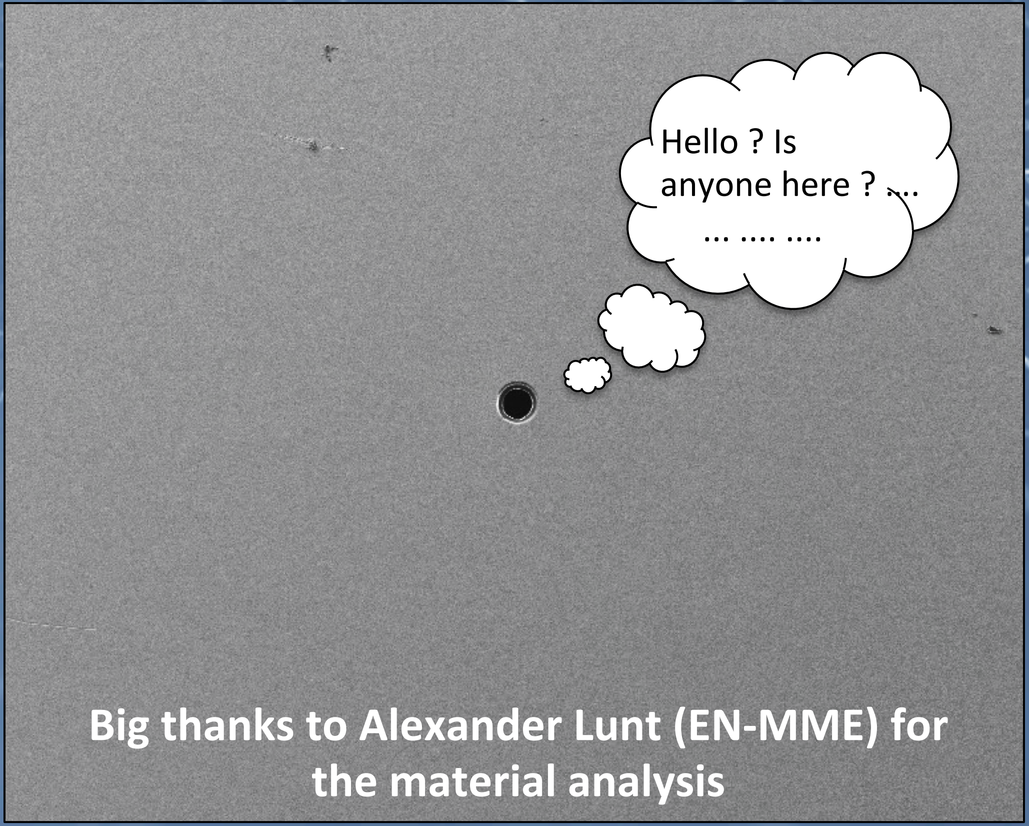
Effects of discharges on GEM detectors – preliminary tests and plans



Big thanks to Alexander Lunt (EN-MME) for the material analysis

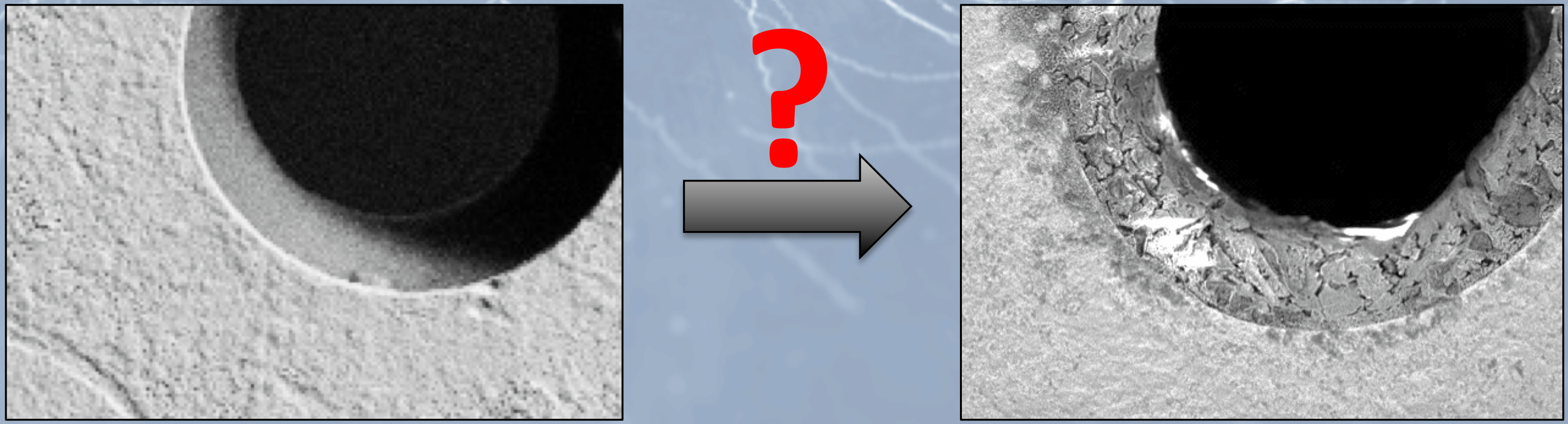
RD51 mini week
20/02/2018

J. A. Merlin
M. Gruchala
A. Shah → CMS GEM
P. Thuiner → RD51 GDD

Starting point

Motivations:

- *Quantify the effect of discharges on single hole, single GEM, multiple GEMs.*
  - Shorts, degradation of the amplification, instability etc …
- *Understand the longevity of GEM-based detectors*
  - Applications for CMS ME0, ESS etc …
- *Quantify the effect of discharges on the readout electronics.*
  - energy released, propagation, damages etc ….



Global Strategy

Single-hole system

→ Vary operation and environmental parameters to extreme conditions (HV, energy, humidity, gas composition etc …)
→ Isolate the components that play a role in the discharge effect.

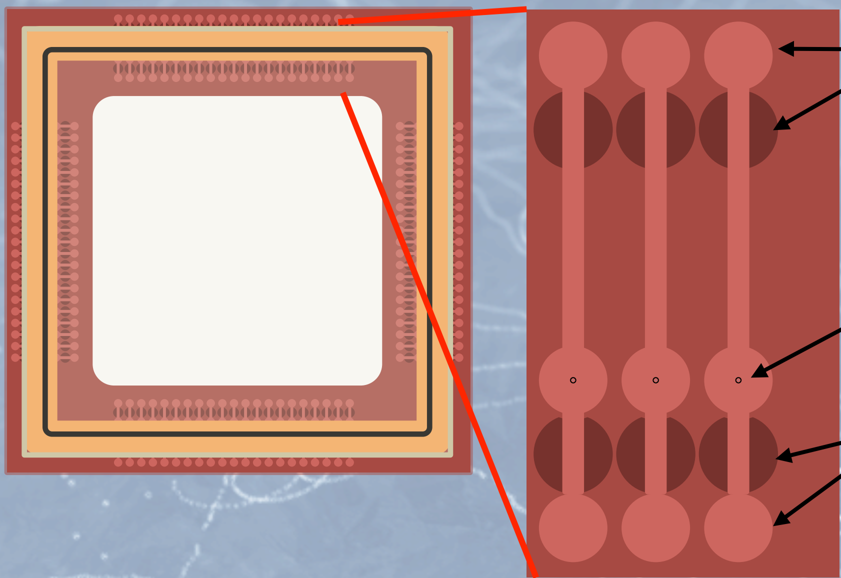
Small pads single/ triple GEM

→ Observe the effect of accumulated discharges on a triple-GEM structure (performance degradation)
→ Measure the discharge probability in different environment (background, particle type etc …)
→ Measure the probability of propagating discharges in CMS conditions

Full size detector

→ Confirm previous observation with full size chambers and final prototypes

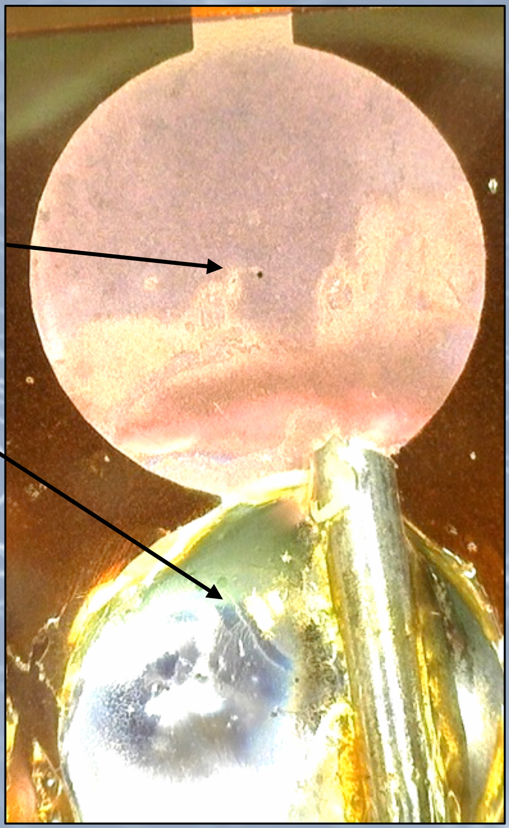
Single Hole – Test Setup

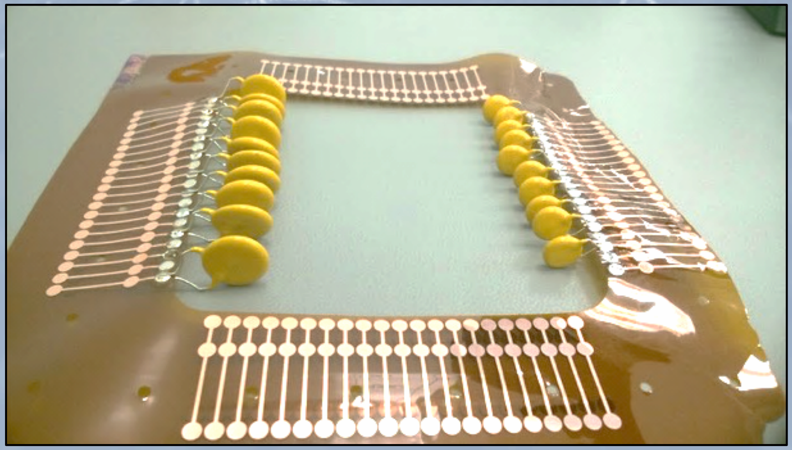


Outer pads to apply voltage

Inner pad with single hole (std dimensions)

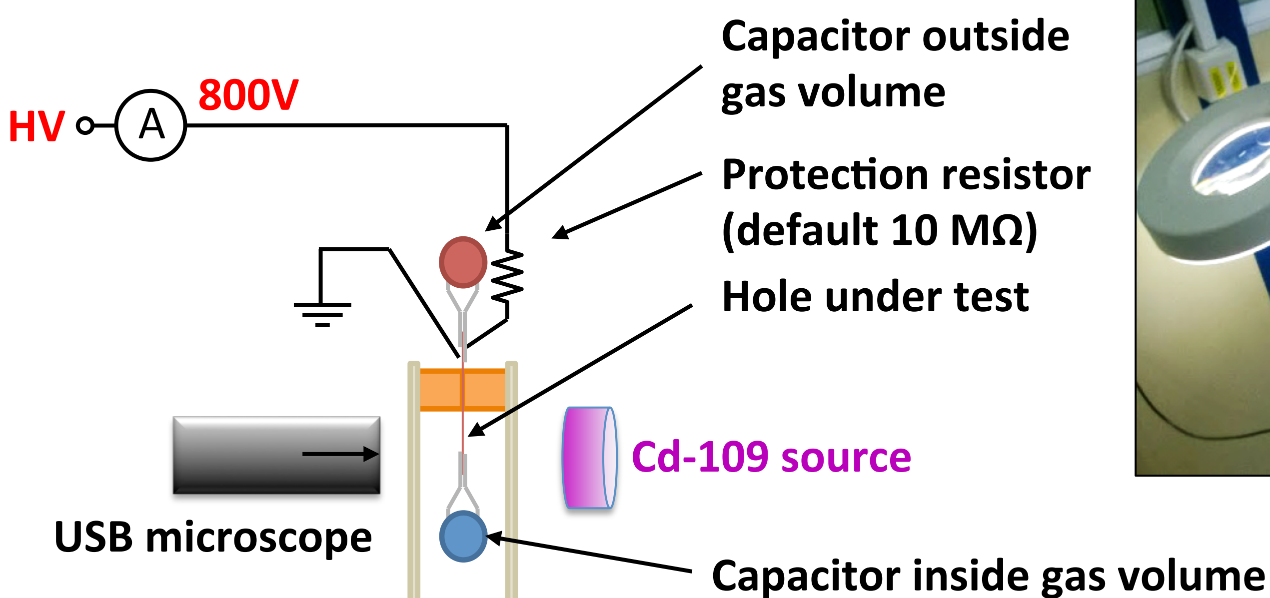
Inner pads for the capacitance

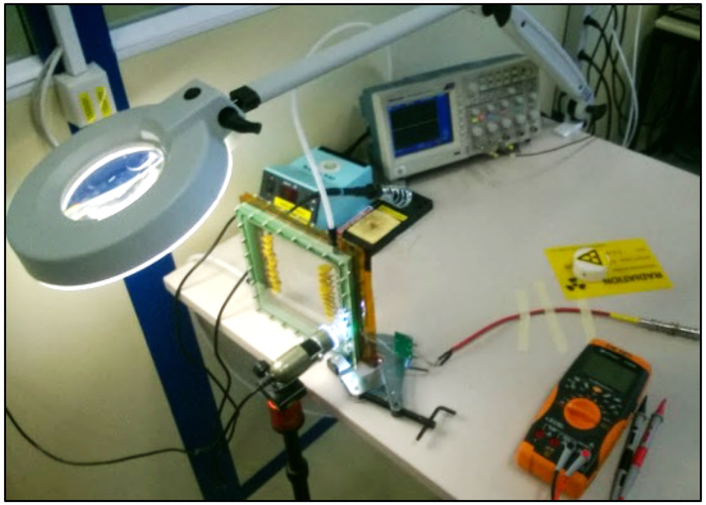


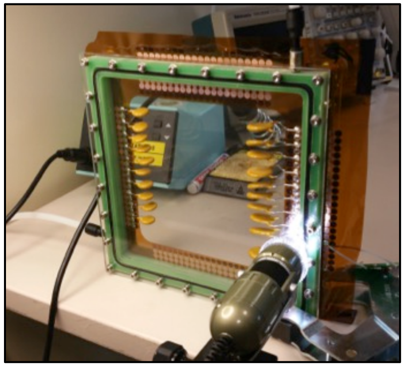


- 1 foil contains about 80 single holes
- Independent HV pads for each hole

Single Hole – Test Setup





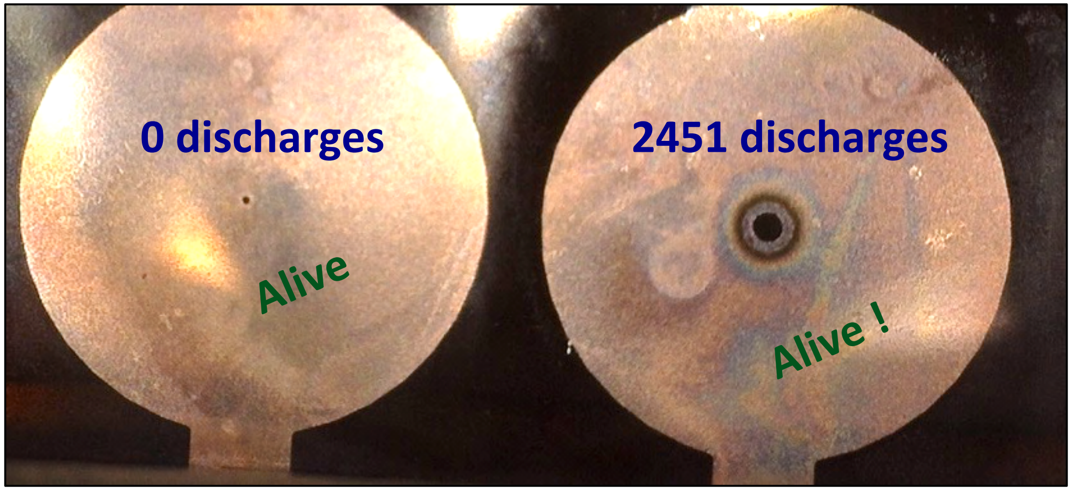


- Set the discharge energy with HV and capacitance
- Trigger the discharge with a Cd109 source (best control, very efficient)
- Measure the hole impedance (or short) via the HV power supply.

Single Hole

➢ *First play → Problem (?):*

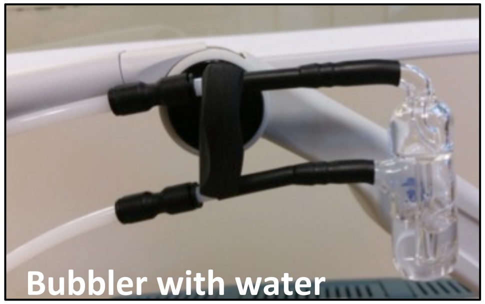
- Not possible to create a short in CMS conditions, even after several thousands of discharges:



STD configuration:
- 10 MΩ protection
- C_{hole} = 5.6 nF
- Trip = HV off
- Ar/CO2 (70/30)

➢ *Same observation with 40-50 holes*

➢ *Tried in "extreme" conditions:*
- High current limit in the HV supply / Long trip time.
- Energy from 0.1 to 10 mJ
- High humidity (60 %RH).

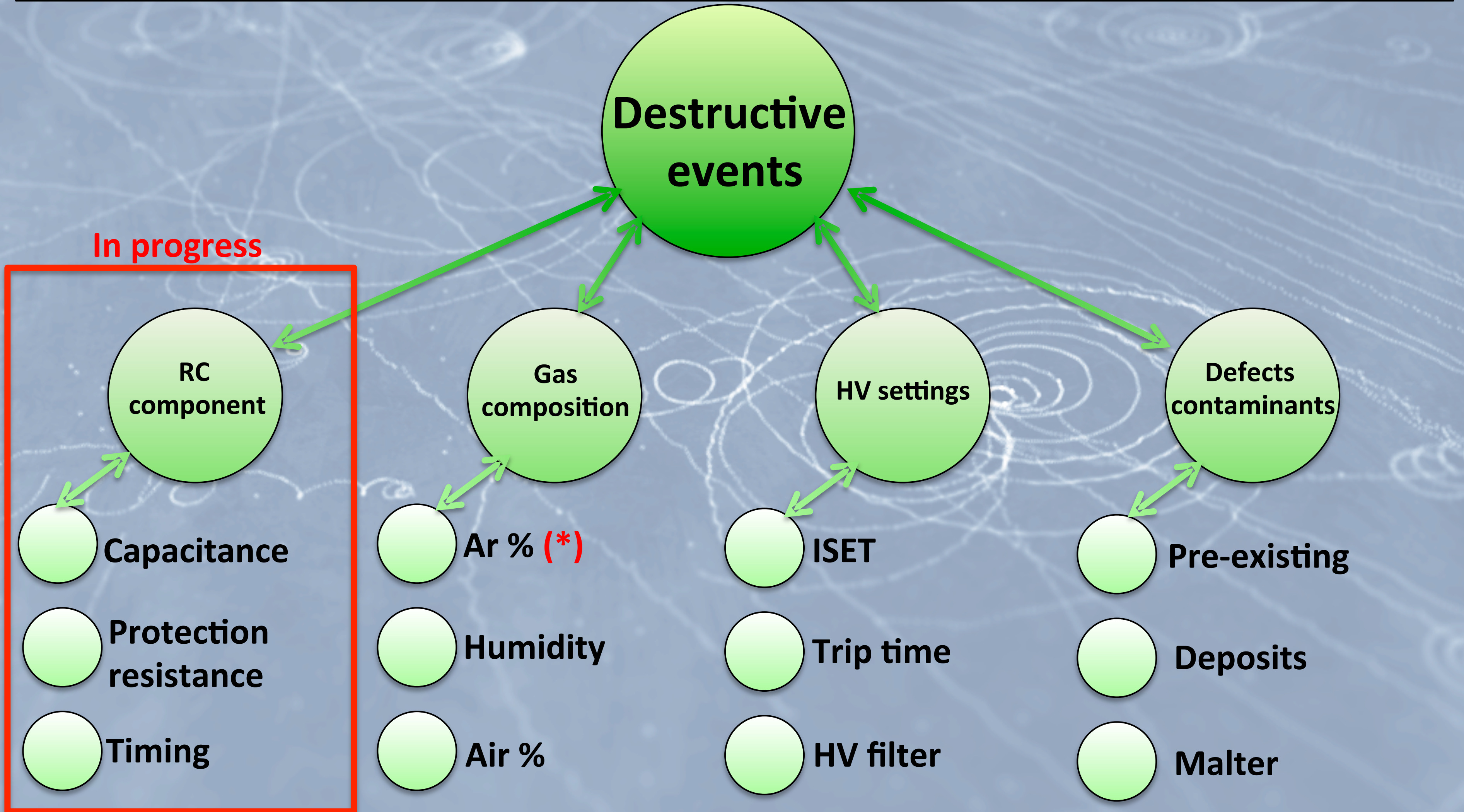


➢ **How to provoke destructive discharges ?**

➢ **What is the hole performance after 5, 10, 100 discharges ?**

Single Hole– Test Strategy

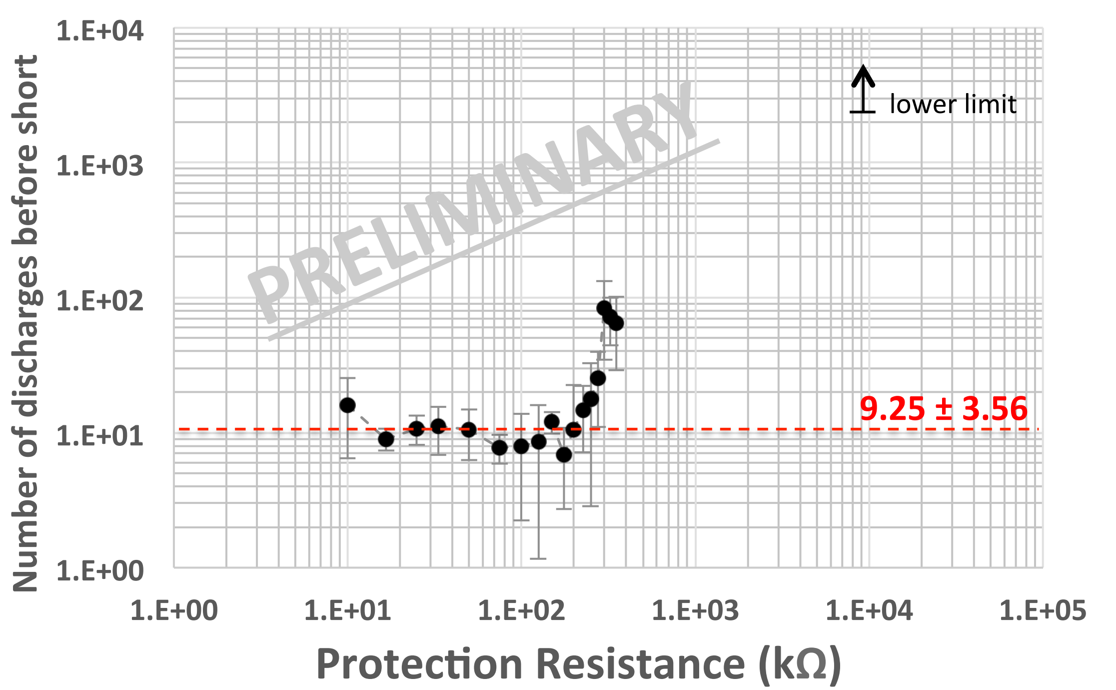
➢ **How to provoke destructive discharges ?**

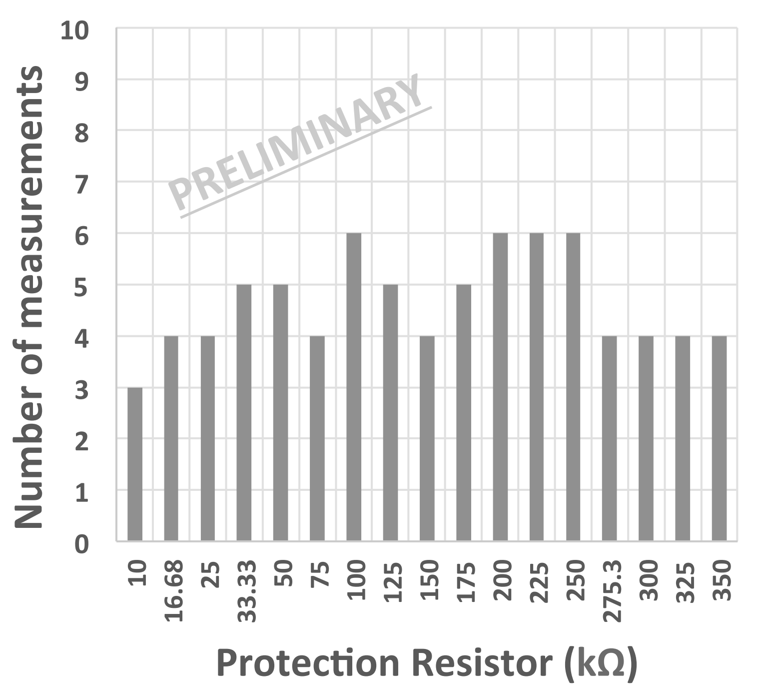


(*) only few times were GEM sectors were lost during the whole CMS GEM R&D phase

Single Hole

- **How to provoke destructive discharges ?**
  - Protection resistance ?
    - → Varying resistance from 0 to 350 kΩ + 10 MΩ
    - → Discharge energy from 1.20 to 1.88 mJ





- **Clear correlation between the resistance and the number of discharges**
- **Longevity increases at R > 200 kΩ → to be continued …**

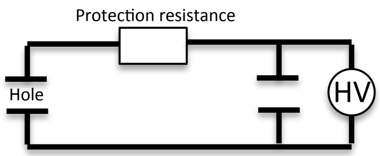
Single Hole System

➢ What is happening at microscopic level ?

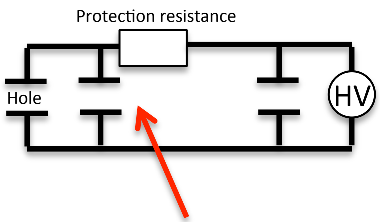
→ Irradiated 20 holes with different accumulation of discharges to understand the build-up effects.

→ All holes can be analyzed with SEM/X-Spec/FIB

10 kΩ protection test:



10 MΩ protection test:



Additional 5-6 nF capacitance

Foil #3

Hole #	Nb discharges	Final state
1	1	ok
2	5	ok
3	5	dead
4	10	ok
5	5	dead
6	9	dead
7	2	ok
8	3	ok
9	7	ok
10	1	dead
11	ref	
12	4	OK (10M)
13	shorted	
14	1	OK (10M)
15	5	OK (10M)
16	10	OK (10M)
17	20	OK (10M)
18	100	OK (10M)

Holes 1–10: 10 kΩ

Holes 12–18: 10 MΩ

Single Hole System

➢ What is happening at microscopic level ?

Foil #3

Hole #	Nb discharges	Final state
1	1	ok
2	5	ok
3	5	dead
4	10	ok
5	5	dead
6	9	dead
7	2	ok
8	3	ok
9	7	ok
10	1	dead
11	ref	
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14	1	OK (10M)
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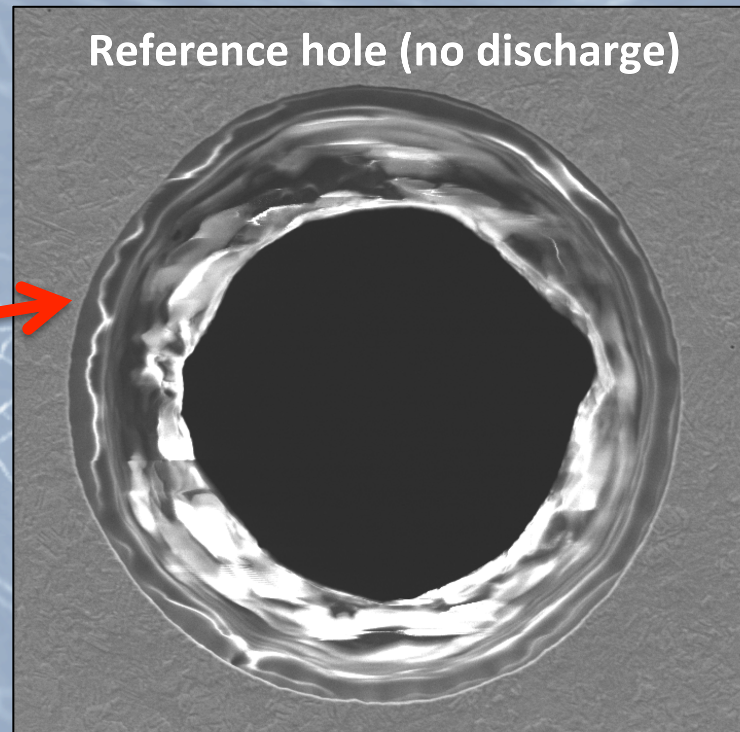
Holes 1–10: 10 kΩ

Holes 12–18: 10 MΩ



Single Hole System

➢ What is happening at microscopic level ?

Foil #3

Hole #	// Nb discharges	// Final state
1	1	ok
2	5	ok
3	5	dead
4	10	ok
5	5	dead
6	9	dead
7	2	ok
8	3	ok
9	7	ok
10	1	dead
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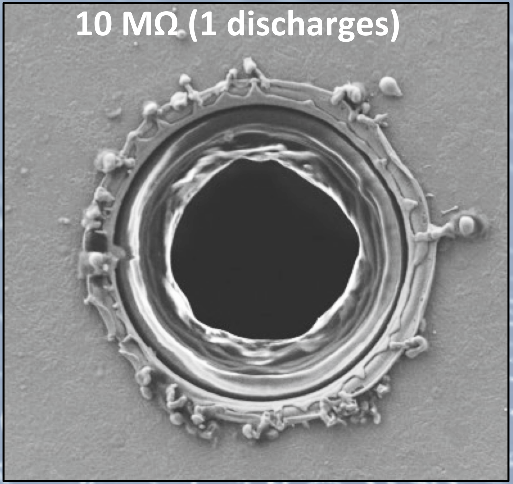
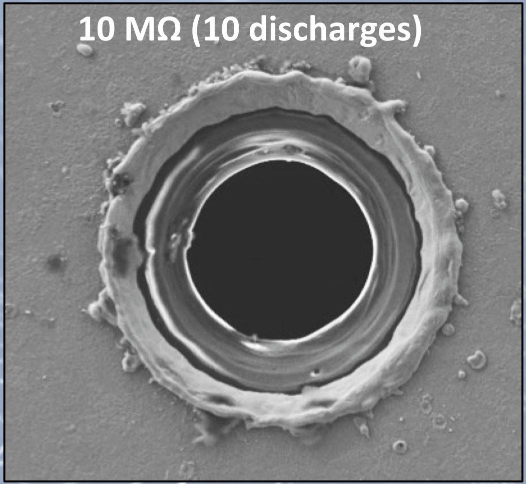
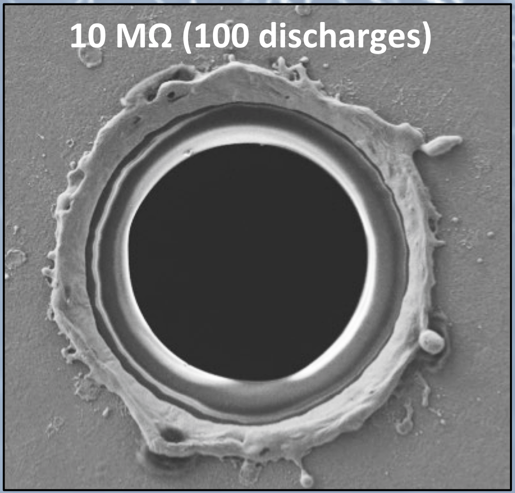
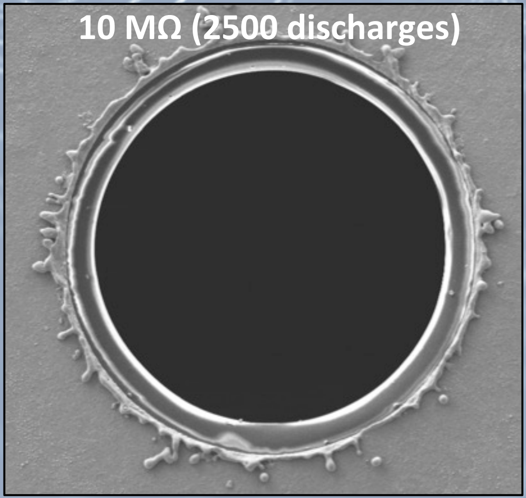
10 kΩ (holes 1–10)

10 MΩ (holes 12–18)









Observations:

- ➢ Holes are still “ok” (no shorts)
- ➢ Diameter is increasing with the accumulated discharges

Single Hole System

➢ What is happening at microscopic level ?

Foil #3

Hole #	Nb discharges	Final state
1	1	ok
2	5	ok
3	5	dead
4	10	ok
5	5	dead
6	9	dead
7	2	ok
8	3	ok
9	7	ok
10	1	dead
11	ref	
12	4	OK (10M)
13	shorted	
14	1	OK (10M)
15	5	OK (10M)
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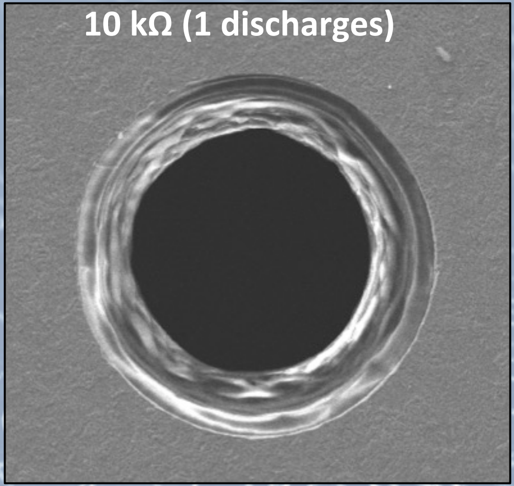
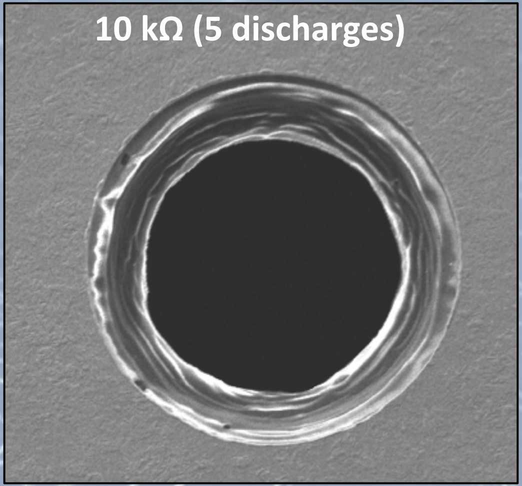
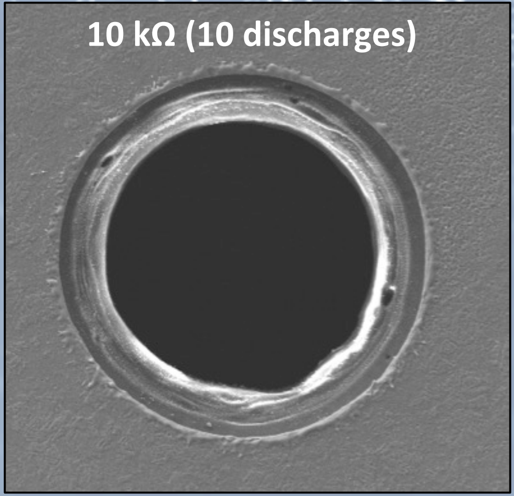
10 kΩ (holes 1–10)

10 MΩ (holes 12–18)


10 kΩ (1 discharges)


10 kΩ (5 discharges)


10 kΩ (10 discharges)

Observations:

- ➢ Holes are still "ok" (no shorts)
- ➢ Copper splashes it less pronounced than before

Single Hole System

➢ What is happening at microscopic level ?

Foil #3

Hole #	Nb discharges	Final state
1	1	ok
2	5	ok
3	5	dead
4	10	ok
5	5	dead
6	9	dead
7	2	ok
8	3	ok
9	7	ok
10	1	dead
11	ref	
12	4	OK (10M)
13	shorted	
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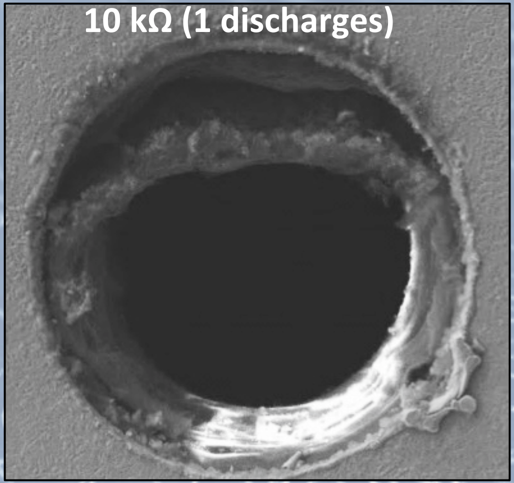
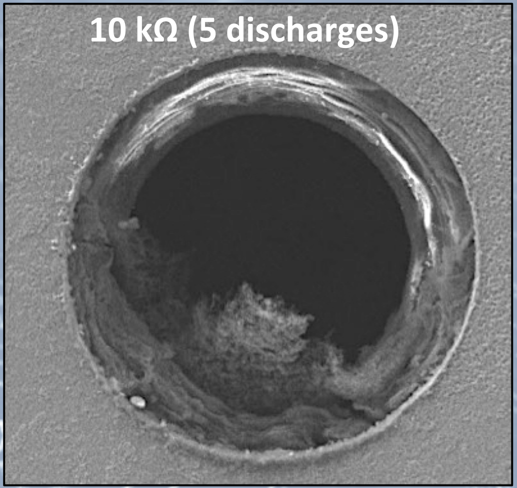
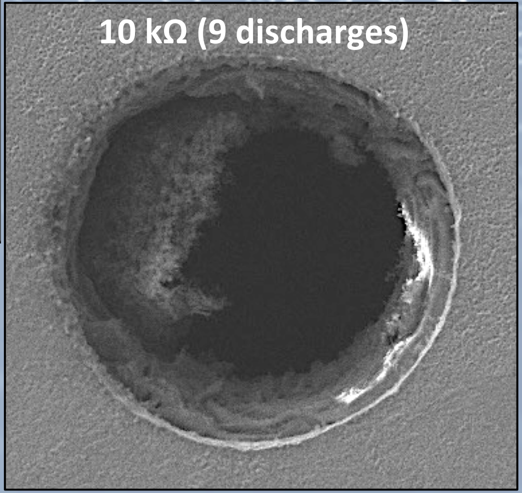
10 kΩ (holes 1–10)

10 MΩ (holes 12–18)







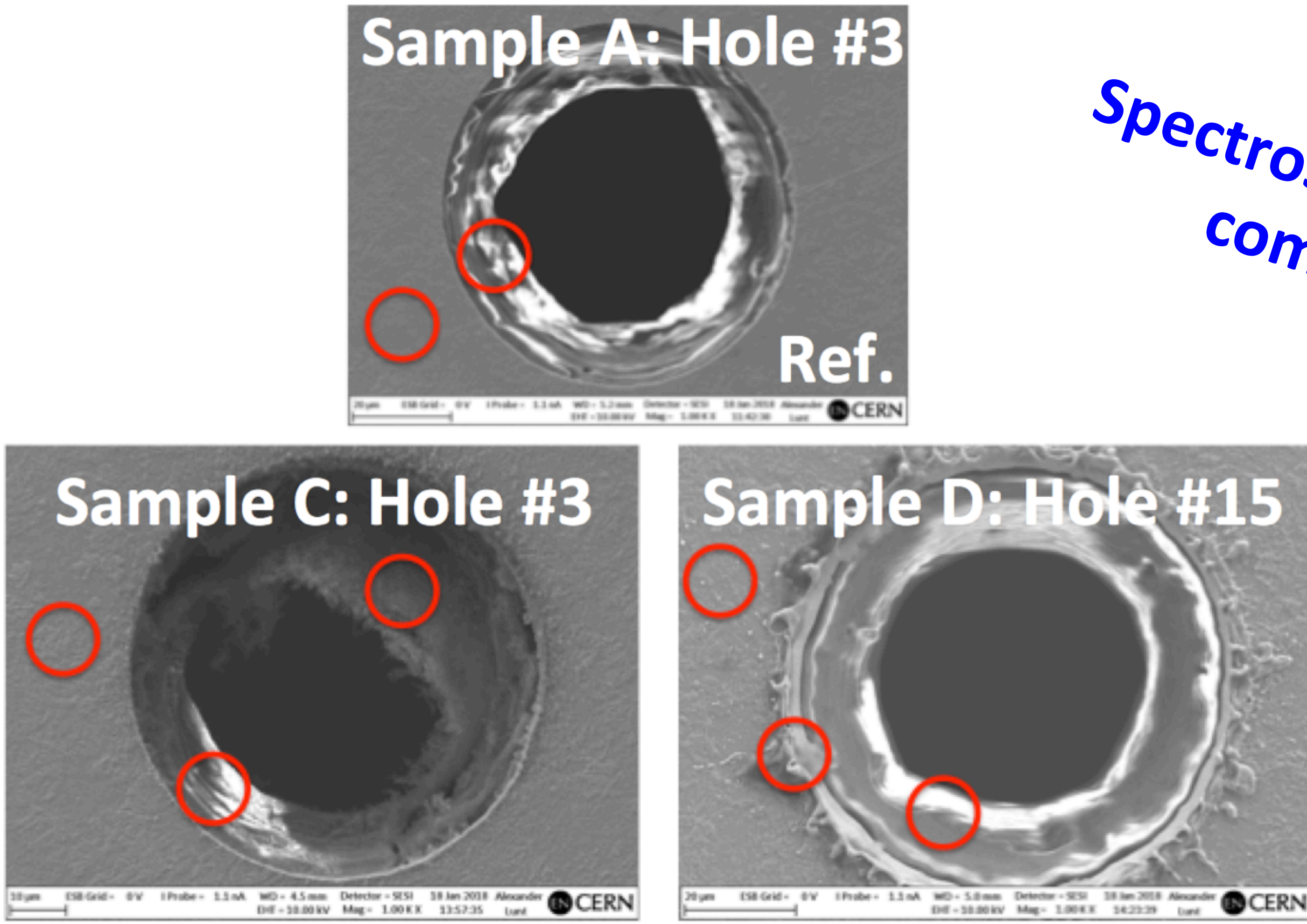
What is the reason for that ?

Observations:

- Holes are dead (shorts)
- Systematic effect, similar shape

Single Hole System

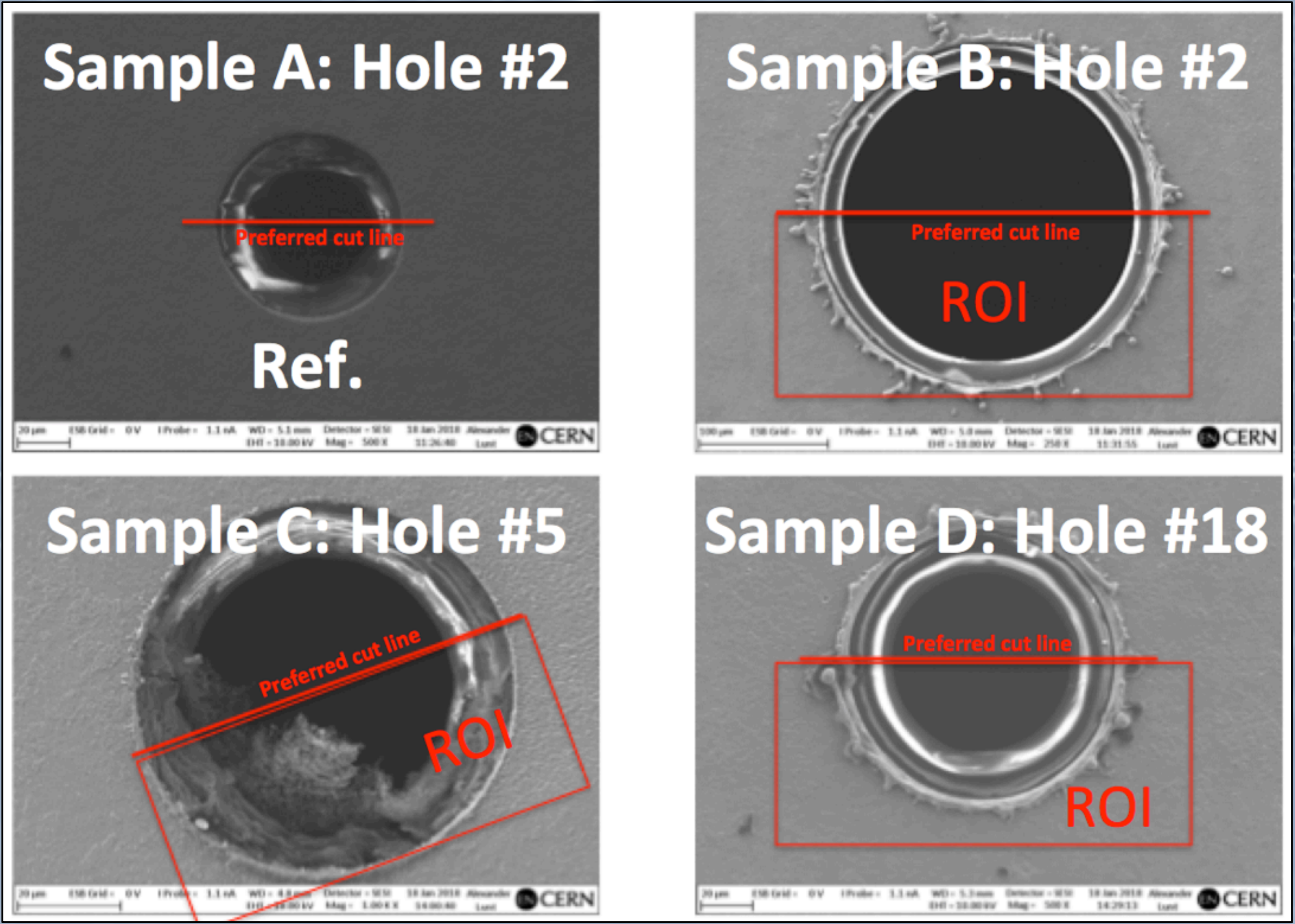
➢ What is happening at microscopic level ?



Spectroscopy (material composition)

Single Hole System

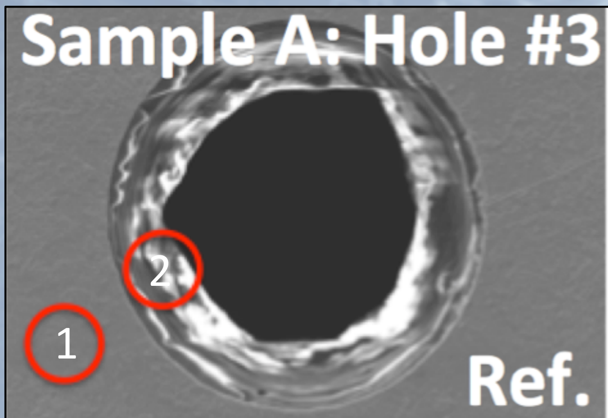
➢ **What is happening at microscopic level ?**

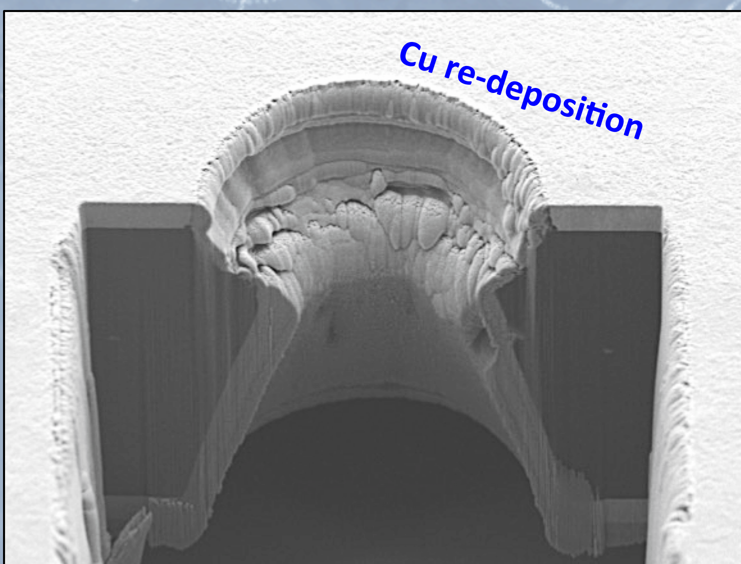


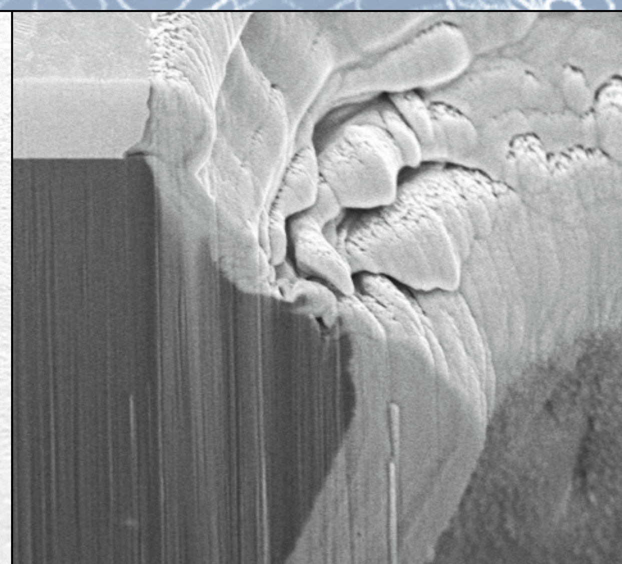
FIB milling

Single Hole System

➢ What is happening at microscopic level ?



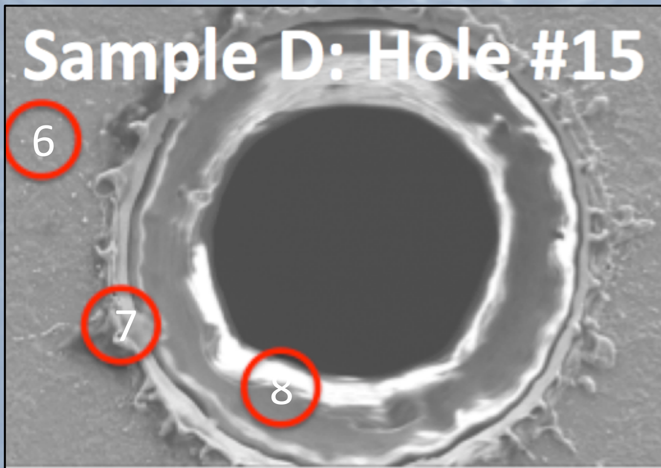




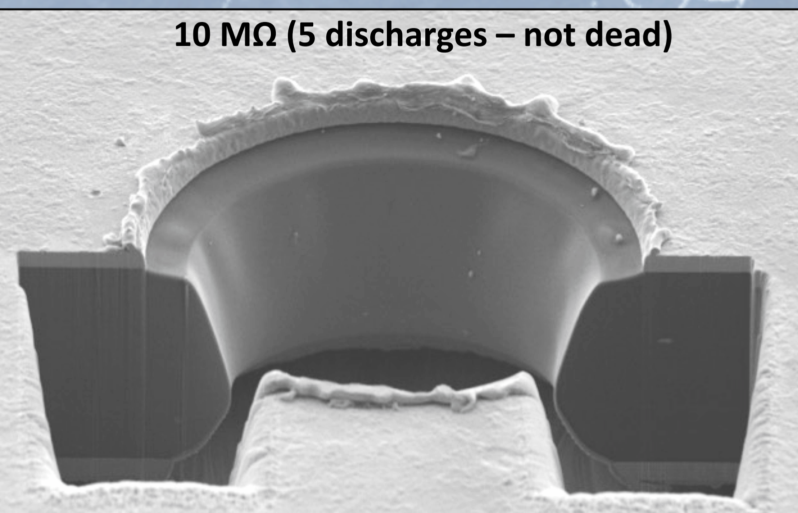
Sample		A-3	
Pos		1	2
C	Wt%	6.35	62.4
	SD	0.15	1.07
N	Wt%	0	0
	SD	0	0
O	Wt%	0.6	18.6
	SD	0.05	0.9
Si	Wt%	0	0
	SD	0	0
S	Wt%	0	0
	SD	0	0
Ca	Wt%	0	0
	SD	0	0
Cu	Wt%	93	19
	SD	0.16	0.87

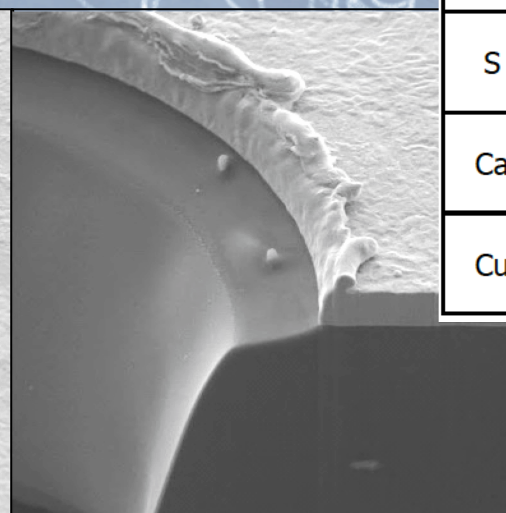
Single Hole System

➢What is happening at microscopic level ?



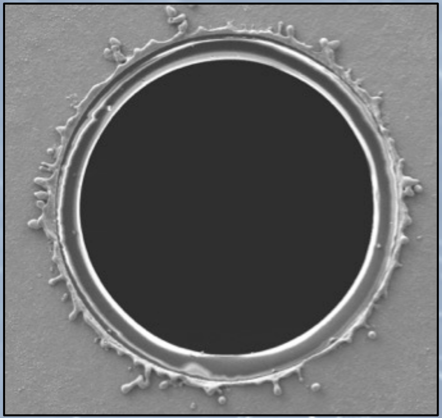
Sample		D-15		
Pos		6	7	8
C	Wt%	3.9	58.3	63.5
	SD	0.1	0.51	0.76
N	Wt%	0	2.07	6.7
	SD	0	0.64	0.9
O	Wt%	0.8	6.26	13.8
	SD	0.1	0.19	0.4
Si	Wt%	0	0	0
	SD	0	0	0
S	Wt%	0	1.49	0
	SD	0	0.09	0
Ca	Wt%	0	1.33	0
	SD	0	0.18	0
Cu	Wt%	95	30.6	16
	SD	0.1	0.36	0.4

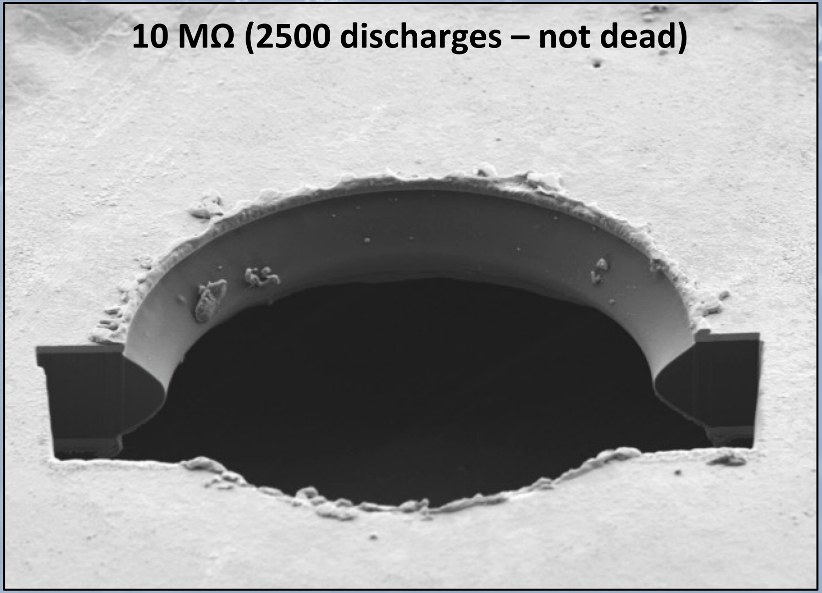

10 MΩ (5 discharges – not dead)

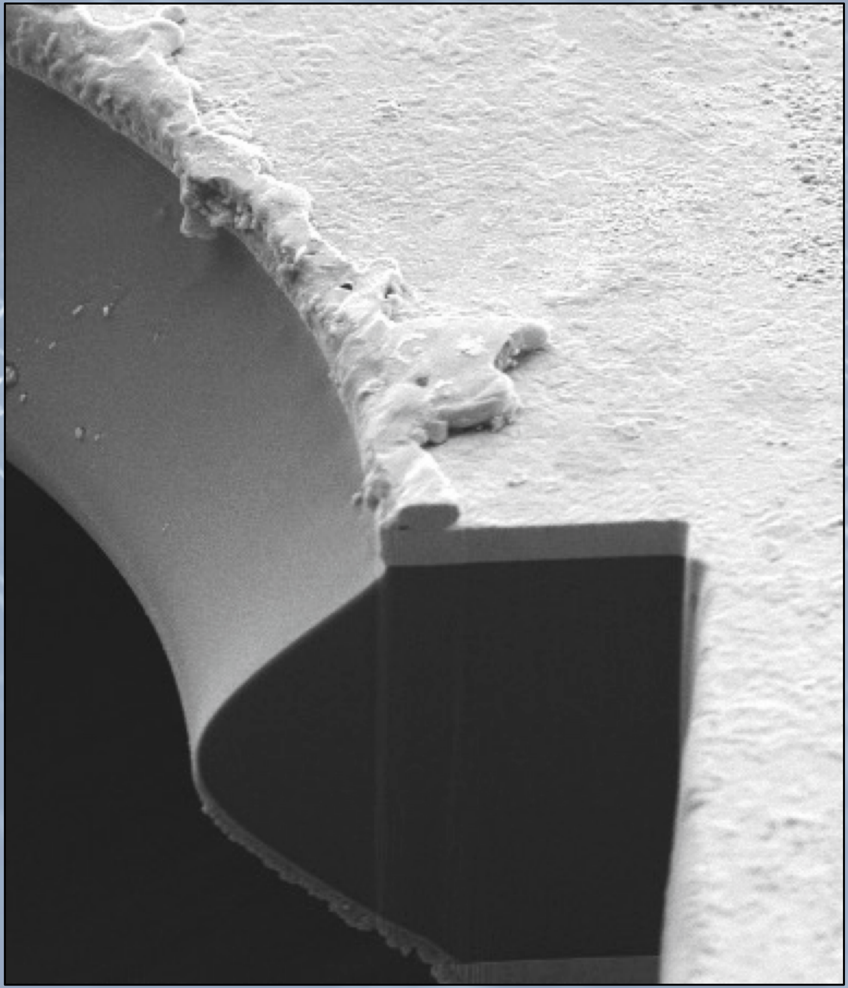


Single Hole System

➢What is happening at microscopic level ?

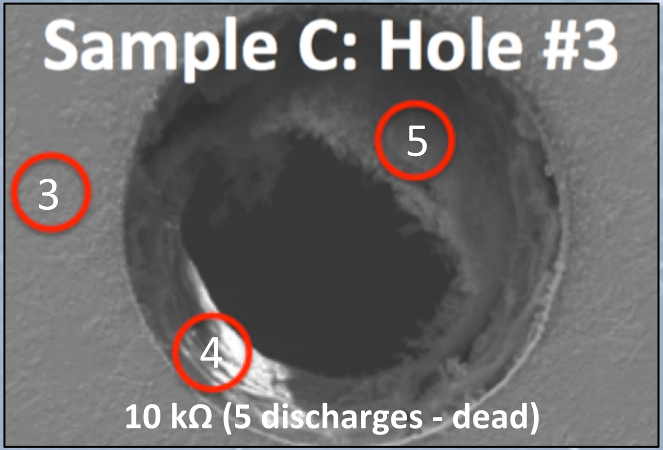




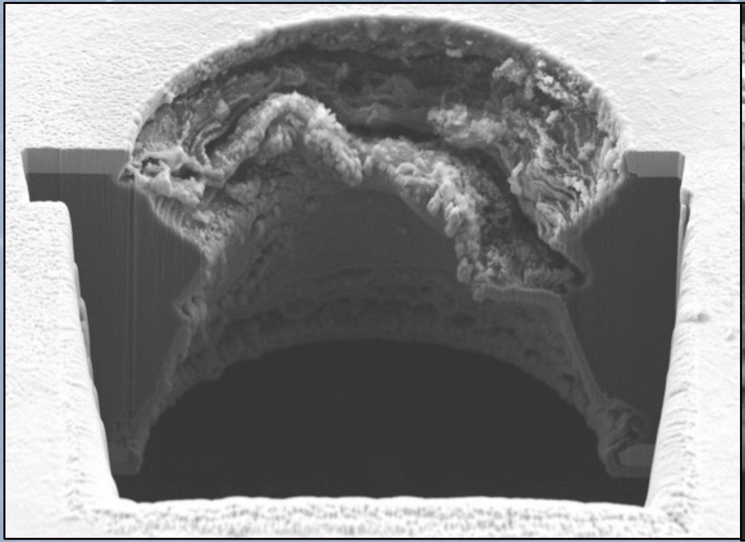


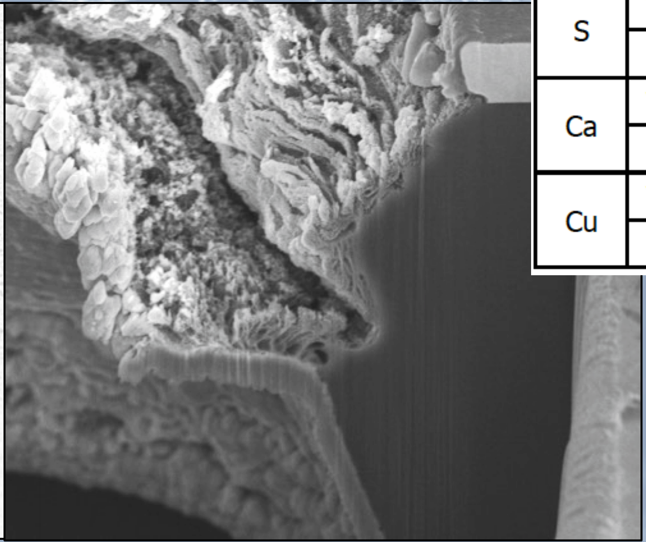
Single Hole System

➢What is happening at microscopic level ?



Sample		C-3		
Pos		3	4	5
C	Wt%	7.21	75.3	93.9
	SD	0.15	0.48	0.13
N	Wt%	0	5.14	0
	SD	0	0.51	0
O	Wt%	0.94	18.6	3.94
	SD	0.05	0.25	0.12
Si	Wt%	0	0.13	2.14
	SD	0	0.04	0.05
S	Wt%	0	0	0
	SD	0	0	0
Ca	Wt%	0	0	0
	SD	0	0	0
Cu	Wt%	91.9	0.9	0
	SD	0.16	0.11	0

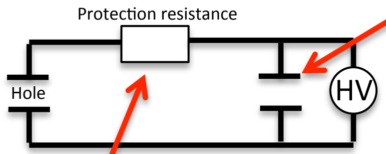




Single Hole System - Summary

➢ What is the role of the RC component ?

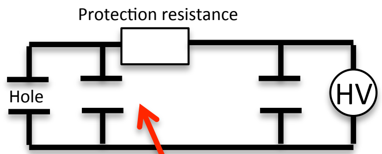
10 kΩ protection test:



Power supply internal capacitance; not under control; difficult to measure.
→ How much this capa participate to discharge energy ?

also de-couples the HV capa

10 MΩ protection test:



Additional capa 6.4 nF

Both tests were supposed to have the same total capacitance, is it true ?
What about timing ?

Single Hole System - Summary

➢What is the role of the RC component ?

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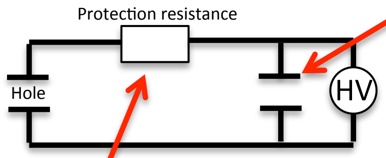

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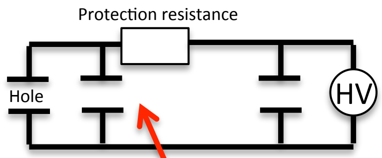

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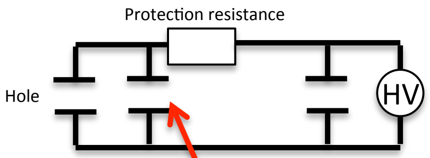
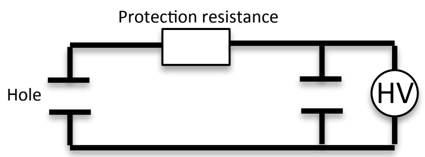


Additional capa 6.4 nF

10 MΩ protection test:



Single Hole System - Summary

➢ **What is the role of the RC component ?**

10 kΩ protection test – no Capa:

*** 10k no Capa ***

Hole #	Nb discharges	Final state
1	1	OK
2	5	OK
3	5	DEAD
4	10	OK
5	5	DEAD
6	9	DEAD
7	2	OK
8	3	OK
9	7	OK
10	1	DEAD

10 MΩ protection test – 6.4nF Capa:

*** 10M with Capa 6.4 nF ***

Hole #	Nb discharges	Final state
11	REF	
12	4	OK
13	shorted before test	
14	1	OK
15	5	OK
16	10	OK
17	20	OK
18	100	OK

10 kΩ protection test – 6.4nF Capa:

*** 10k with Capa 6.4 nF ***

Hole #	Nb discharges	Final stat
22	100	OK
23	10	OK
24	2	OK
25	1	OK
26	REF	

PRELIMINARY

10 MΩ protection test – no Capa:

*** 10M no Capa ***

Hole #	Nb discharges	Final stat
27	100	OK
28	10	OK
29	1	OK
30	REF	

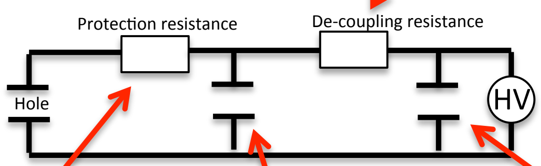
PRELIMINARY

Single Hole System - Plans

➢ What is the role of the RC component ?

New design:

High resistance to de-couple HV capa

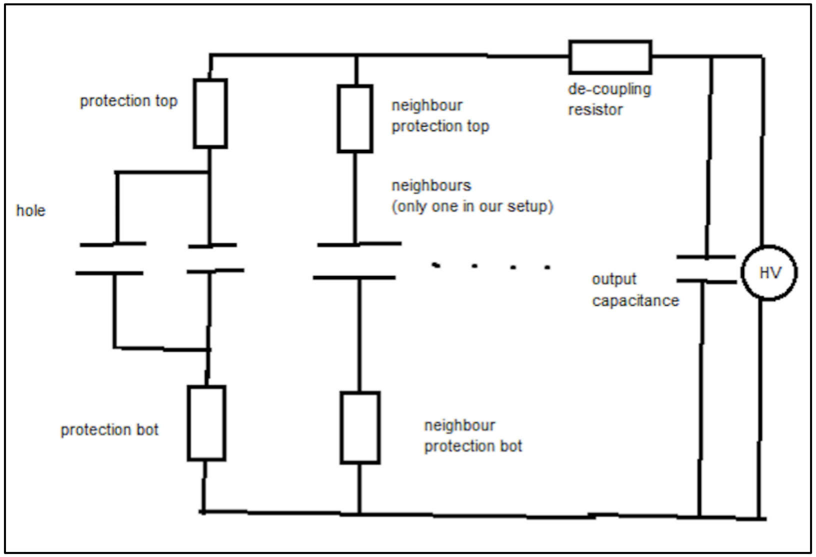


ignored

"energy pool" (can also represent neighbor sectors)

How much of the energy in the "pool" is transferred to the discharge through the protection resistance ? How does that affect the discharge effect ?

Simplified schematics



- **Understand the role of the capacitance and resistance during discharges**
- **New PCB designed for playing with RC components**

Small GEM Pad

➢ **What is the hole "performance" after x accumulated discharges ? What about larger scale ?**

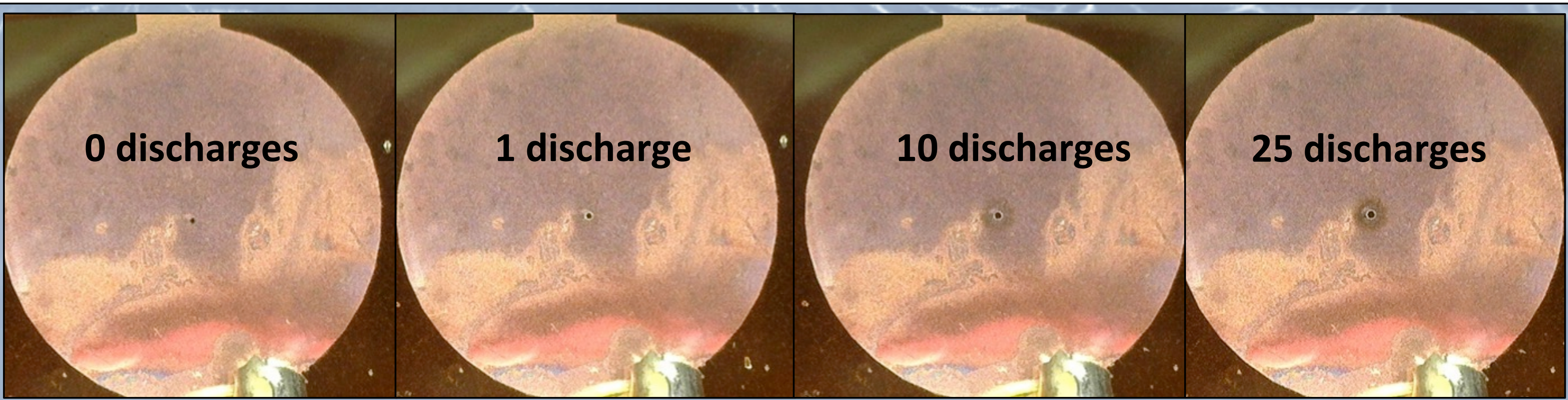
-Discharge propagation/probability ?

- **→ effects on next GEMs, after/before amplifications ?**
- **→ effects of background (space-charge)?**

- Influence on GEM performances ?

- **→ evolution of effective gain**
- **→ GEM stability, discharge probability etc …**

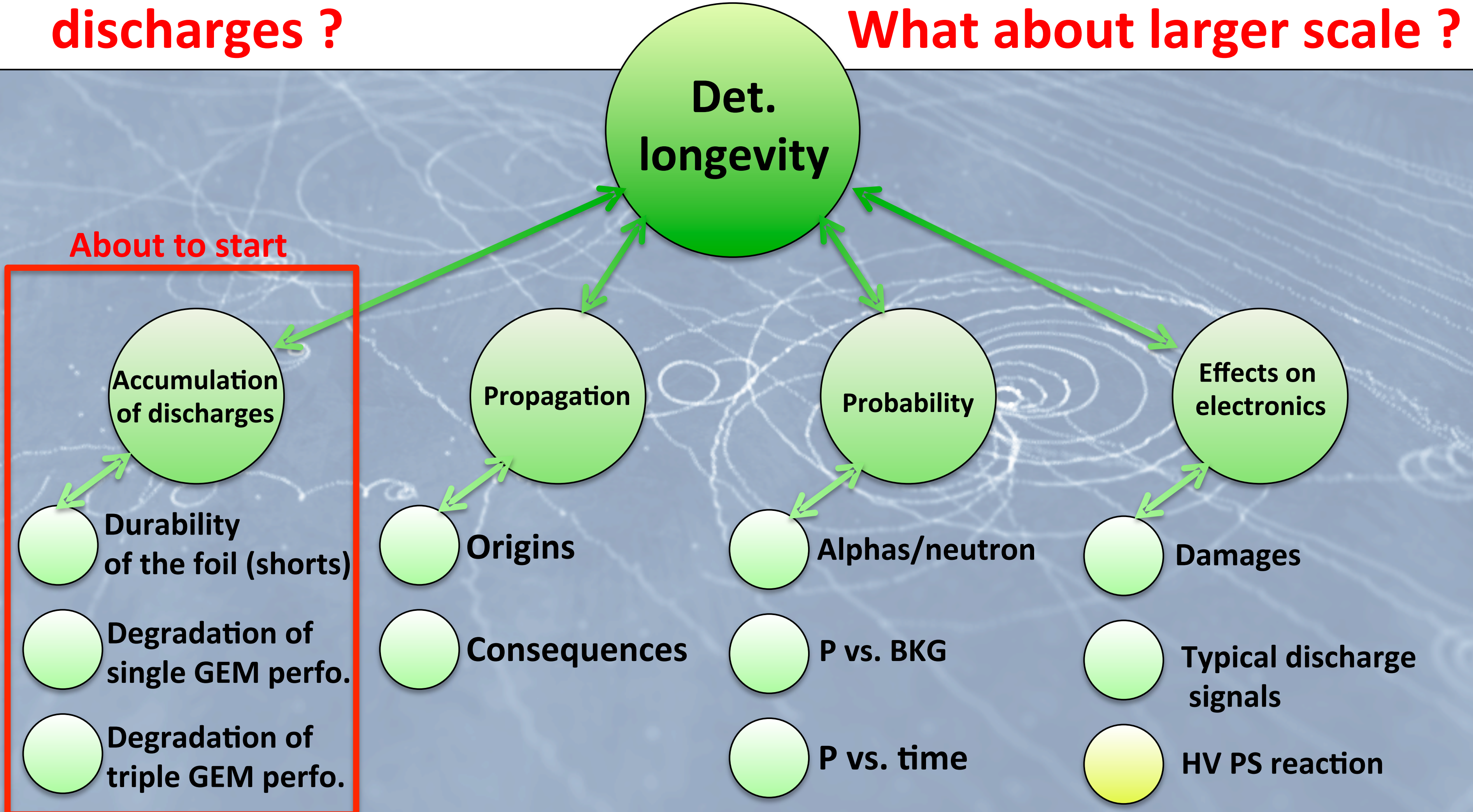
Requires another specific setup (not single hole)



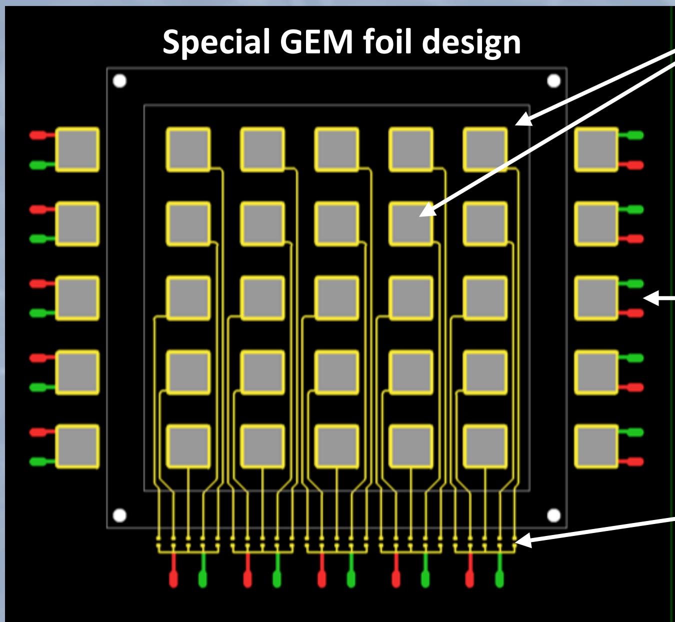
Small GEM Pad – Test Strategy

➢ **What is the hole "performance" after x accumulated discharges ?**

What about larger scale ?



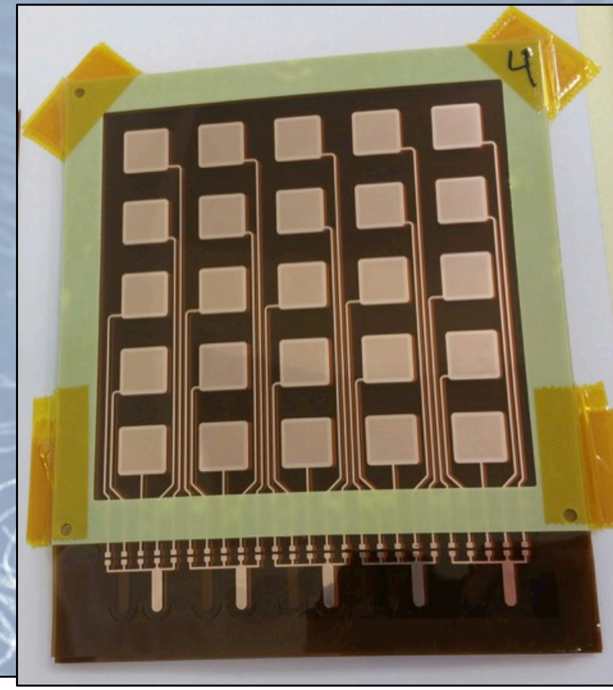
Small GEM Pad - Setup



Multiple 1x1 cm^2 GEM pads to test different configurations

Samples for SEM analysis

0Ω bridges to disconnect damaged pads



Comments:

- Possibility to assemble single or triple GEM structures with 25 independent GEM pads
- Systematic analysis with SEM/X-Spec/FIB

Additional Studies:

- Dedicate GE1/1 size chamber for advanced testing in realistic conditions (RO electronics ? MC power supply/Divider ? Etc … to be defined)

Summary and Plans

Main Goals:

- Determine the parameters that defines the discharges and their consequences.
- Tune these parameters to reduce or increase the effect of discharges in GEM detectors

Three Setups:

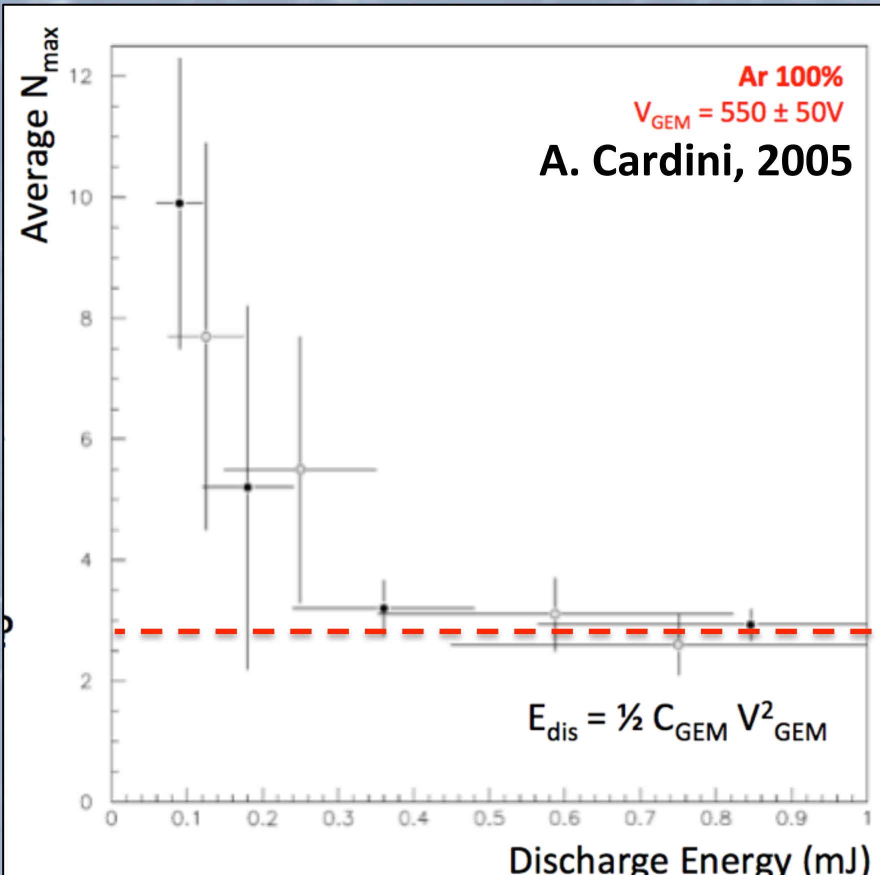
- Single hole setup:
  - → can power single GEM holes independently (ideal for destructive tests)
  - → study discharge effect vs protection resistance, energy, gas mixture.
  - → study the evolution of the hole geometry after discharges
- Single/triple-GEM setup (sectorized): (ideal for destructive tests)
  - → propagation of discharges, with/without background, effects on the large GEMs
  - → study of detection characteristics vs. accumulated number of discharges (5, 10, 100/ cm^2 etc…)
- STD triple-GEM 10x10 and full-size setup:
  - → Effects of discharges on electronics (VFAT, APV, PS etc …)

(near) Future Plans:

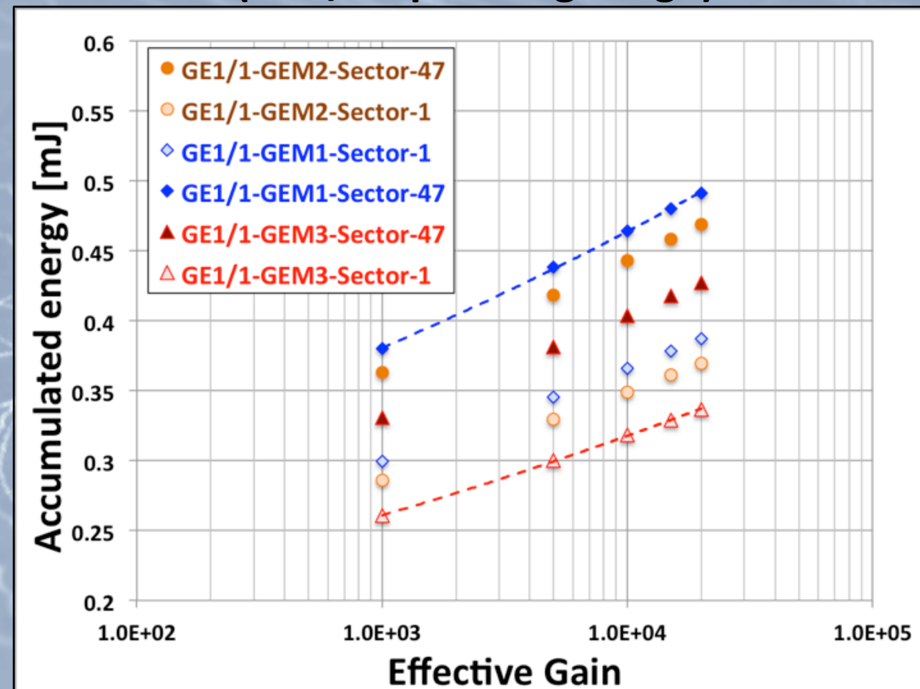
- Detailed study of RC influence on discharge effects.
- Scale–up the test samples toward realistic detectors.
- Quantify the GEM degradation vs accumulated discharges

Starting point

Motivations: how many discharges before the GEM is shorted



Operating in CMS conditions (GE1/1 operating range)

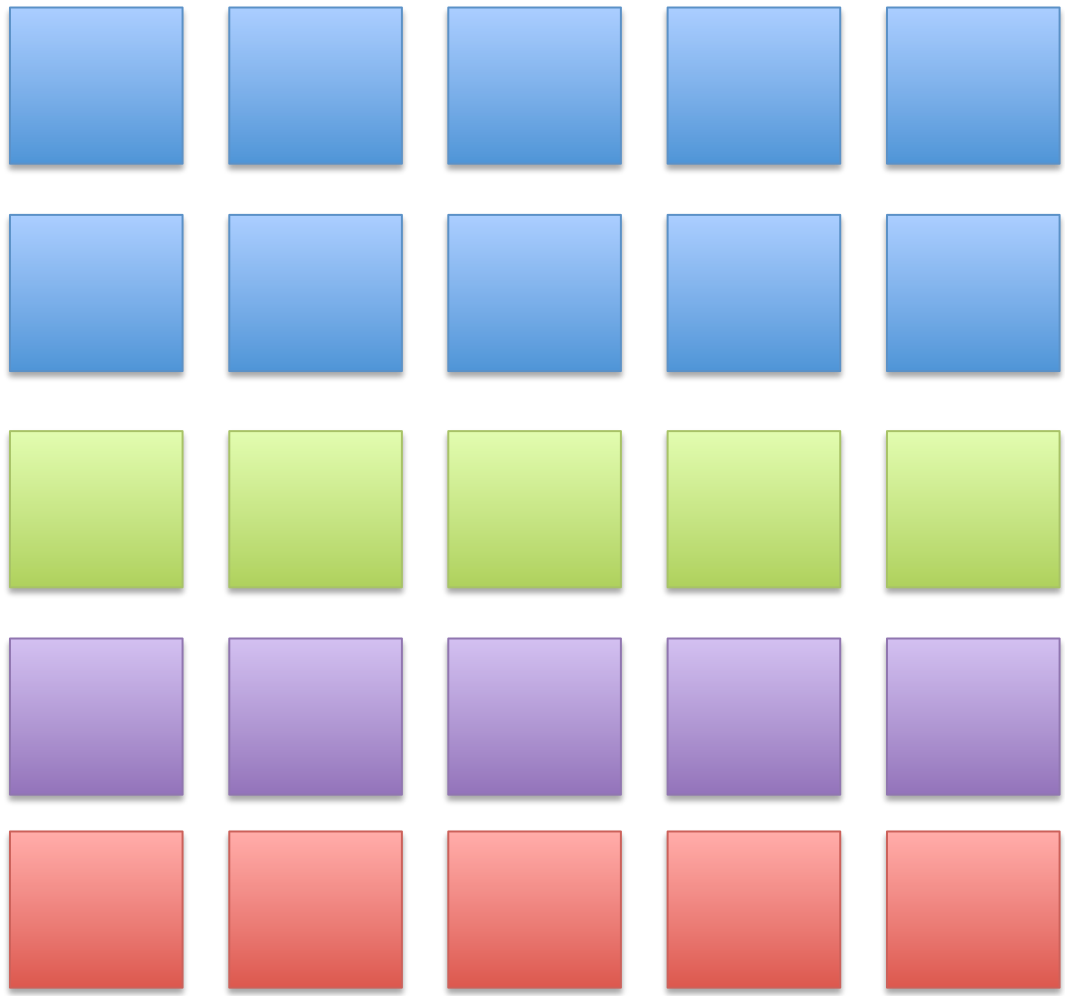


Typical capacitance : 5-6 nF
Typical GEM voltage : 350 -380 V

Goals:

- What is the discharge limit in Ar/CO_2 (70:30) ?
- How to increase the survivability to discharges (no shorts)?

Detector operation vs. accumulated discharges



Operation vs. accumulated discharges

Discharge w/ alphas

Discharge w/ neutrons ?

Propagation ? (pending, following ALICE studies)

Raw #1

Raw #2

Raw #3

Raw #4

Raw #5

Detector operation vs. accumulated discharges