DC breakdown experiments for CLIC

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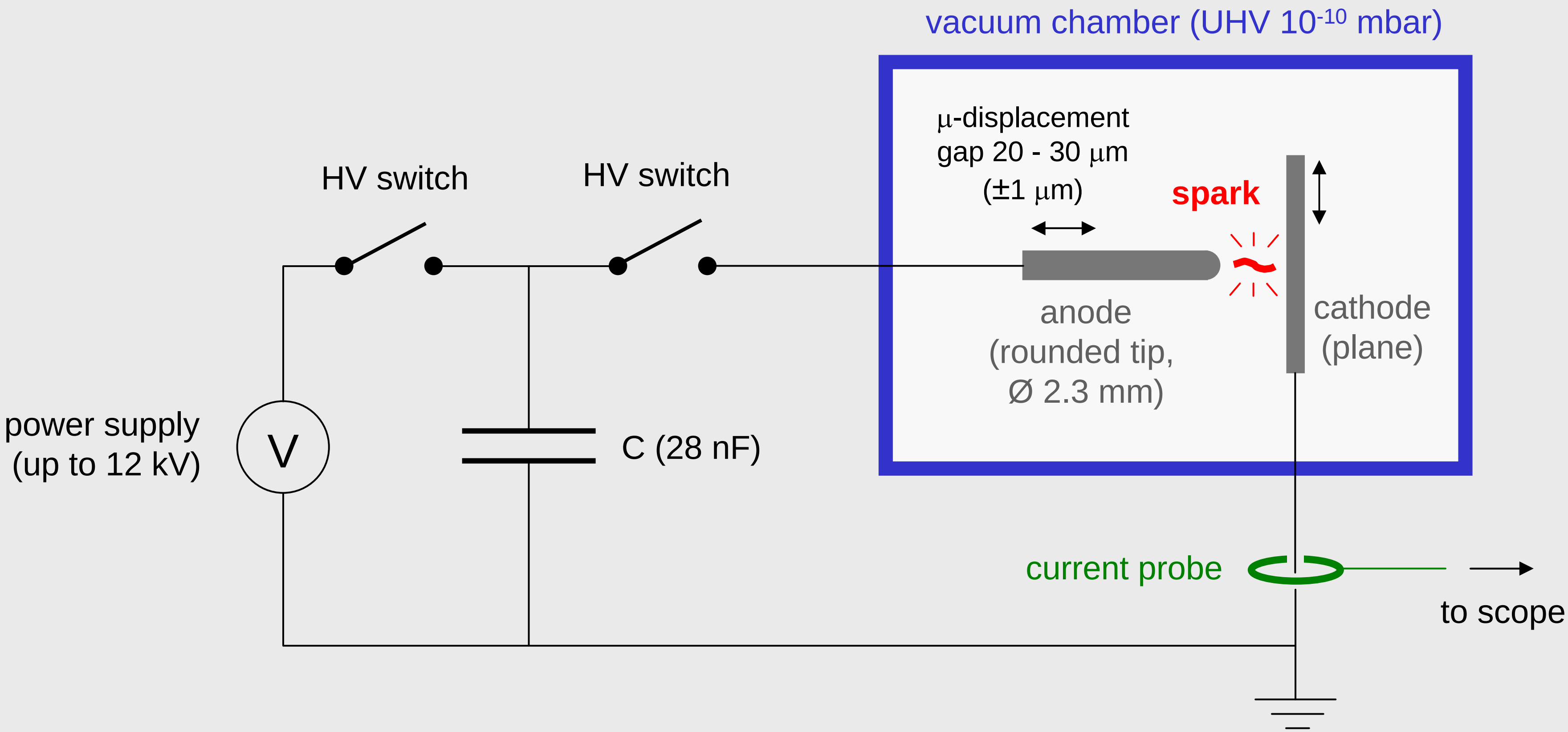
Why do we study DC breakdowns ?

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, …)
- DC breakdowns are easier to understand and to model *(…really ???)*

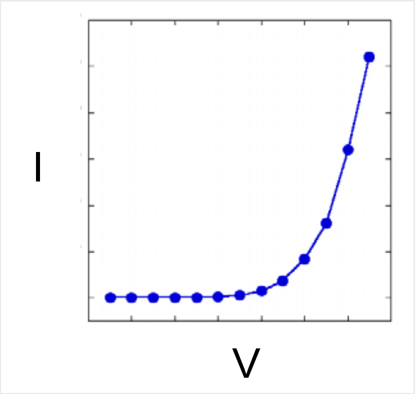
→ **Additional inputs for the design and the choice of the RF CLIC structures (materials, preparation, …)**

Experimental set-up



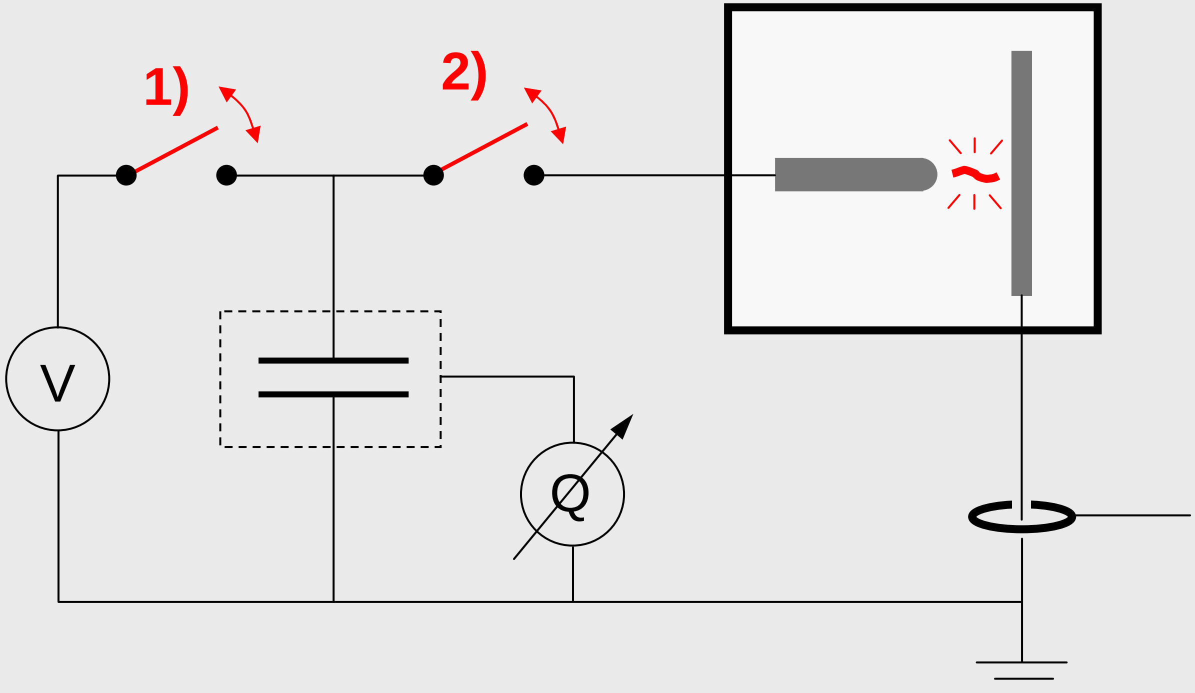
- max. field : 12 kV / 20 μm = 600 MV/m
- typ. spark energy : ½ · (28nF) · $(10kV)^2$ = ~ 1 J

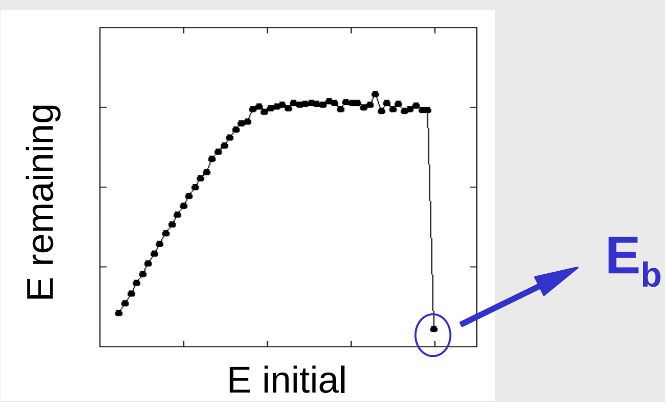
1^{st} type of measurement : field emission

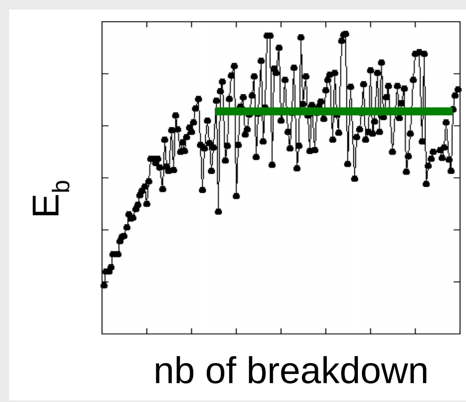


→ β

2^{nd} type of measurement : breakdown field E_b



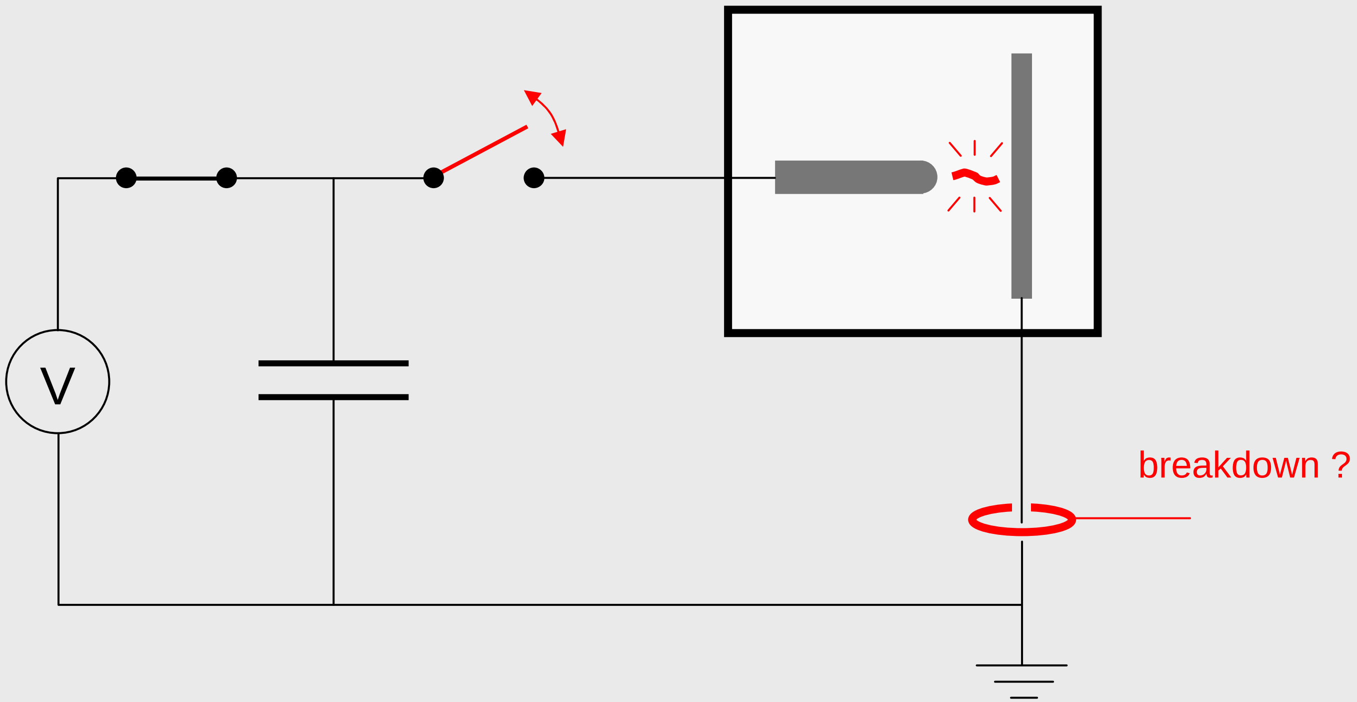


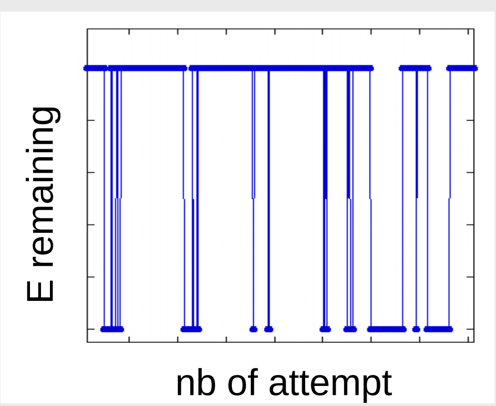


conditioning curve,

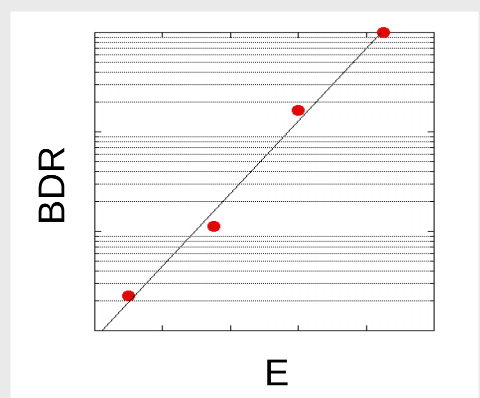
saturated field $\overline{E_b}$

3rd type of measurement : breakdown rate





BDR



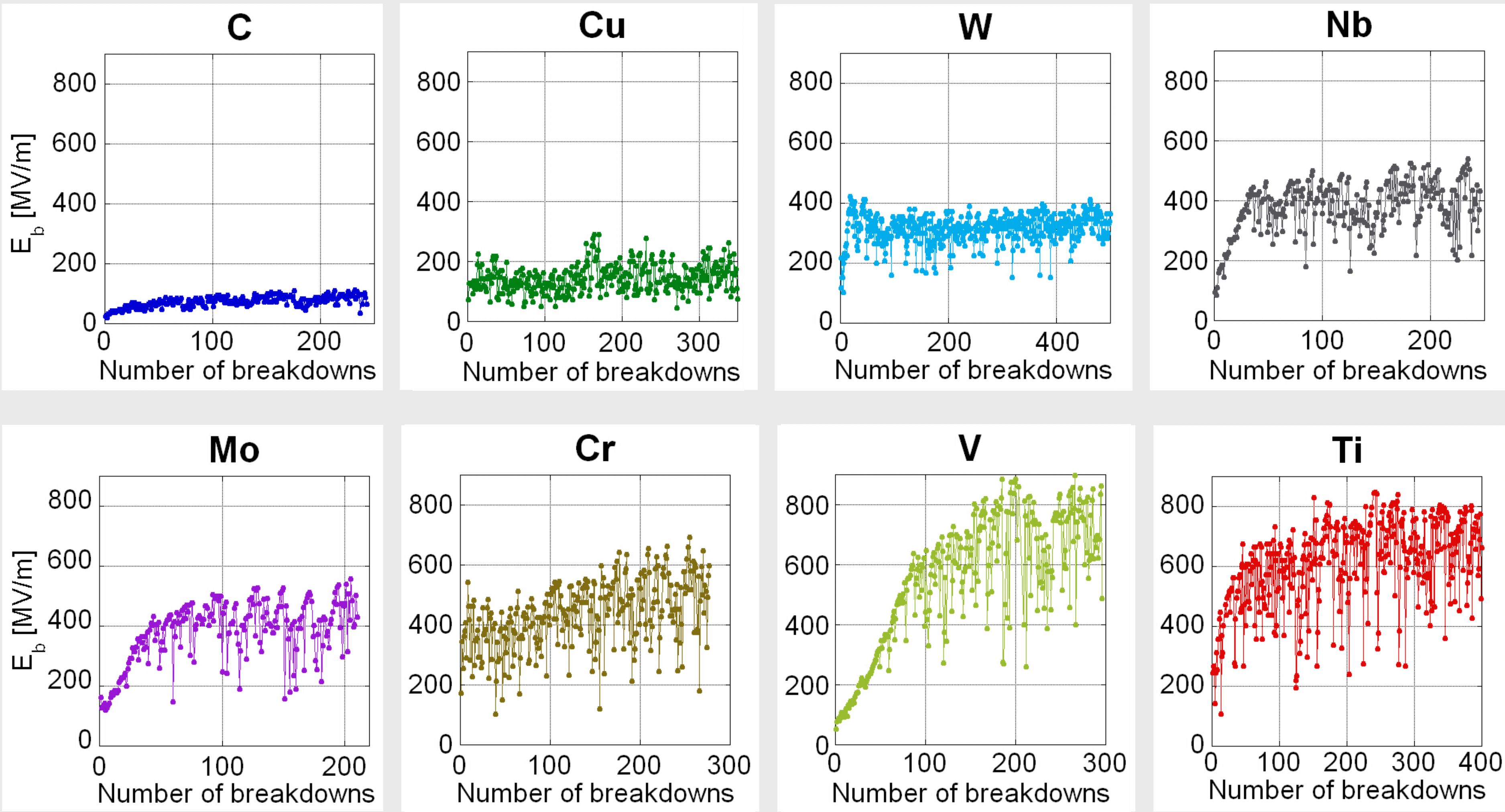
breakdown rate vs field

DC vs RF : what is similar and what is not

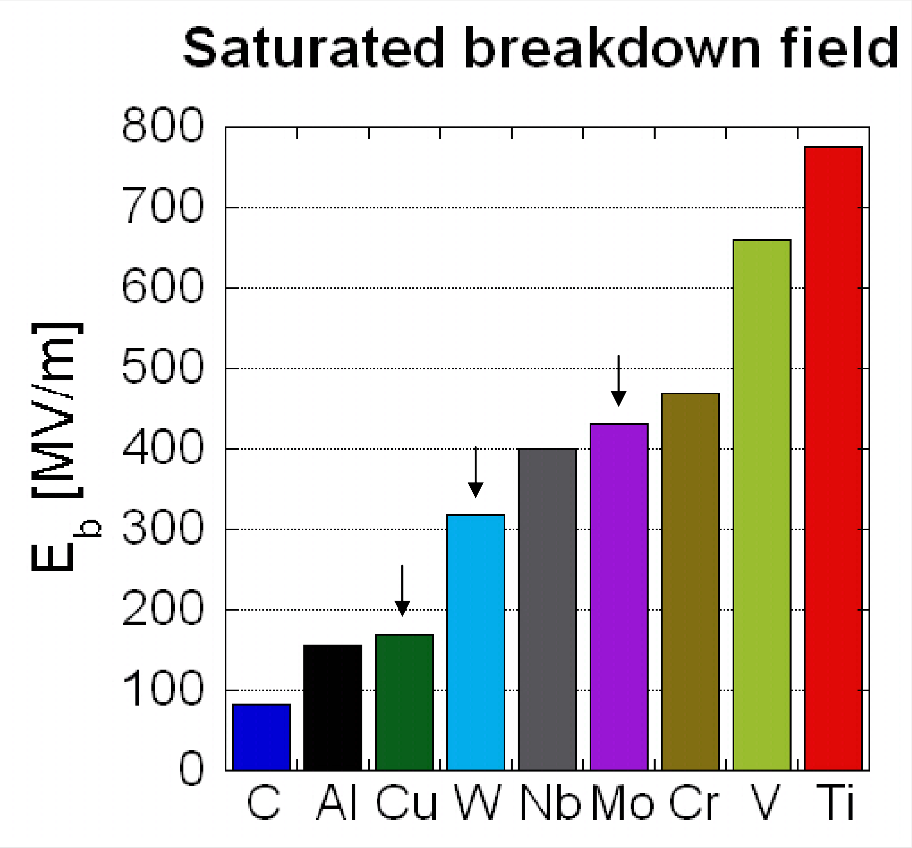
- pulse duration : 100 ns (RF) ←→ s (DC)
- area exposed to field : Ø cm (RF) ←→ Ø 100 μm (DC)

- field : 100 MV/m
- energy : 1 J
- UHV
- breakdown initiation : protrusions, field emission, melting, evaporation, gas release, fatigue, …

Conditioning curves of pure metals



Ranking of pure metals



- conditioning speed

Cu	"immediate"
Mo	~ 50 sparks
V	~ 100 sparks

- gap instability

Cu	< 24 %
Mo	< 10 %
Ti	< 50 %

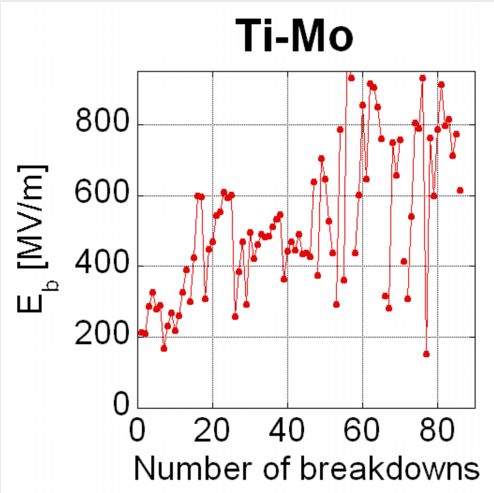
(max. gap variation after a full conditioning experiment)

- difficult to point out **1** dominant physical property, combination of several ones

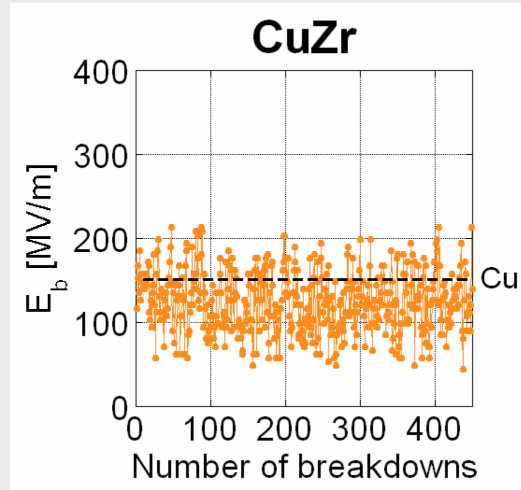
(melting point, heat of fusion, thermal conductivity, electrical conductivity, vapour pressure, surface tension, ...)

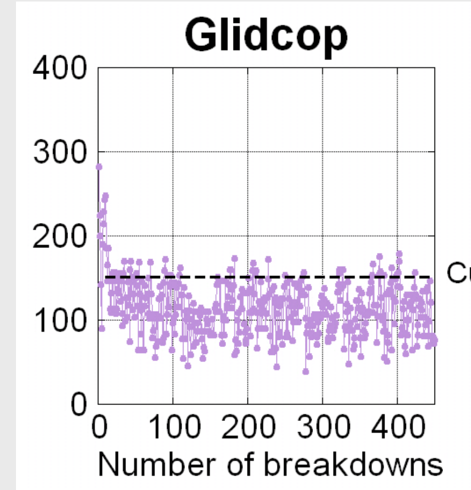
→ **Cu, W, Mo : same ranking as in RF (30 GHz tests)**

Other materials : Alloys

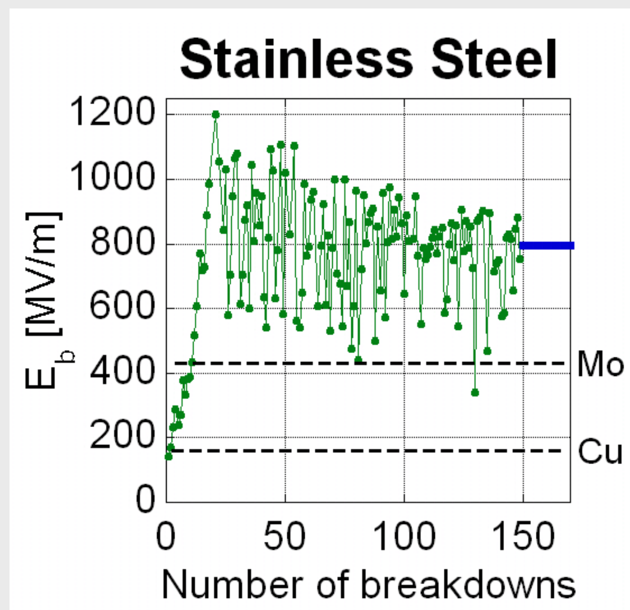


gap highly unstable!





- latest measurement :

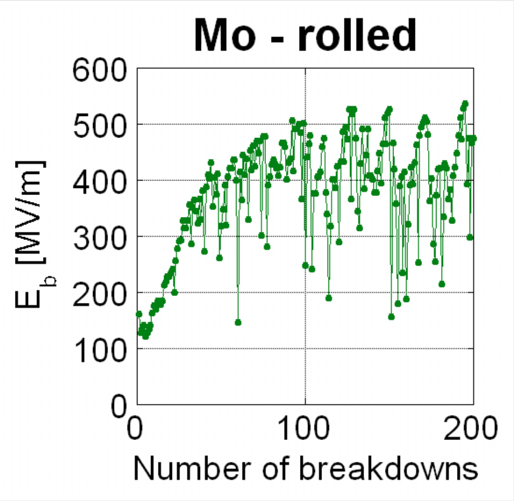


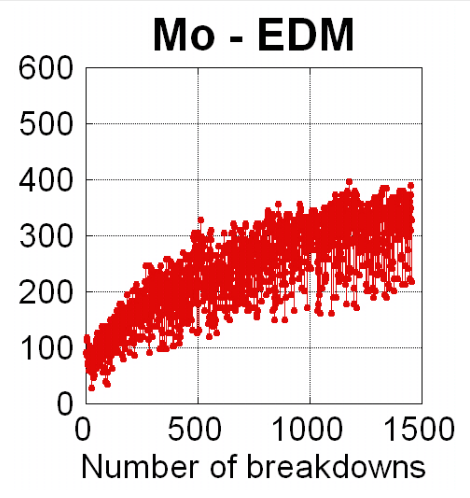
$\overline{E_b}$ > 800 MV/m !

(conditioned in 20 sparks and gap quite stable)

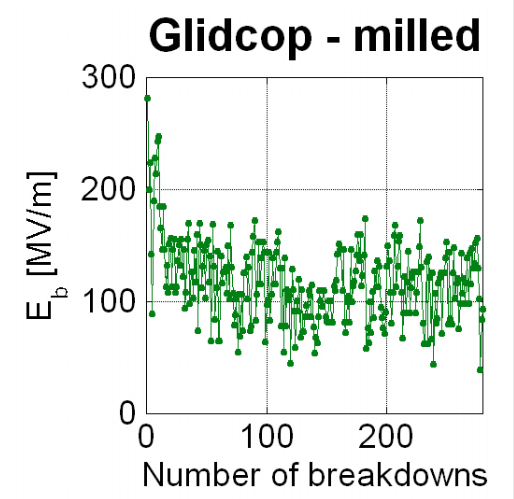
Effect of the surface finishing

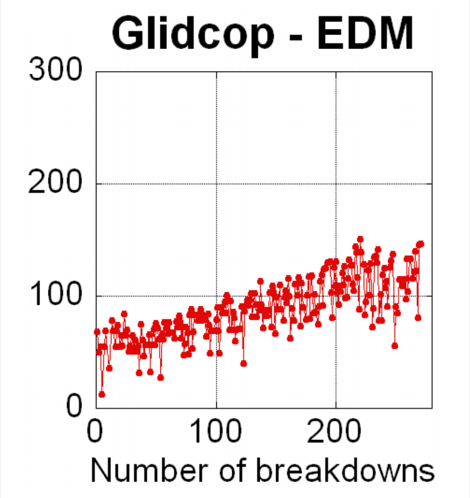
- Mo





- Glidcop

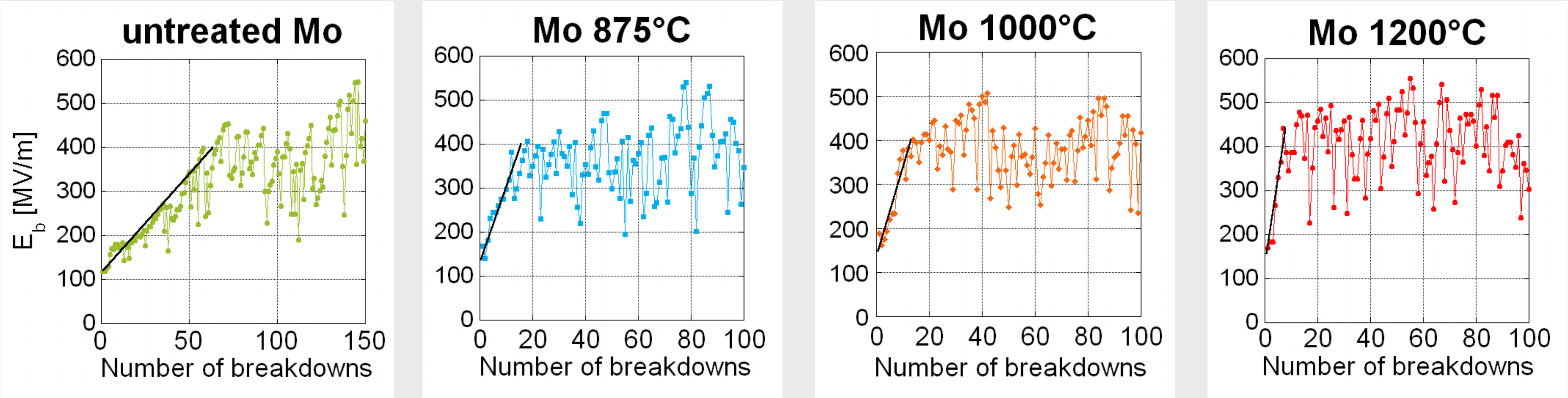




→ EDM : ~ same saturated field, but much slower conditioning speed (due to surface modification, higher roughness)

Ex-situ heat treatment (Mo, 2h)

- conditioning speed improved



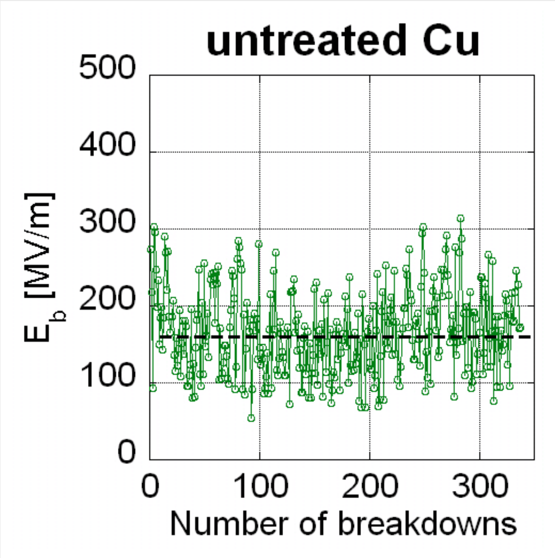
~ 60 sparks (to reach 400 MV/m) | ~ 15 sparks | ~ 12 sparks | ~ 10 sparks

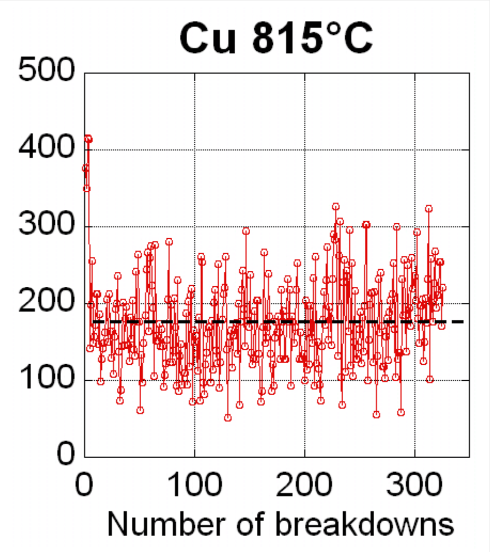
- XPS measurements : amount of Mo oxides at the surface reduced after heat treatment
- Hardness measurements : 1000°C and 1200°C samples are recrystallized, 875°C sample is ***not*** recrystallized

→ same saturated field
conditioning speed improved by oxides reduction
2h at 875°C is a good choice (to be tested soon on RF structures)

Ex-situ heat treatment (Cu, 2h)

- slight improvement in saturated field (10%)





- KEK results

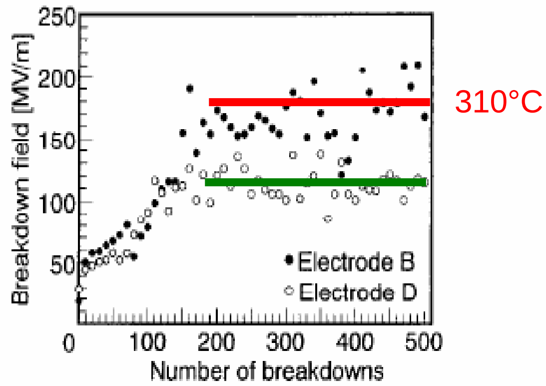


Figure 4. Breakdown properties of electrodes B (heat treated) and D (non-heat treated), which were machined from a 20% reduction material.

Kobayashi *et al.*, Vacuum **47** 745 (1996)

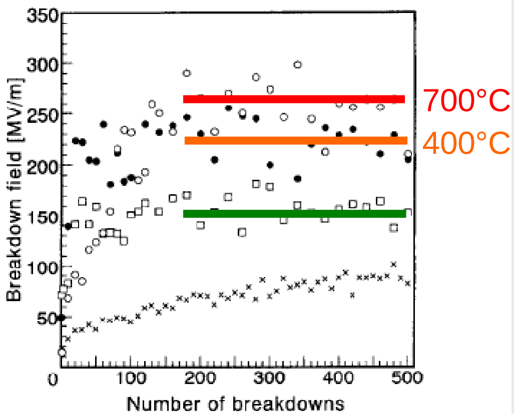
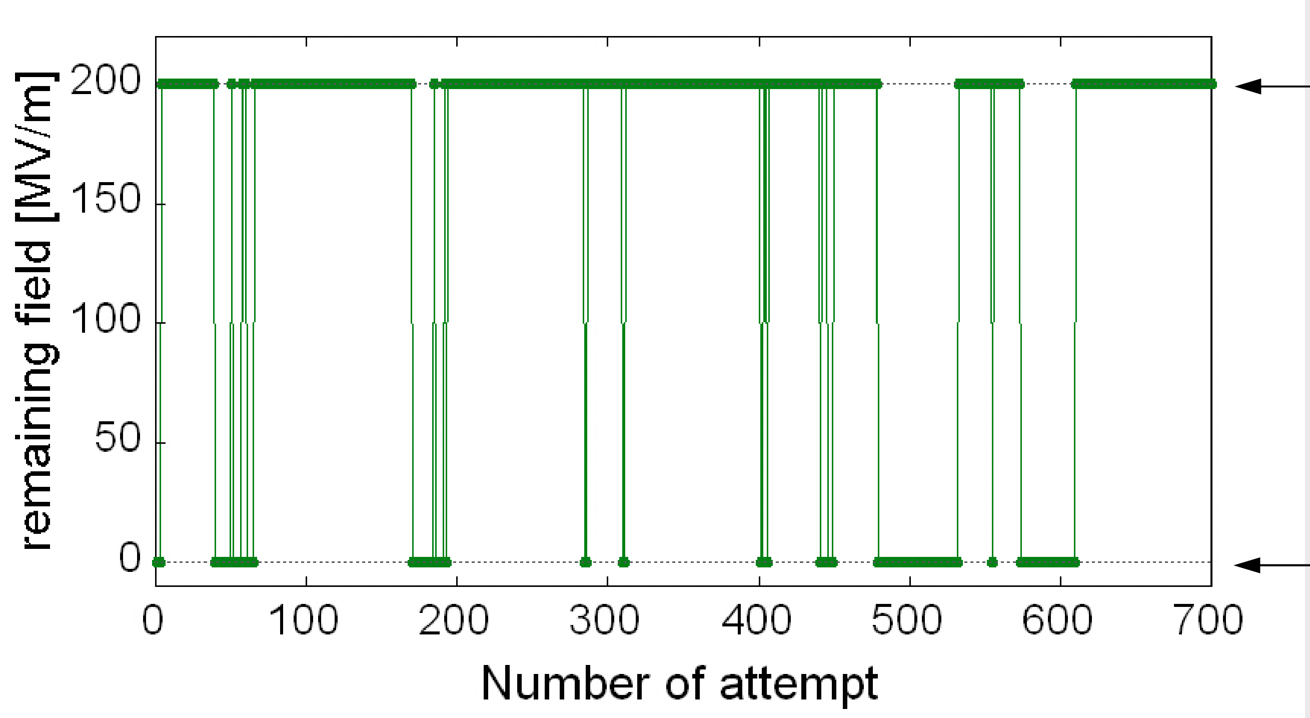


Figure 3. Breakdown properties of OFC electrodes processed by diamond turning and heat treatments. × lathing only, □ diamond turning and non-heat treatment, ● heated at 400°C, ○ heated at 700°C.

Breakdown rate : sparks distribution

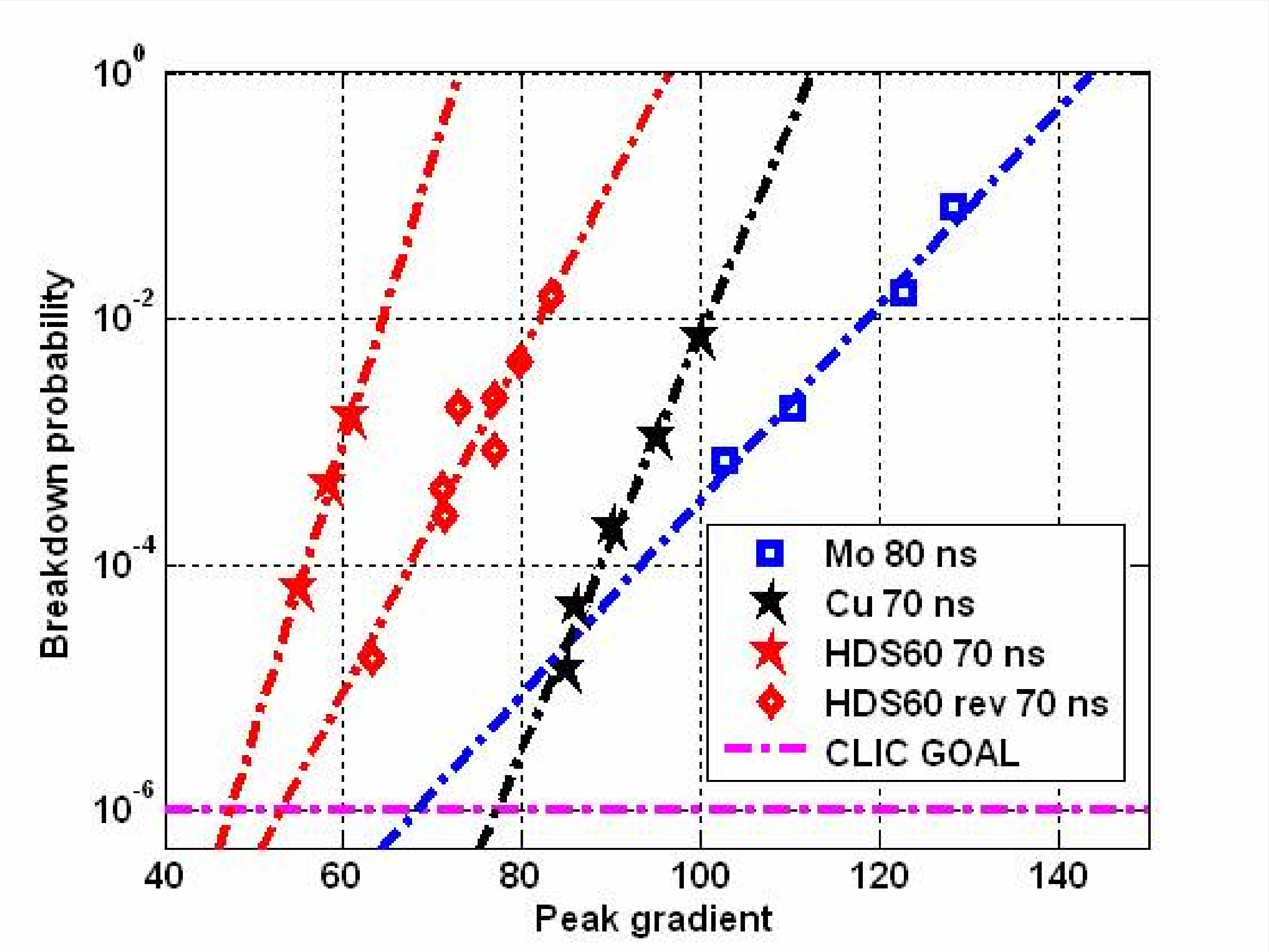
- breakdowns are randomly distributed, but come often by groups



- experimentally difficult to go under a breakdown probability of 10^{-4}

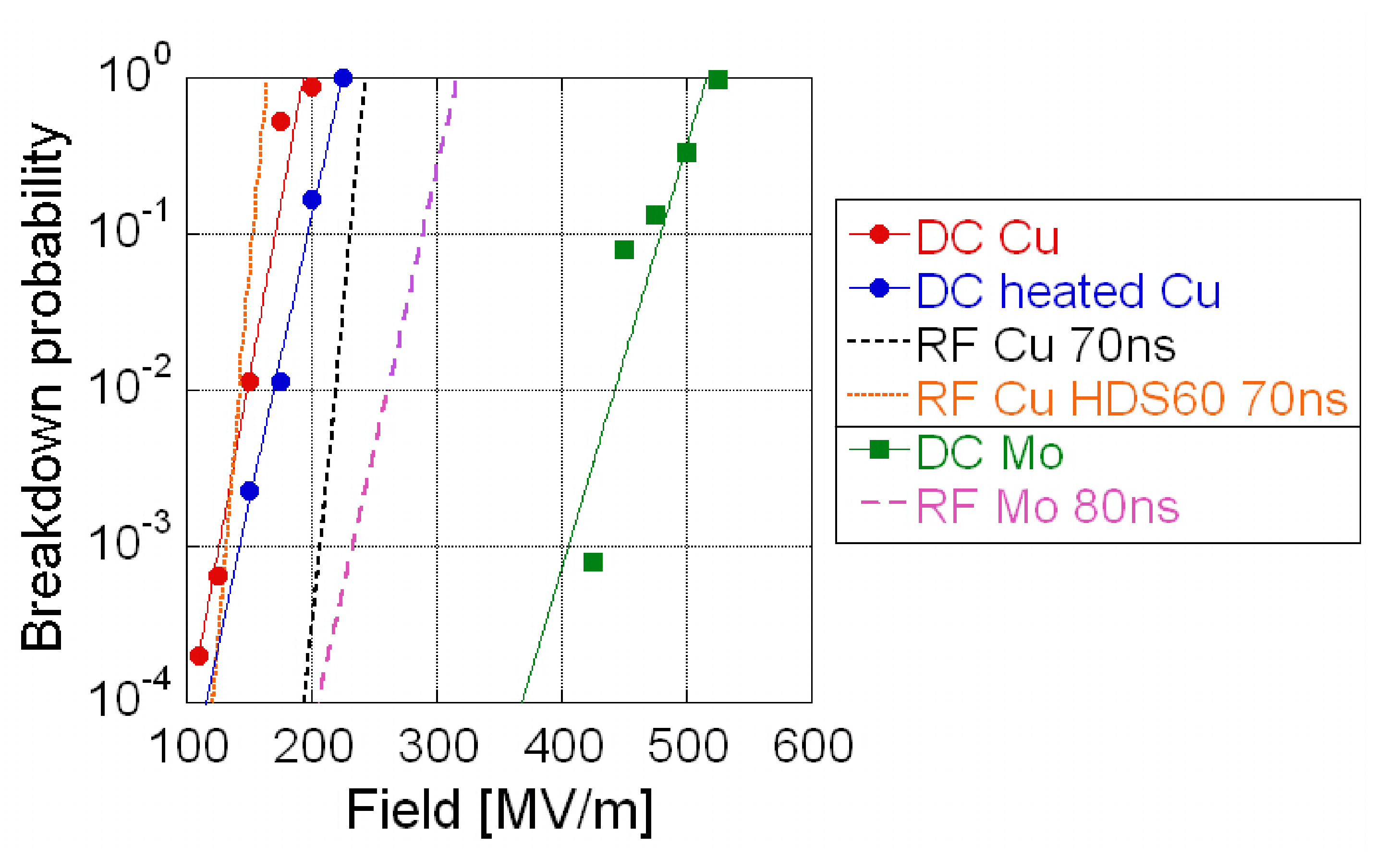
(time consuming, poor statistics, frequent mechanical problems with HV switch)

Breakdown rate vs field : RF (30 GHz)



→ points are aligned in a log(P) vs field plot

Breakdown rate vs field : DC



slope:
1 decade every…

23 MV/m
27 MV/m
13 MV/m
11 MV/m
37 MV/m
28 MV/m

Same trend as in RF measurements → consistent for comparison
Slopes are different, but Cu steeper than Mo in both cases

Summary

- Various metals and alloys have been tested (E_b, cond. speed, gap stability)
- Saturated breakdown field of Cu, W, Mo
  - same ranking in RF and DC
- Stainless Steel
  - very high gradient, to be confirmed
- Heat treatment of Mo
  - increase in conditioning speed by removing oxides
- DC breakdown rate measurements
  - Breakdown probability increases exponentially with applied field
  - DC – RF : different slopes, but Cu steeper than Mo