DC spark experiments for CLIC :

test of new materials, heat treatments and breakdown rate measurements

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TS-MME

CLIC meeting

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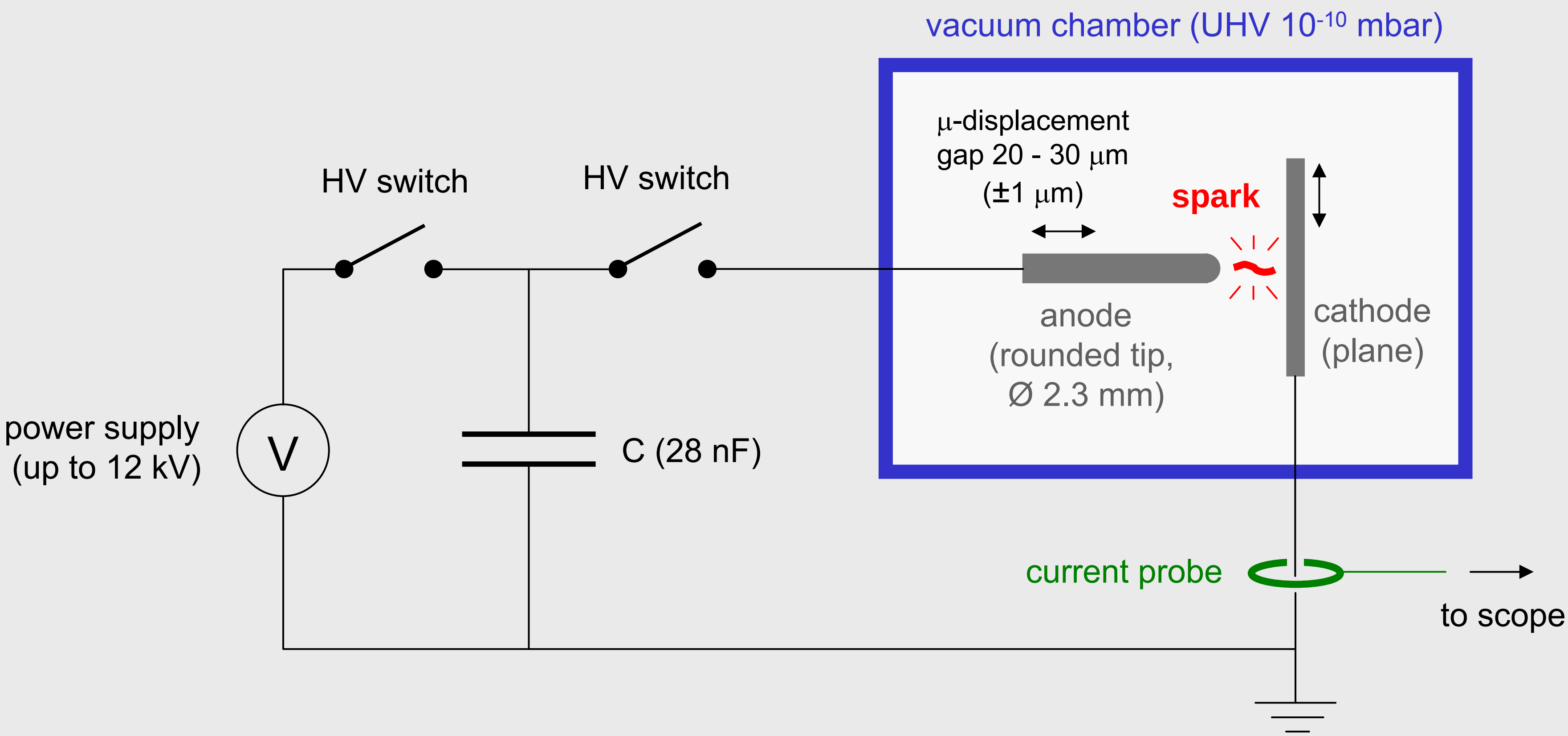
Outline

- Experimental setup
- New materials tested (since last presentation by Trond, in january 07)
- Heat treatments of Mo and Cu in oven
- Breakdown rate results
- Conclusions

Experimental set-up



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

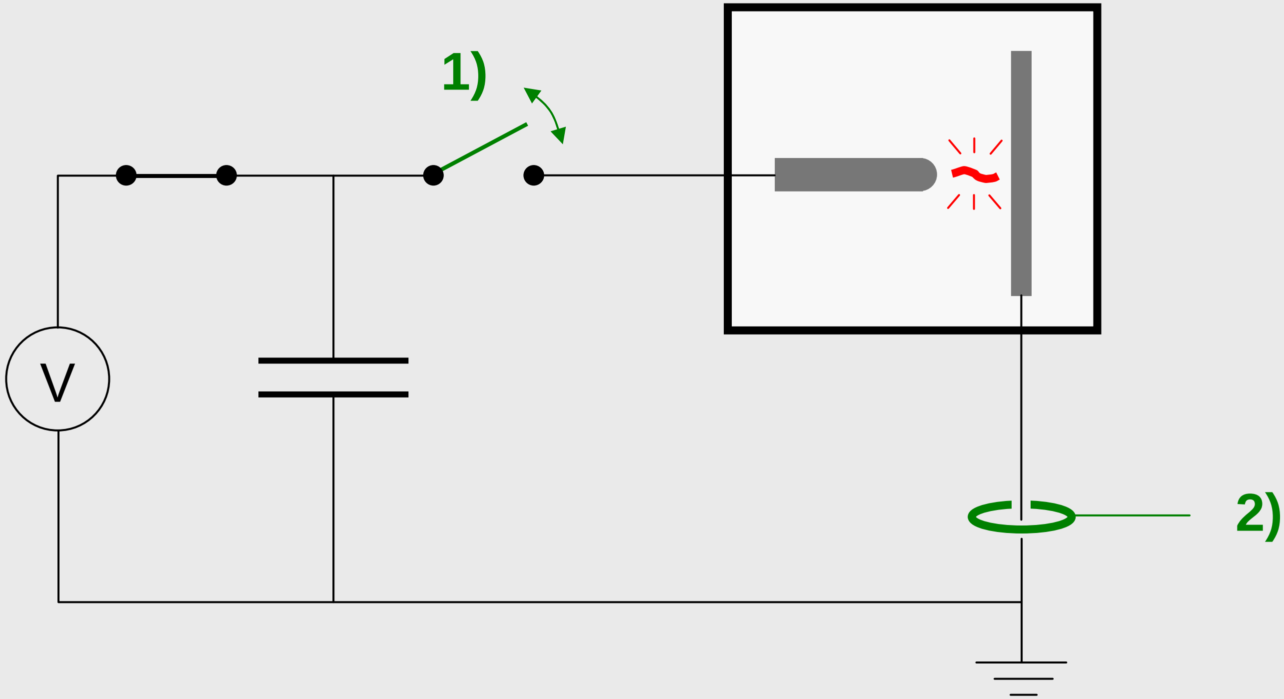
Types of measurement

NEW !

A) Field emission $\longrightarrow \beta$

B) Breakdown field E_b $\longrightarrow$ conditioning curve, saturated field $\overline{E_b}$

C) Breakdown rate $\longrightarrow$ breakdown probability vs field



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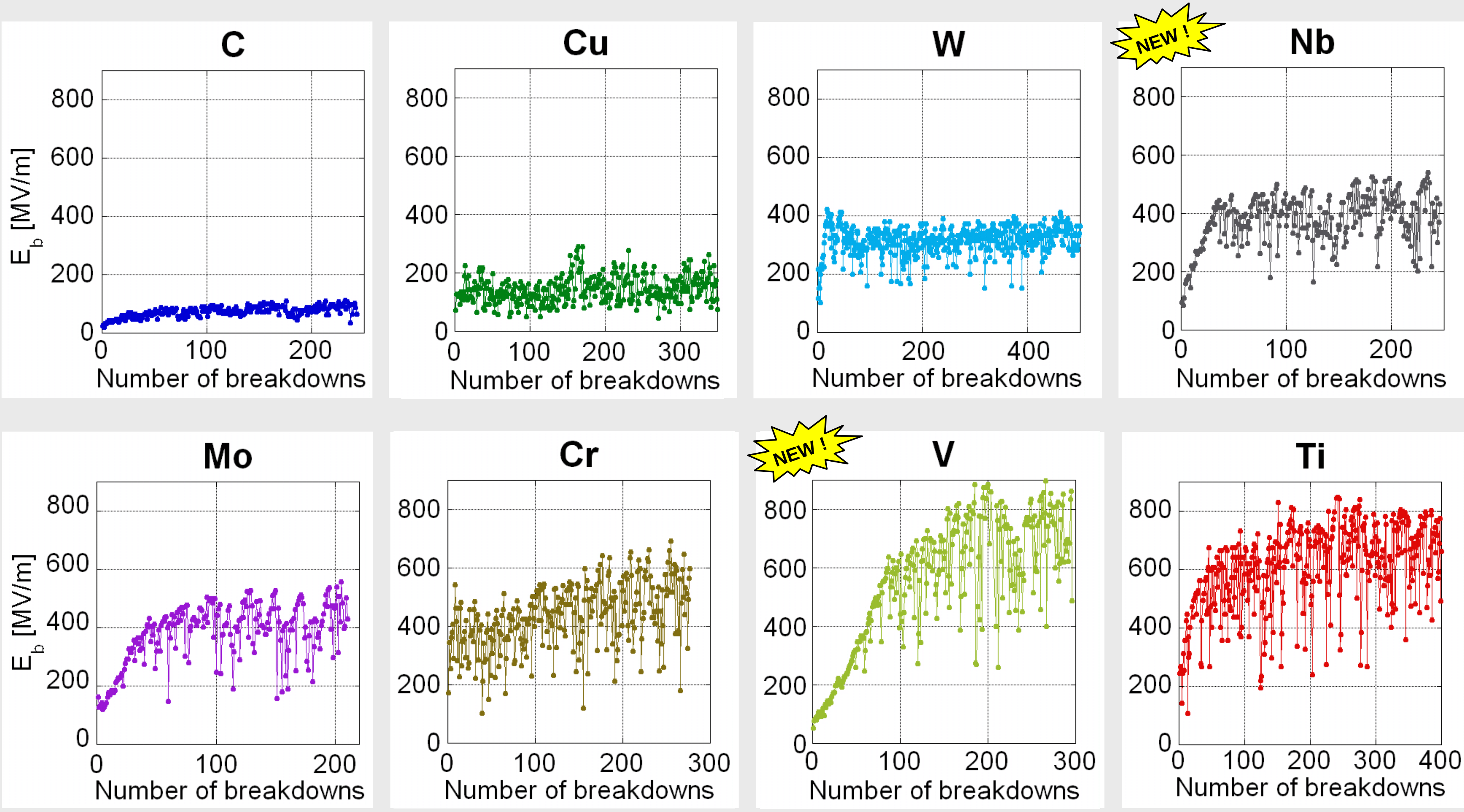
Conditioning curves of pure metals

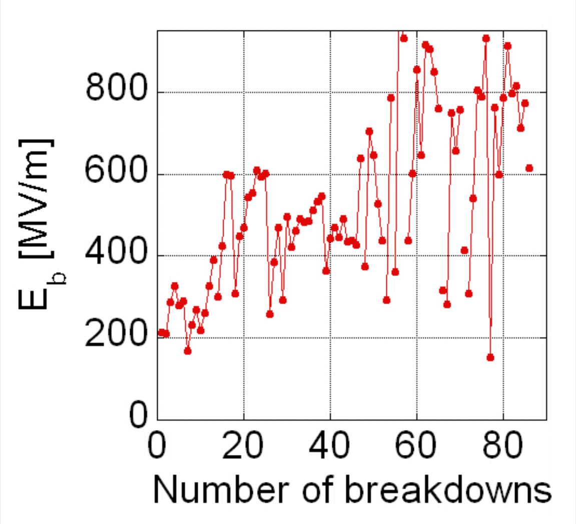


assumption: ‘good material’ = refractory ; oxides easily reduced

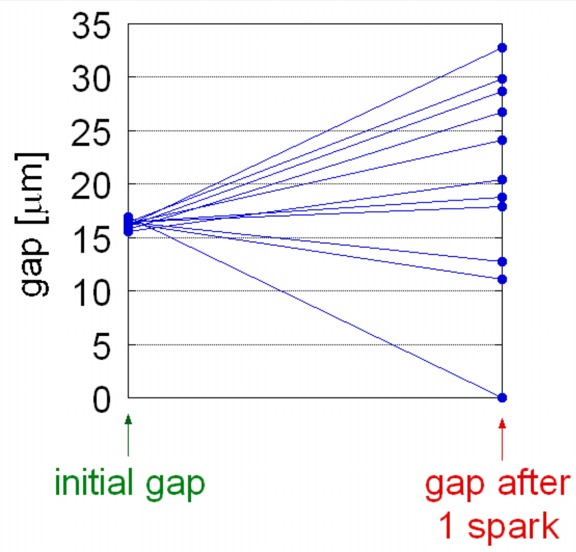
Alloys

- Ti – 15% Mo

Thanks to PX Group and to Gonzalo for the sample.

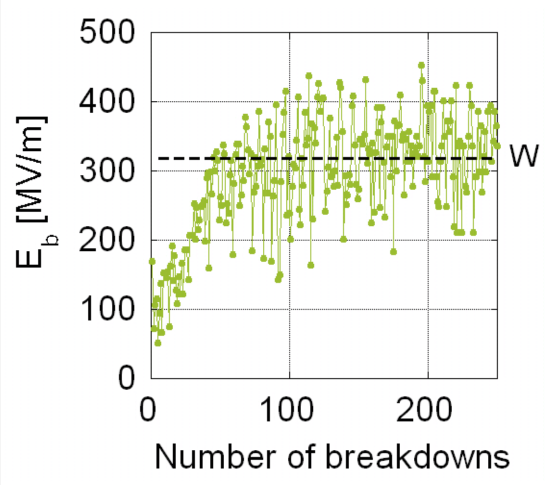


gap highly unstable!



- Tungsten carbide (10% Co)
  (tests are running now)

Thanks to DIXI Polytool and to Gonzalo for the sample.



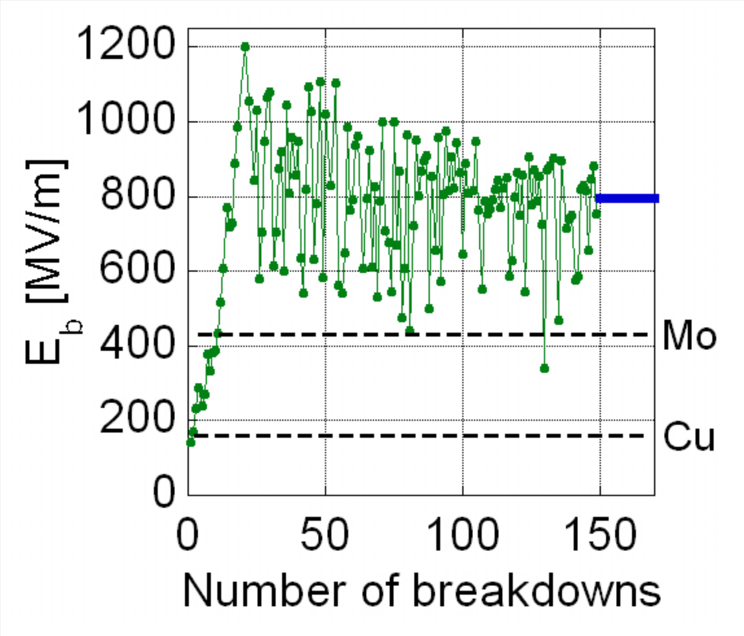
Stainless Steel (316LN)

- very high saturated field
  - $\overline{E}_b$ = 830 MV/m

NEW RECORD!

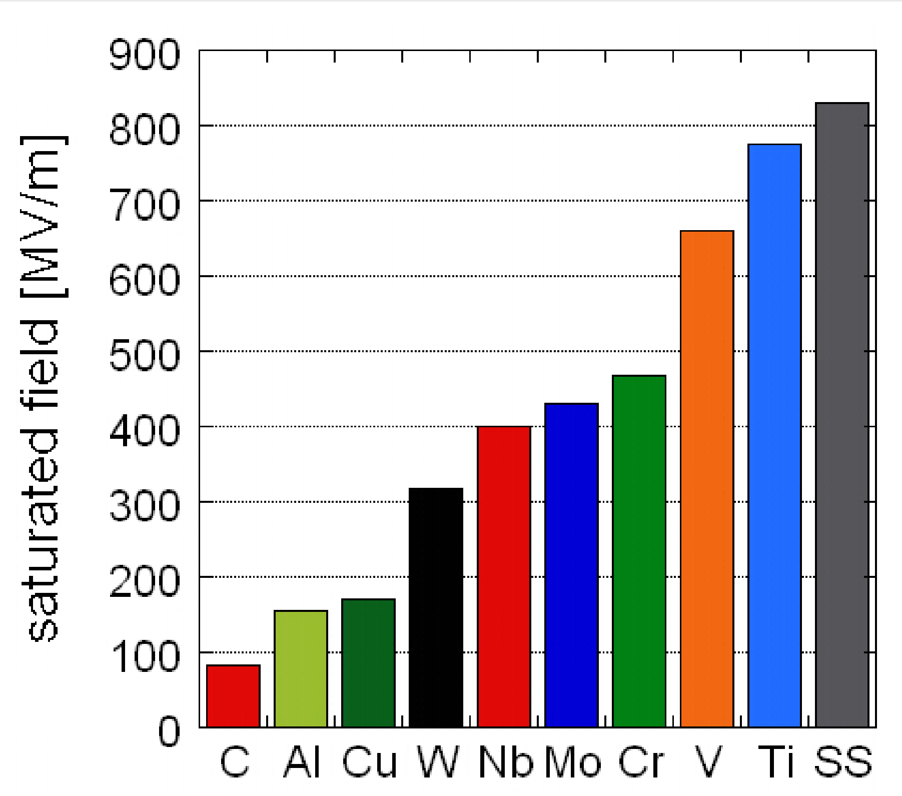
- fast conditioning speed
  - 20 sparks
- gap quite stable (similar to Mo, Cu)
- very small beta value after conditioning
  - $\beta \approx 6$
- large standard deviation (E_b)
  - $\sigma \approx$ 200 MV/m
- Such high fields are critical for this setup!
  - gap ≈ 9 μm, really small…

→ SS: low conductivity. Add Cu coating ?



	$\overline{E}_b$ [MV/m]	< β >	βE_b [GV/m]
Cu	170	46	7.8 (±1.3)
Mo	430	16	6.9 (±1.9)
SS	830	6	5 (±1.4)

Ranking of materials



• conditioning speed

Cu	"immediate"
SS	~ 20 sparks
Mo, Ti	~ 50 sparks
V	~ 100 sparks

• gap instability

Mo	< 15 %
Cu, SS	< 25 %
Ti	< 50 %

(max. gap variation after a full conditioning experiment)

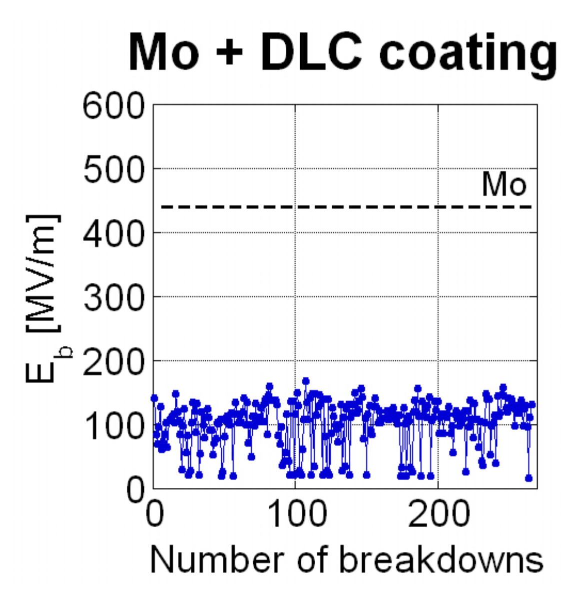
- broad range: 100 – 1000 MV/m
- difficult to point out **1** dominant physical property, combination of several ones

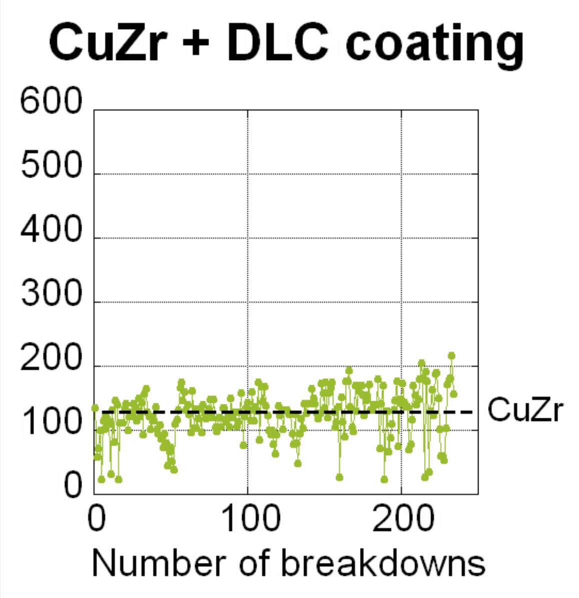
  (melting point, heat of fusion, thermal conductivity, electrical conductivity, vapour pressure, surface tension, work function, …)

Other materials

- Metals with 2 μm DLC coating
  (idea: increase thermal conductivity to evacuate heat)

Thanks to DIARC and to Samuli for the samples.





- ready to be tested : Ta
  Cu + Cr coating
  'home-made' Ti-Mo
  Mo, W machined with EDM
  chemically polished Cu

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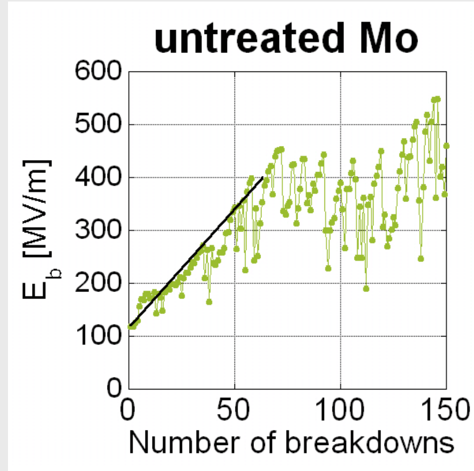
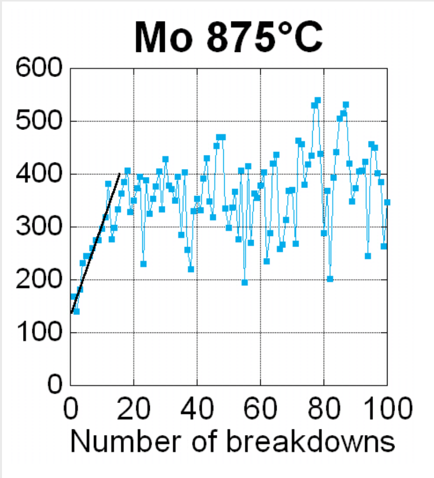
Ex-situ heat treatment in oven (Mo, 2h)

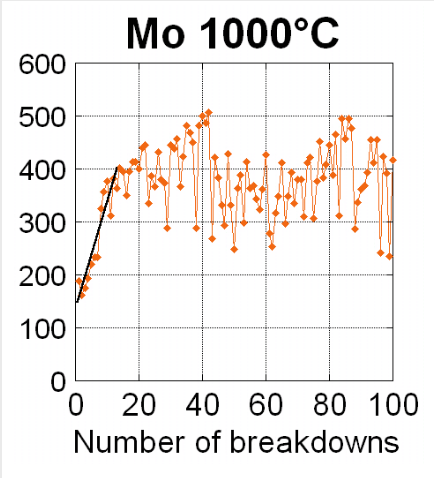
Thanks to Ivo Wevers for the treatments.



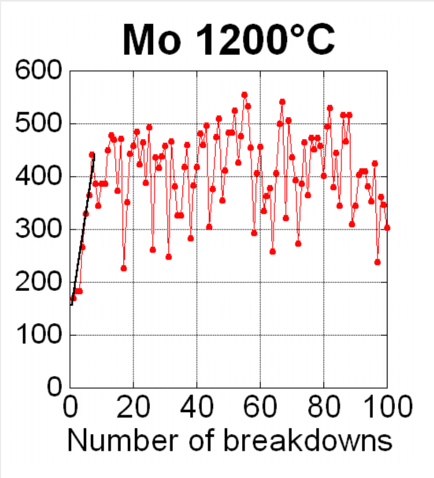
~ 60 sparks (to reach 400 MV/m)



~ 15 sparks



~ 12 sparks



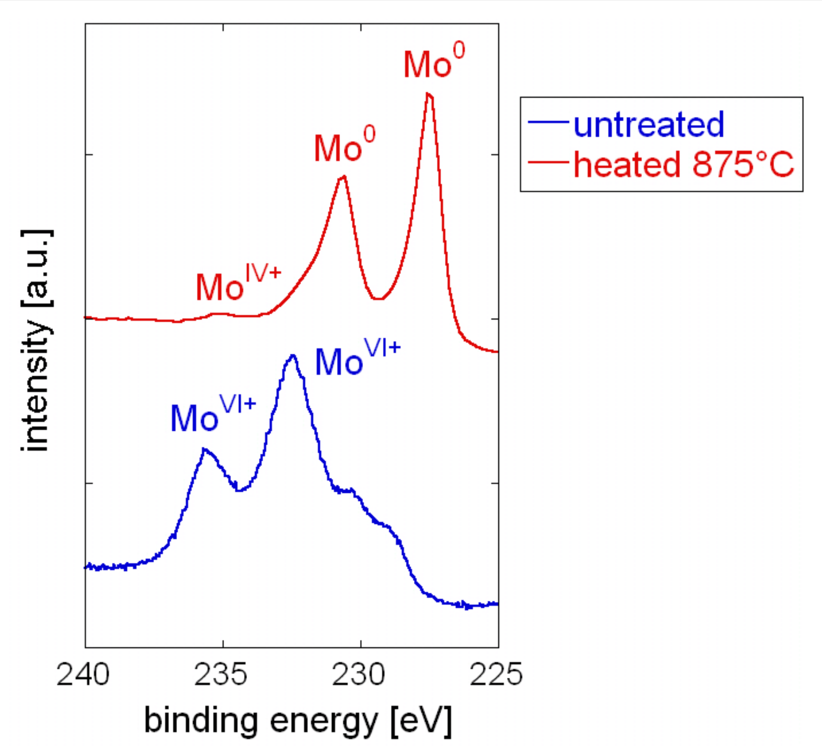
~ 10 sparks

→ same saturated field, conditioning speed improved

Ex-situ heat treatment in oven (Mo, 2h)

- XPS measurements :

Amount of Mo oxides at the surface reduced after heat treatment



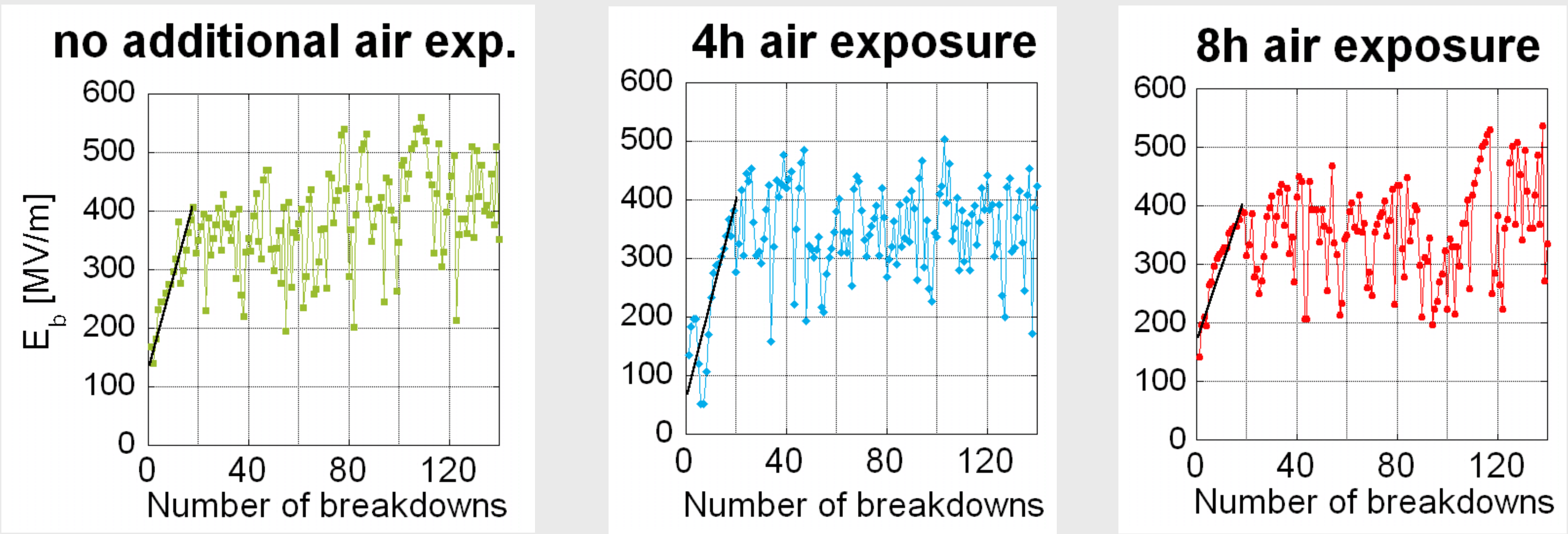
- Hardness measurements : 1000°C and 1200°C samples are recrystallized, 875°C sample is ***not*** recrystallized

Thanks to Alex Gerardin for the measurements.

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

Effect of dry air exposure after heat treatment (Mo 875°C)

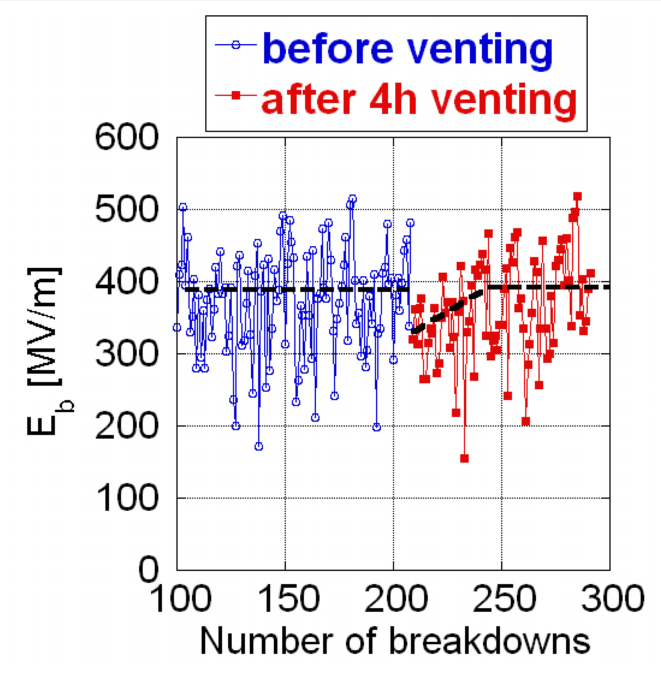
- no significant degradation on virgin spots after 8 hours exposure (~ mounting time of structures in CTF)



- confirmed by XPS : oxidation still negligible after 8h air exposure

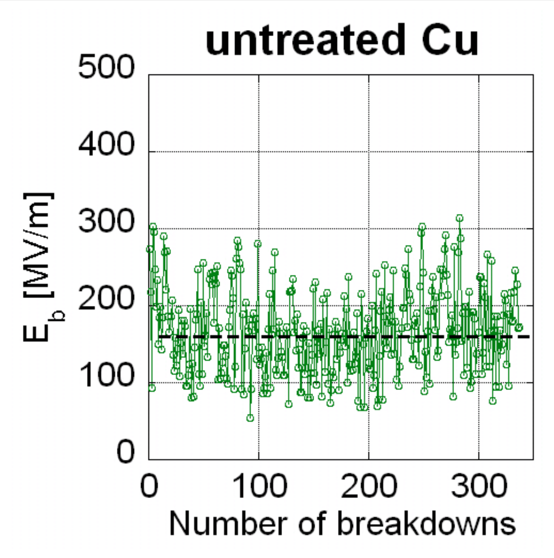
Effect of dry air exposure after heat treatment (Mo 875°C)

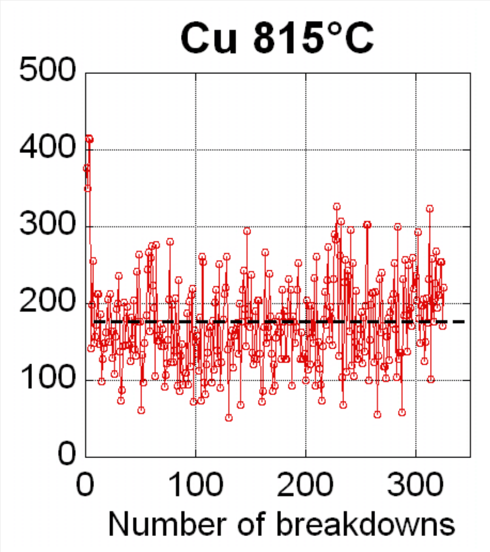
- small degradation on conditioned spots after 4 hours exposure



→ conditioned spot : more reactive to oxide formation

Ex-situ heat treatment in oven (Cu, 2h)





- Slight improvement in saturated field (10%)

Thanks to the brazing team for the treatment.

- Saitama University results (1996)

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

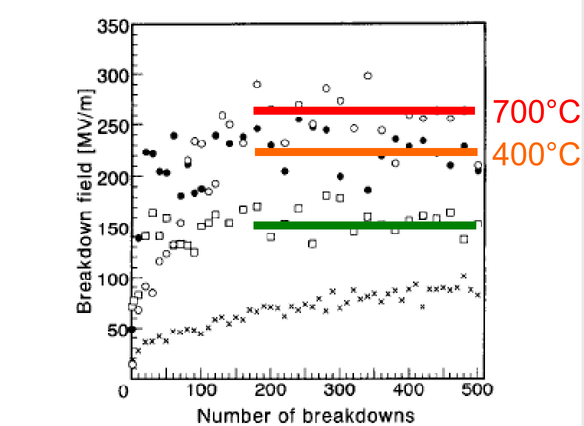


Figure 3. Breakdown properties of OFC electrodes processed by diamond turning and heat treatments. × lathing only, □ diamond turning and non-heat treatment, ● heated at 400°C, ○ heated at 700°C.

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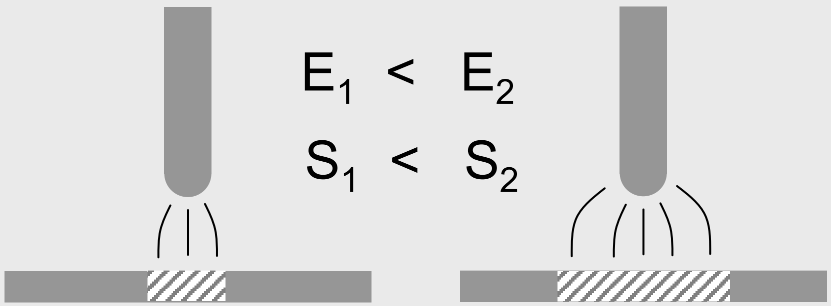
Breakdown rate : procedure

1. conditioning of the spot
2. find field for BDR = 1
3. to reach lower BDR, decrease field by 25 MV/m steps at least

   (≈ max. variation in E due to gap changes during 1 run, max. 'precision' in E)

- works not well by increasing E :

  sparks mostly grouped at the beginning of the run (due to emitters located in the 'uncleaned' area?)

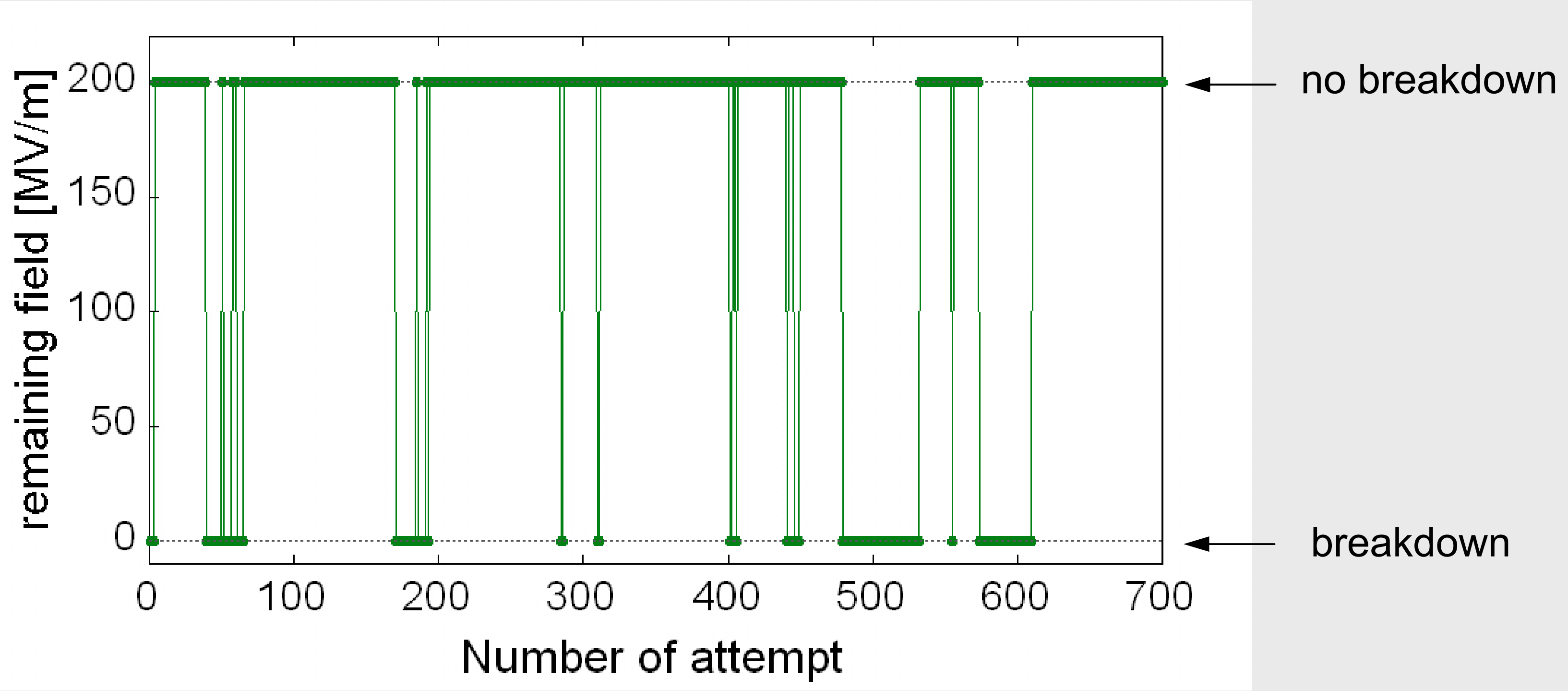


- ~ 6 sec / attempt
- experimentally difficult to go under a breakdown probability of 10^{-4}

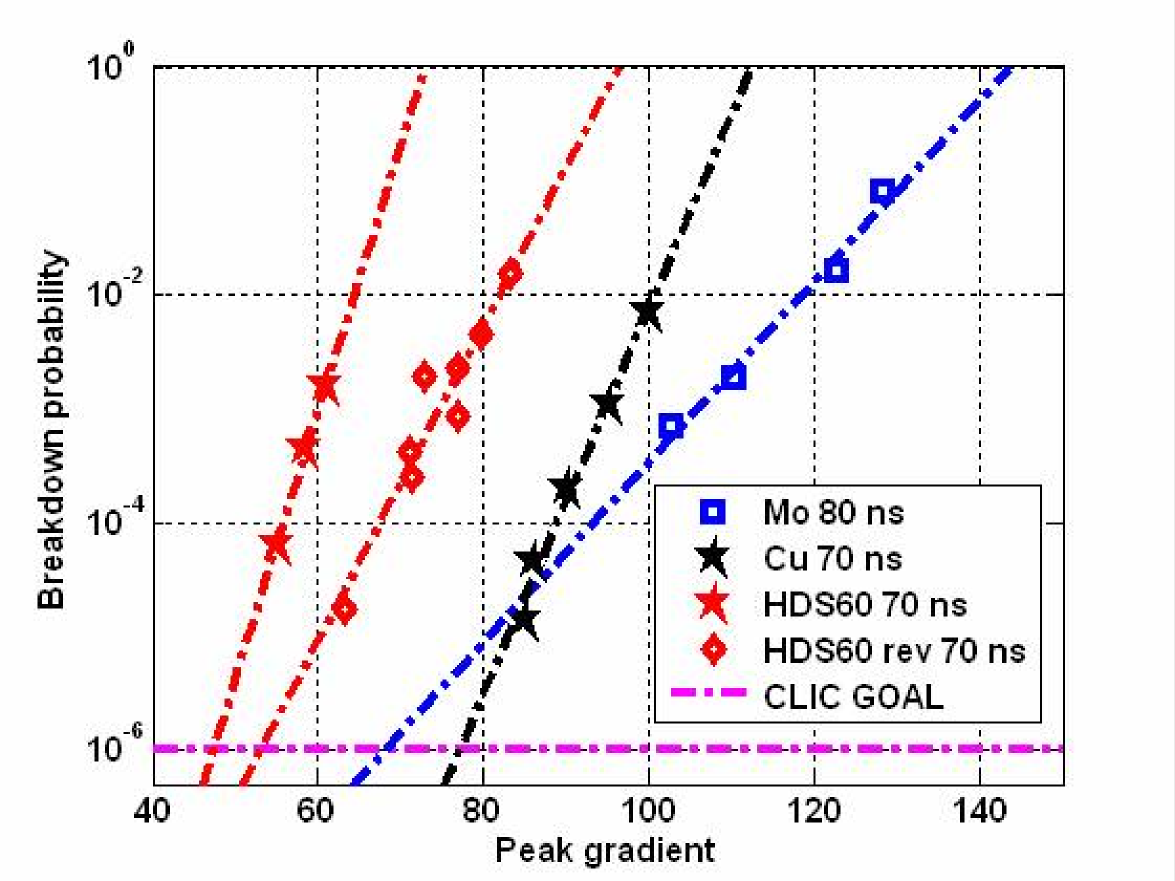
  (time consuming, poor statistics, frequent mechanical problems with HV switch)

Breakdown rate : sparks distribution

- breakdowns are randomly distributed, but come often by groups

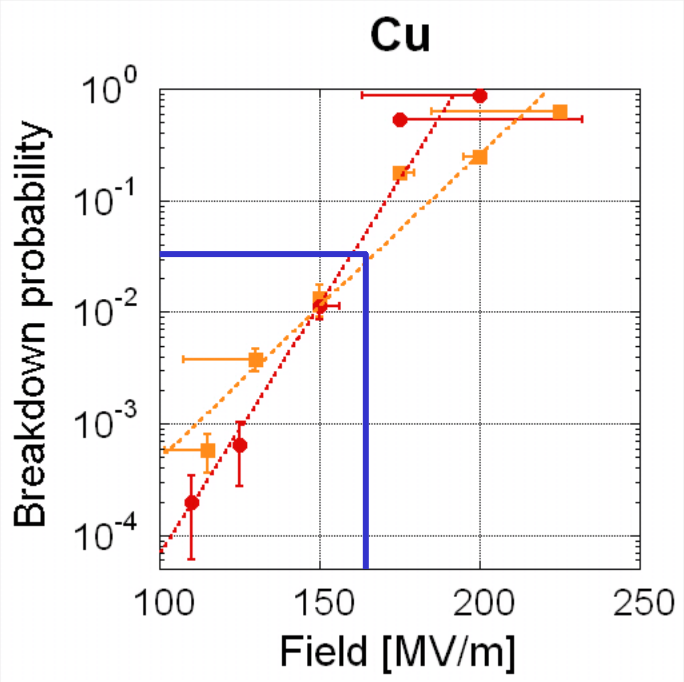


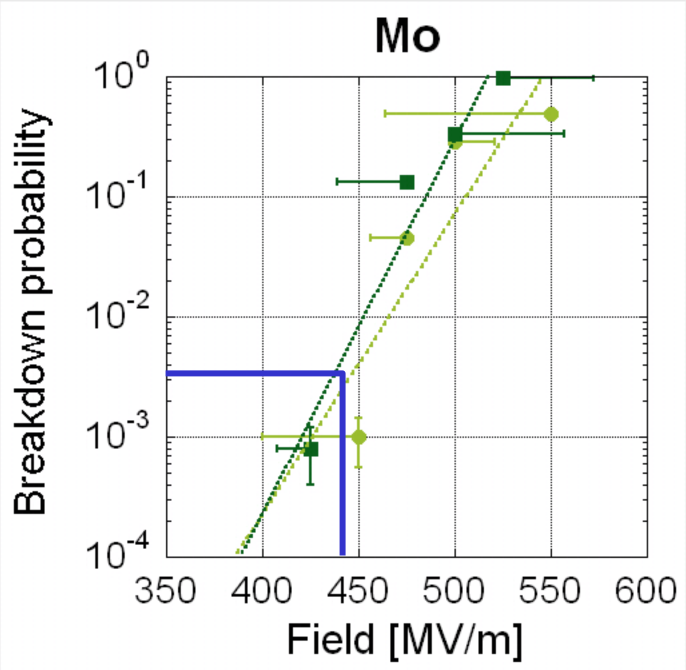
Breakdown rate vs field : RF (30 GHz)



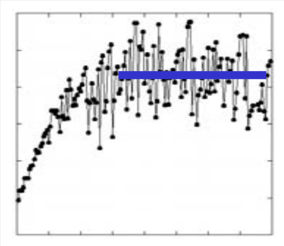
→ Points are aligned in a log(P) vs E plot. ***And in DC ?***

Breakdown rate vs field : DC



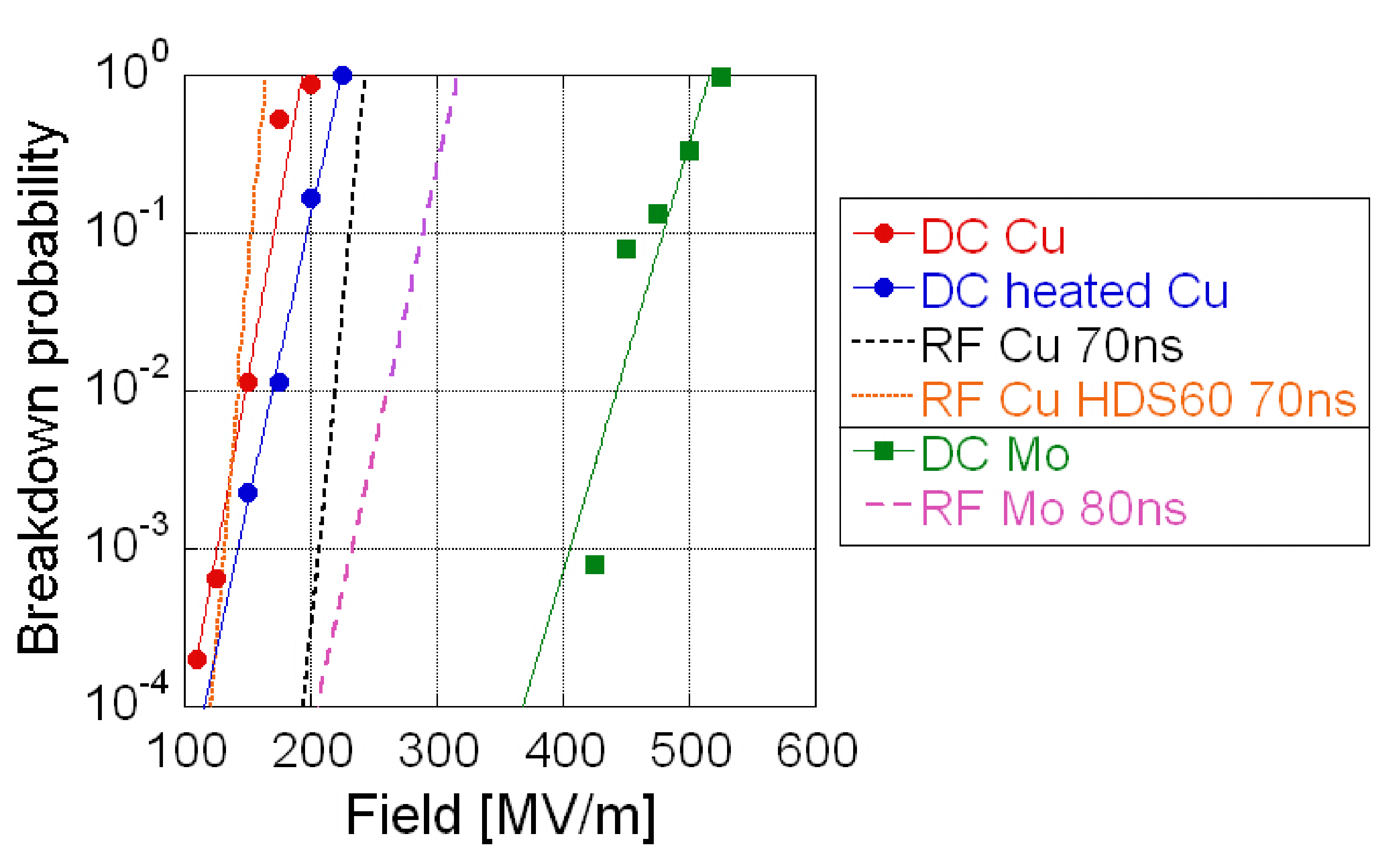


→ Same trend as in RF measurements → comparison possible



NB: low BDR @ saturated field (~ 10^{-2})

Breakdown rate vs field : RF & DC (1st version)



absolute slope:
1 decade every…

28 MV/m (±6)
27 MV/m (±3)
13 MV/m
11 MV/m

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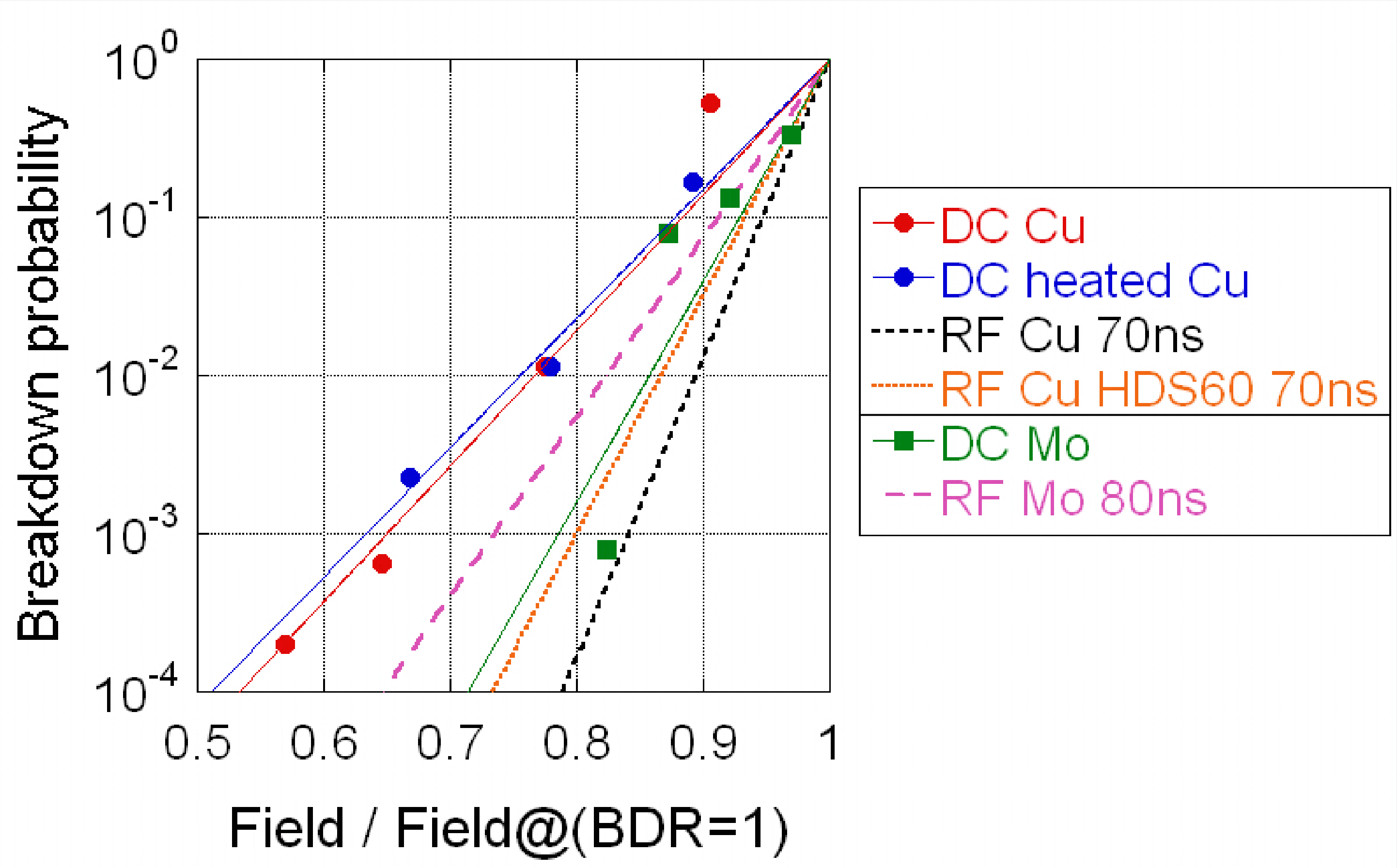
37 MV/m (±5)
28 MV/m

NB: RF data are plotted vs <u>surface field</u>

→ RF & DC slopes are different
Cu steeper than Mo in both cases

Breakdown rate vs field : RF & DC (2nd version)



slope:
decades over 20% of field@(BDR=1)

1.7 (±0.4)
1.6 (±0.1)
3.8
3

2.8 (±0.4)
2.3

Normalization : 'how many decades do we gain if we decrease the max. field by X%'

→ RF & DC slopes are different for Cu, similar for Mo
Mo steeper than Cu in DC

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Summary

- Various metals and alloys have been tested (E_b, cond speed, gap stability)
  - Stainless Steel : highest saturated breakdown field, gap stable
  - difficult to understand the ranking of materials…
- Heat treatment of Mo
  - increase in conditioning speed by removing oxides
  - no deterioration after 8h air exposure
- Heat treatment of Cu
  - slight increase in saturated field
- DC breakdown rate measurements
  - Breakdown probability increases exponentially with applied field
  - DC – RF : different slopes, Cu steeper than Mo (?)

Outlook

- Continue tests of materials, coatings & surface preparation
- More breakdown rate
- Optical Emission Spectroscopy of the spark (feedthrough with optical fiber)
  - composition, temperature, density
  - pre-breakdown

- 2nd DC spark system will run in a few weeks…

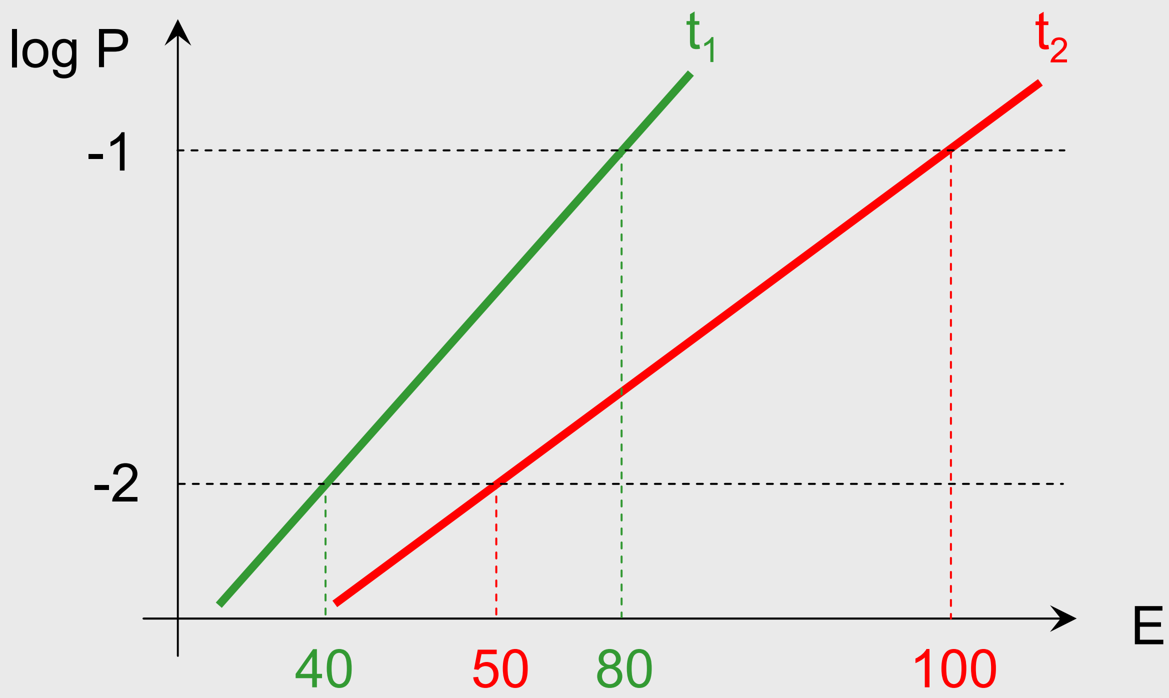
lots of work done by Yngve Levinsen

  - up to 30 kV
  - energy of sparks can be changed
  - run BDR and tests of materials in parallel

Thank you !

Slope ?

- Schematic pulse length dependence in RF (same structure)



$$\frac{1\text{ dec.}}{(100-50)} \neq \frac{1\text{ dec.}}{(80-40)}$$

$$\frac{1\text{ dec.}}{\frac{(100-50)}{100}} = \frac{1\text{ dec.}}{\frac{(80-40)}{80}}$$

→ absolute slope is not relevant
normalize fields by field at a fixed BDR

Materials properties

	sat. brkd field MV/m	melting point °C	boiling point °C	heat of fusion J/mm^3	heat of evaporation J/mm^3	thermal conductivity W/mK	electrical conductivity 10^6 Ohm^{-1}m^{-1}	vapor pressure at melt. point Pa	vapor pressure at 1080°C Pa	vapor pressure at 1680°C Pa	surface tension	density kg/m^3	Z	work function eV
Cu	**170** (7)	1083 (9)	2567 (8)	1.8 (7)	42 (7)	401 (1)	59.6 (1)	0.05 (1)	5E-2 (8)	2E2 (7)		8920	29	4.65
W	**315** (6)	3410 (1)	5660 (1)	3.7 (1)	87 (1)	174 (2)	18.9 (2)	4.27 (7)	4E-21 (1)	7E-11 (1)		19350	74	4.55
Nb	**400** (5)	2468 (4)	4742 (3)	2.4 (4)	63 (3)	53.7 (6)	6.9 (6)	0.075 (2)	1E-15 (3)	4E-7 (3)		8570	41	4.3
Mo	**440** (4)	2617 (3)	4612 (4)	3.4 (2)	63 (3)	138 (3)	18.7 (3)	3.47 (6)	2E-13 (4)	1E-5 (4)		10200	42	4.6
Cr	**470** (3)	1857 (6)	2672 (7)	2.3 (6)	48 (6)	93.7 (4)	7.7 (4)	990 (8)	7E-3 (7)	4E2 (8)		7200	24	4.5
V	**660** (2)	1890 (5)	3380 (5)	2.4 (4)	53 (5)	30.7 (7)	4.9 (7)	3.06 (5)	8E-8 (5)	1E-1 (5)		5960	23	4.3
Ti	**780** (1)	1660 (7)	3287 (6)	1.5 (8)	40 (8)	21.9 (8)	2.3 (8)	0.49 (3)	2E-6 (6)	5E-1 (6)		4540	22	4.33
SS	**830**	~1510 (8)				15	1.3					7950	-	
Ta	**?**	2996 (2)	5425 (2)	2.9 (3)	68 (2)	57.5 (5)	7.6 (5)	0.77 (4)	1E-19 (2)	1E-10 (2)		16600	73	4.25
WC	**310**	2780	6000			84	1.4					14450	-	