Delay Times in Breakdown Triggering

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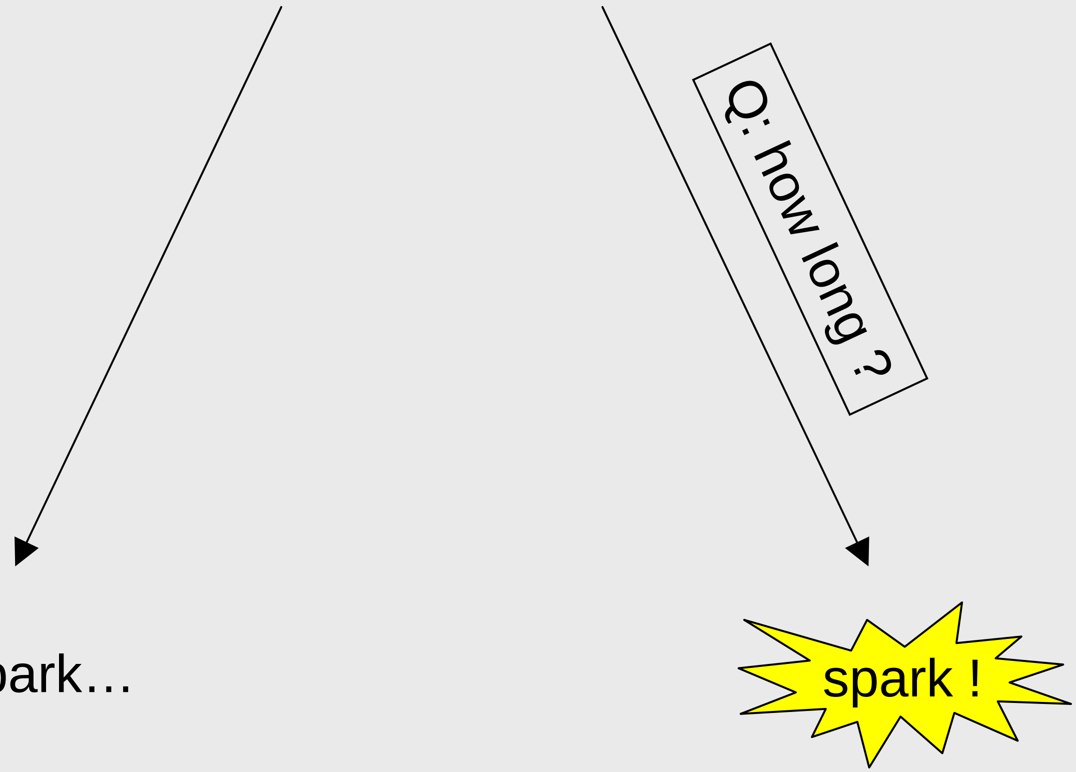
Time matters

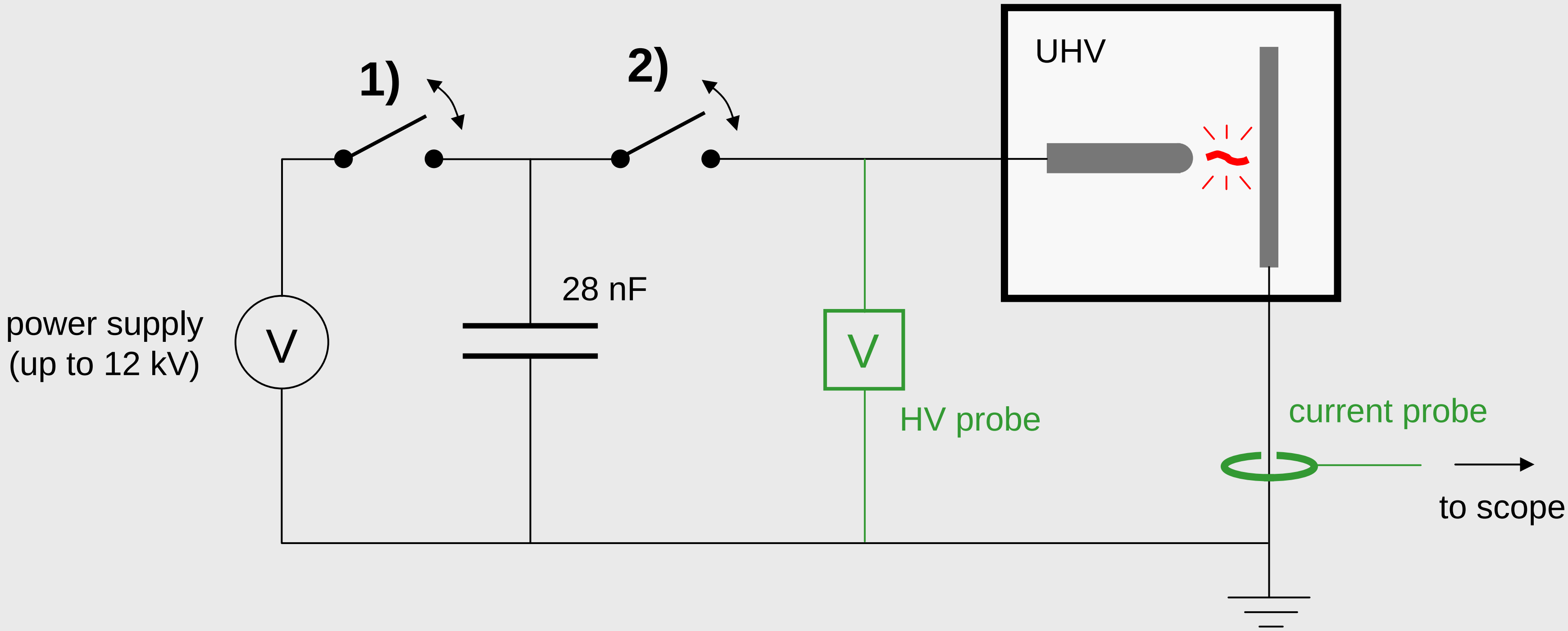
- t_0 : high voltage is applied between the electrodes



- $t > t_0$: no spark…

→ Study of delays can give information about the breakdown mechanism

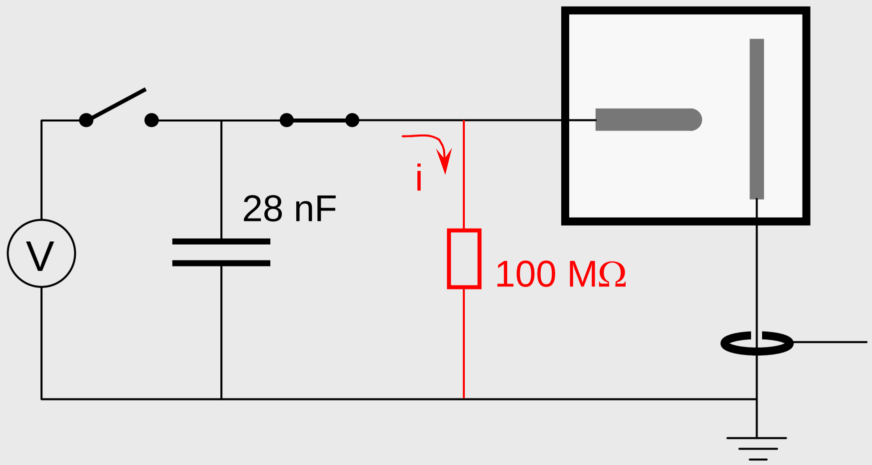
DC spark : experimental set-up



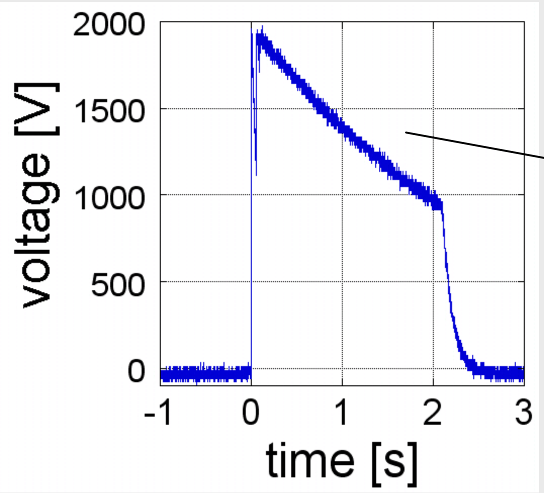
- Charged capacitor connected to the electrodes during 2 sec, through a high current mechanical relay
- Voltage and current measured with probes, connected to a scope
  - HV probe : 20kV, 75MHz, 1:1000, 100MΩ
  - current transformer : 500MHz, 1kA peak
  - scope : 1GHz

DC spark : experimental set-up

NB: slow discharge of the capacitor during the voltage ‘pulse’ due to finite resistance of HV probe (RC circuit)

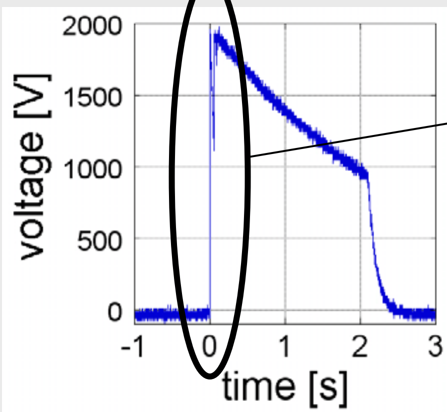


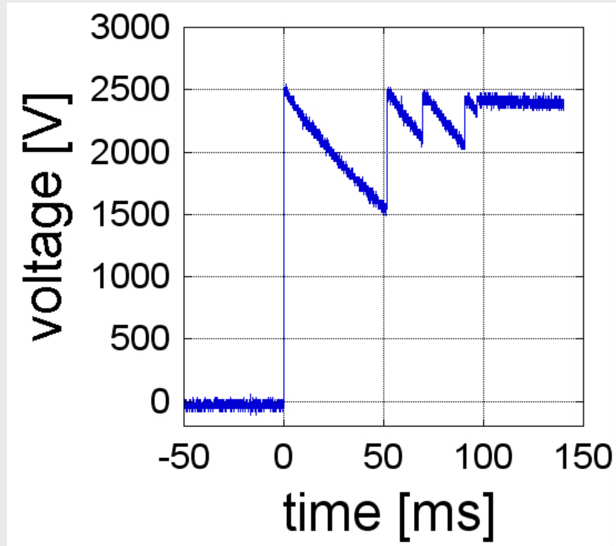
- resulting ‘pulse’ :

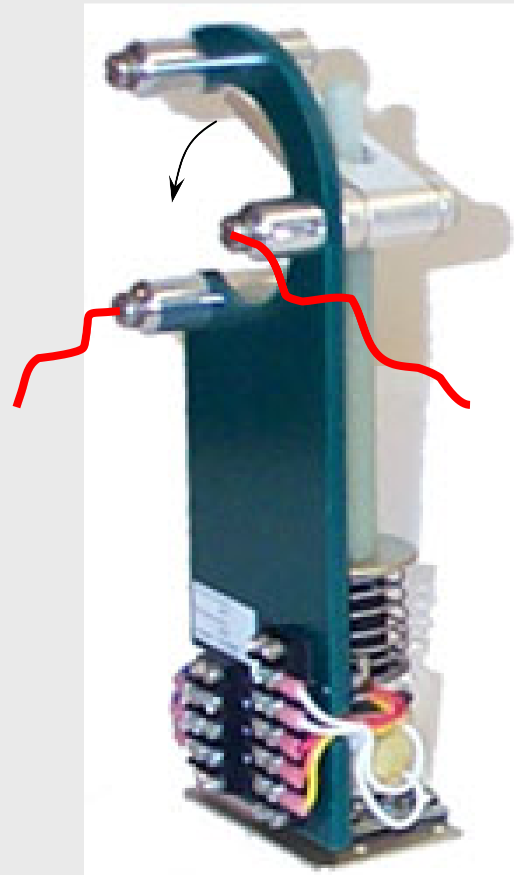


circuit time constant :
τ = RC = 2.8 sec

DC spark : experimental set-up







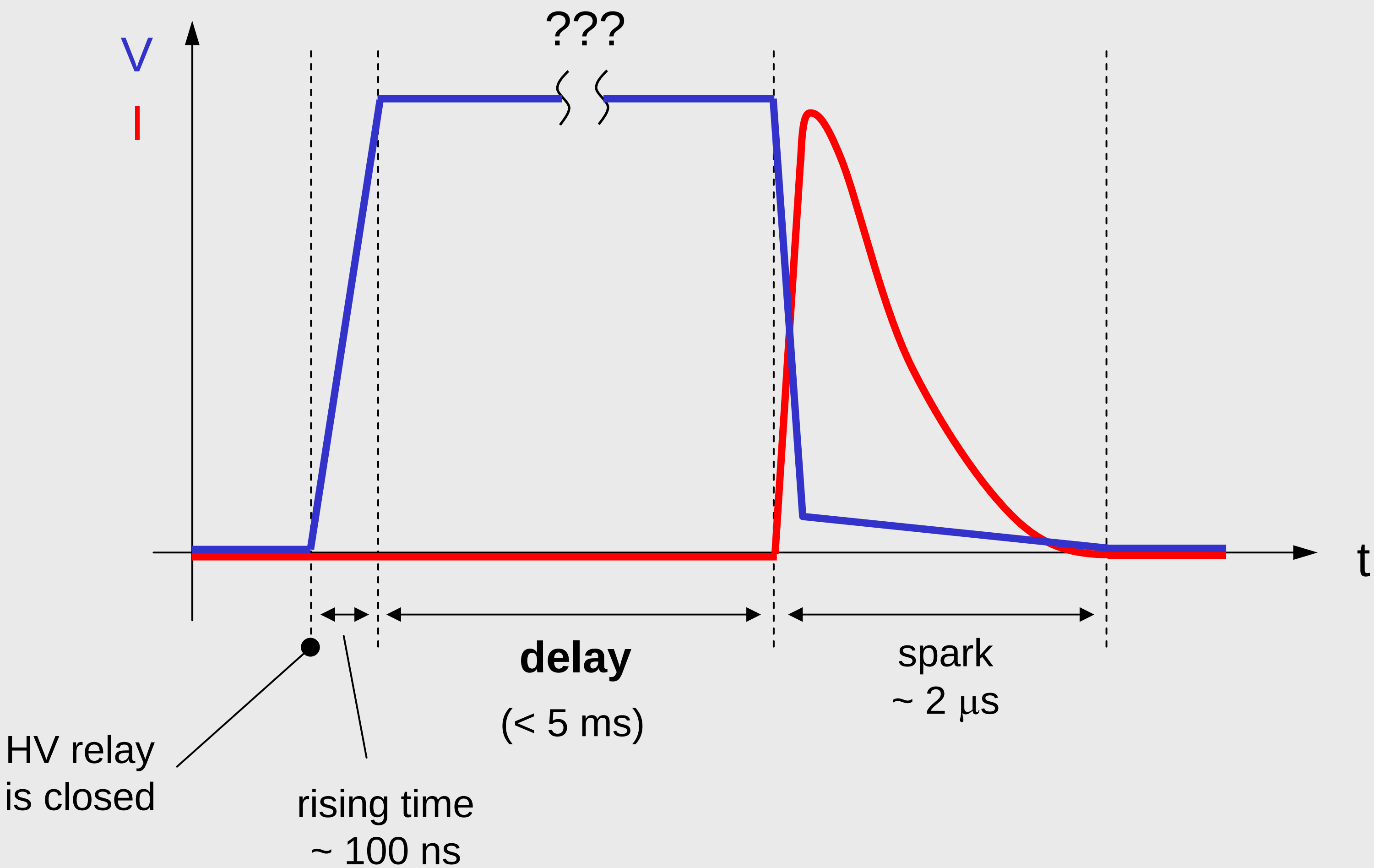
- The moving part of the mechanical relay is bouncing sometimes (loss of contact)

→ …but voltage pulse is 'flat' over at least 5 ms

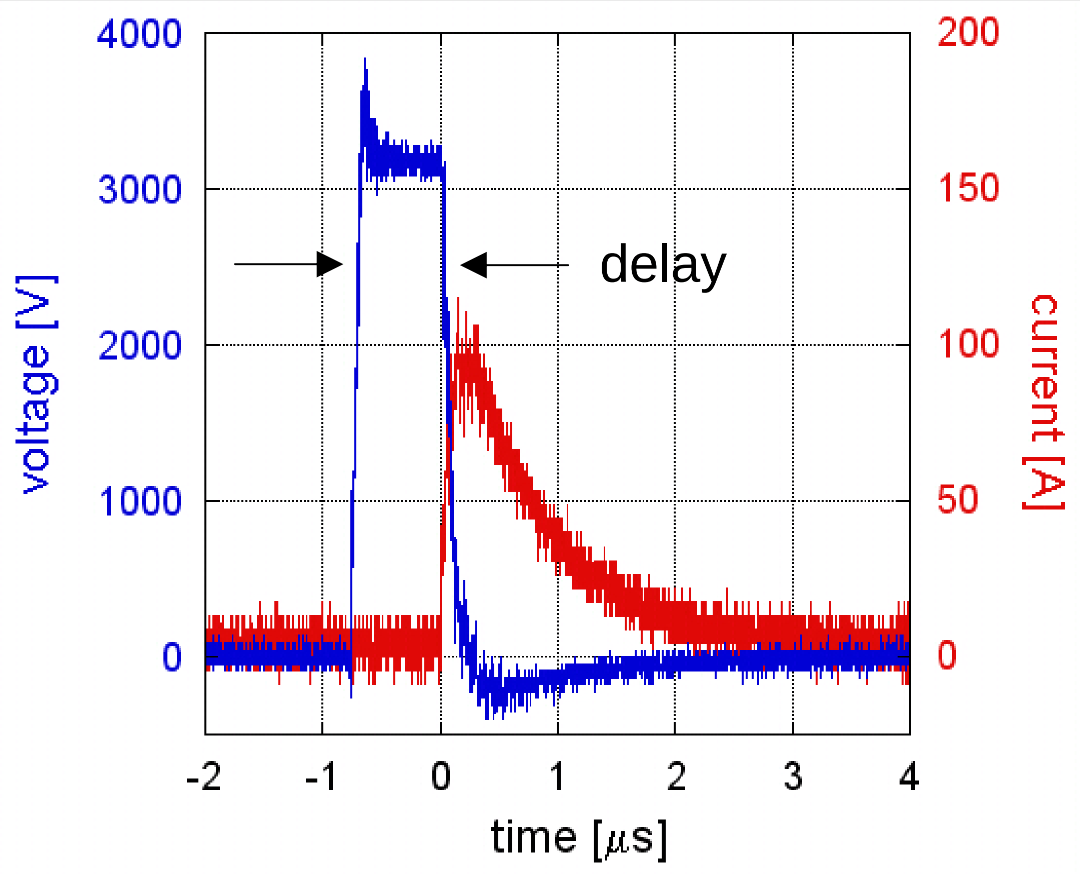
(and 5 ms = max. delay observed)

Timing diagram of a spark

- Schematic evolution of the **voltage** and **current** across the electrode gap

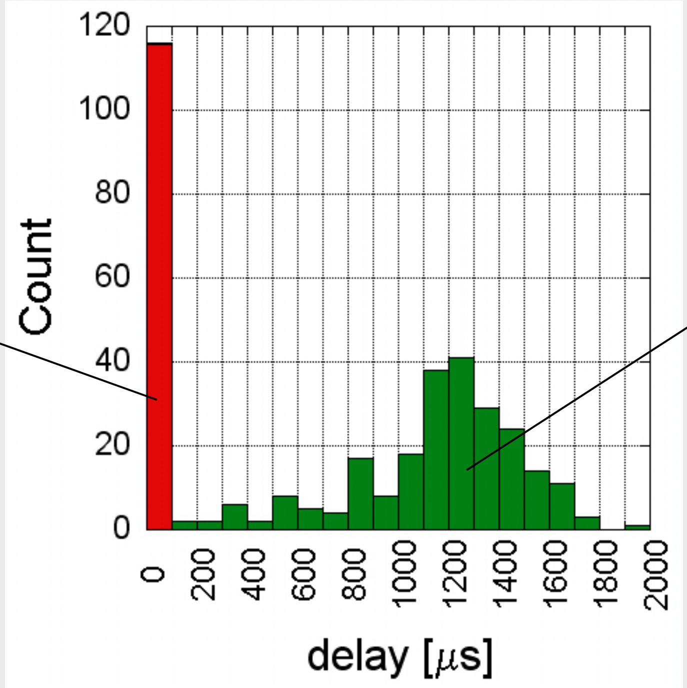


Example of a spark



Delay times with Mo electrodes

- Histogram of delays

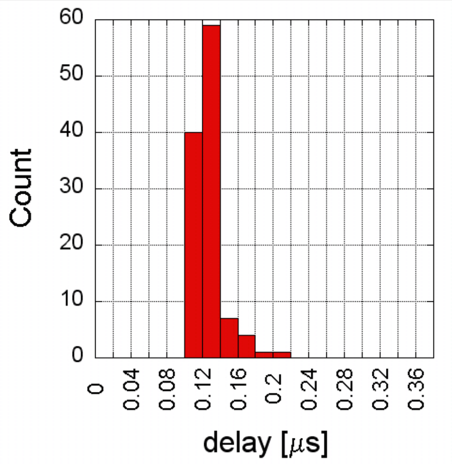


population #1
'immediate' brkds

average : 129 ns
(σ = 16 ns)

population #2
'delayed' brkds

average : 1.17 ms
(σ = 0.33 ms)



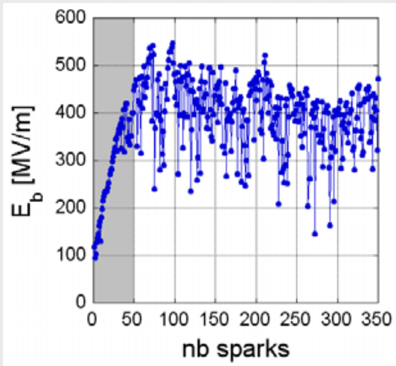
voltage rising time: ~ 100 ns

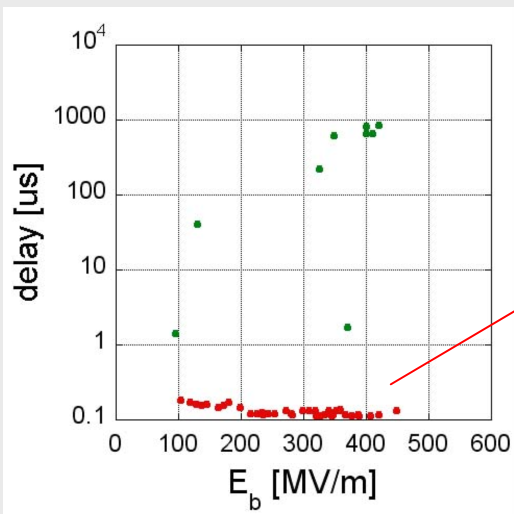
- 2 populations, separated by a gap (1 – 100 µs)

→ Two different breakdown mechanisms ?

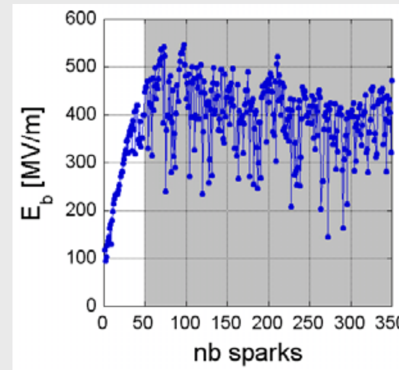
Delay times with Mo electrodes

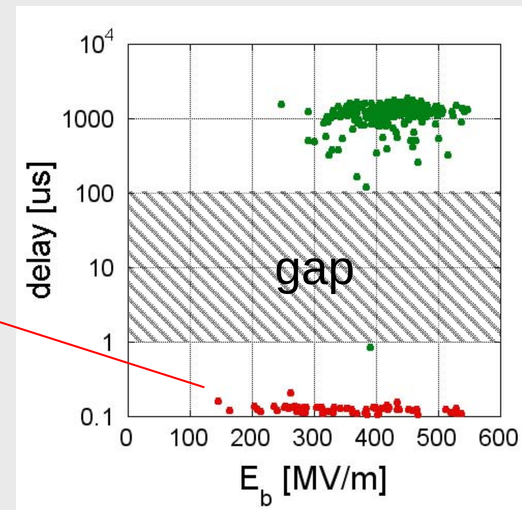
- Delays during conditioning





- Delays after conditioning





percentage of delays < 200 ns :

82%

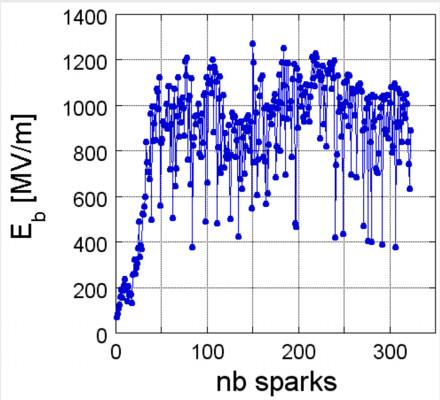
24%

immediate brkds dominate during conditioning

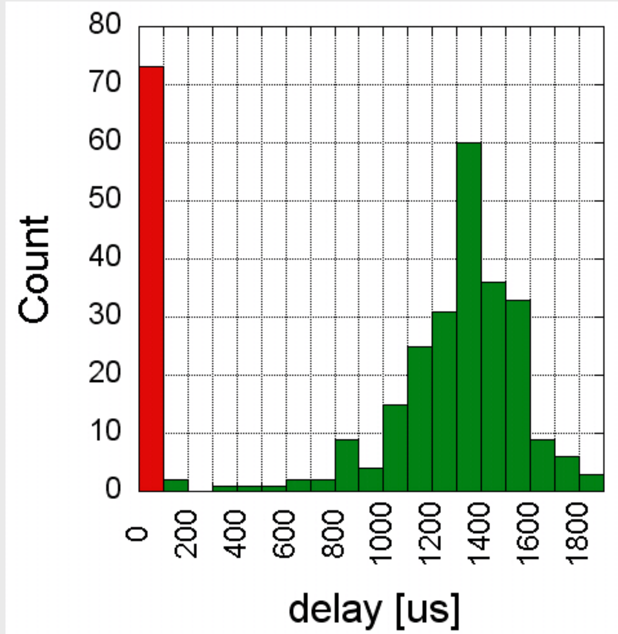
delayed brkds dominate after conditioning

Delay times with stainless steel electrodes

- Conditioning



- Same tendency



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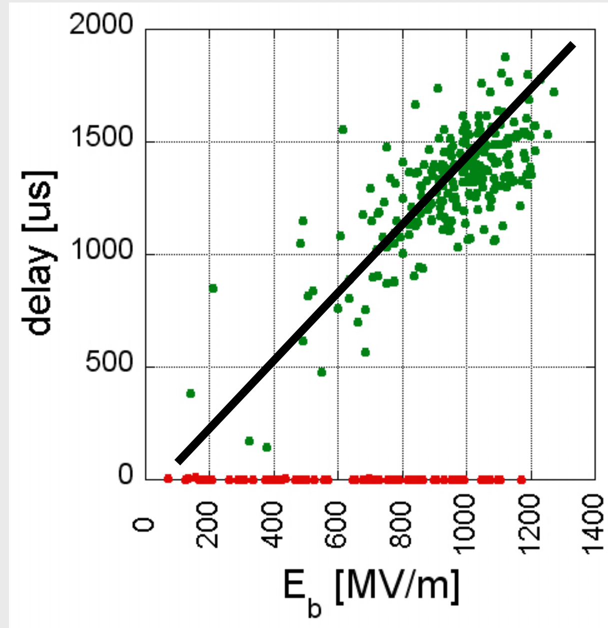
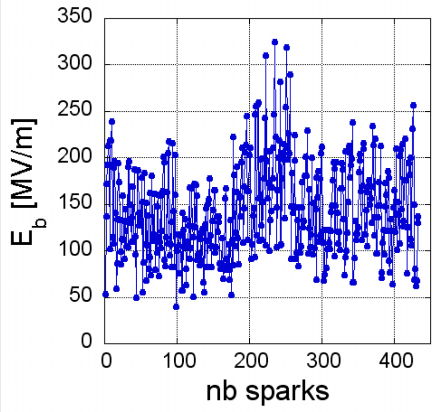


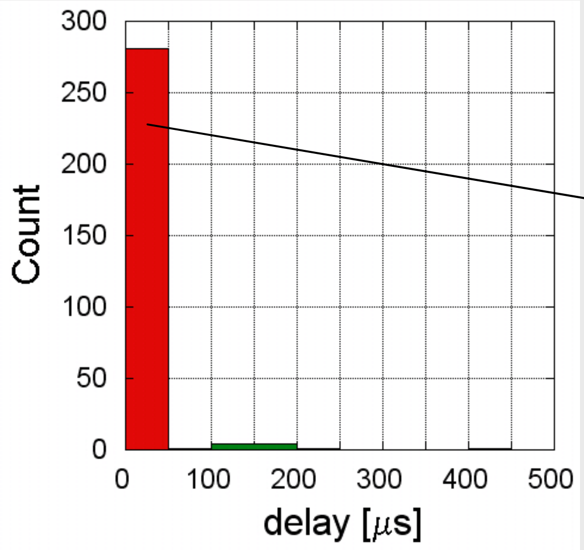
- both populations observed at every field, but
  - ➢ immediate breakdowns dominate during conditioning
  - ➢ delayed breakdowns dominate after conditioning
- pop. #2: delays increase linearly with breakdown field ???

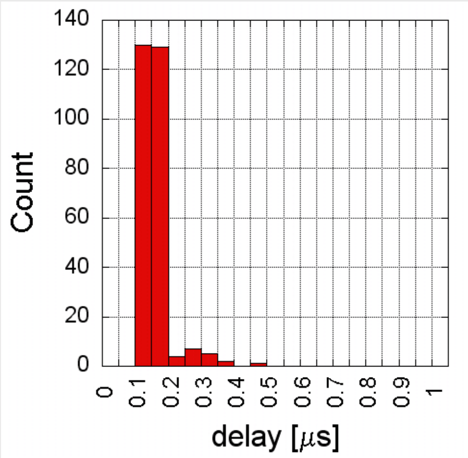
Delay times with copper electrodes

- Cu : 'immediate' conditioning, lower breakdown field

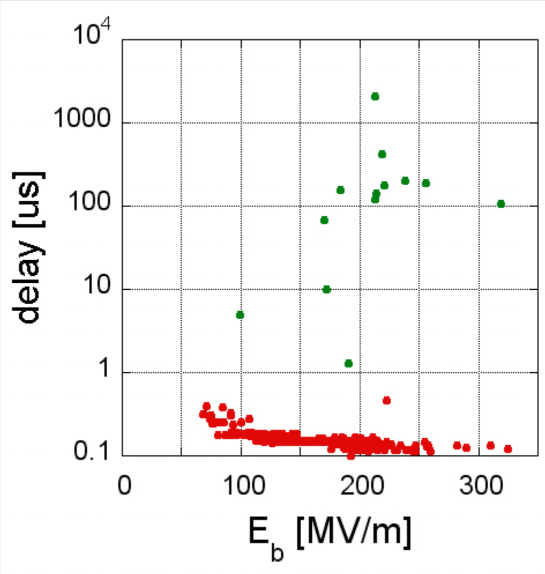


- Large majority of immediate breakdowns

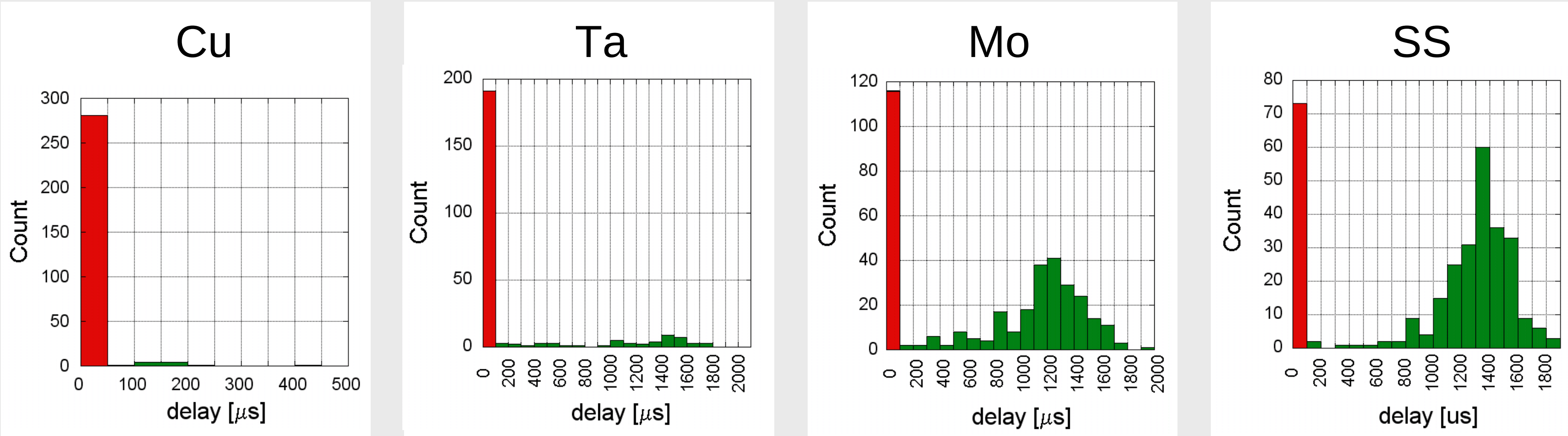




average : 163 ns
(σ = 44 ns)



Delay times with different materials



$\overline{E}_b$ = 170 MV/m | $\overline{E}_b$ = 300 MV/m | $\overline{E}_b$ = 430 MV/m | $\overline{E}_b$ = 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

Summary

- Two populations of delays observed :
  - immediate breakdowns (average ~ 120 ns)
  - delayed breakdowns (from 0.1 to 5 ms, average ~ 1.3 ms)
- Both populations observed at every field
  - during conditioning mostly immediate brkds
  - after conditioning mostly delayed brkds
  - delays ~ breakdown field? (SS)
- Two different breakdown mechanisms?
  - immediate: associated with surface contamination? gas desorption?
  - delayed: once the surface is cleaned?
- Repartition of delayed / immediate breakdowns
  - depends on the material
  - the ratio of delayed brkds R increases with the average breakdown field of the material
- Next : in BDR mode

ideas are welcome!

Thank you !