DC breakdown experiments for CLIC

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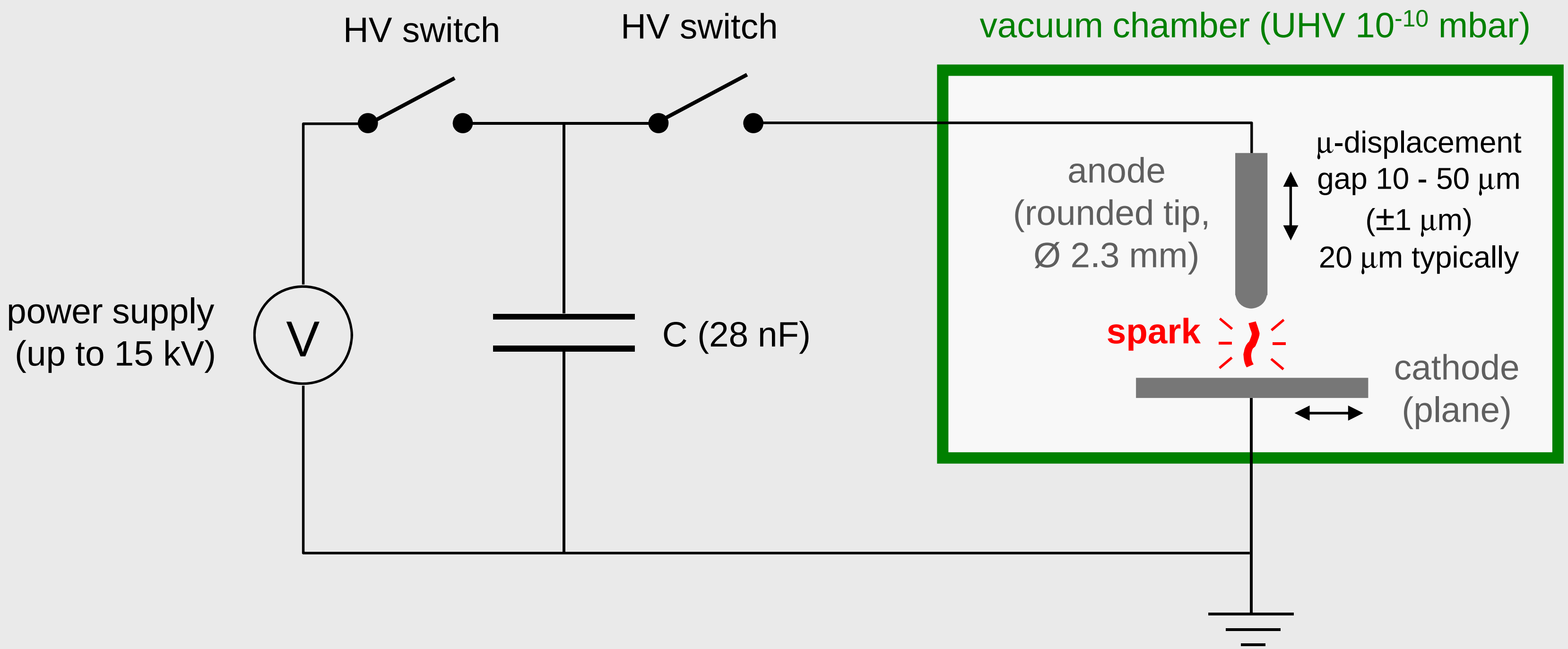
Why do we study DC breakdowns ?

Materials requirements for CLIC:
→ high gradient
→ low breakdown rate
→ low structure deterioration after breakdown

- Simple set-up to produce DC sparks
- DC tests are faster and more flexible
- Investigation of :
  - new materials
  - surface treatments (mechanical, chemical, plasma, heat, …)
- An easier (?) way to study and understand breakdown mechanisms

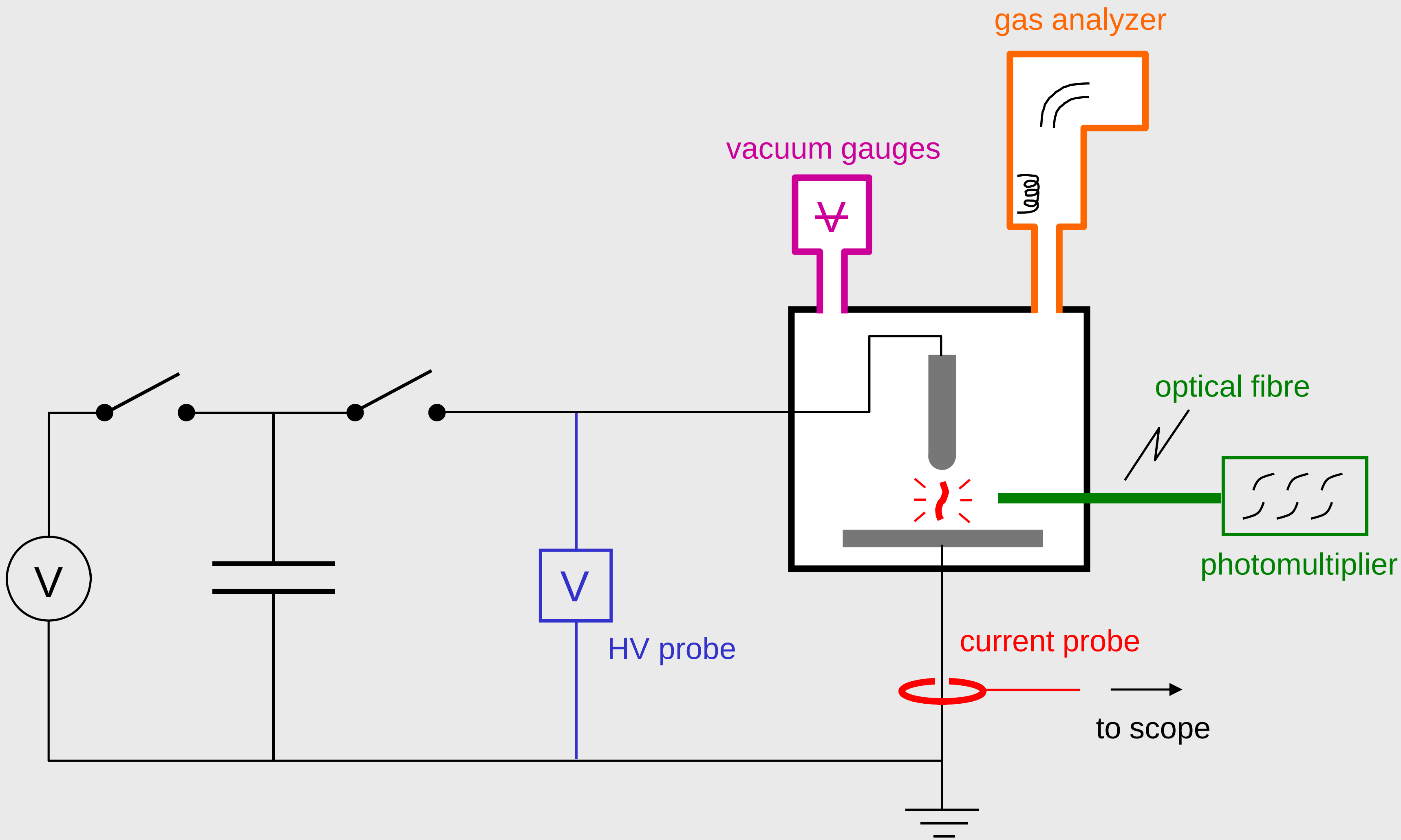
→ **Additional inputs for the design and the choice of the RF CLIC structures (materials, preparation, …)**

Experimental set-up : “ the spark system ”

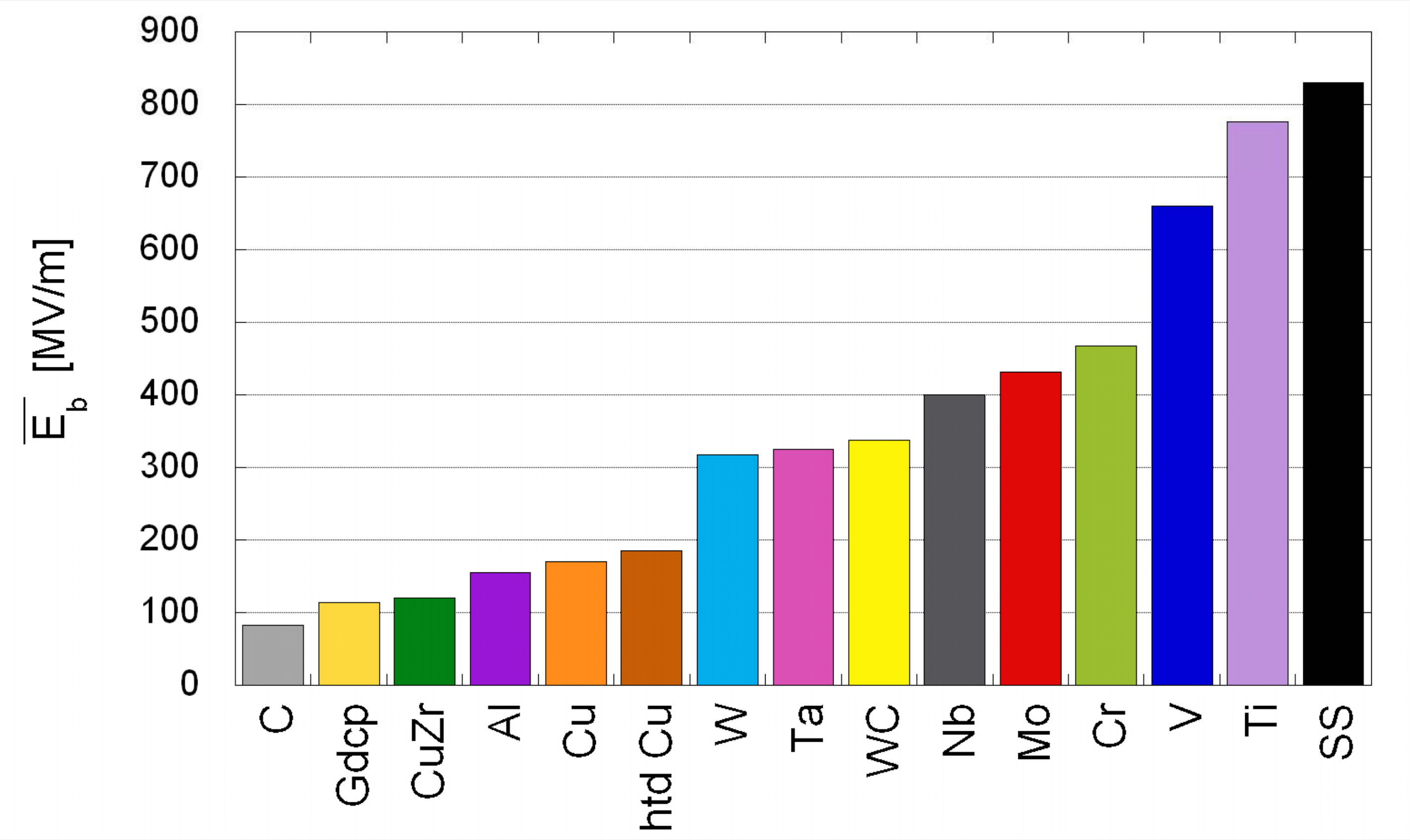


- Two similar systems are running in parallel now
- Types of measurements :
  1) Field Emission (→ β)
  2) Conditioning (→ breakdown field E_b)
  3) Breakdown Rate (→ BDR vs E)

Experimental set-up : diagnostics

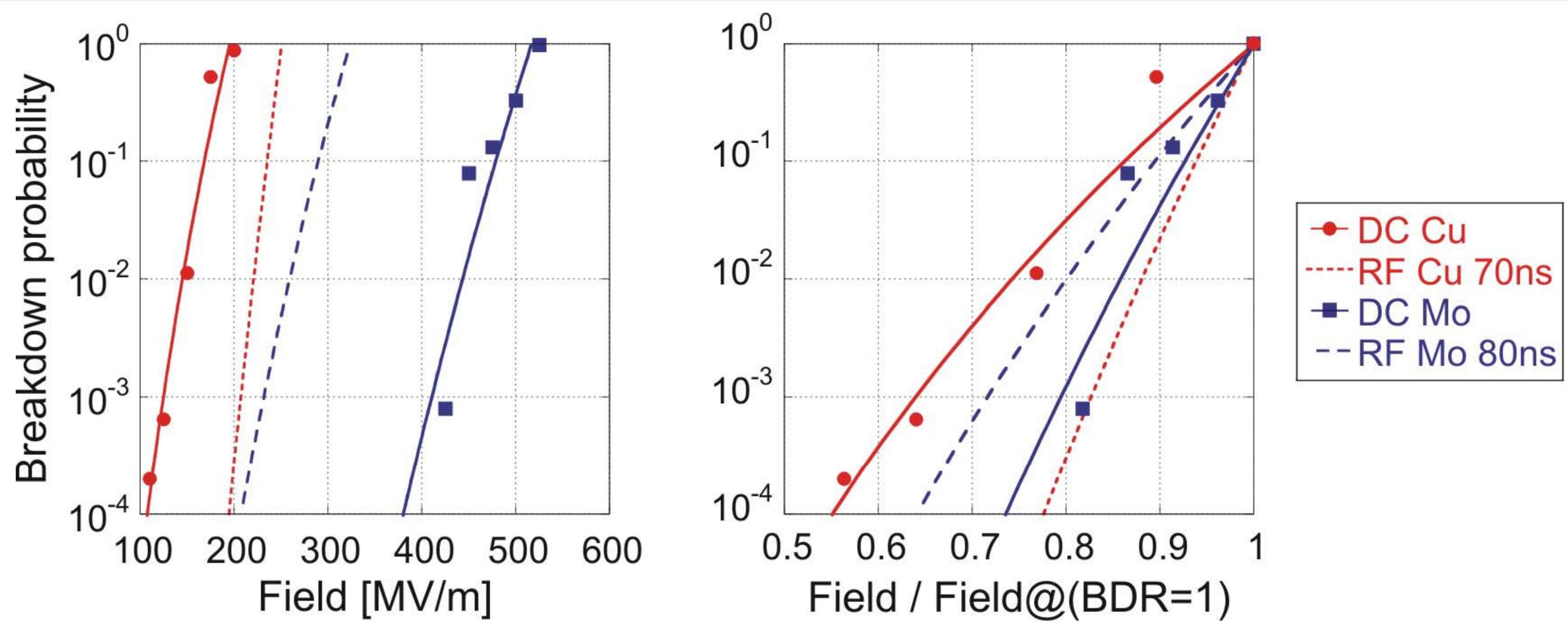


Breakdown field of materials (after conditioning)



- difficult to point out **1** dominant physical property, combination of several ones
  (melting point, heat of fusion, thermal conductivity, electrical conductivity, vapour pressure, surface tension, …)
- Cu < Mo < Stainless Steel

Breakdown Rate : DC & RF (30 GHz)



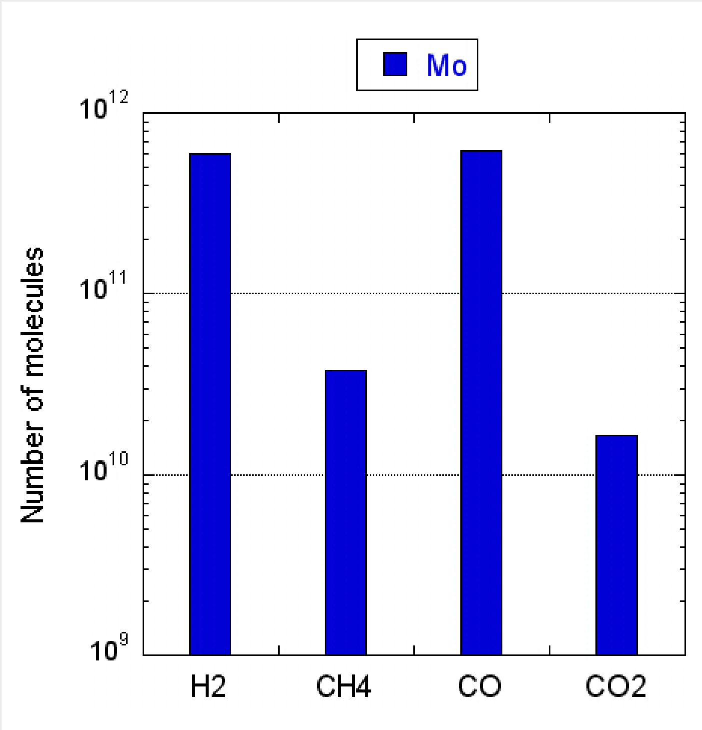
γ = power in the fit

BDR ~ E^{γ}

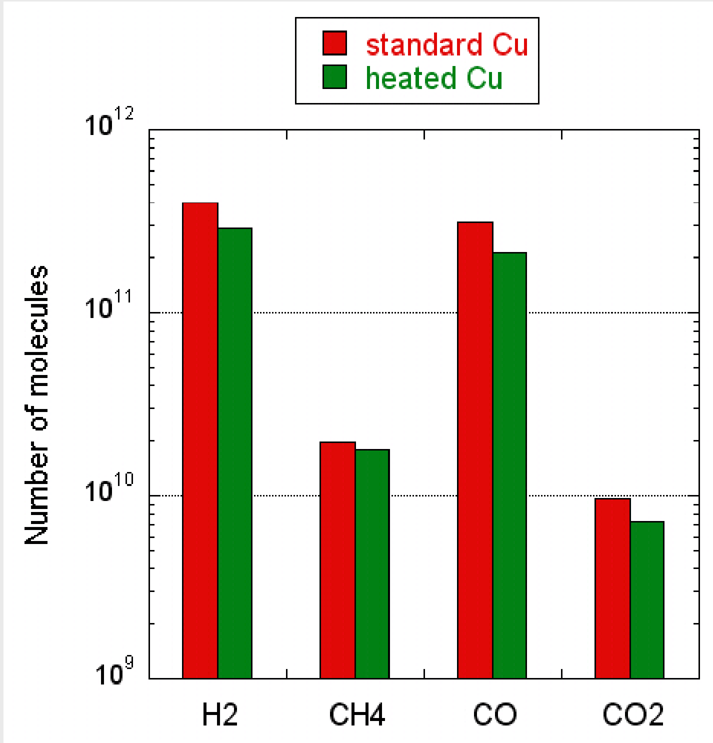
	DC	RF
Cu	10 - 15	30
Mo	30 - 35	20

Same trend in DC and in RF, but difficult to compare 'slopes'

Gas released during a breakdown



0.95 J / spark



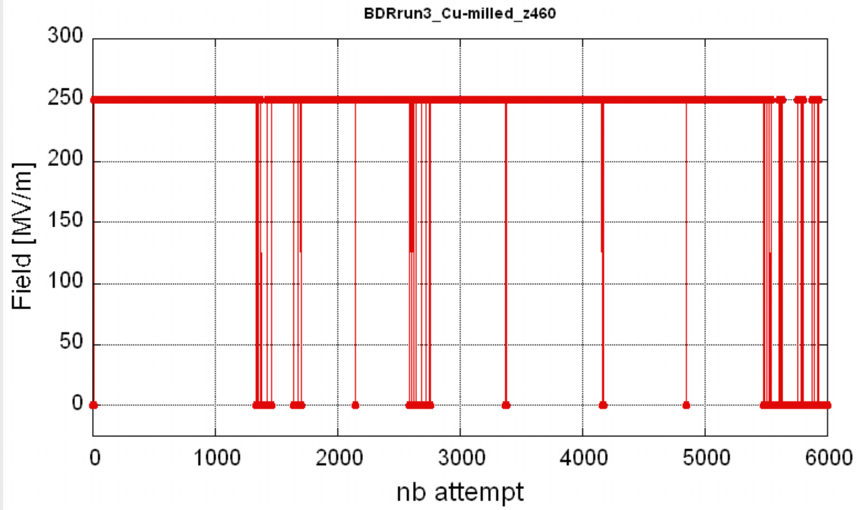
0.8 J / spark

(heat treatment: ex-situ, 815°C, 2h, UHV)

- Same gases released, with same ratios
  - ➢ Outgassing probably dominated by Electron Stimulated Desorption (ESD)
- Slight decrease due to heat treatment ?

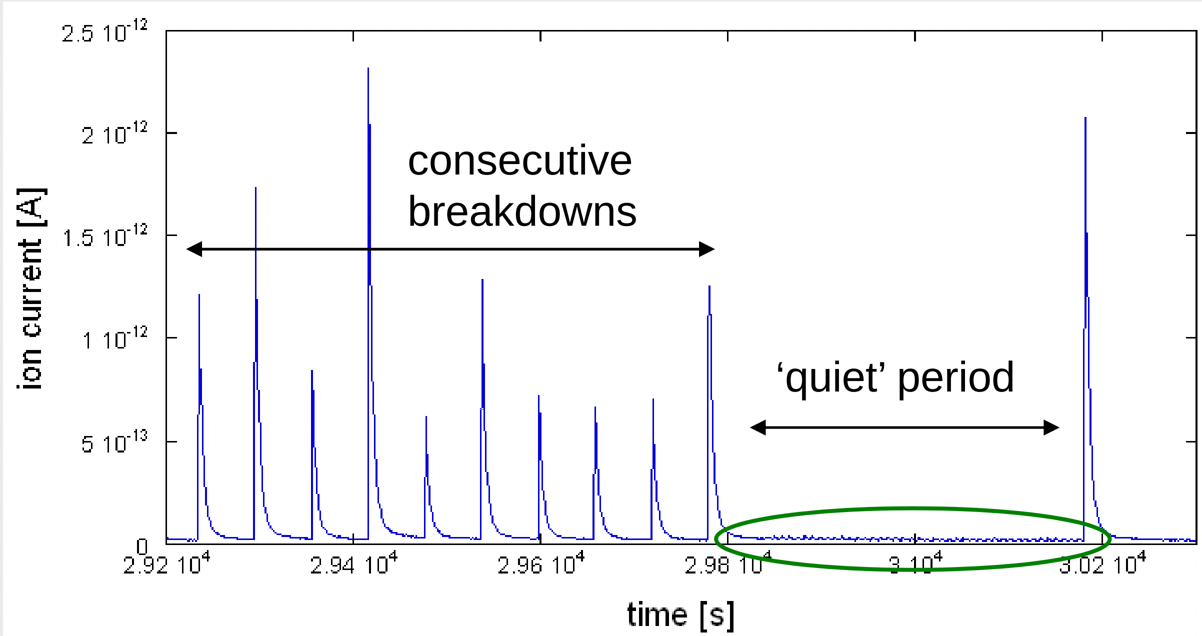
H_2 outgassing in Breakdown Rate mode (Cu)

- Run at BDR = 0.1
- Clusters of sparks and 'quiet' periods

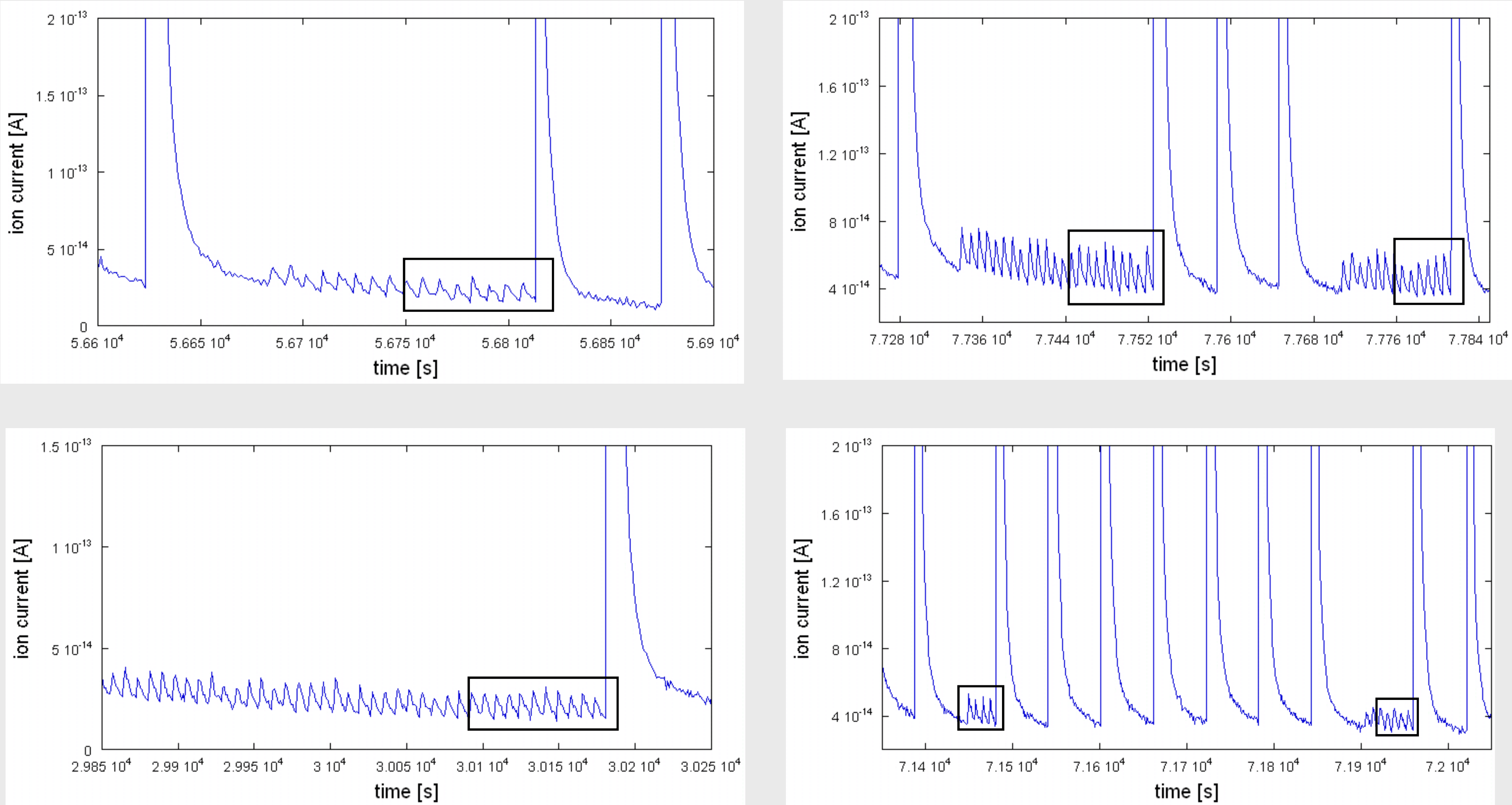


- H_2 outgassing

slight outgassing during 'quiet' periods



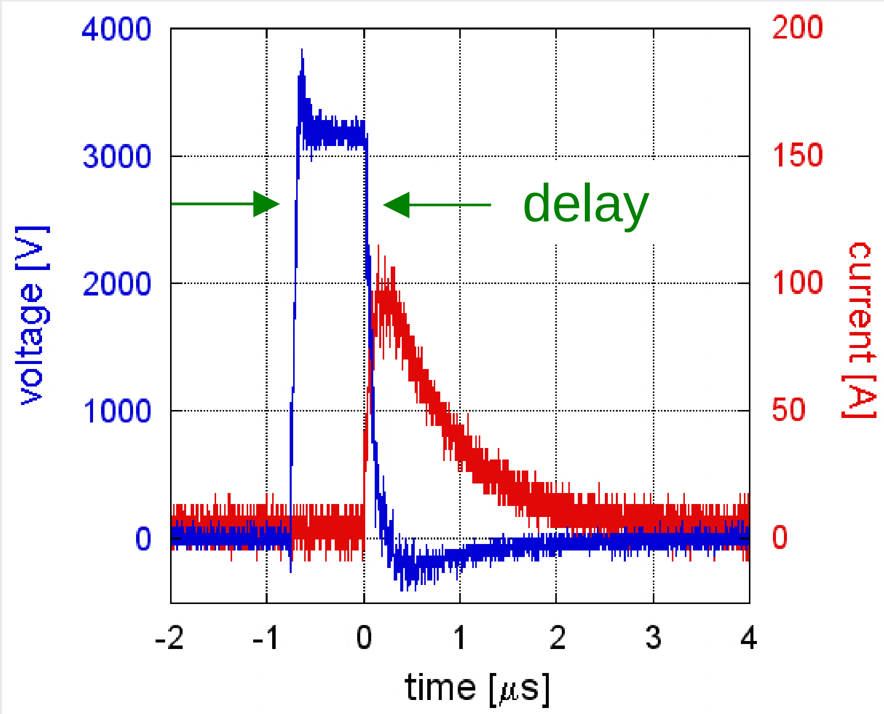
H_2 outgassing in Breakdown Rate mode (Cu)



→ no visible increase in outgassing just before a breakdown cluster

Time delays before breakdown

- Voltage rising time : ~ 100 ns
- Delay before spark : **???**
- Spark duration : ~ 2 µs

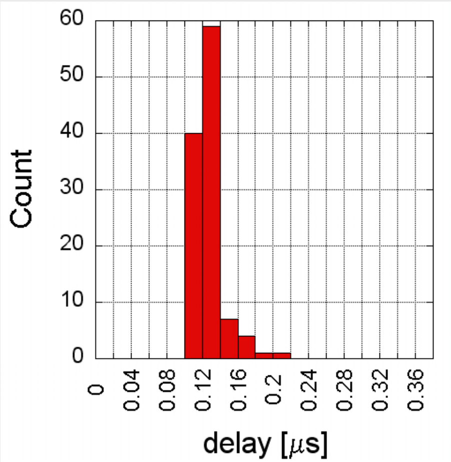


Time delays with Mo electrodes

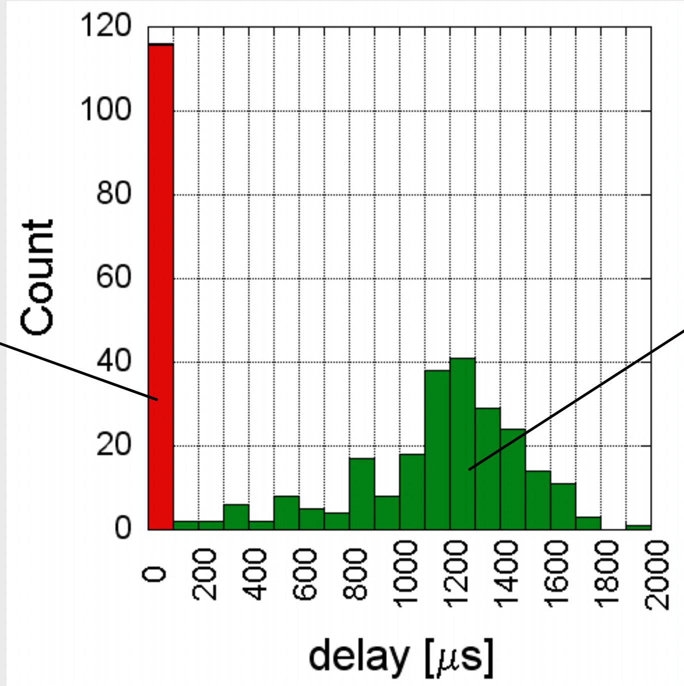
- Histogram of delays

population #1
'immediate' brkds

average : 129 ns
(σ = 16 ns)



voltage rising time: ~ 100 ns



population #2
'delayed' brkds

average : 1.17 ms
(σ = 0.33 ms)

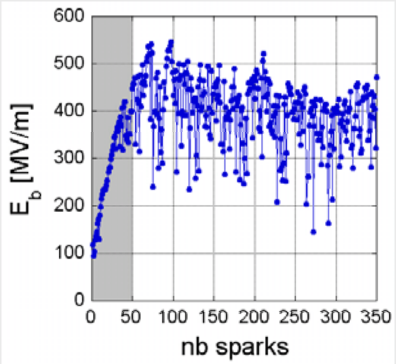
Two populations

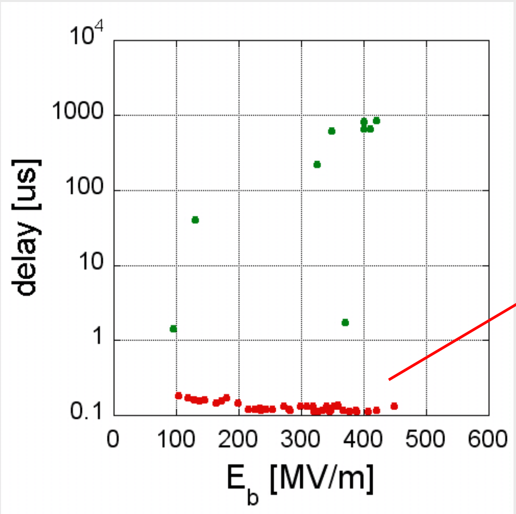
↓

Two different breakdown mechanisms ?

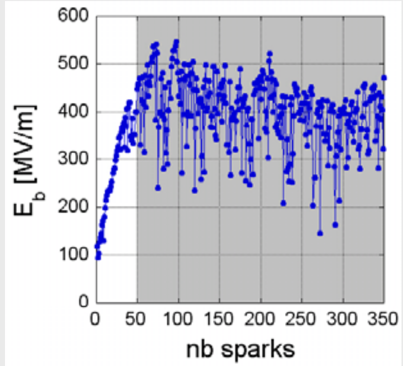
Time delays with Mo electrodes

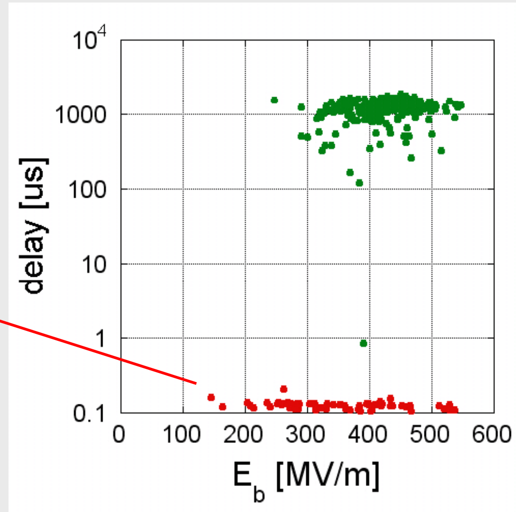
- Delays during conditioning





- Delays after conditioning





percentage of delays < 200 ns :

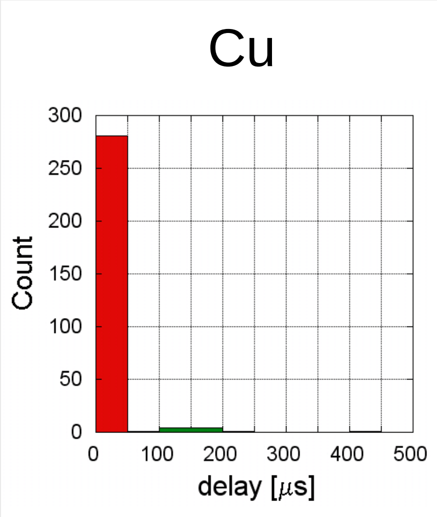
82%

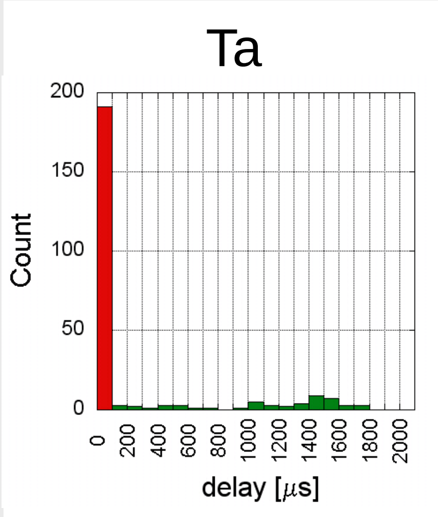
24%

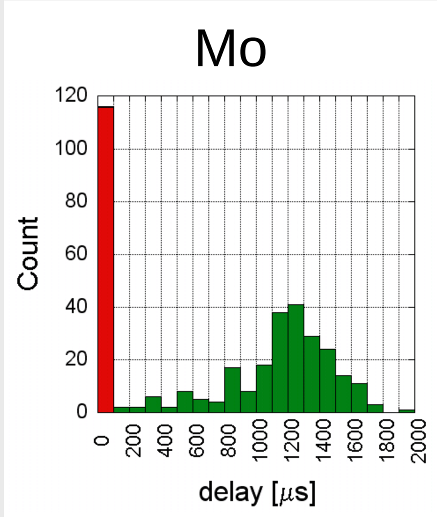
immediate brkds dominate during conditioning

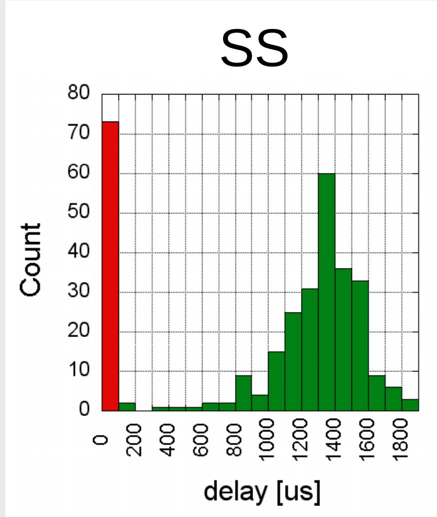
delayed brkds dominate after conditioning

Time delays with different materials









$\bar{E}_b$ = 170 MV/m — $\bar{E}_b$ = 300 MV/m — $\bar{E}_b$ = 430 MV/m — $\bar{E}_b$ = 900 MV/m

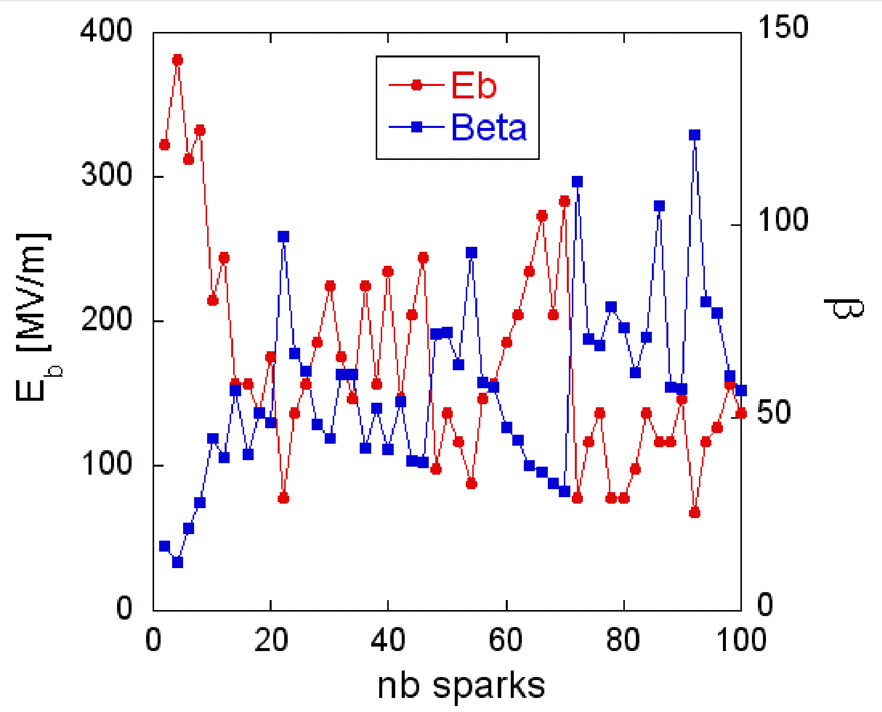
R = 0.07 — R = 0.29 — R = 0.76 — R = 0.83

R = fraction of delayed breakdowns (excluding conditioning phase)

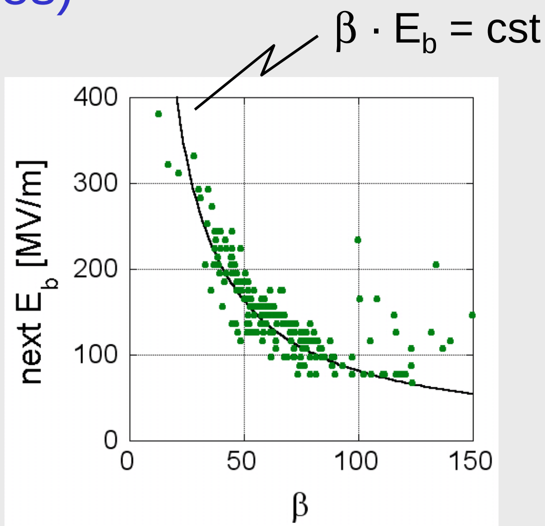
→ R increases with average breakdown field *(but why ?!?)*

Evolution of β & E_b during conditioning measurements

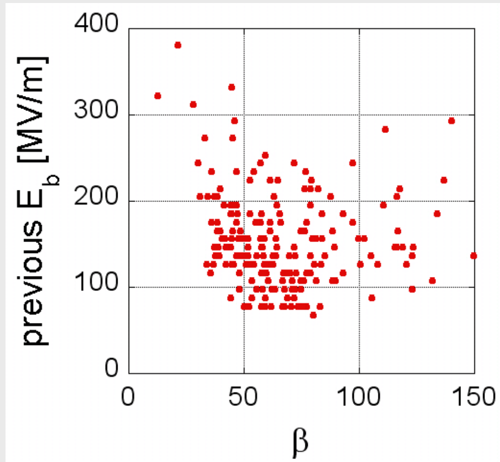
- Measurements of β after each sparks (Cu electrodes)



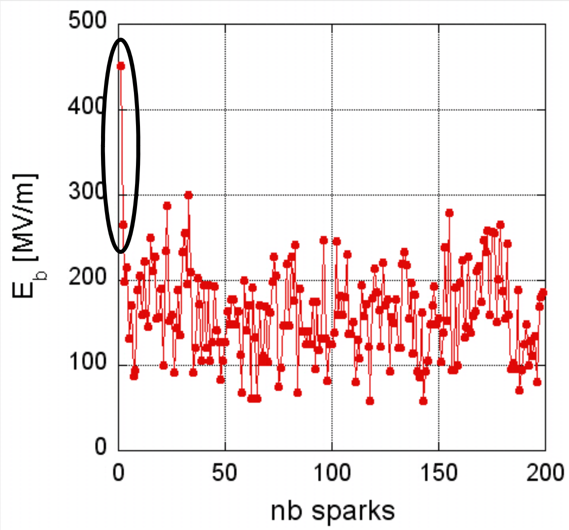
$\beta \leftrightarrow$ next E_b **correlation**



$\beta \leftrightarrow$ previous E_b **no correlation**

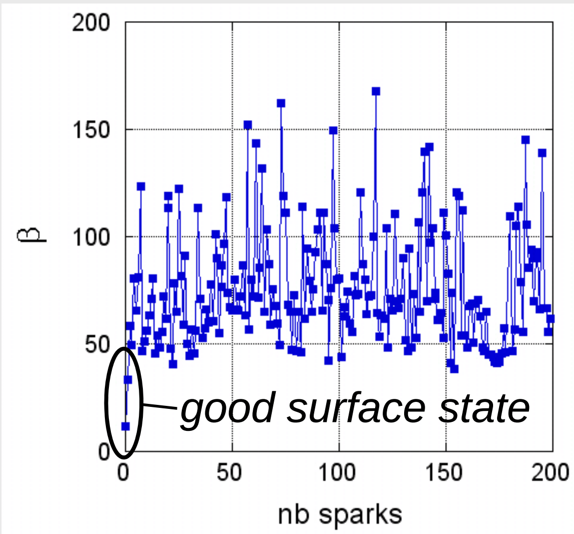


Local field $\beta \cdot E_b$



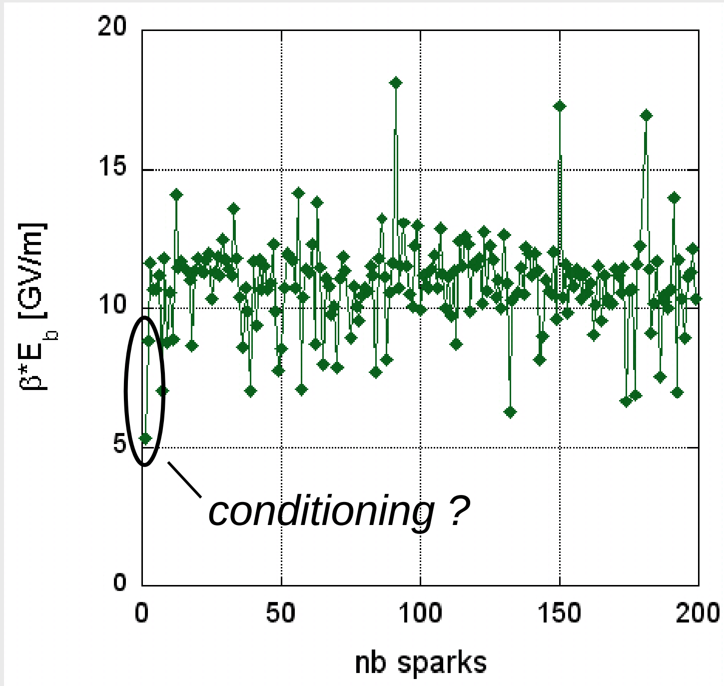
$\overline{E_b}$ = 159 MV/m

(± 32%)



$\overline{\beta}$ = 77

(± 36%)

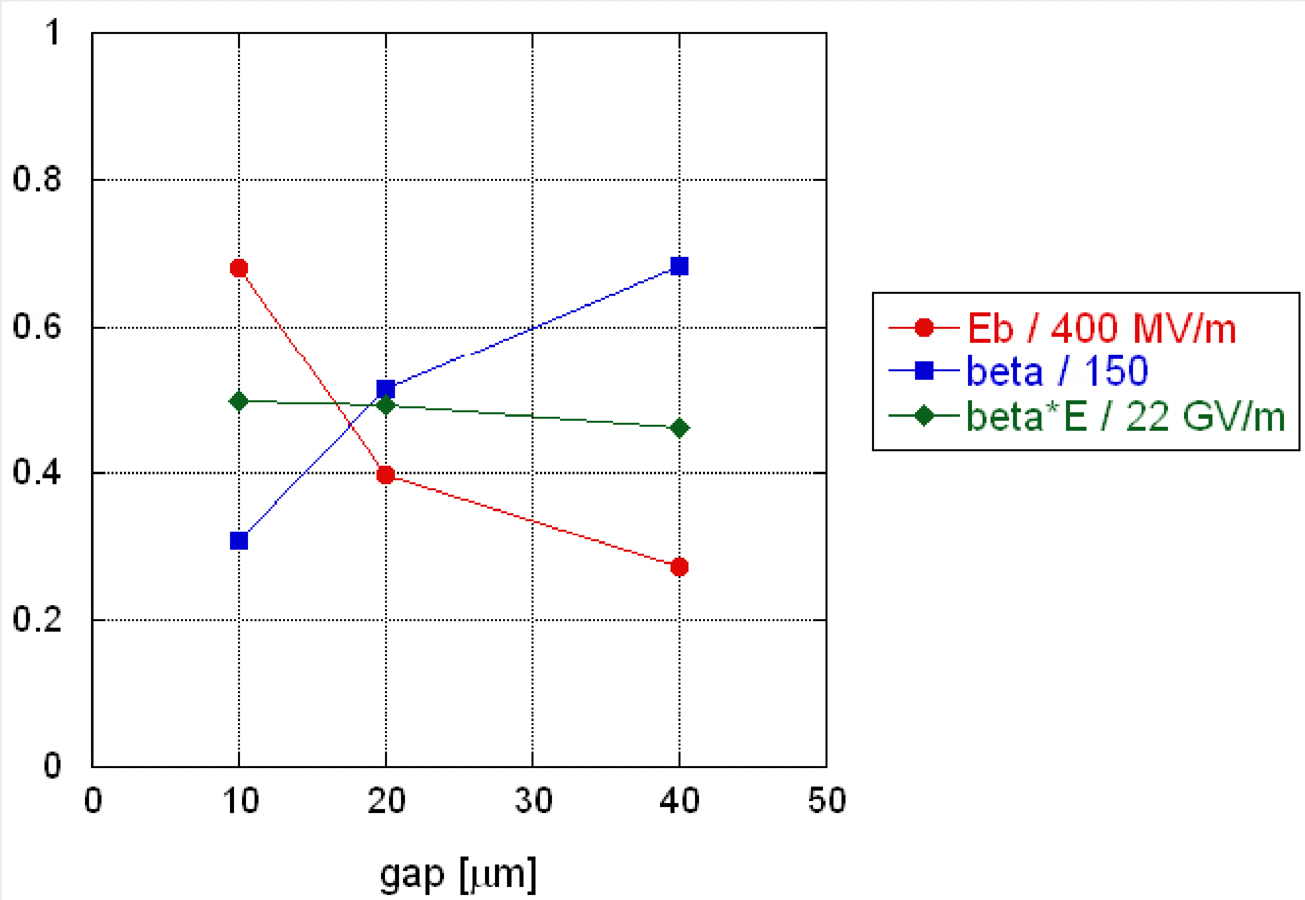


$\overline{\beta \cdot E_b}$ = 10.8 GV/m

(± 16%)

→ Local field = cst = 10.8 GV/m for Cu

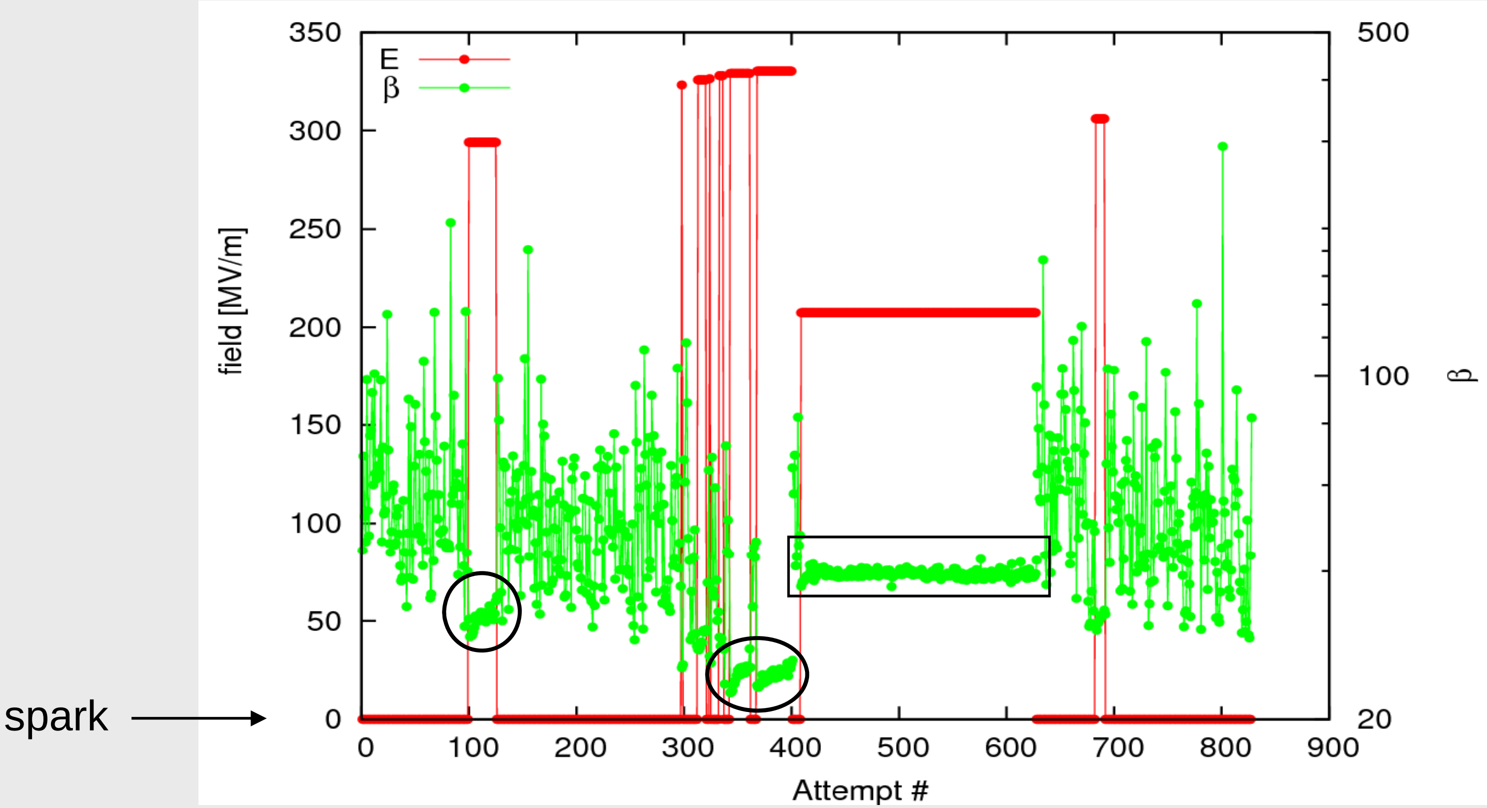
Gap dependence of E_b, β and $\beta \cdot E_b$



→ $\beta \cdot E_b$ is the constant parameter

(cf. Alpert *et al.*, J. Vac. Sci. Technol., **1**, 35 (1964))

Evolution of β during BDR measurements



- quiet period ←→ low β
- β seems to increase (a few %) during a quiet period ***if E is sufficiently high***

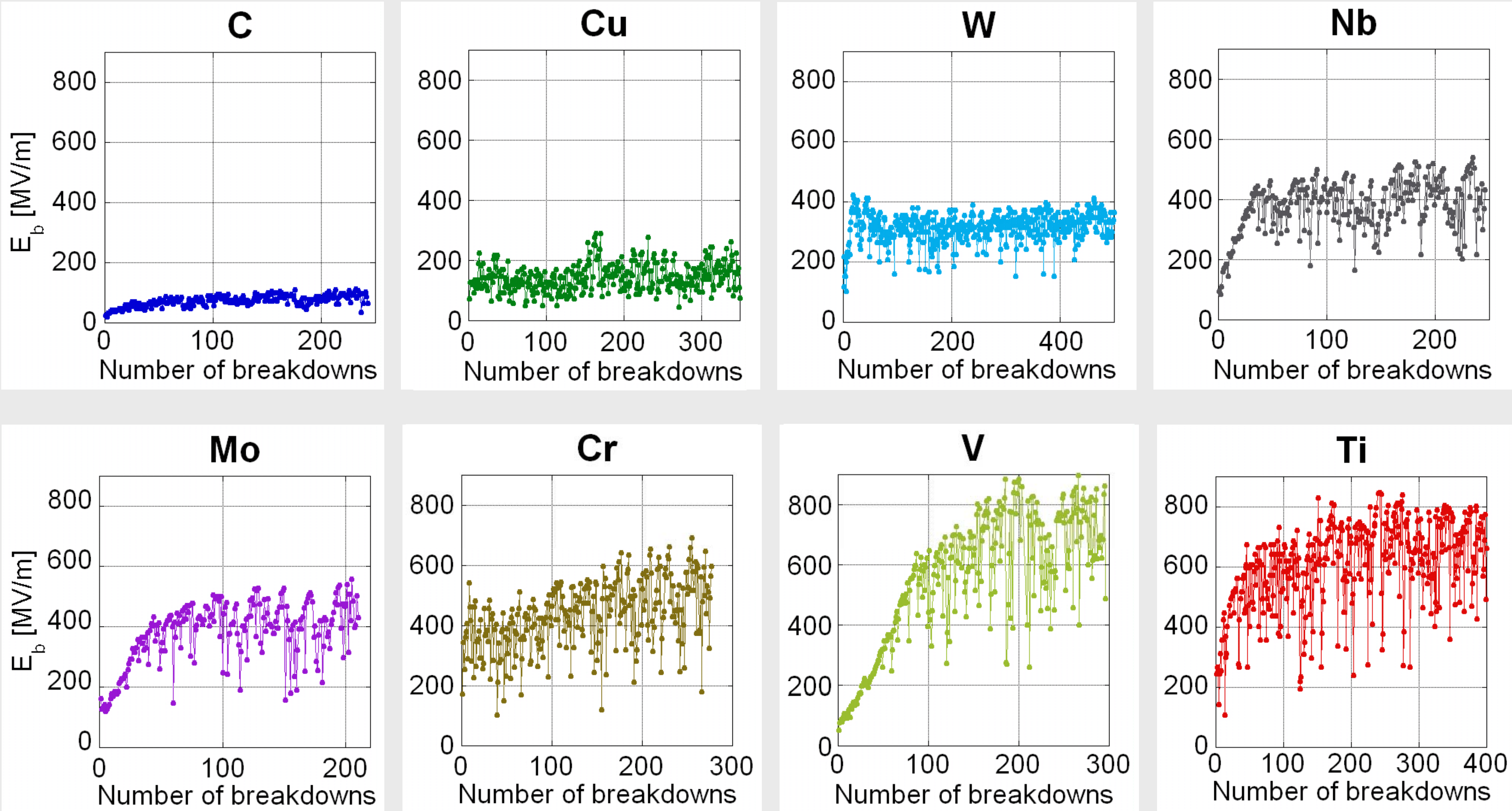
➡ Are small tips pulled by the field? (we need more data)

Summary

- Various metals and alloys have been tested (E_b, cond. speed, gap stability)
  - breakdown field : Cu < Mo < Stainless Steel
- DC Breakdown Rate
  - same trend as in RF : BDR ~ E^{γ}
- Outgassing during a breakdown
  - H_2 and CO released
- Time delays before breakdown
  - two populations observed : immediate and delayed breakdowns
  - repartition depends on material and conditioning state
- Evolution of β and E_b
  - Local field $\beta \cdot E_b$ is constant (10.8 GV/m for Cu)
  - in BDR mode (no spark), β seems to slightly increase with high field

Thank you !

Conditioning curves of pure metals



Surface treatments of Cu

- Surface treatments on Cu only affects the very first breakdowns

	rolled sheet / heat treatm.	milling	Subu	electro-polishing
β before 1st spark	~ 15 - 20	~ 20	~ 25 - 30	~ 15 - 20
1st brkd field [MV/m]	~ 200 - 400	~ 300 - 500	~ 150 - 200	~ 300 - 400

- After a few sparks: ~ 170 MV/m, β ~ 50 for every samples

→ The first sparks destroy rapidly the benefit of a good surface preparation

And in RF ? Sparks are distributed over a much larger surface…
Treatments are maybe still useful