From natural mutation to DC breakdown

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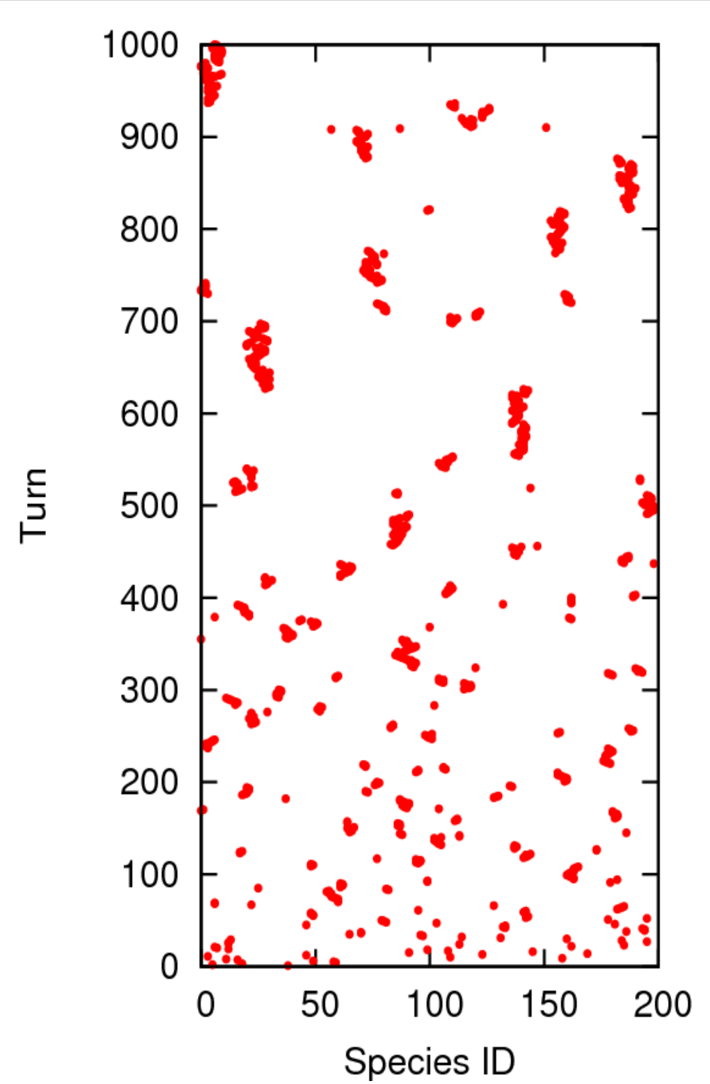
Motivation

- Understand statistics in DC Spark
- Develop a better understanding of breakdowns (long term, compared to most models which concentrates on one breakdown)
- Test hypotheses of how breakdowns modifies the surface over time

Background



- Bak and Sneppen (1993): ”Mutation avalanches” can occur from **undirected** random behaviour
- Each species have a random number, a weakness parameter
- Weakest species mutate, along with its closest neighbours
- Mutation is simply selecting a new random number (**no preferences**)
- After a few turns, local bunches are observed
- No assumptions about what the parameter is, other than it is a ”weakness parameter”

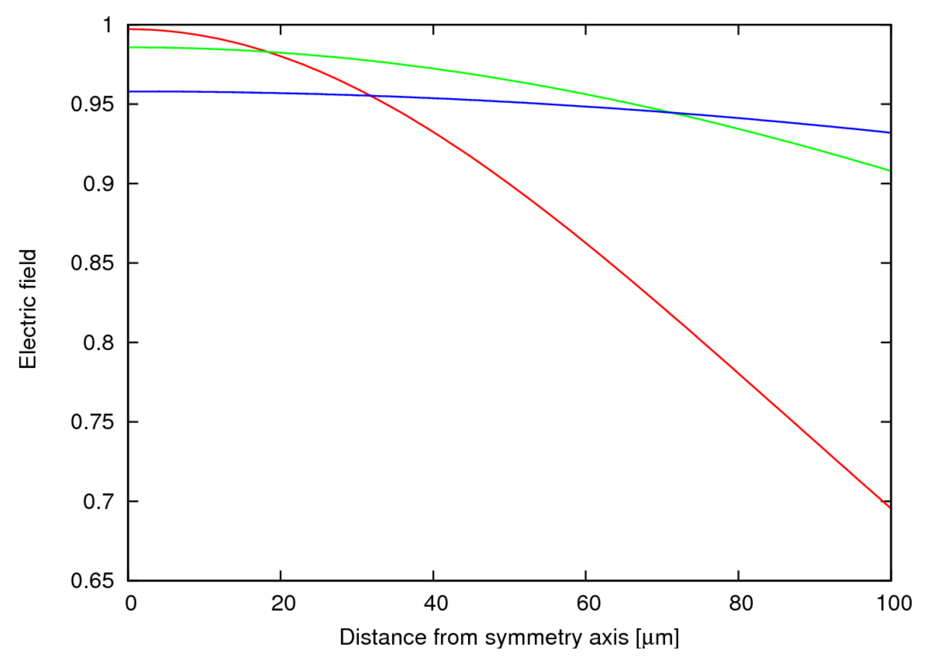
The link

- Breakdowns are (assumed by some) triggered by a weakness parameter (β, but could be more complex)
- Breakdowns often occur in bunches
- ”Turn based”
- Neighbourhood of a breakdown origin is also affected

The basic model

- Cathode surface have n number of weak points (protrusions)
- Positions are initially chosen randomly, but kept fixed for simplicity
- Each weak point have a weakness parameter (β)
- Actual DC tip-plane field distribution is used, with typical gap distances (usually 20 μm unless otherwise specified)

The basic model



- Actual cathode field distribution used
- Graph shows electric field distribution on cathode normalized in units of parallell plate field (V/d)
- 20 µm (red), 50 µm (green), 100 µm (blue) gap distances

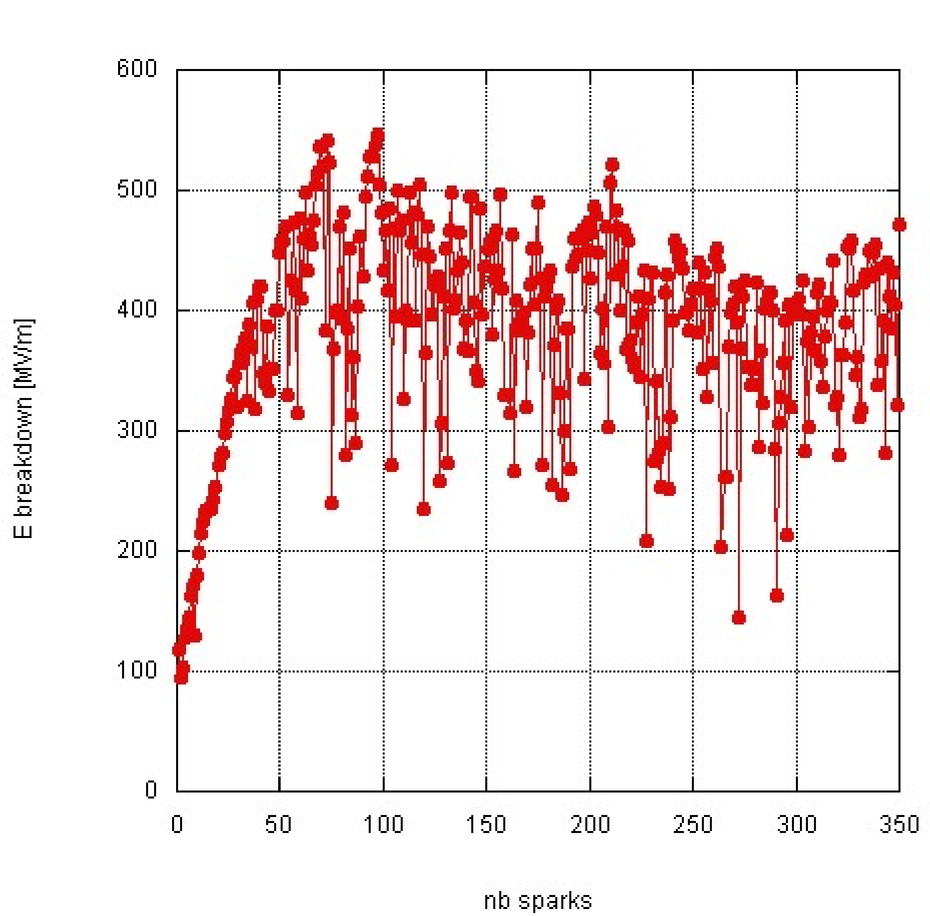
The basic model

- If a limit βE is reached, a breakdown occurs
- If no breakdown occurs, field emission is assumed capable of slight modification of the protrusion sites
- After a breakdown, a new weakness parameter is chosen for the location, according to a given distribution (i.e. no history of breakdown energy)
- Neighbouring locations redistributed in same way

DC breakdown

- Initial conditioning is understood by an initial rougher surface (higher β values)
- Initial β values taken from Gaussian distribution with mean 40, standard deviation of 10
- After breakdown, β values are taken from Gaussian distribution with mean 30, standard deviation of 2
- Field emission => Markov chain (Gaussian distribution with mean equal to previous value, standard deviation small and **proportional to local field**)

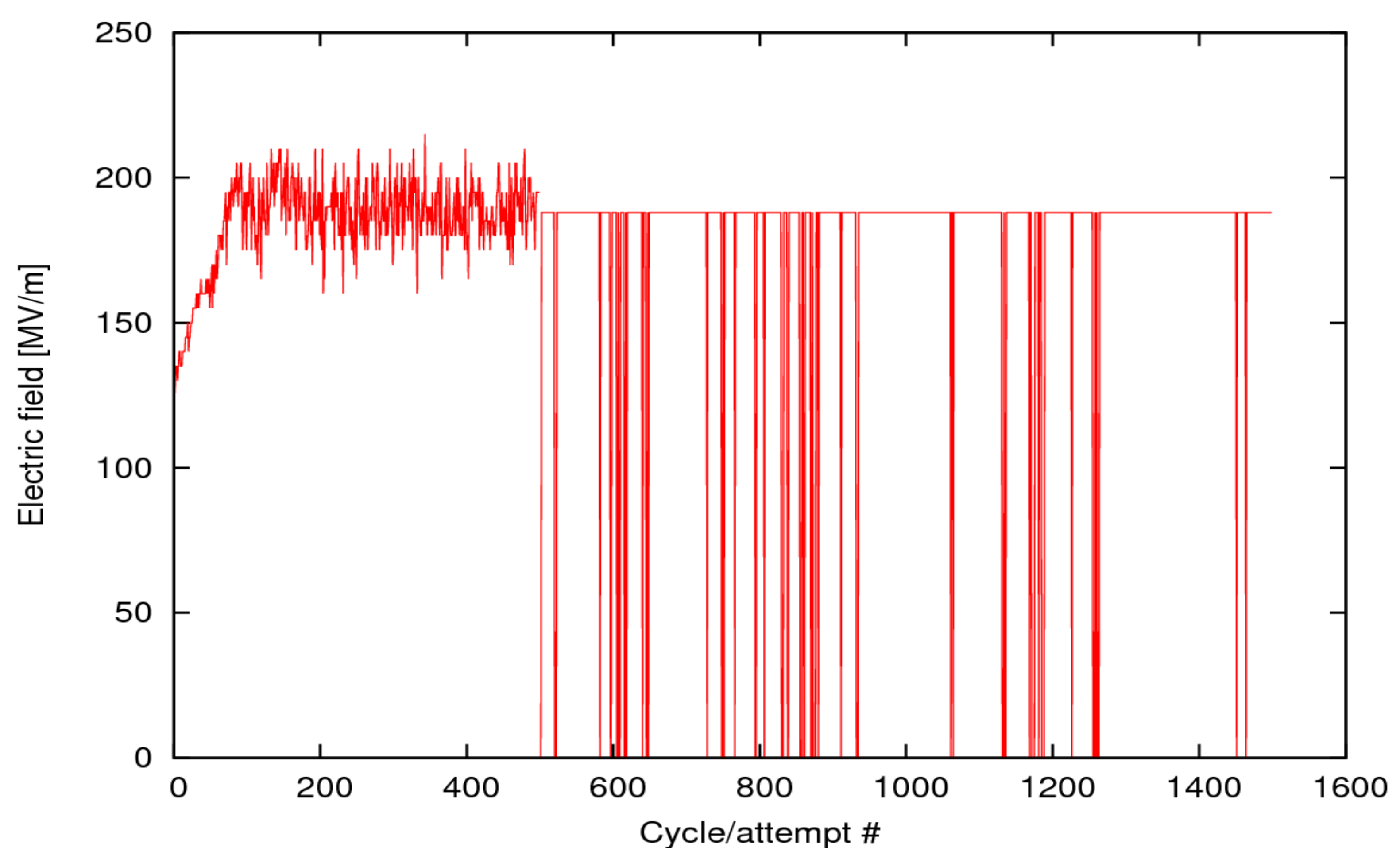
DC breakdown



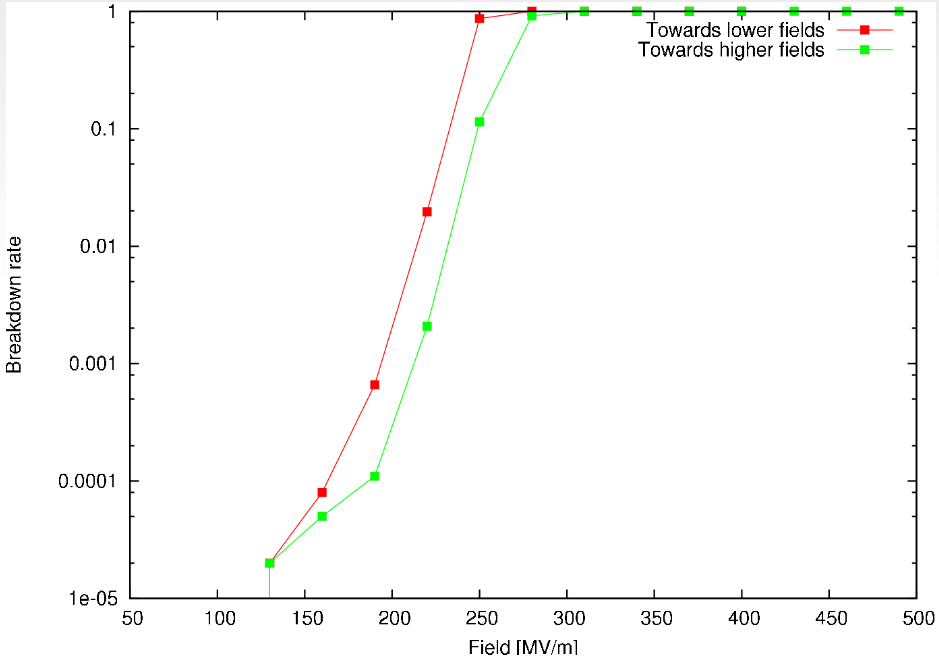
Courtesy A. Descoeudres

- Rapid conditioning, followed by fluctuation around a mean breakdown field, denoted saturated breakdown field
- Some materials show conditioning (e.g. Mo), some do not (e.g. Cu)
- Breakdown rate at saturated breakdown field found to be a few percent

DC breakdown



DC breakdown

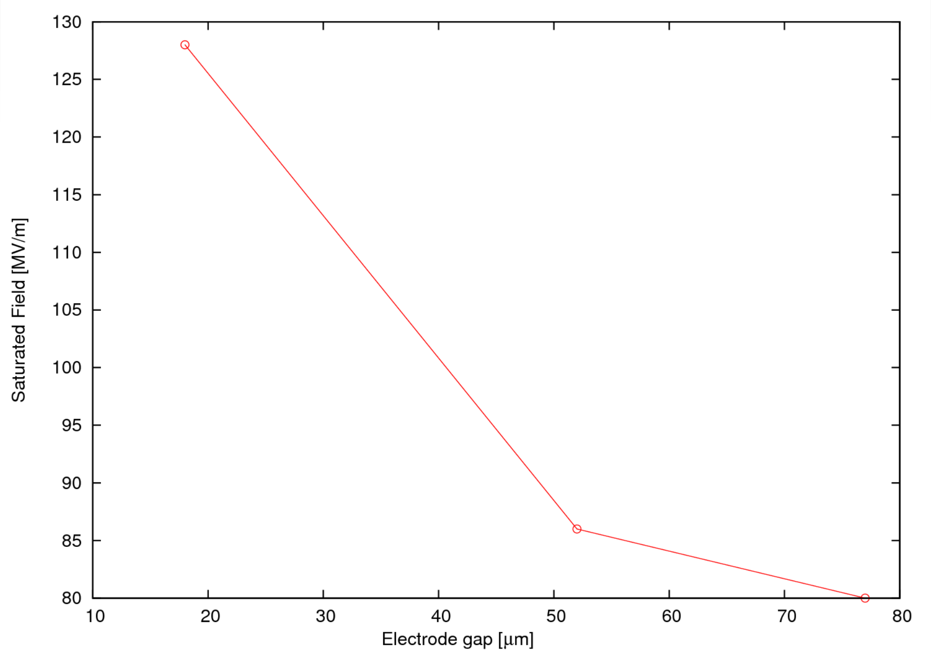


- 100k attempts at each field value
- First decreasing field until 0 breakdown rate, then increasing again
- Similar ”directional dependence” found in experiments

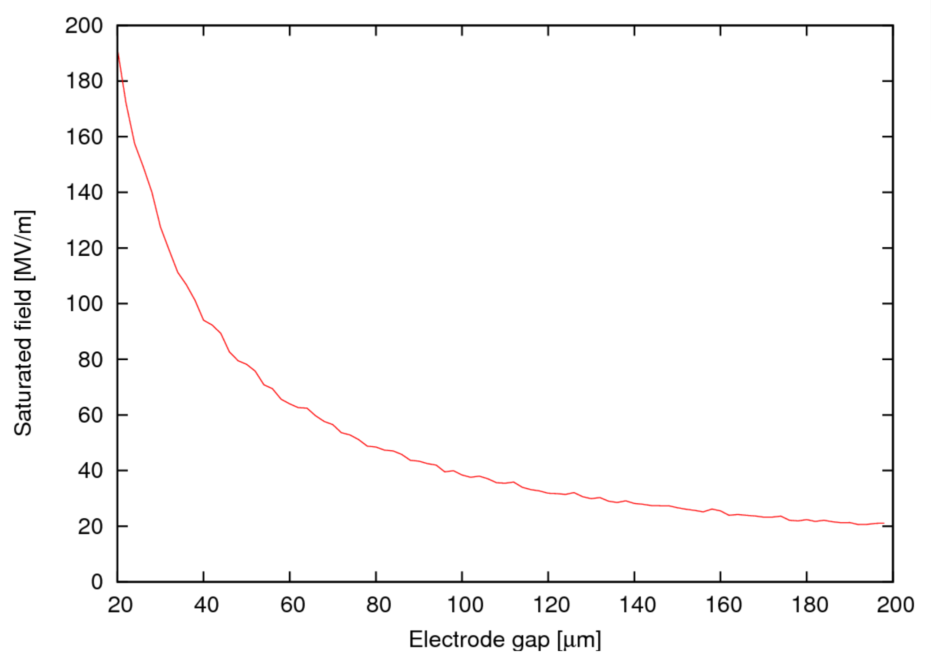
DC breakdown

Electrode gap distance dependence for saturated breakdown field

Experiment

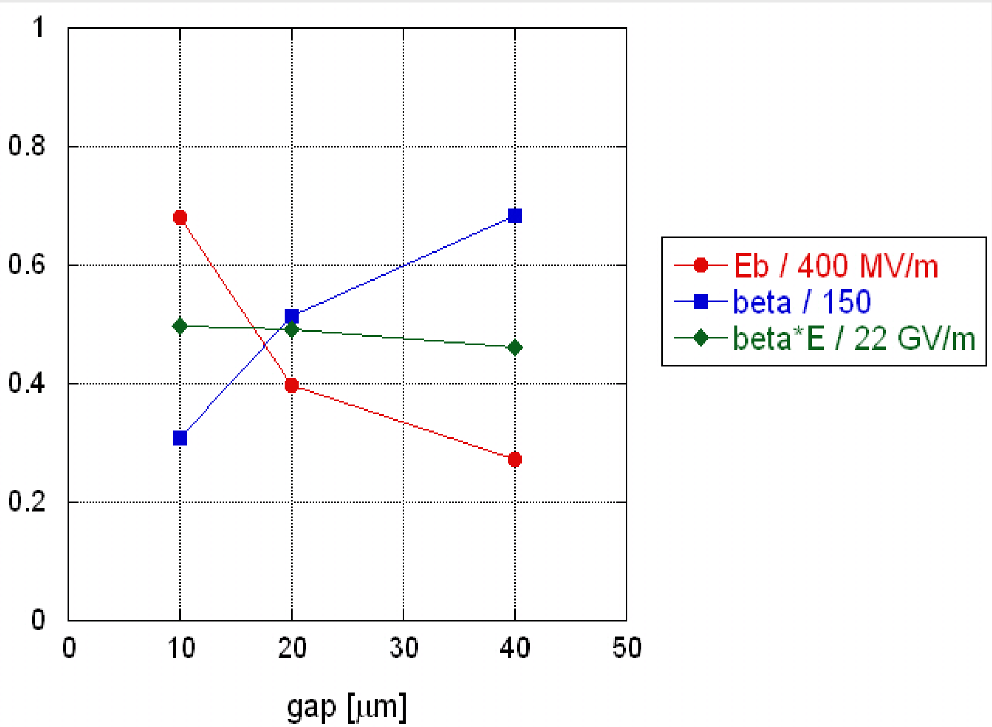


Model



DC breakdown

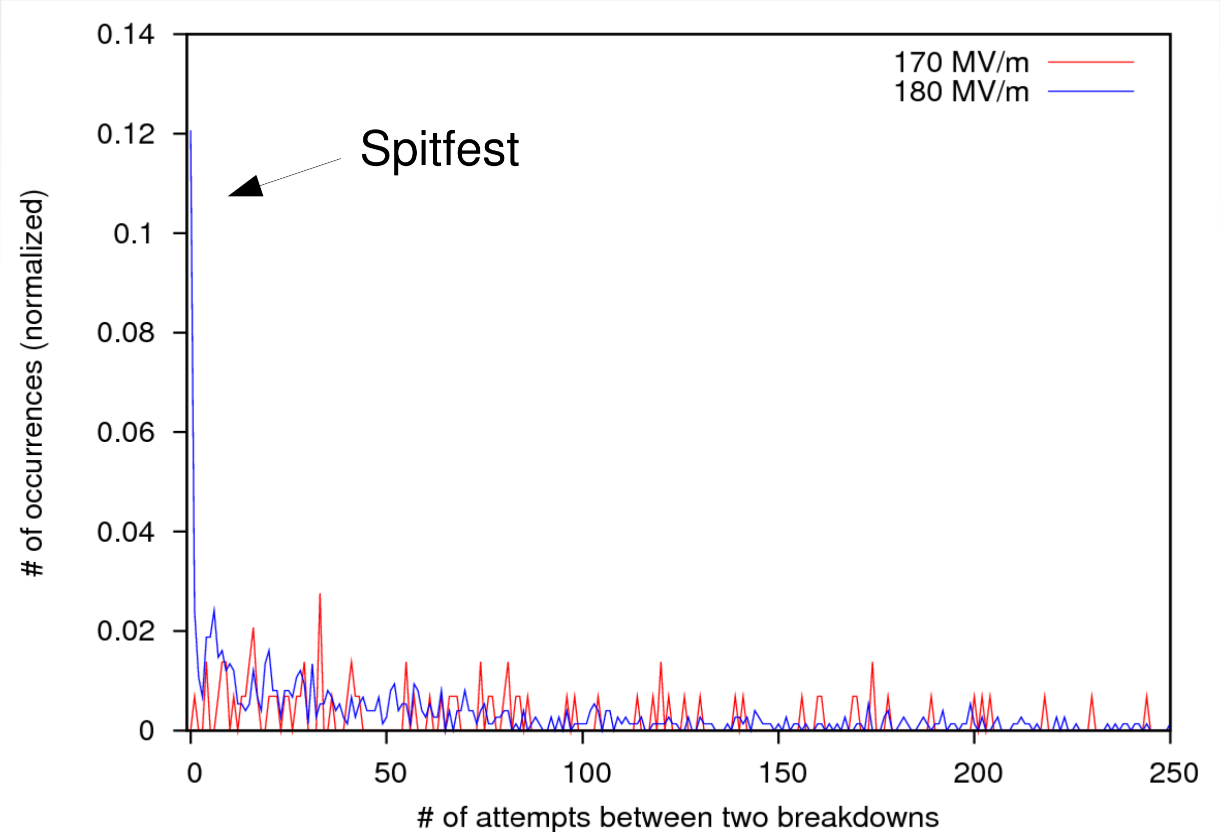
- Gap distance dependence on molybdenum electrodes (A. Descoueudres)
- Local breakdown field is independent on gap distance, macroscopic breakdown field is not!
- But macroscopic breakdown field is what we are actually interested in...



Courtesy A. Descoueudres

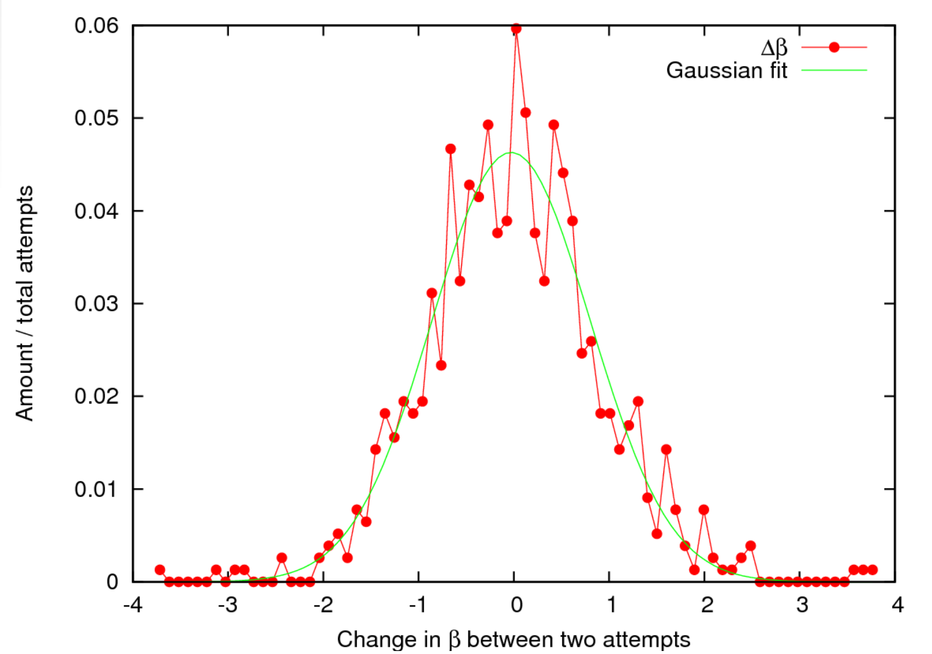
Spitfest

- Spitfest / bunching of breakdowns
- Only visible for higher breakdown rates
- A rather abrupt transition in the simulation

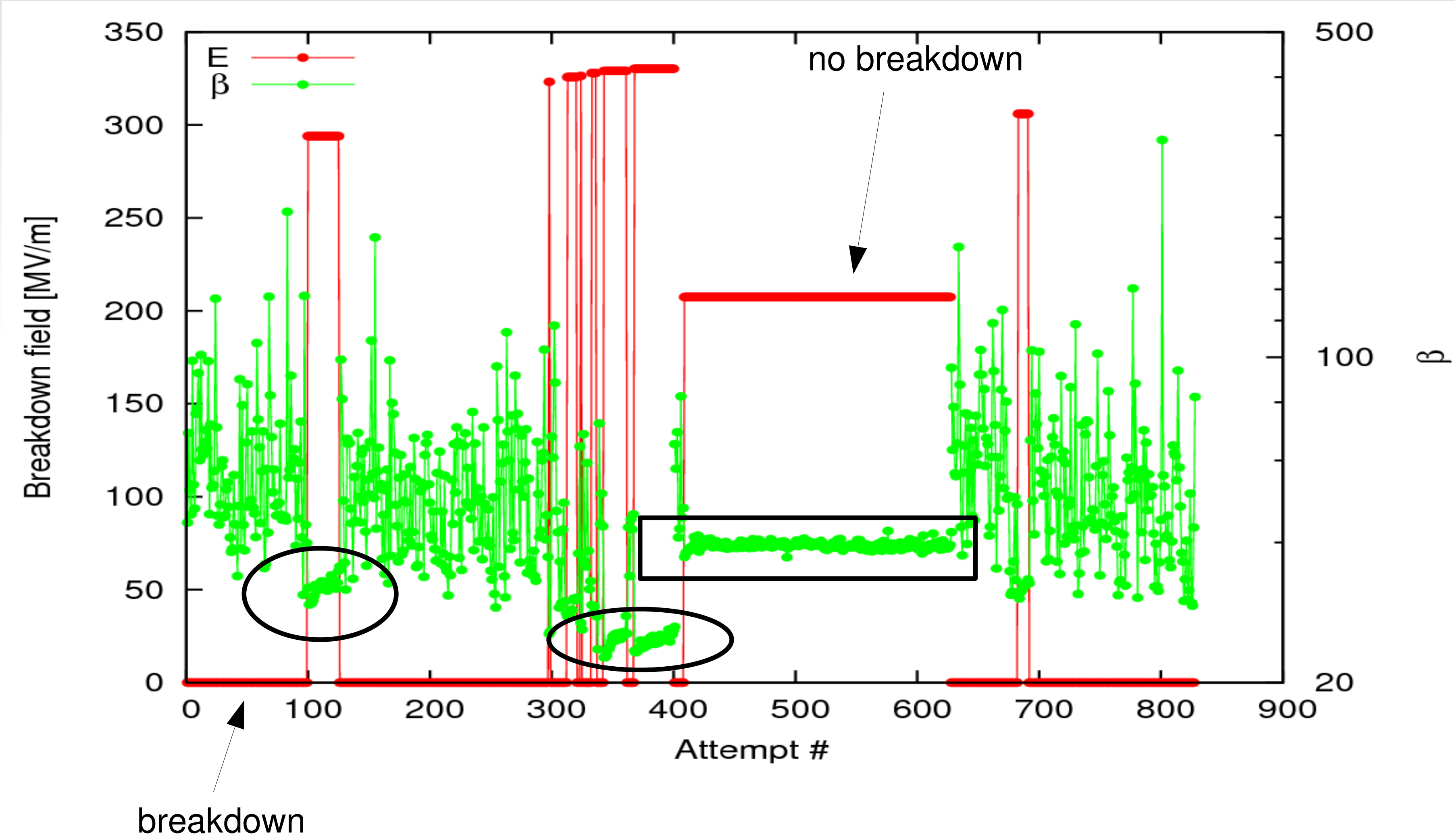


Field emission modification

- 1500 attempts without breakdown
- E = 225 MV/m
- Measured β between each attempt
- Assuming $\sigma_{total} = \sqrt{\sum \sigma^2}$
- Found that β change according to Gaussian distribution with mean ~0, st.dev. ~0.8
- Found in simulation that st.dev. ~0.3 **looked** reasonable for this field value



Field emission modification



Some observations

- The randomness we observe in experiments does not exclude a fixed limit for breakdown initiation
- The bunchedness (spitfest) in breakdown rate experiments can be understood from simple statistics
- It is not necessarily straight forward to compare results from DC Spark to RF results
- Saturated breakdown field is dependent on geometry / ”probed area”

Backup slides

Field emission

- Without any surface modification, this model can also easily calculate field emission if the weakness parameter is assumed to be β (correct tip-plane cathode field distribution is used)
- Gives a gap distance dependence on the measured β
- Plot of $\ln(\frac{I}{E^2})\ vs.\ \frac{1}{E}$ gives β from the slope of the curve (straight line for Fowler–Nordheim field emission)

Field emission