# Breakdown statistics in the large-electrode DC spark system

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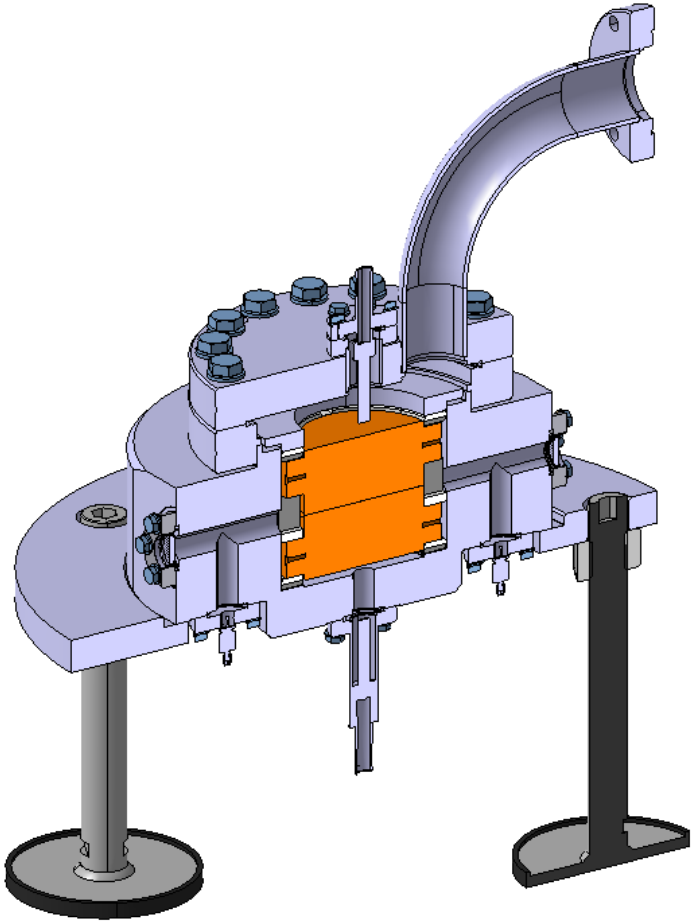
# The Large-Electrode System

(a.k.a. the ”Fixed Gap System”)

- Consists of two precision-manufactured parallel disc electrodes (diameter 62 mm) in a vacuum chamber
- An interchangeable ceramic insert sets the inter-electrode gap distance
- Key feature is the large parallel surface, making system more analogous to RF structures than previous DC spark systems with pin-plane electrode geometries
- Measurement control system can apply voltage pulses of amplitude up to 8 kV and length up to 8 μs, at repetition rate of 1 kHz



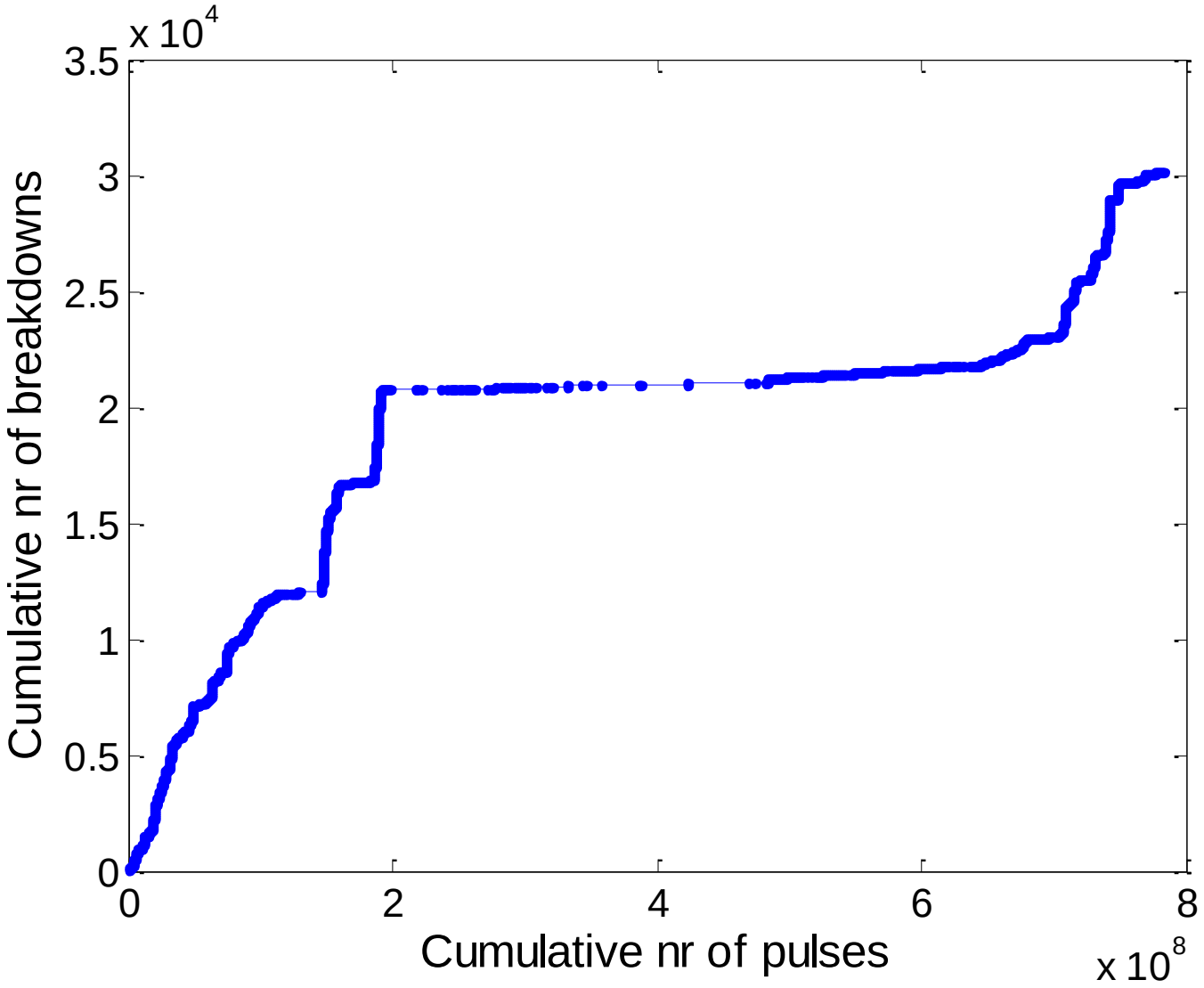
# Overview of experiment

- A pair of much-used, already conditioned, electrodes was used to minimize conditioning during the experiment

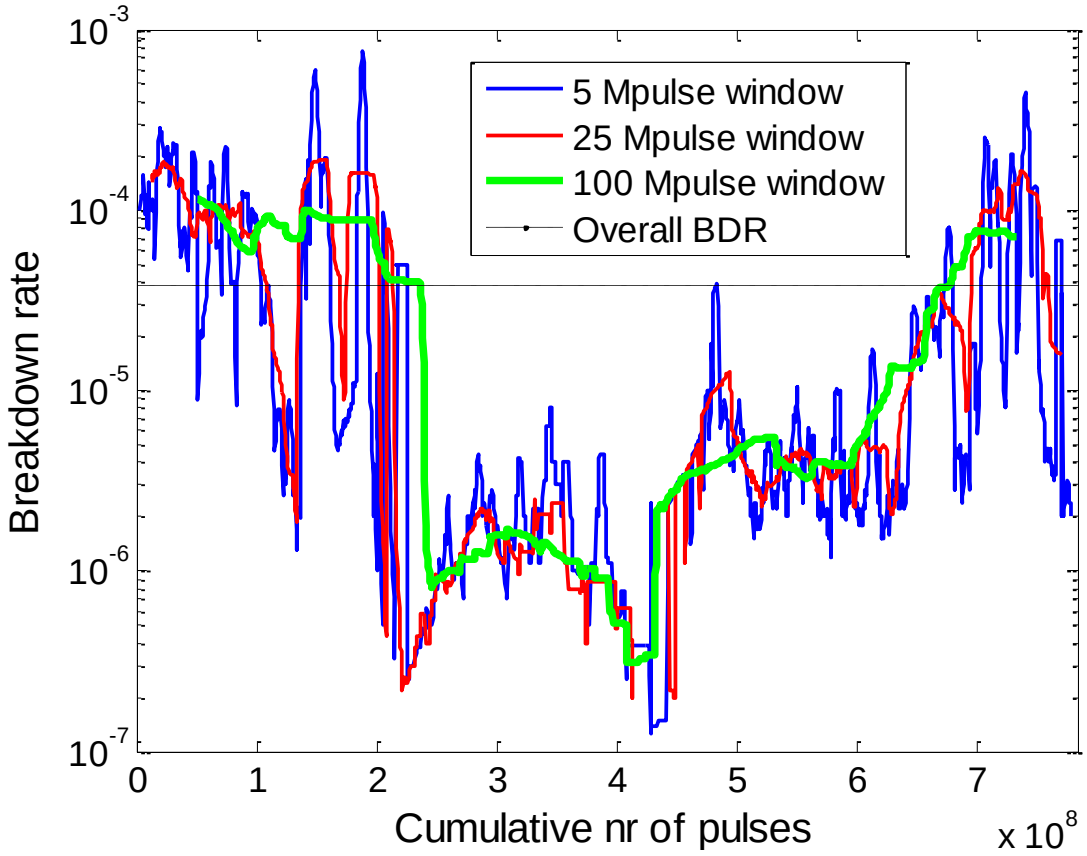
- Electrodes were set 60 µm apart, subjected to sequences of voltage pulses of amplitude 2.3 kV, length 6 µs, rep rate 1 kHz. In each sequence, voltage was ramped up as 1 - exp(-t) towards the max voltage, reaching 99% of it at about 1400 pulses. When a breakdown happened, pulsing stopped, and number of pulses in the sequence recorded. After waiting 30 s for the system to recover, the next pulse sequence was started.

- A total of 30108 breakdowns happened over 784 million pulses over a measurement run lasting 24 days, giving an aggregate breakdown rate (BDR) of 3.84e-5
  - Mean number of consecutive pulses before breakdown was 26 040, median was 1248
  - Largest number of pulses before breakdown was 44 791 343

# Cumulative nr of pulses vs breakdowns



# Breakdown rate change over time

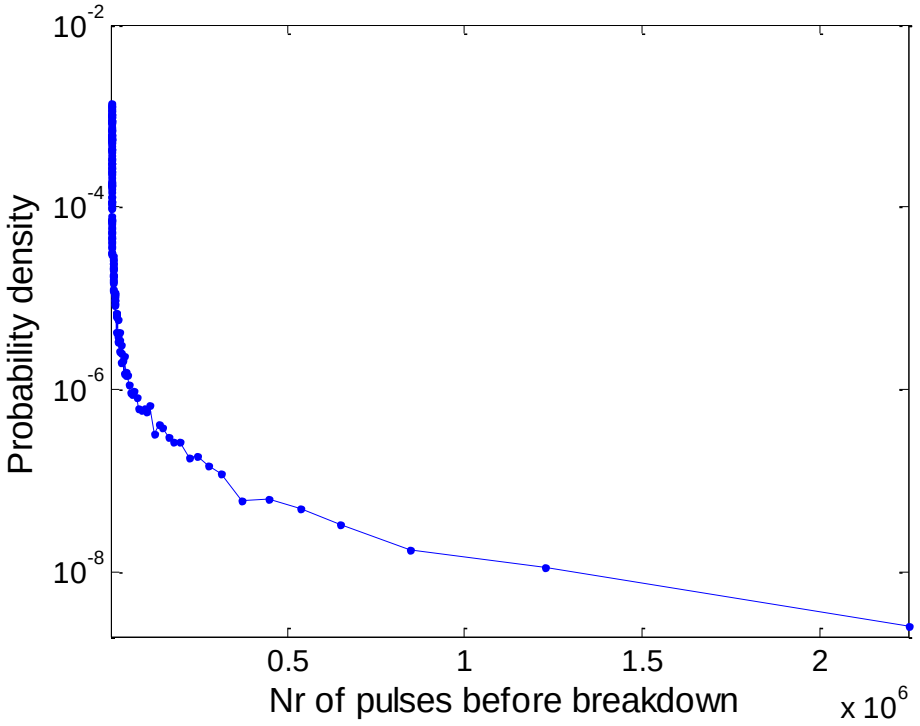



Change in breakdown rate over the course of the measurement run is shown here, calculated by counting the number of breakdowns in a sliding window of number of pulses, shown with different window sizes

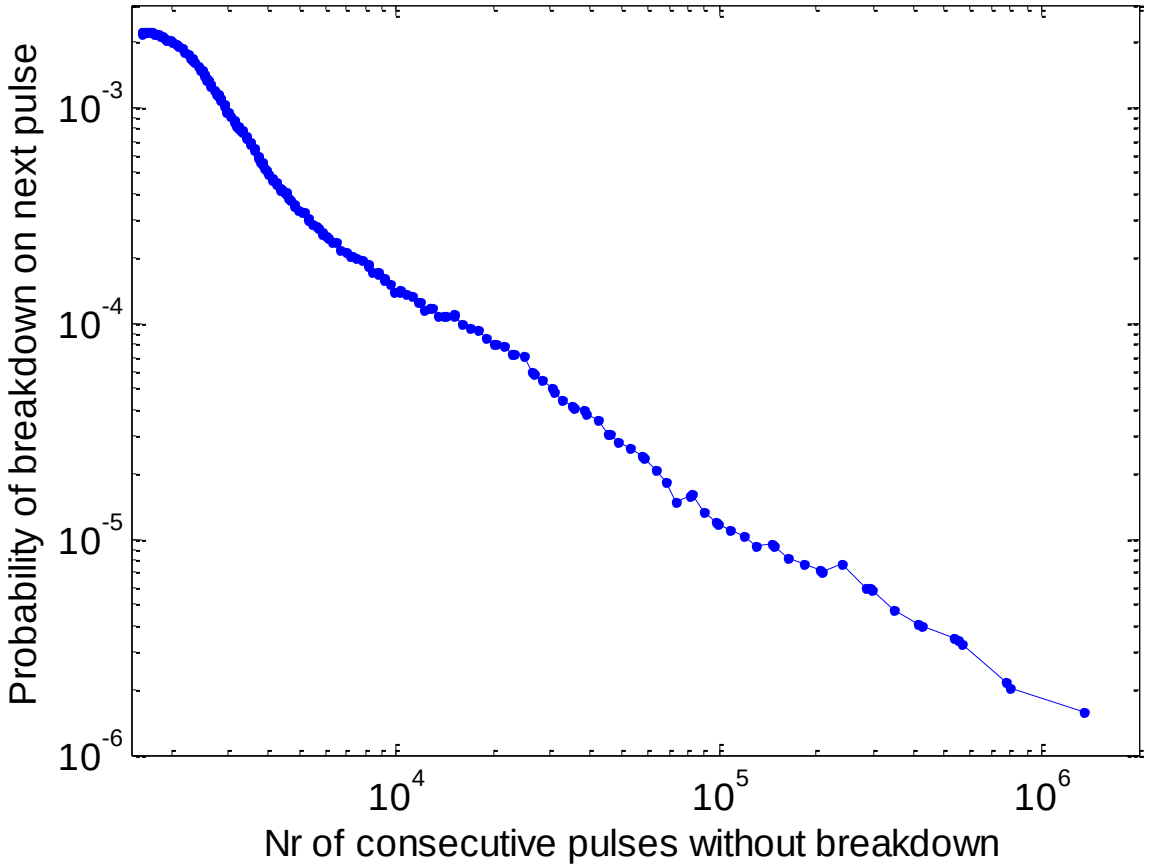
# Statistics of nr of pulses before BD

- Distribution of nr of pulses before BD. Data is shown with a logarithmic y-axis as a straight line then corresponds to Poisson statistics, with a slope proportional to BDR. The changing slope shows the non-Poissonian nature of the data.

- By fitting lines to segments of the probability density, we can obtain the probability of having a breakdown on the next pulse, as a function of how many consecutive pulses we have already had without BD



# Statistics of nr of pulses before BD (continued)

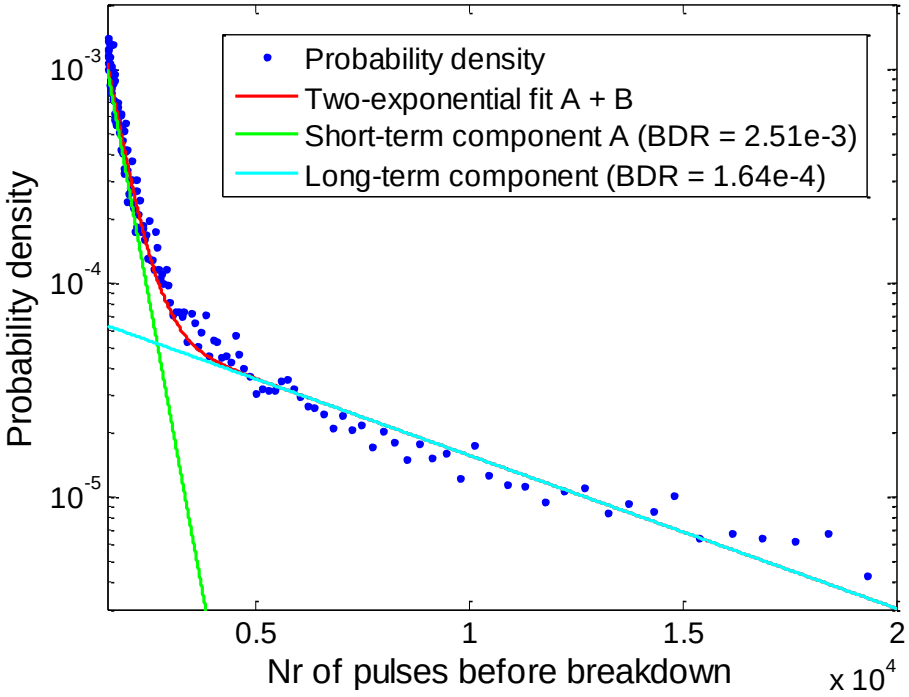


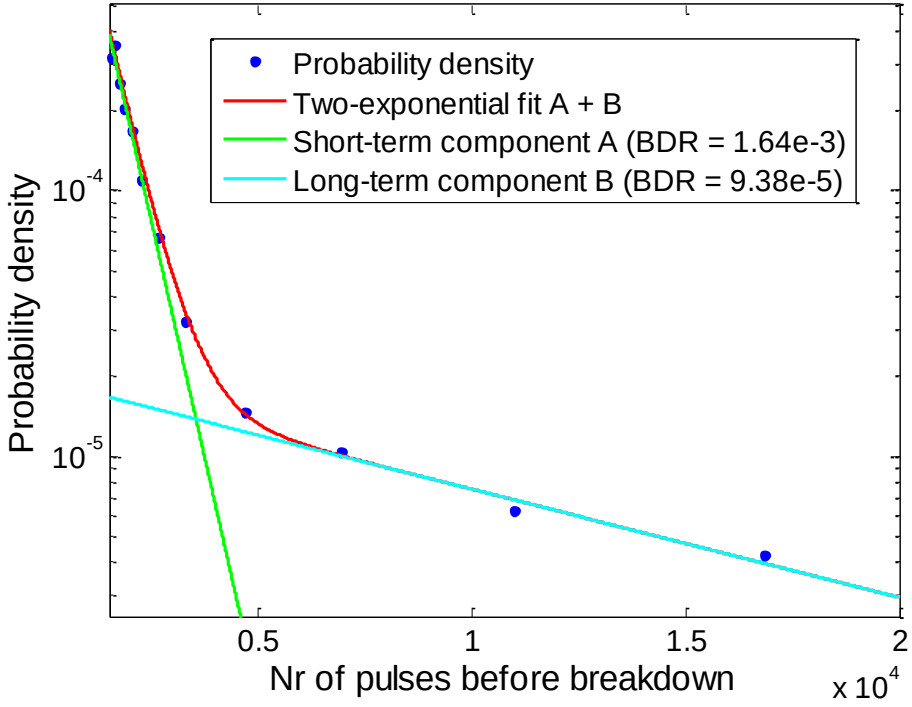

We see that every pulse without BD cumulatively decreases the probability of having a BD on the next, without any visible convergence towards any ultimate value

# Two-Rate Model

- 93% of all breakdowns happened before 20000 pulses, thus the early part of the distribution is of particular interest
- Hypothesis: Each breakdown is either a primary breakdown, or a follow-up breakdown enabled by a previous breakdown through śome mechanism
  - Primary breakdowns happen at a lower rate but can always happen, regardless of the state of the system
  - Follow-up breakdowns happen at a higher rate, but only when the necessary conditions are present
- Thus, the obtained distribution of nr of pulses to breakdown is a superposition of two Poissonians

# Two-Rate Model (continued)




Shown are the Two-Rate Model fit to the distribution up to 20000 pulses, for the experiment (left, 2.3 kV, 6 µs pulse length) and a recent run with other parameters (right, 2.5 kV, 5.83 µs pulse length). The model fits the data remarkably well. The latter run has lower BDRs for both components, but the ratio between the two rates is remarkably close (15.3 and 17.5)

# Conclusions

- Even when run at constant conditions, breakdown rate in a large-electrode structure varies over a few orders of magnitude over the long run
- Breakdown statistics don't seem to become Poissonian after any amount of consecutive pulses without breakdown, as far out as the data is sufficient to study
  - Short-term conditioning?
  - On the other hand, changes in BDR over the measurement make interpretation of tail-end of distribution more difficult
- Two-Rate Model developed by us decently explains breakdown statistics in the lower end of the distribution, and is consistent with previous knowledge about breakdown clustering