emitter.

Summary

- Pre-breakdown dark current measurements were analyzed assuming single and multiple emitters.
- Splitting in the local current histogram was observed in both needle-plate and plate-plate configurations.
- This splitting can be a result of additional current emitters, each with its own field strength.
- In some cases, two emitters are not a good enough fit for the results despite the small number of points. These cases also have a lower correlation.
- Low-correlation splits are probably a result of the larger effective tunneling area of the plate-plate configuration.
- In order to analyze low-correlation splits better current resolution is required.

Future plans:

- Further analysis of existing measurements – We want to be able to find a property that has a clear dependence on the E field and to better quantify the correlation.
- Hope for additional dark current measurements.
- Correlating observed current fluctuation with other types of signals.