Investigations of the long-term stability of a GEM-TPC

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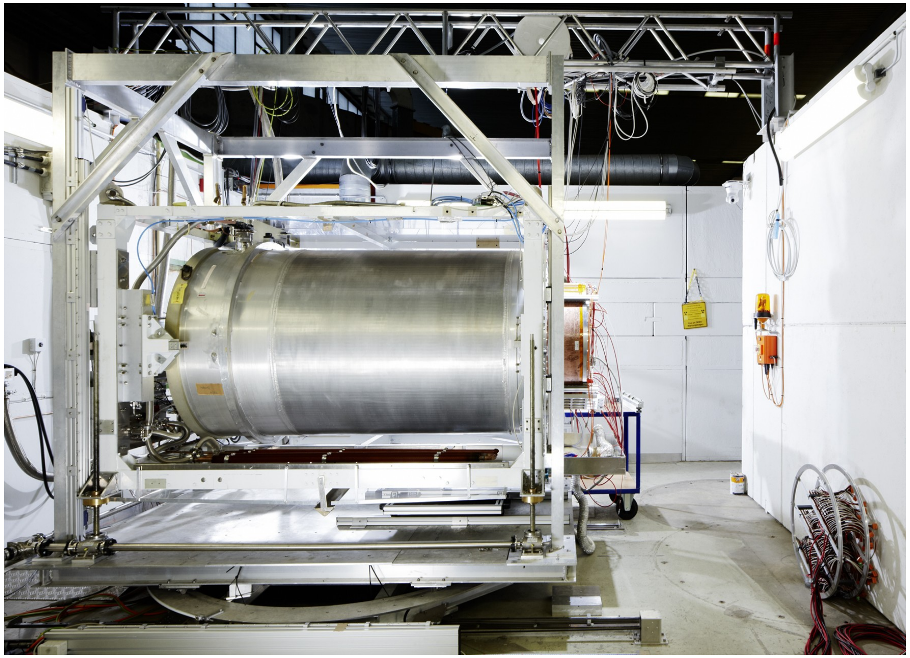
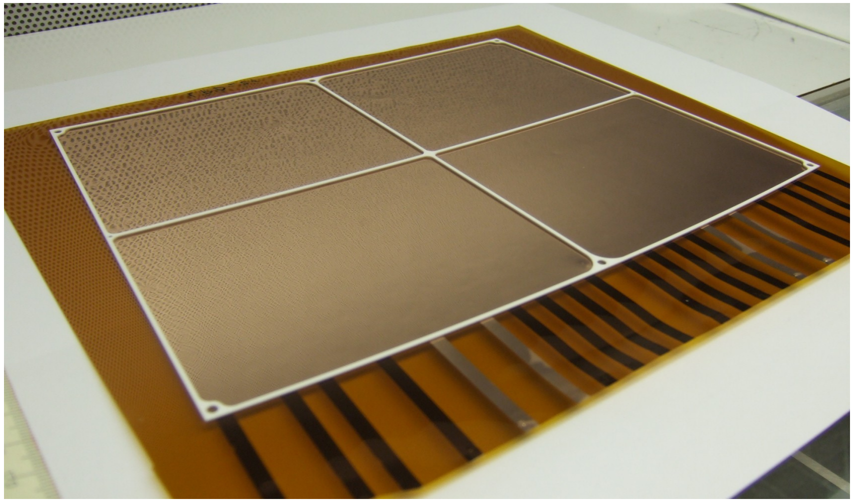
2016, Santander

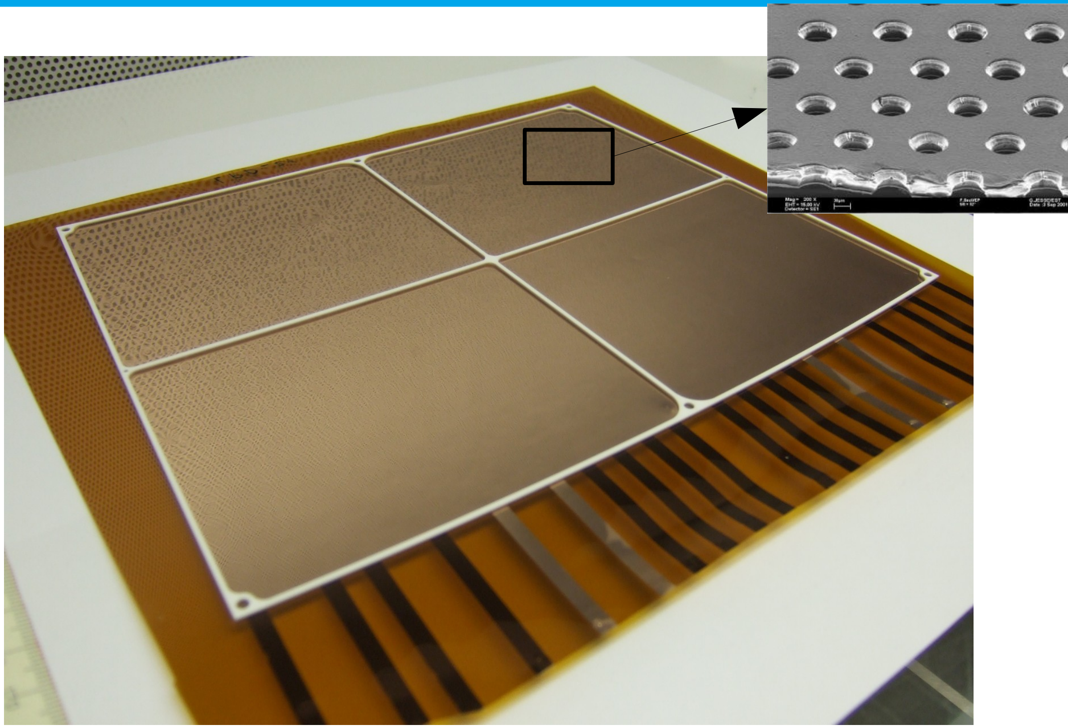
Goal of the Study



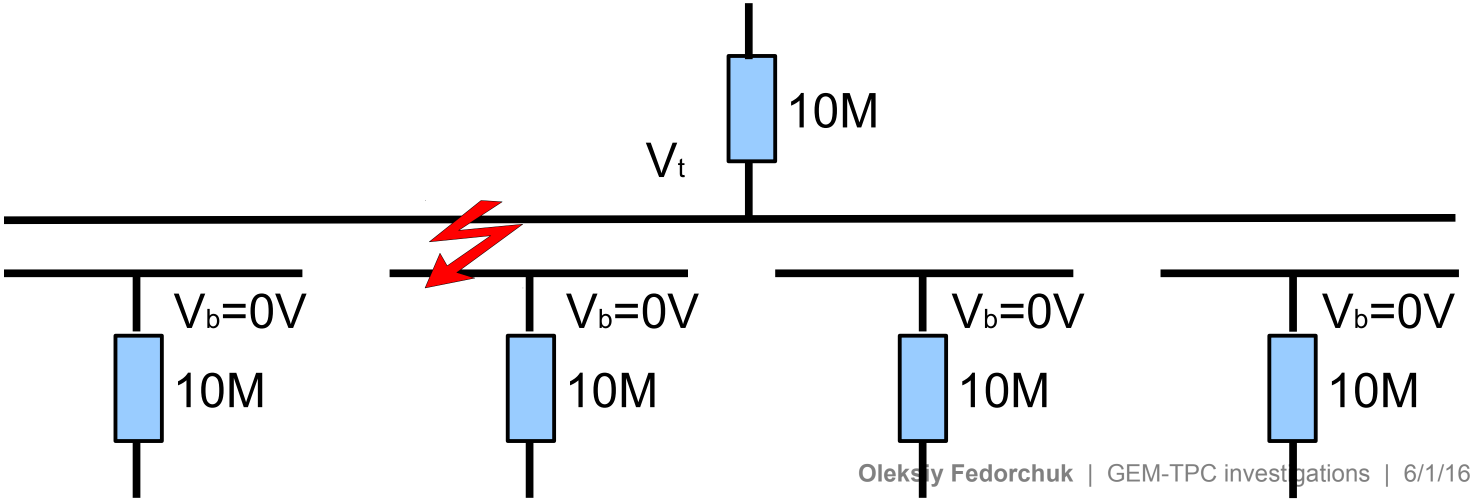


- Have built and operated TPC with triple GEM readout
- Test beam in March 2013 and later in Fall 2013 showed a problem with the high voltage long-term stability
- After several weeks of stable operation
  - Several observed discharges
  - 1 destructive discharges with extreme conditions
  - 2 destructive discharges at the end of Test Beam
- **Goals of this study:**
  - Study the discharge process
  - Understand the cause of GEM destruction
  - Find the way to increase GEM resistance to destructive consequences of a discharge

GEM structure and connection

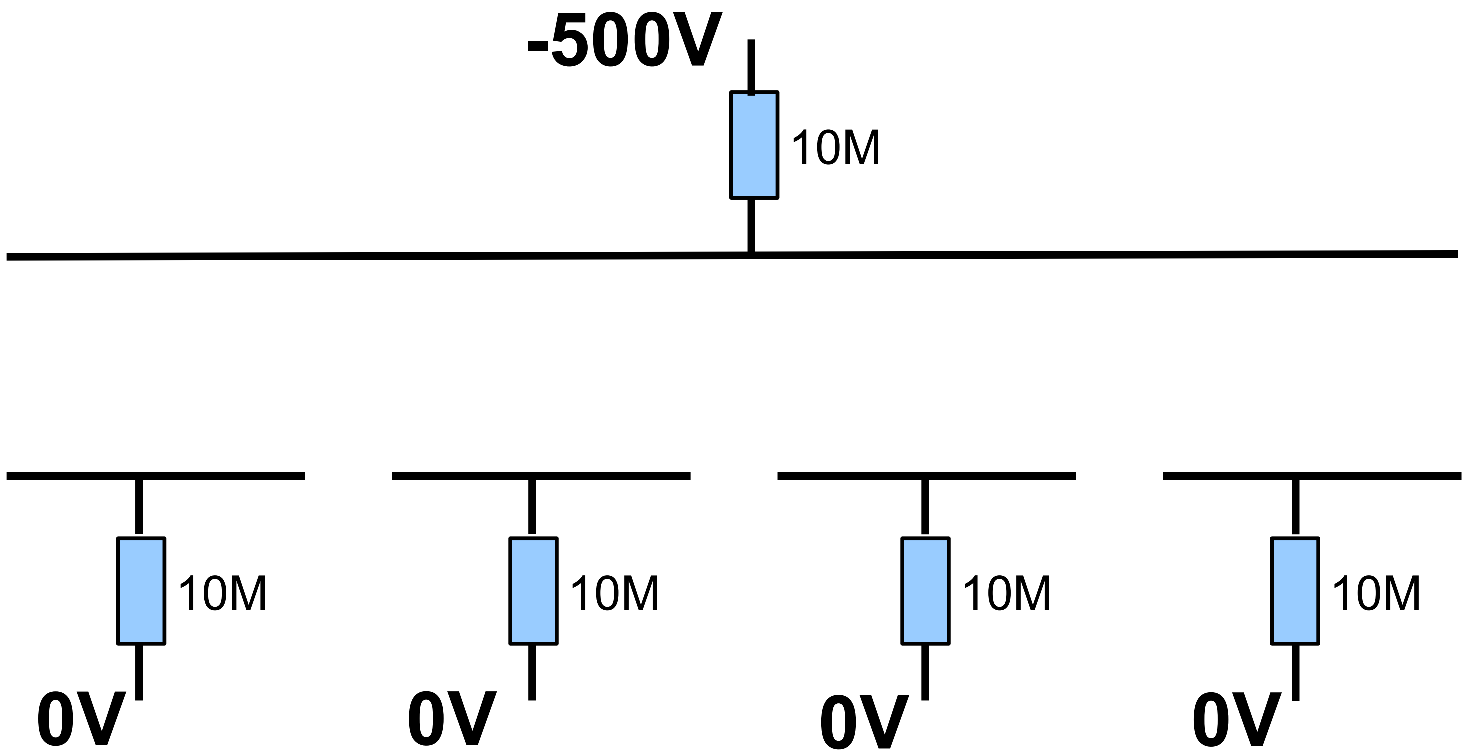


- previous experience with smaller (10x10) GEMs showed no problem
- study in detail the larger modules
- note: all measurements are based on small statistics of destroyed GEMs, drawing conclusions is difficult

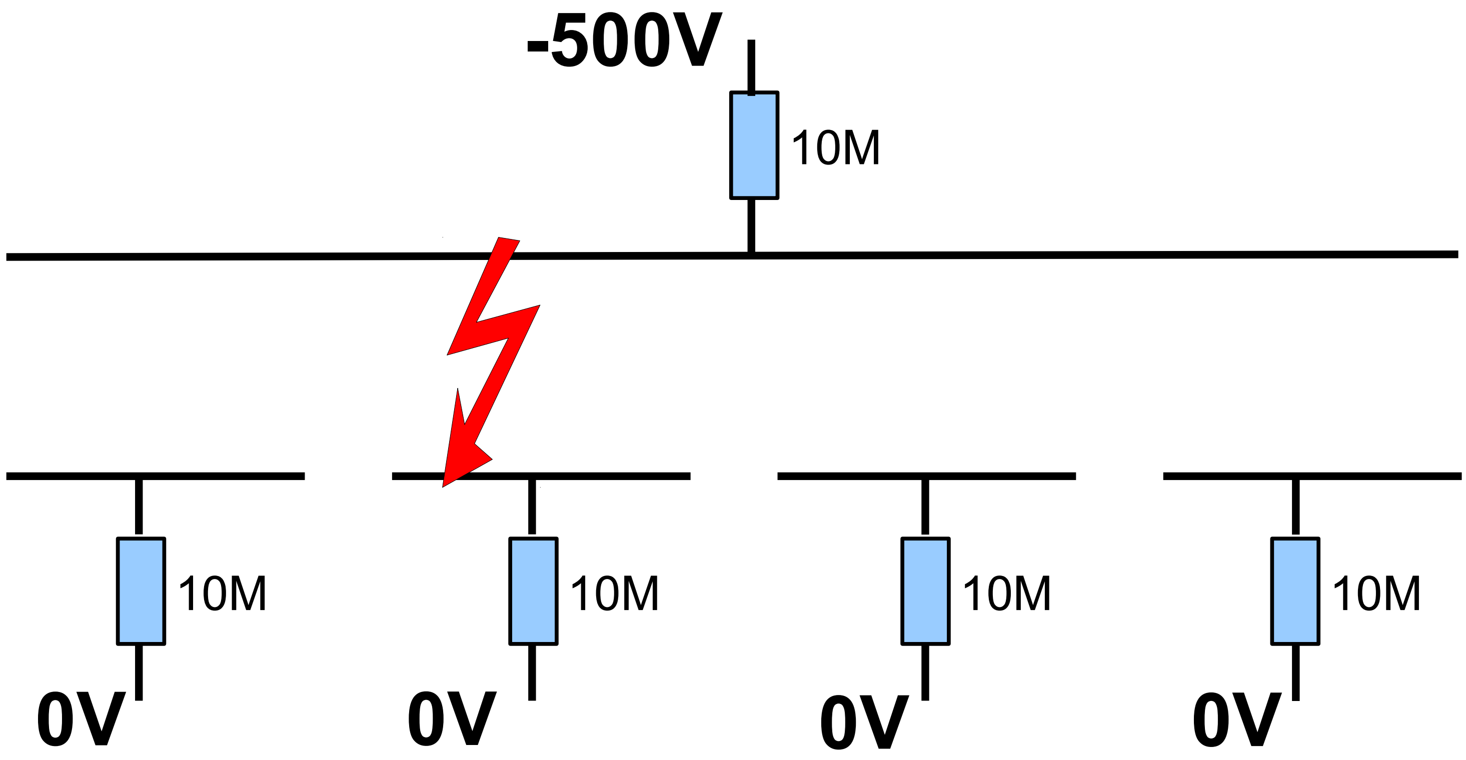


General voltage behavior

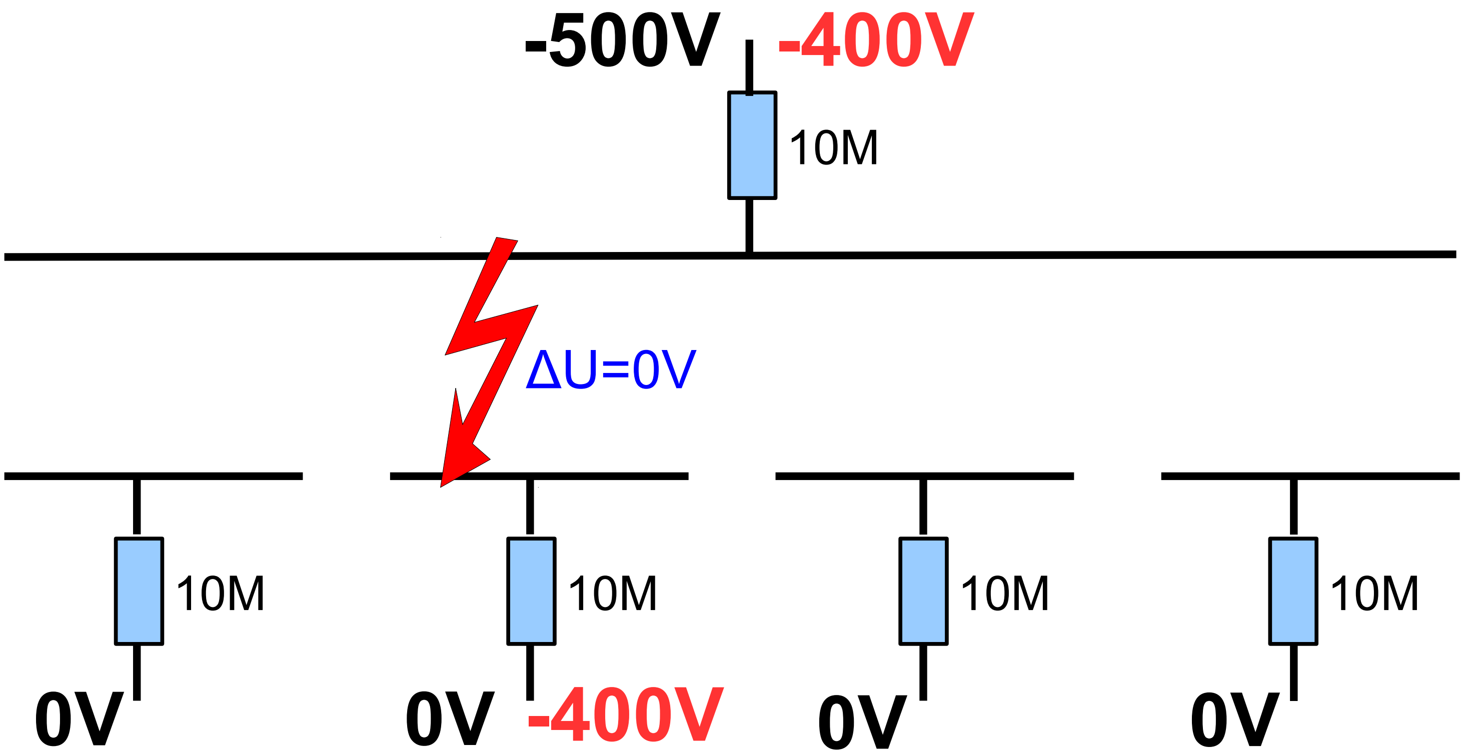
GEM voltage distribution evolution



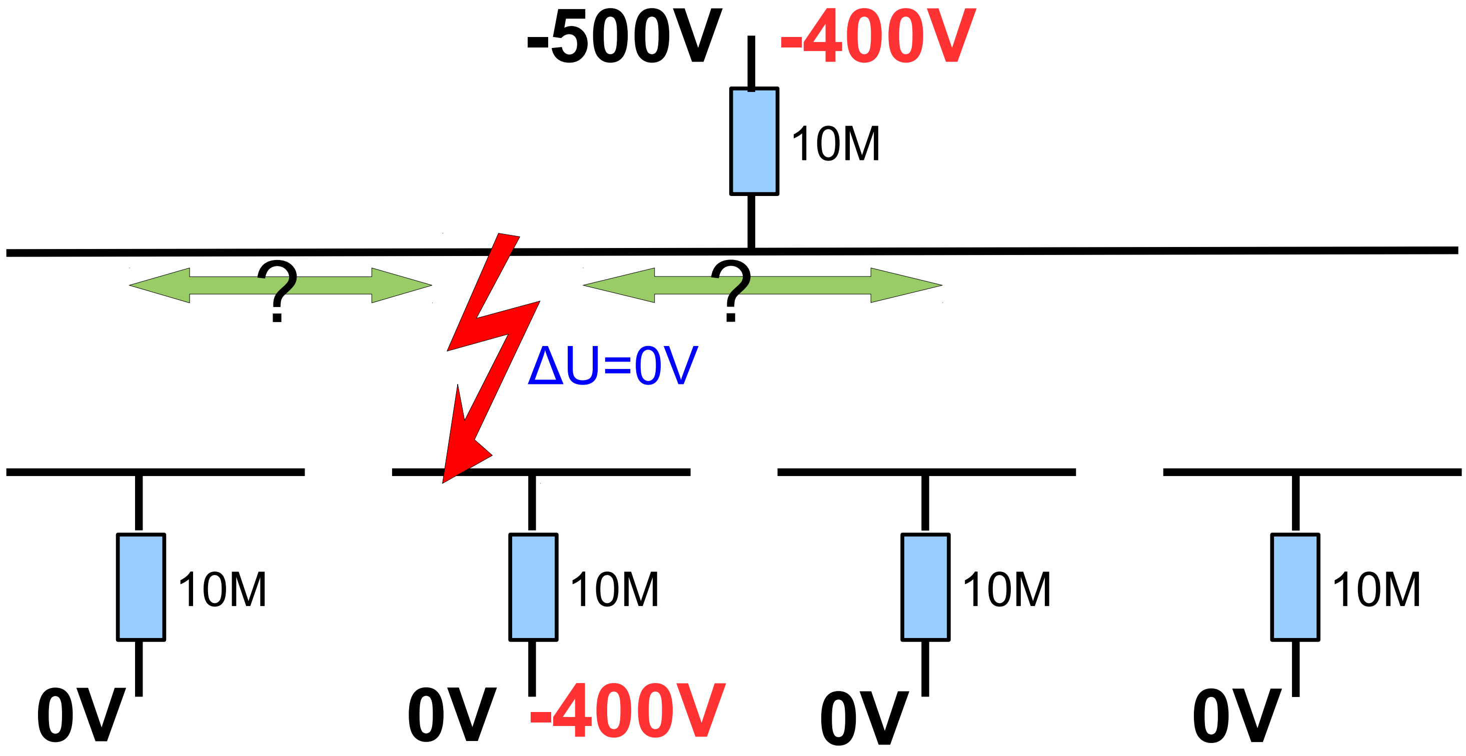
GEM voltage distribution evolution



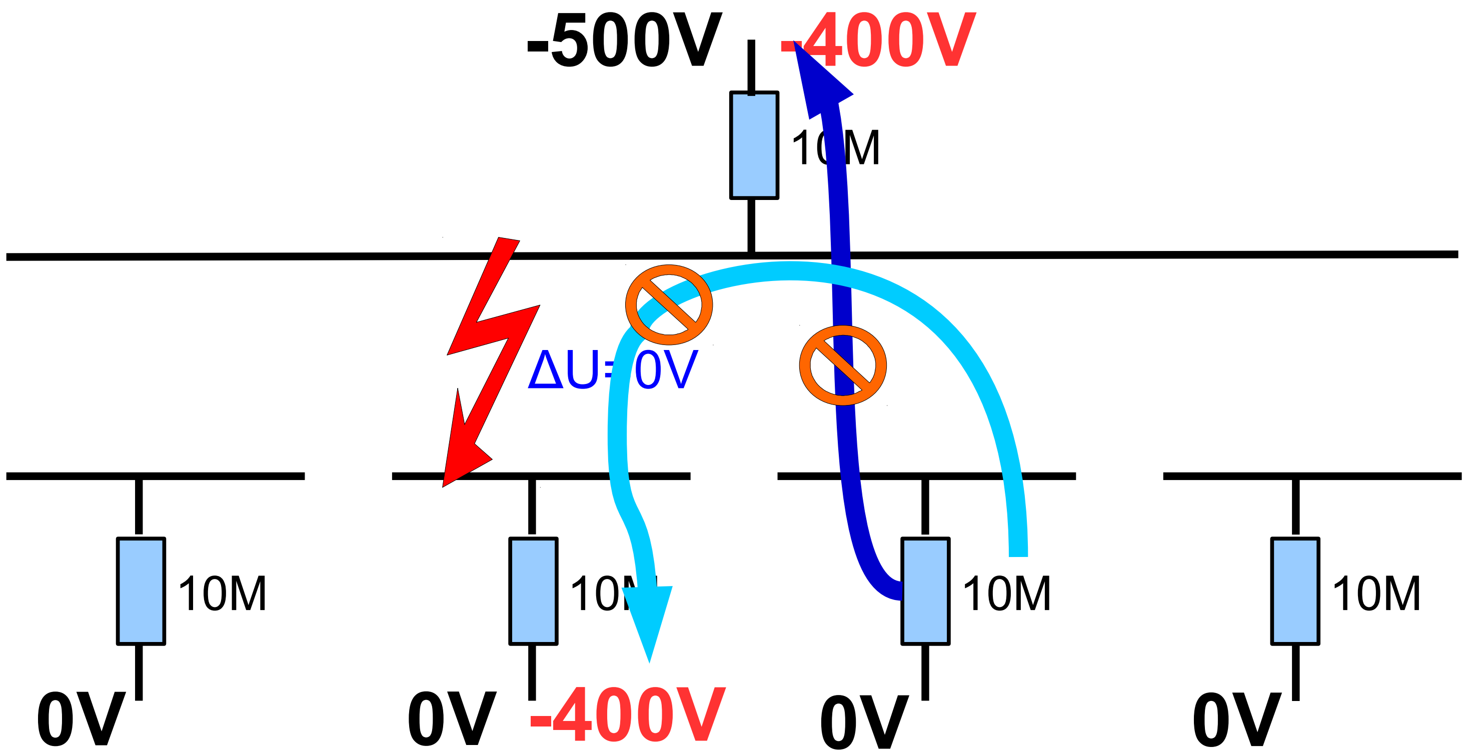
GEM voltage distribution evolution



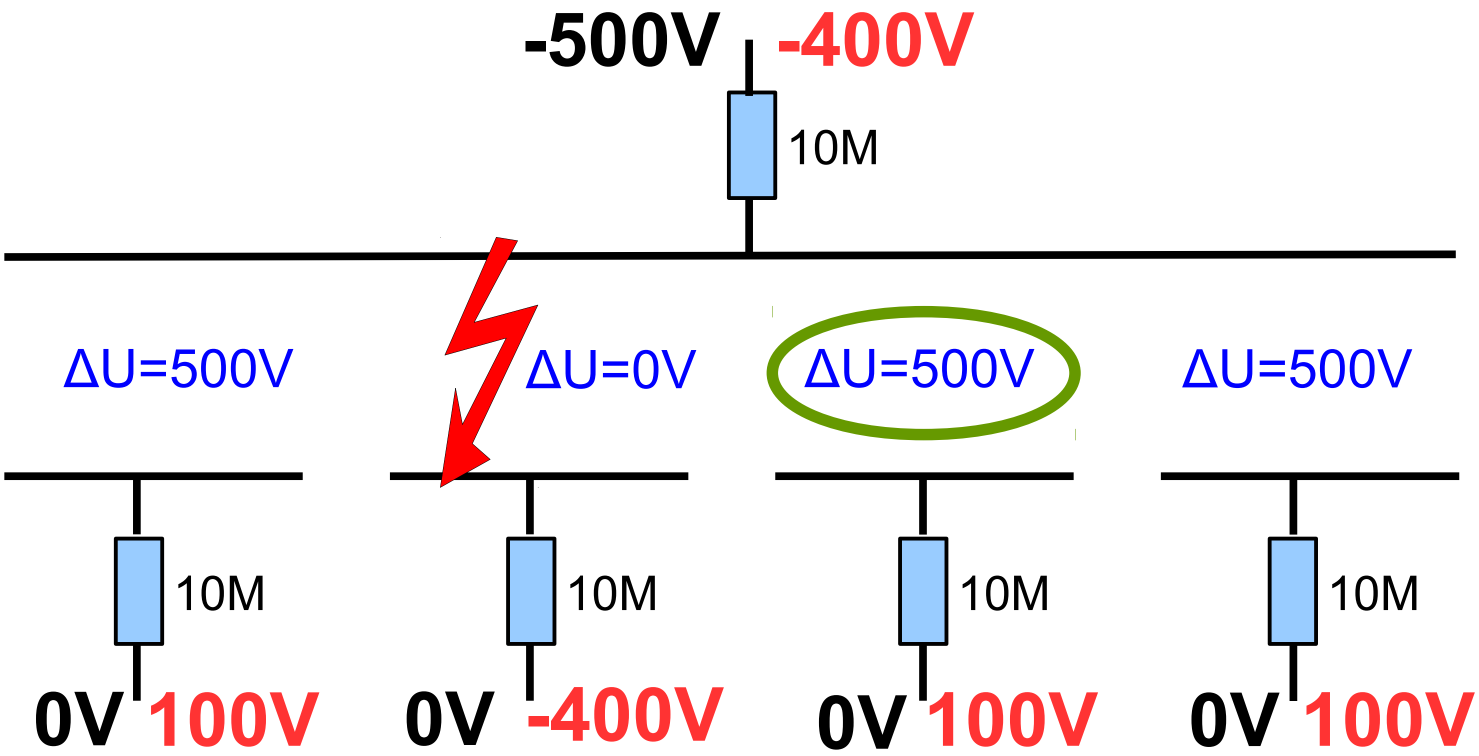
GEM voltage distribution evolution



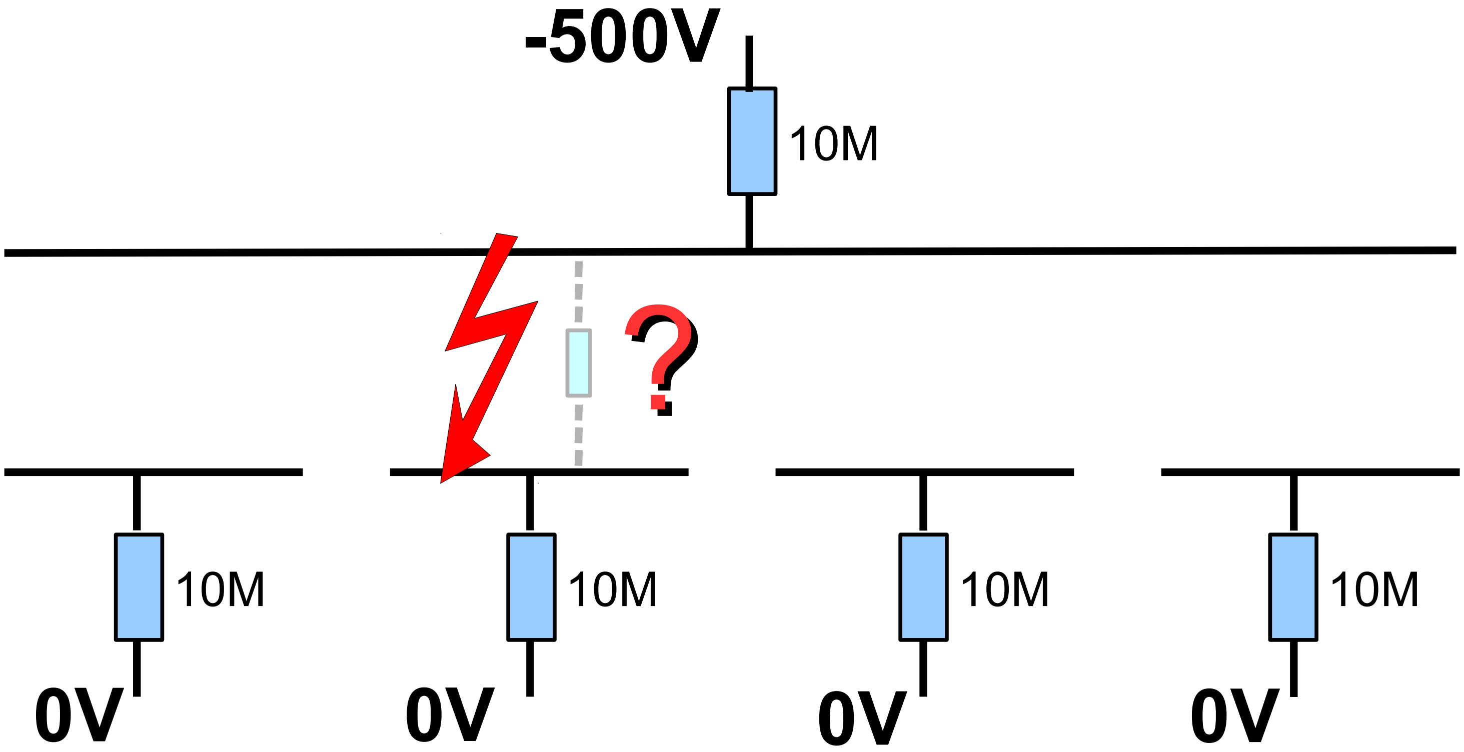
GEM voltage distribution evolution



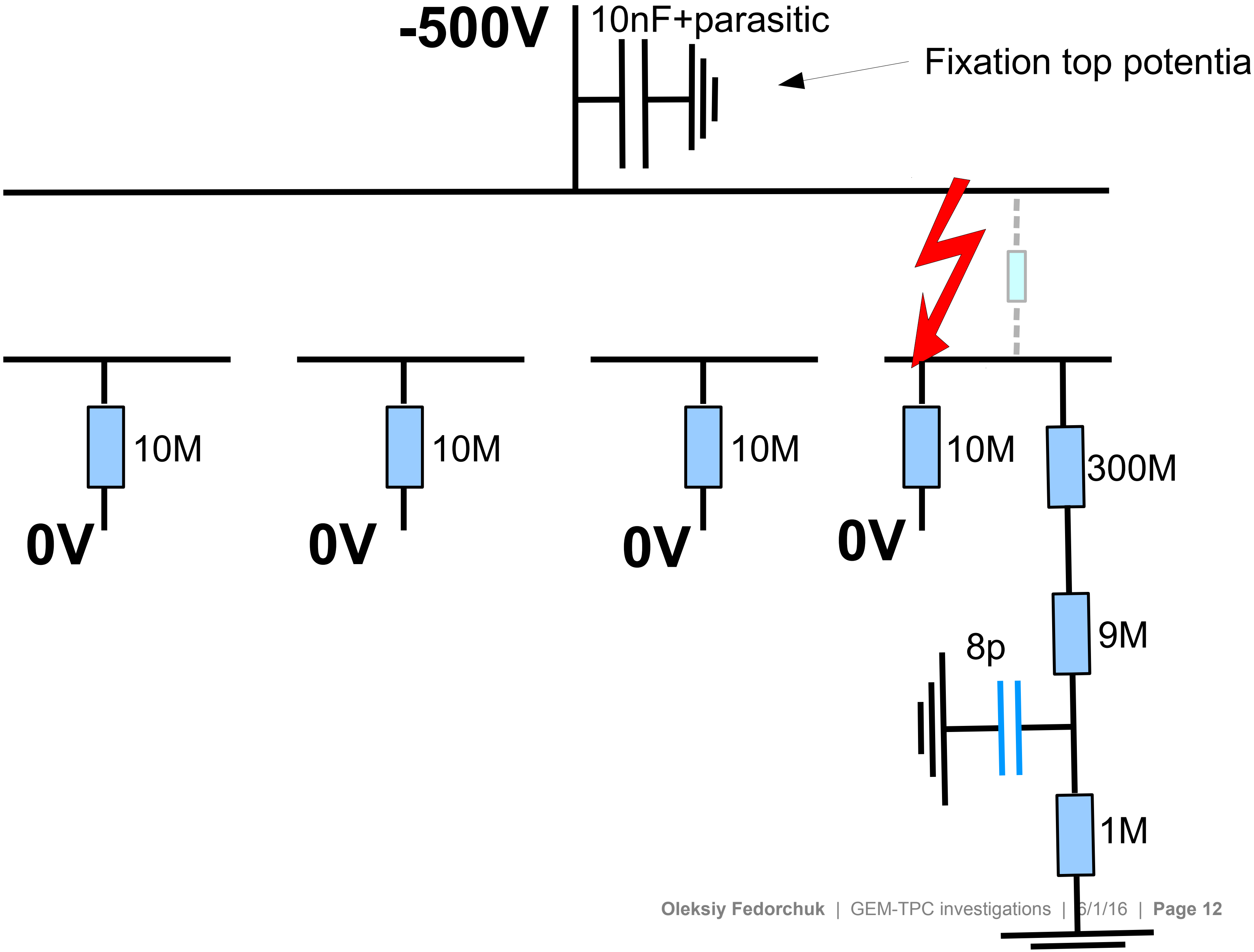
GEM voltage distribution evolution



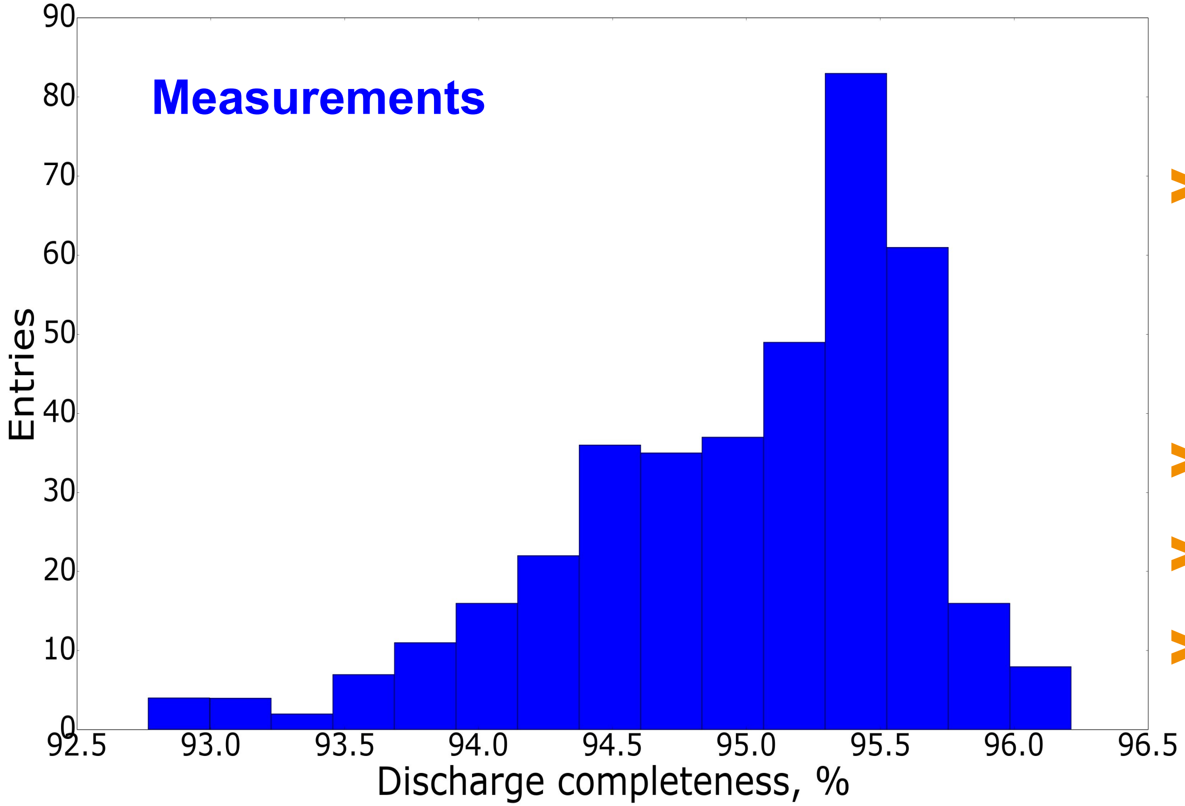
GEM voltage distribution evolution



GEM voltage distribution evolution



Discharge completeness. Comparison voltage drop experimentally and with Spice simulation



- Accordingly to results discharge is happening to about **95%**.
- This respond to about 3_Ohm resistance between GEM sides during a discharge.
- OR?
- Resistor tolerance?
- Parasitic capacitance?

- **Destructive discharge has been observed at from 250V to 710V**

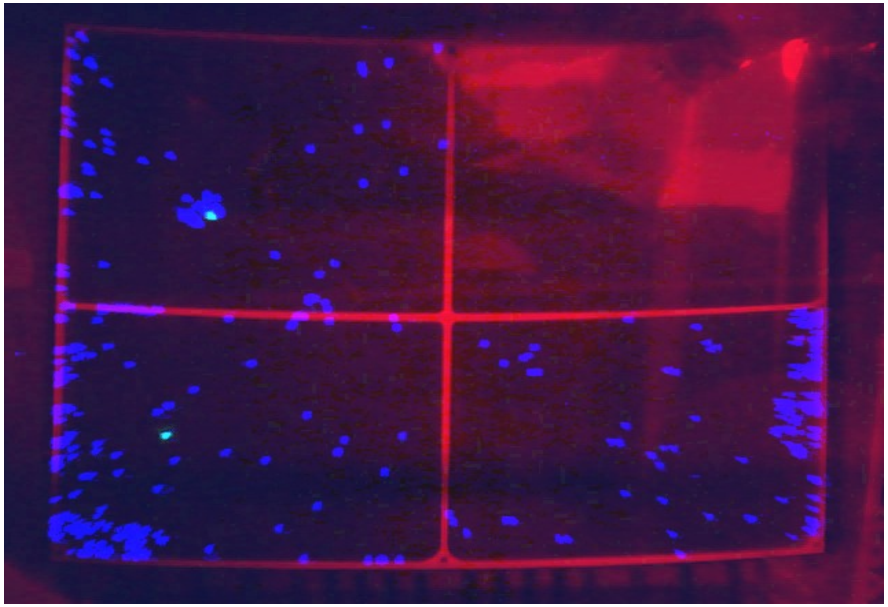
Conclusions?

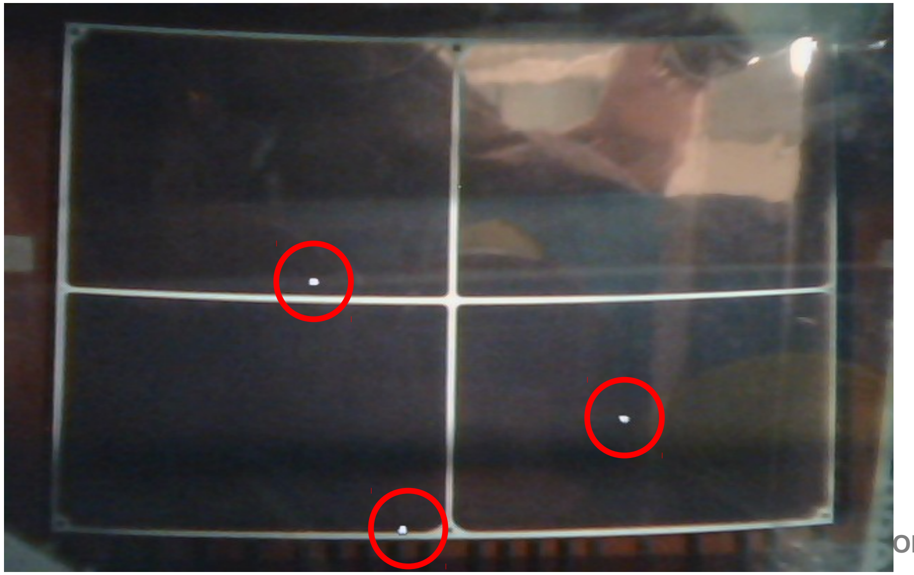
Intermediate conclusions (I)

- We haven't found charge sharing between sectors in electrical approach.**(Spice + experiment)**
- Discharges is full. Close to 100% **(experiment)**
- Dependence of destruction on voltage(discharge energy) in a broad range has not been found **(experiment)**

Oscillations chapter

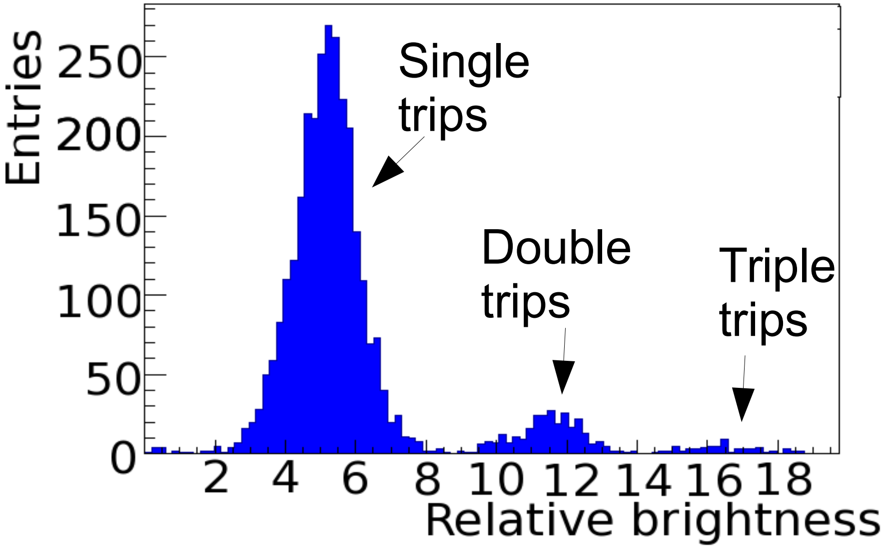
Experimental setup (EXTREME CONDITIONS IS USED)





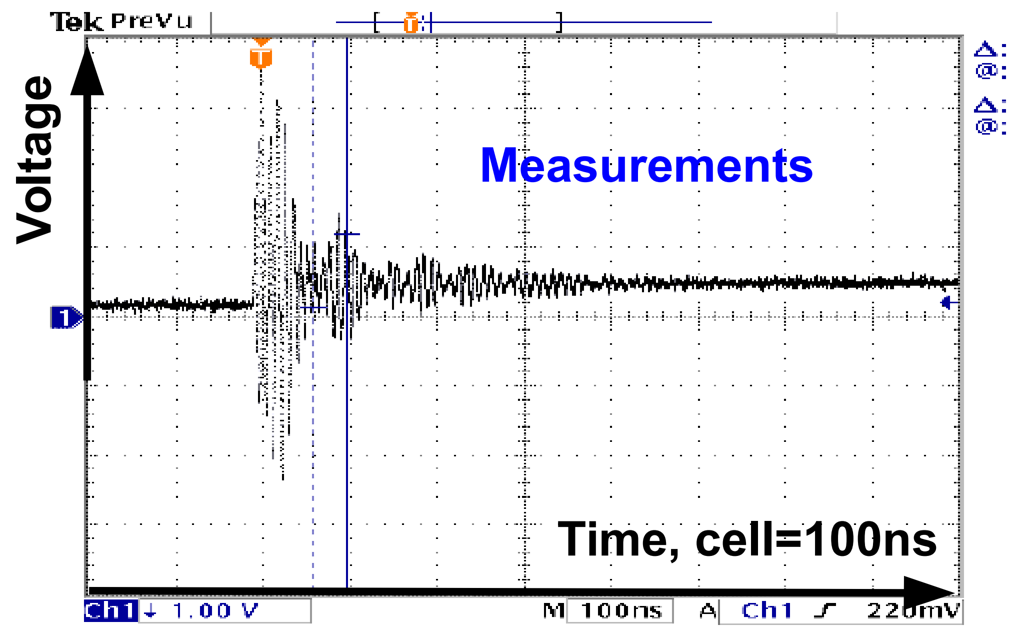
- We built a system to observe the light produced by discharges
- Light integrated over couple of thousands discharges
- U=650V (N2) instead of 250V(P5) or 360V (T2K)

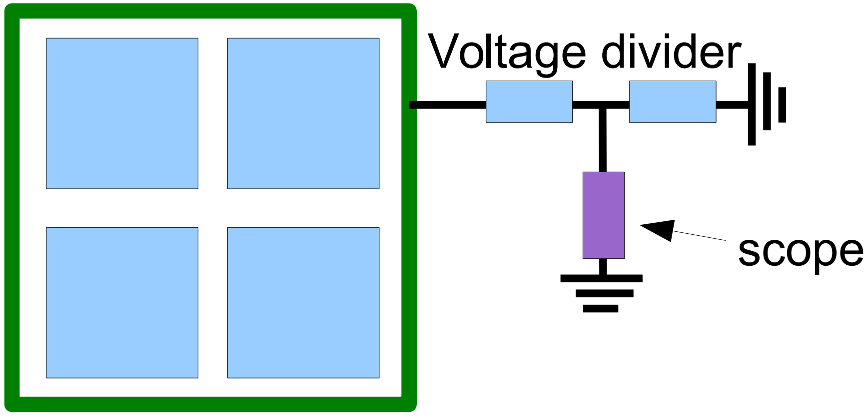
Discharges light intensity

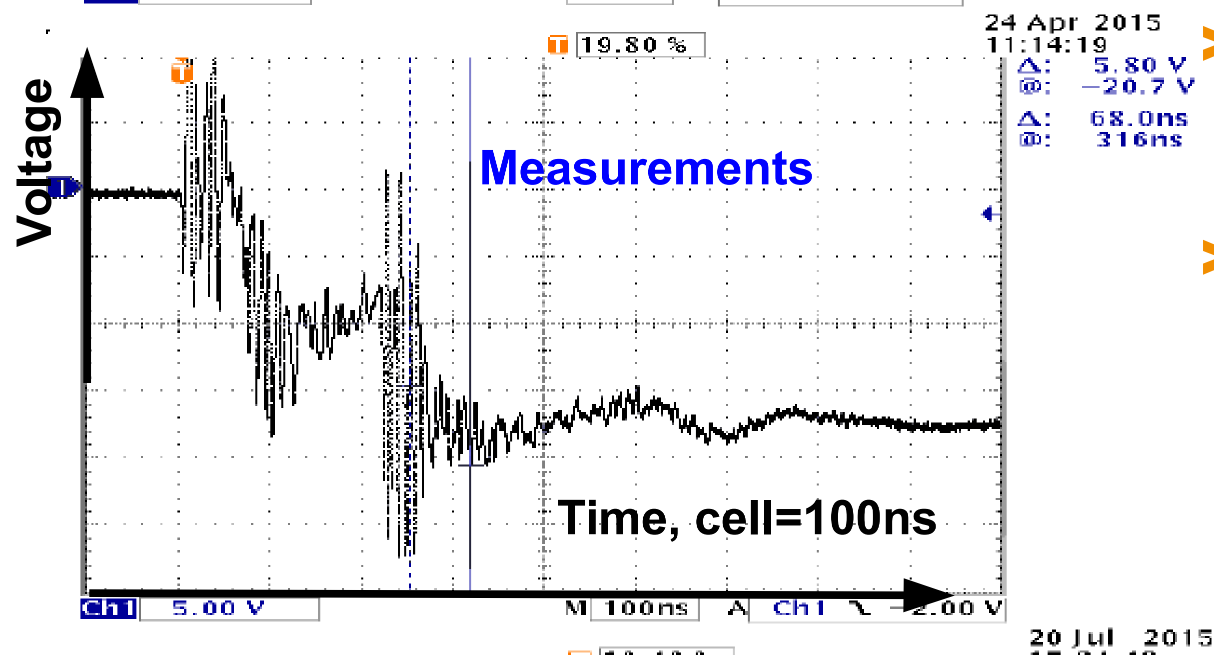


- **observe multiple discharges: They happen in different sectors (within one time frame of 33ms)**

Oscilloscope measurements



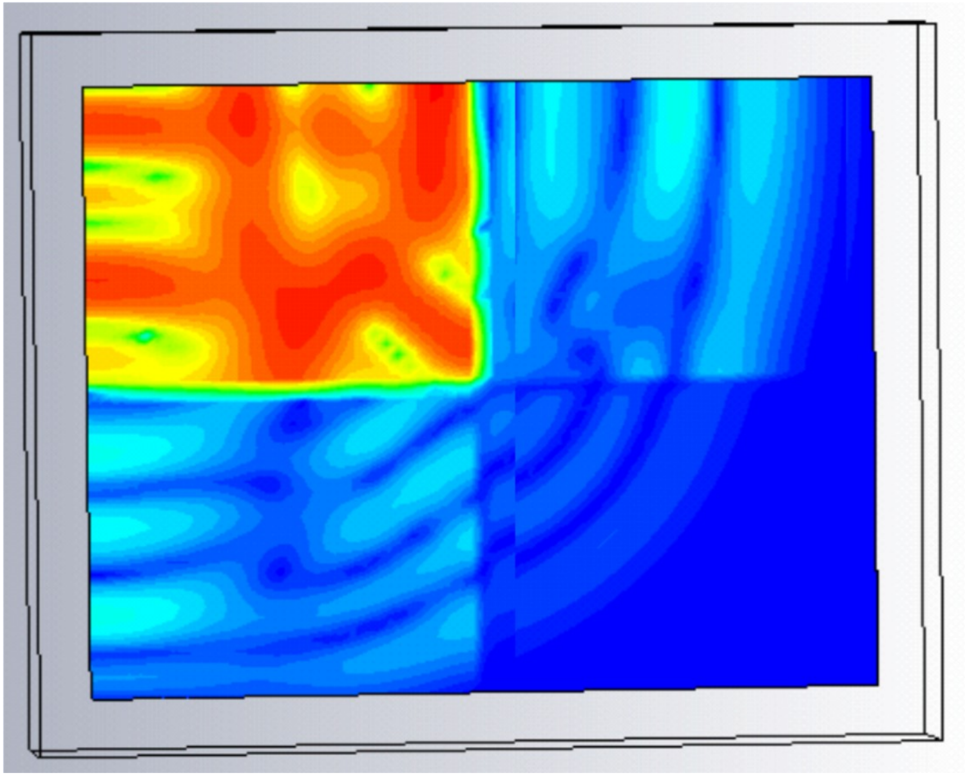


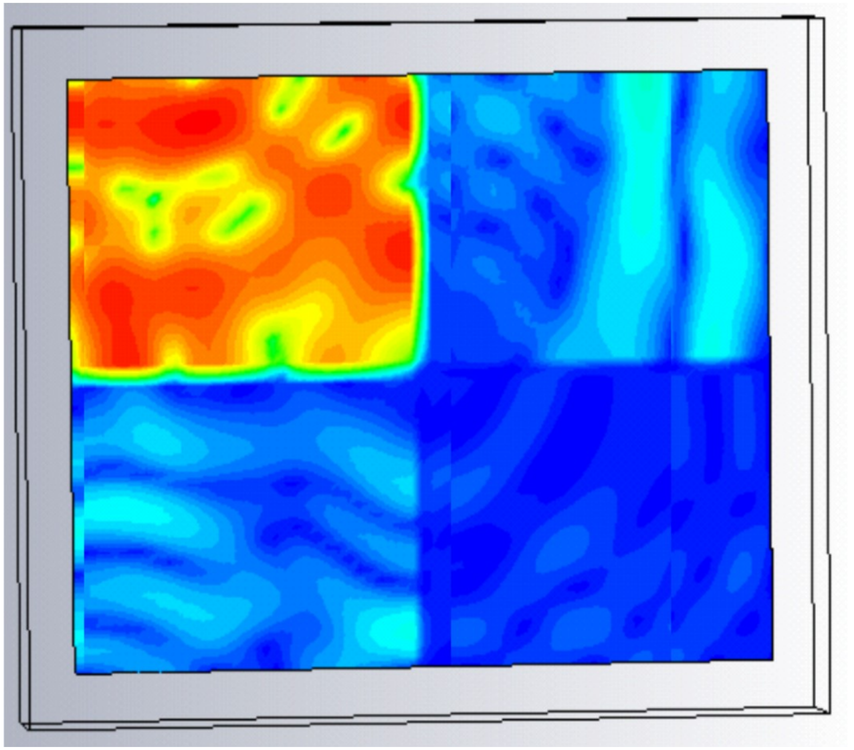


- we observe oscillations of the potential after a spark
- we observe a clear sequential behavior of multiple discharges
- we suspect that the oscillations enhance the probability for multiple discharges

Discharge simulations

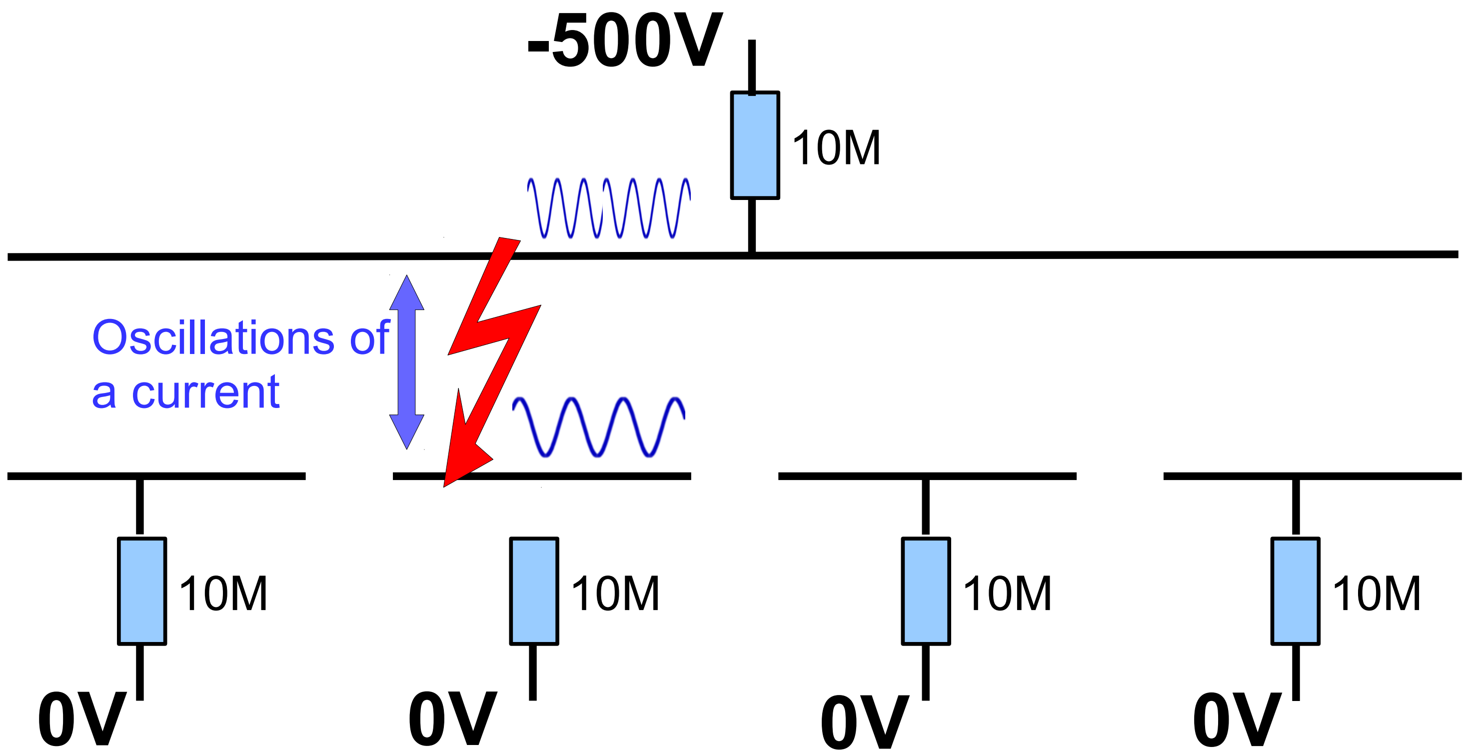
- Discharge causes current oscillations on GEM surface in different sectors (CST® simulations)





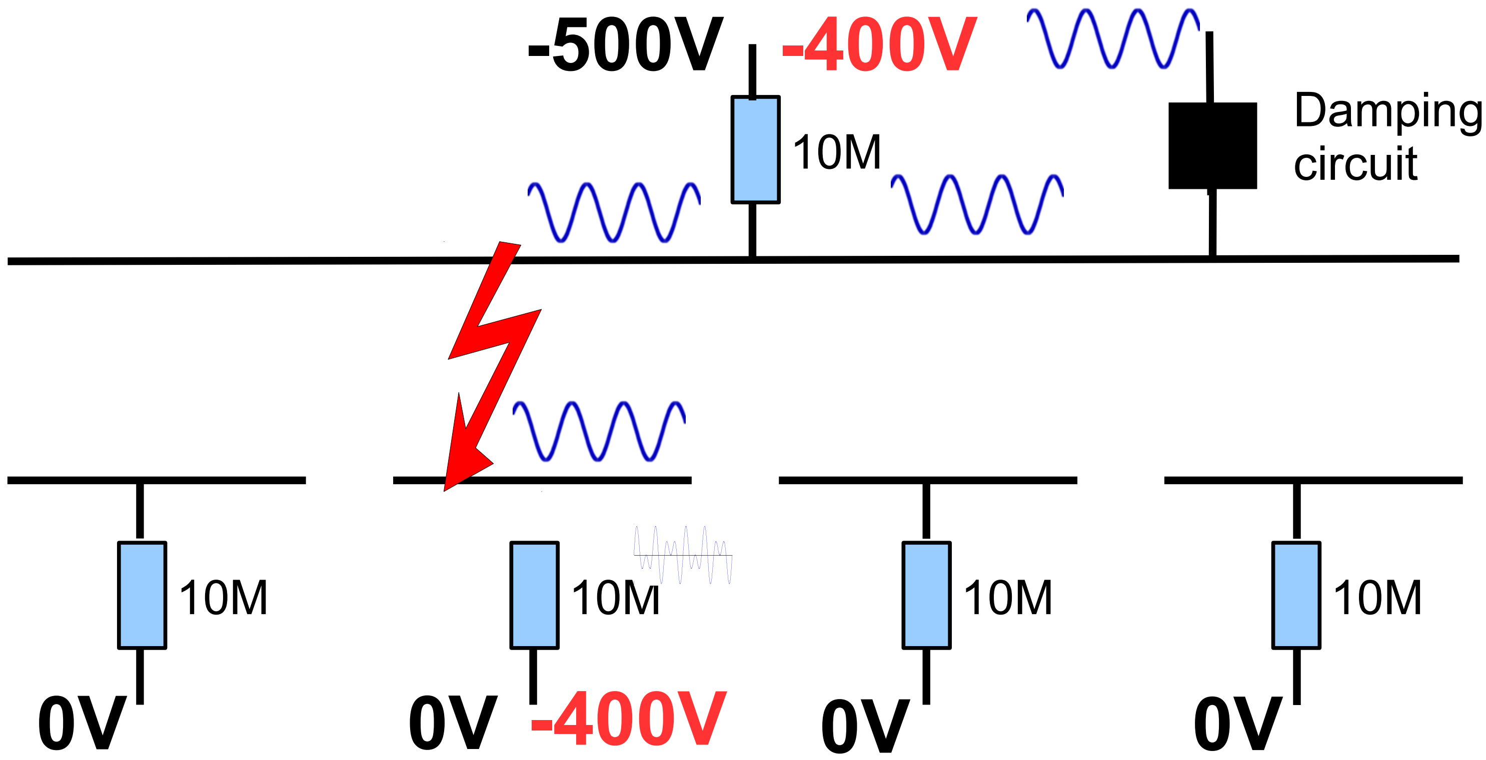
- **Voltage oscillations caused by electromagnetic wave reflected from borders.**
- Unfortunately, quantitative comparison yet not possible because of absence precise model (at least discharge shape and plasma effects).

Current oscillations idea



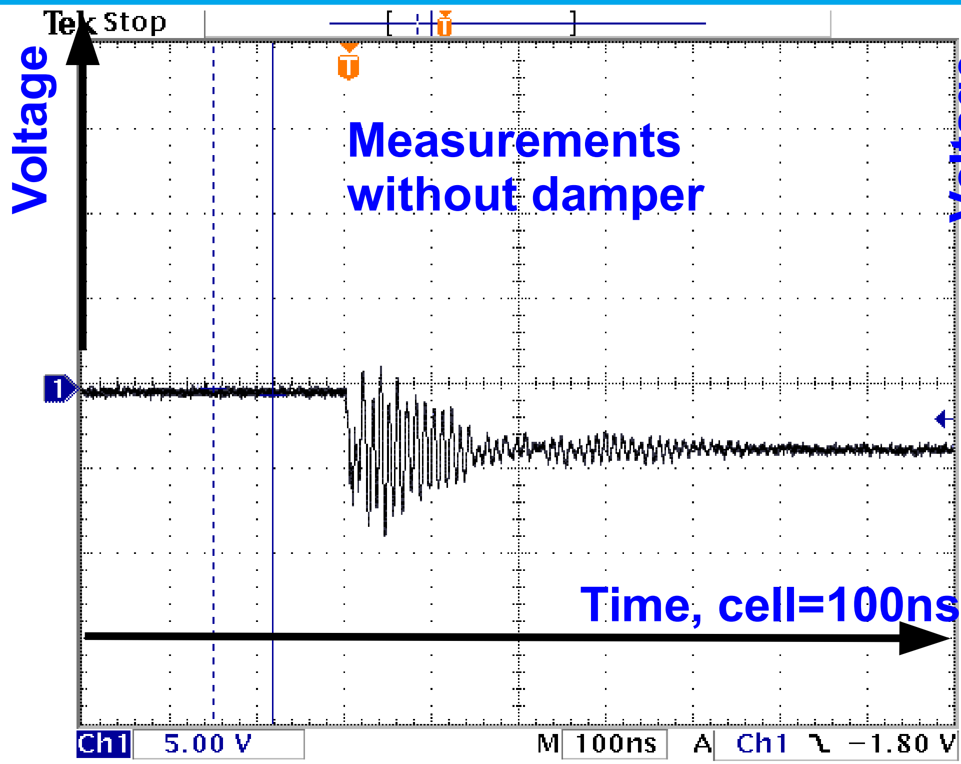
- If the lifetime of a plasma channel is bigger than **charge transfer time + oscillations period,** than we can receive current oscillations

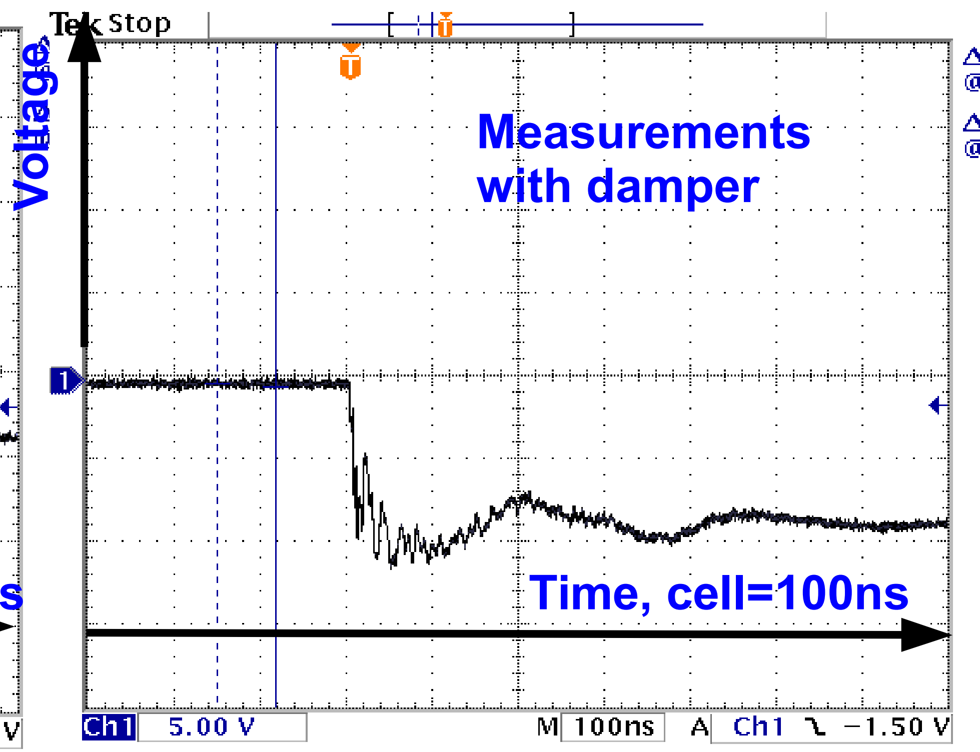
Oscillations dumper idea



- Idea is to connect additional circuit that will be transparent for the oscillations and will stabilize voltage.

Filter implementation experimental effect (neighbor sector)

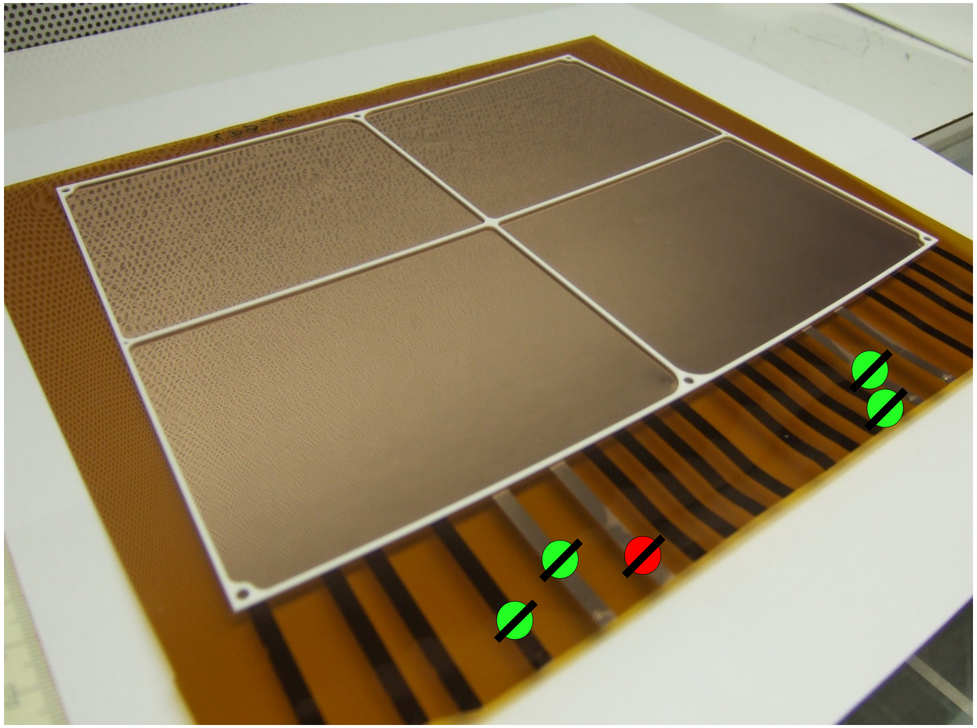


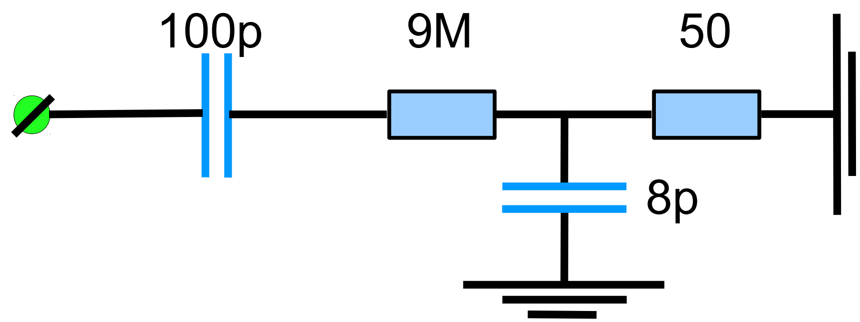


520V	Without RC (22hours)	With RC (47hours)	Without RC again (63hours)
Registered discharges	**166**	**75**	**75**
Multy discharges among	**13**	**0**	**5**

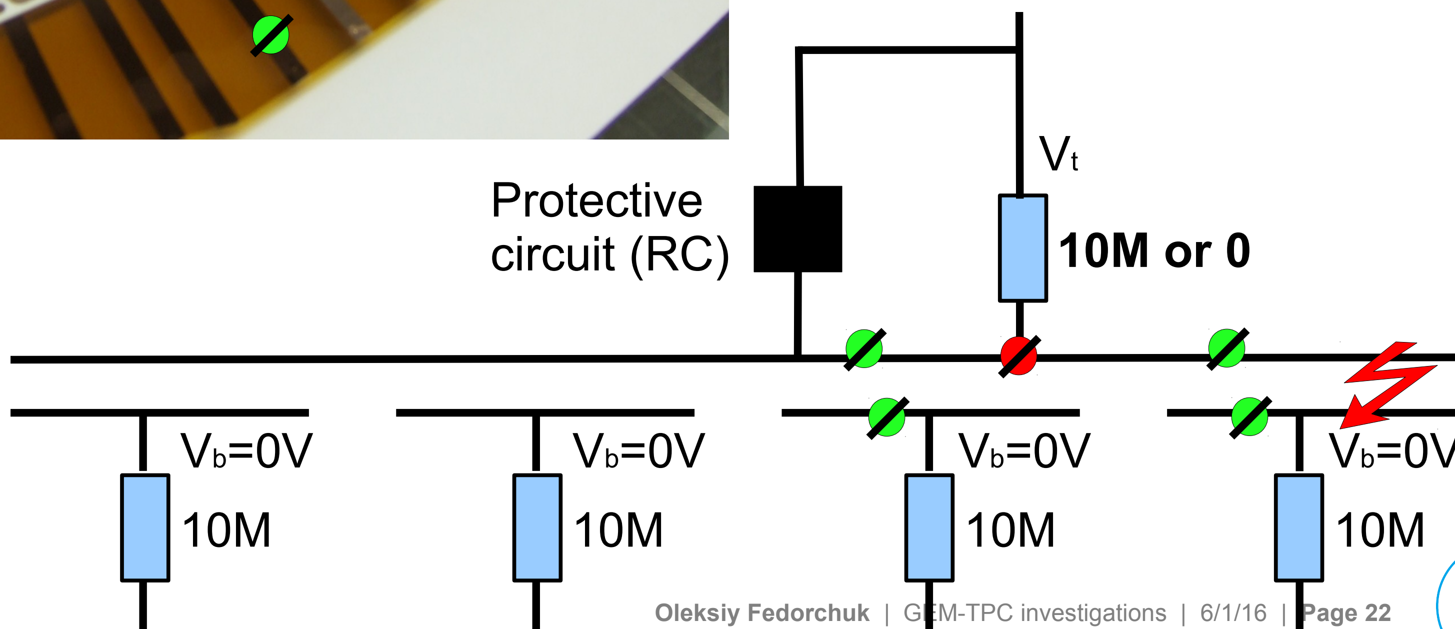
> **Increasing voltage leads to increase oscillations and appearance of multiple discharges**

GEM scope connection and frequency filtration

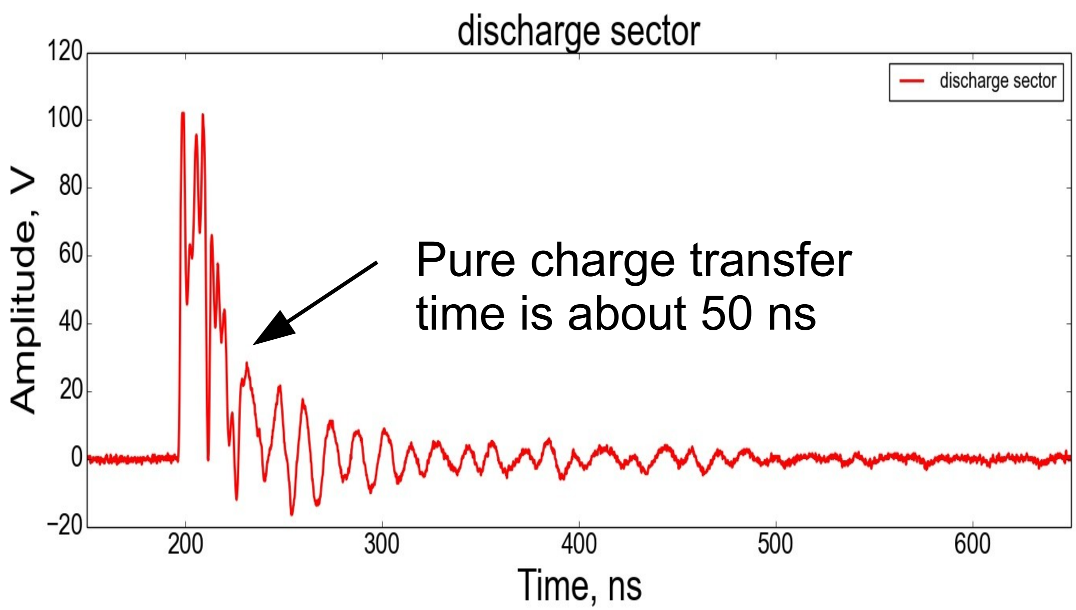


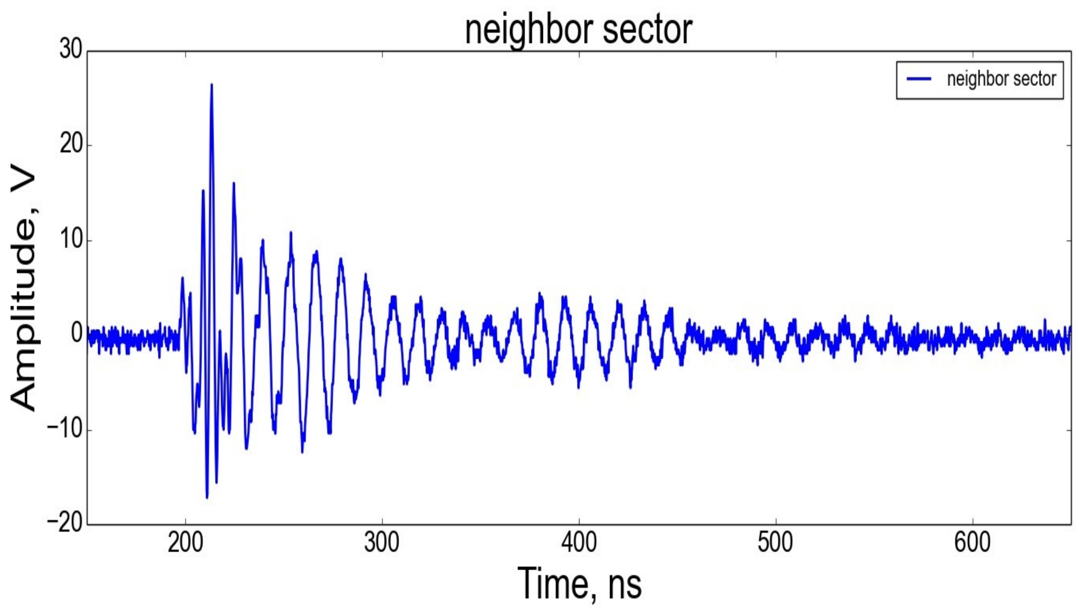


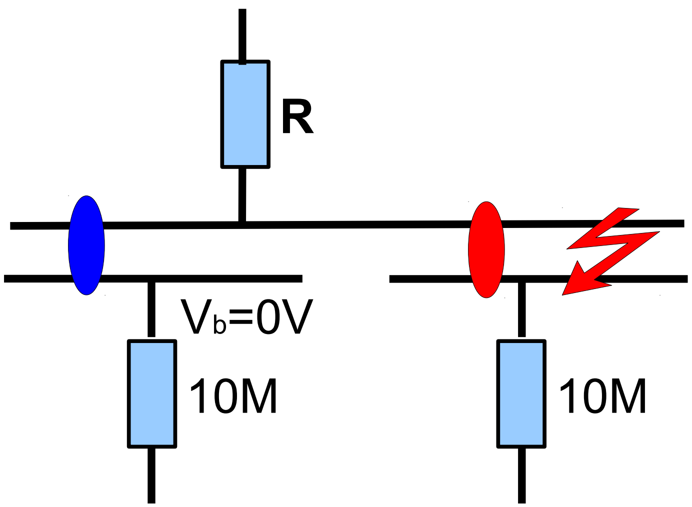
— Power supply connection point



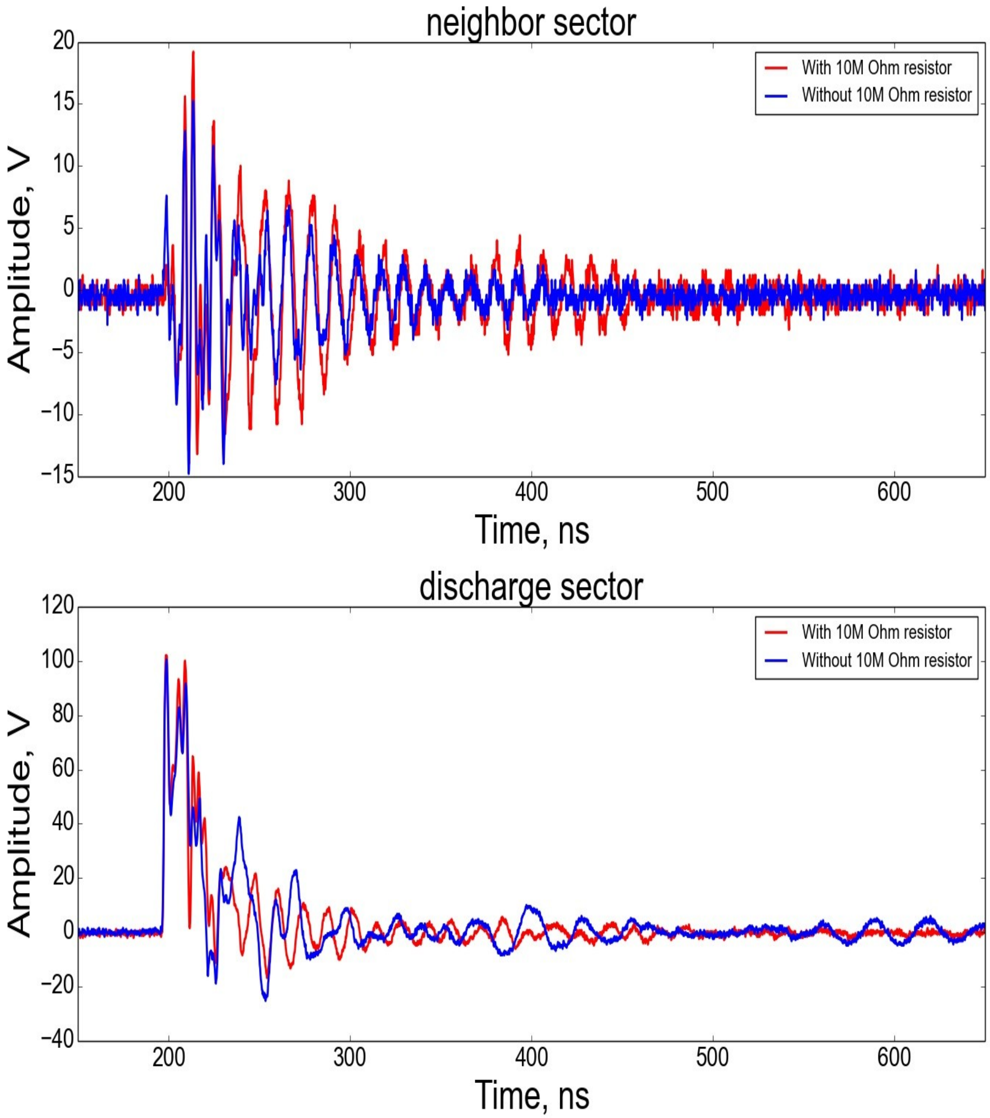
Voltage between sectors look like this

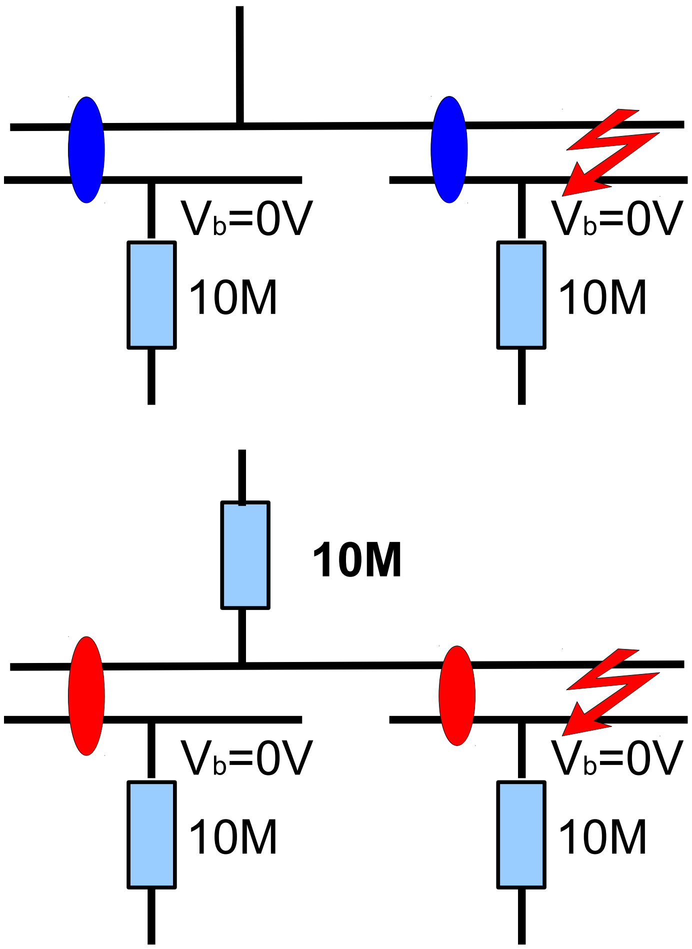






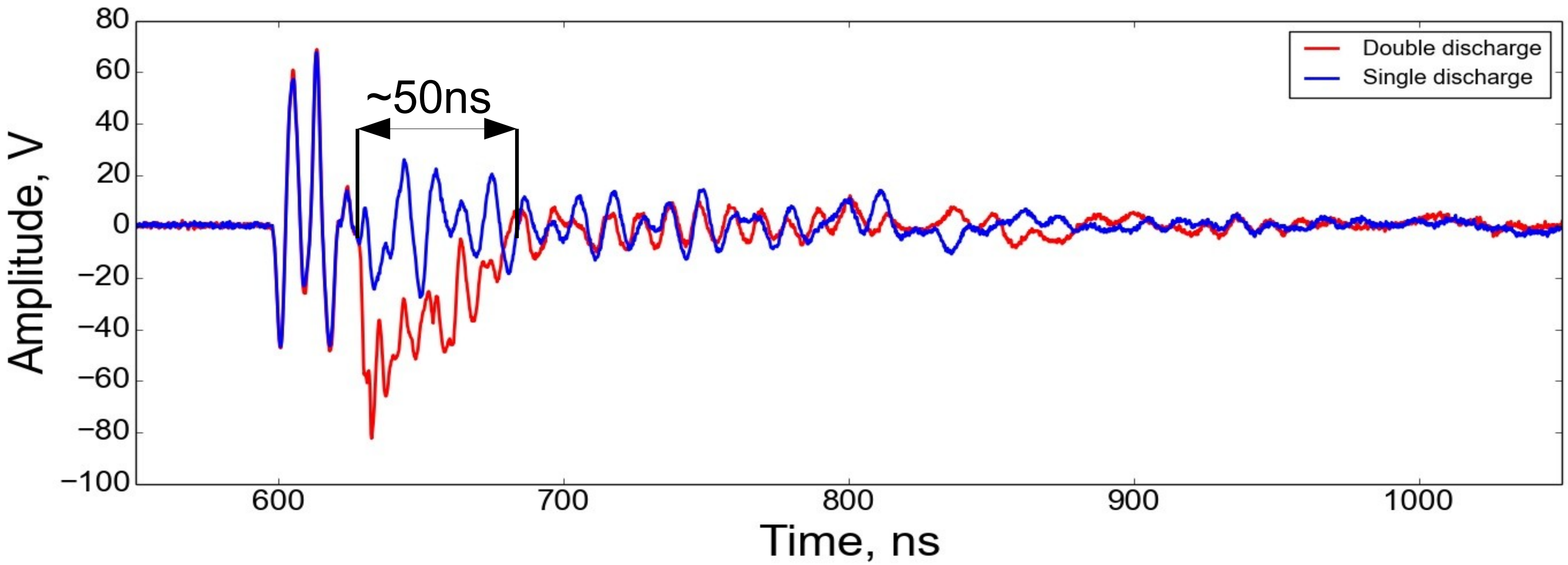
Voltages: discharge side and neighbor side

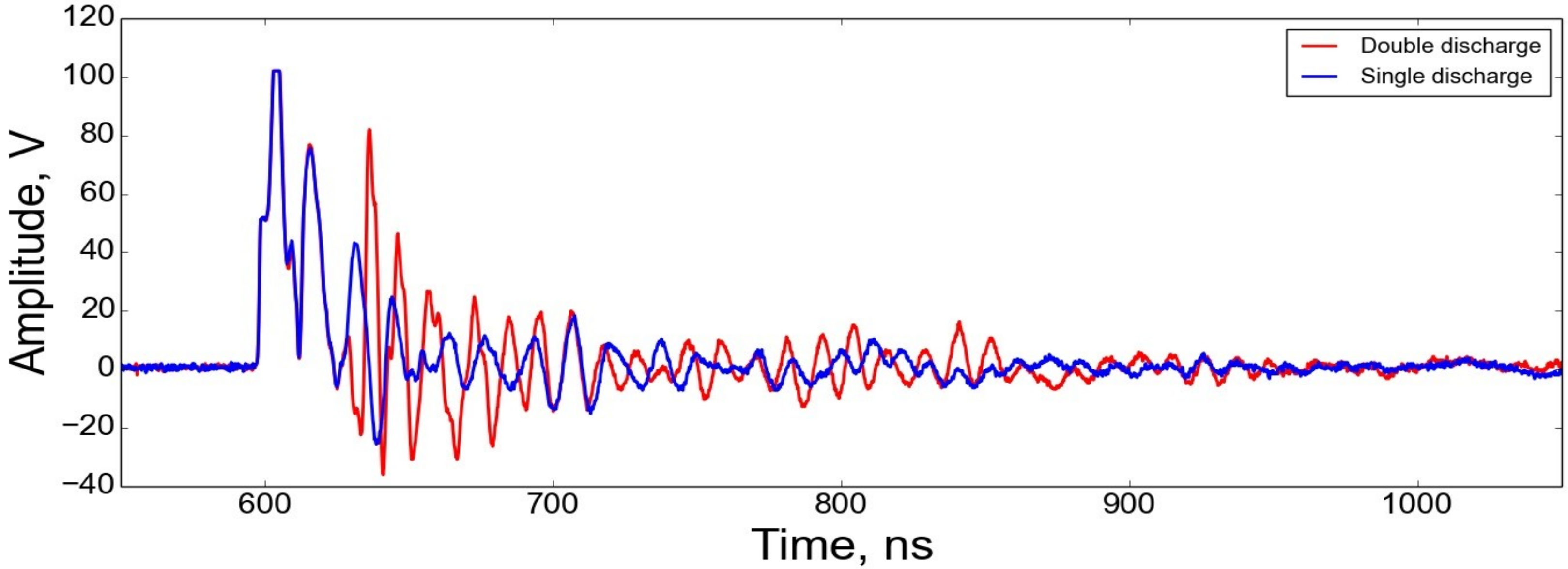




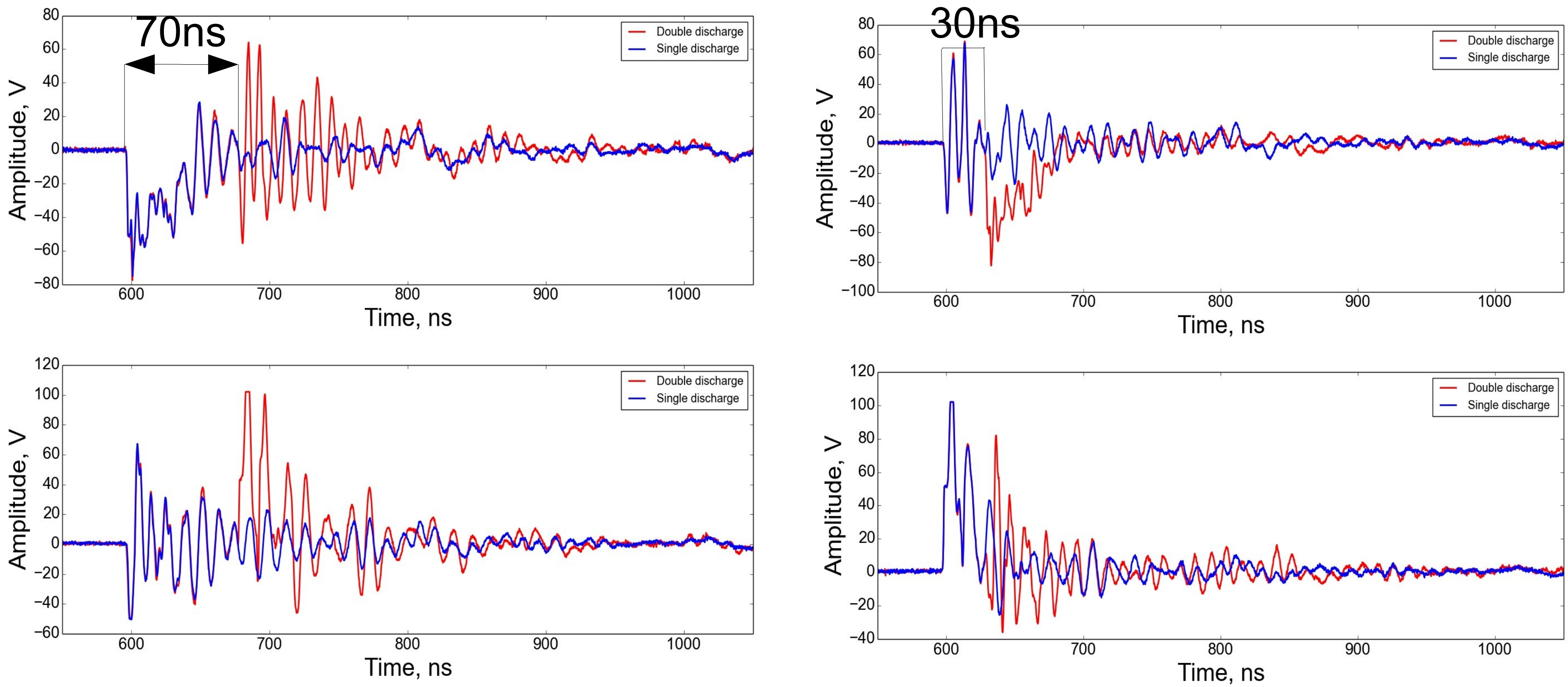
Neighbor sector shows less iscillations

Double discharges profile. First part of the double discharge (red) is overlayed with single one (blue)





Double discharges profile



- Blue curve is a single discharge
- First part of a double discharge is not seenable, because single discharge has completely same profile
- Time between discharges is not the same

Role of scope as a filter

- Old measurements

520V	Without RC (22hours)	With RC (47hours)	Without RC again (63hours)
Registered discharges	**166**	**75**	**75**
Multy discharges among	**13**	**0**	**5**

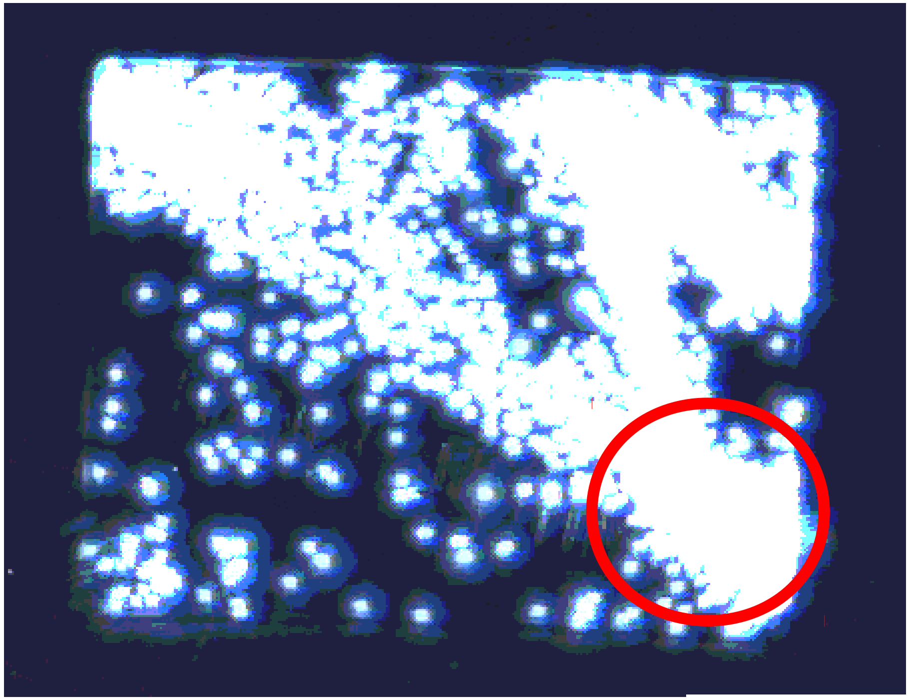
- Repeating of this measurements with 4 attached scope channels shows with and without filter multiple discharge level ~5% instead of ~14% expected.
- This make us a hint that scope itself works as a filter
- In addition this means that that all previous scope pictures already was changed by a presence of the scope

Intermediate conclusions (II)

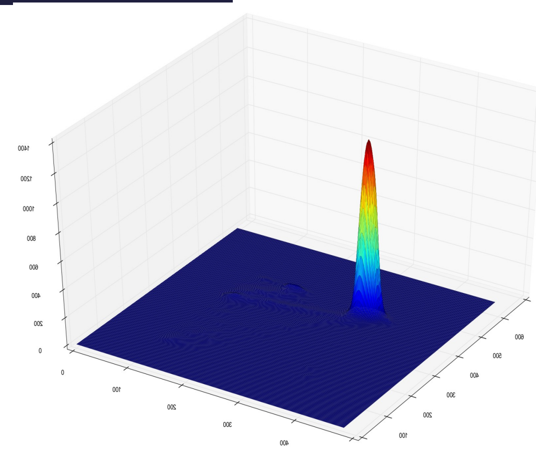
- We see observe multiple discharges (30-150 ns time difference).
- The oscillations are triggered by a discharge in one GEM
- We see evidence that introducing a filter (damper) can significantly reduce the multiple discharge rate
- We can see pure charge transfer time about 50 ns, but it is not clear how comparable is it with plasma channel lifetime

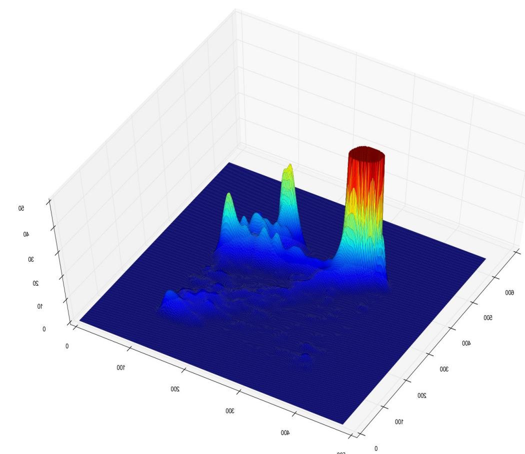
Oxide protection

Observations of ultimate high number of discharges

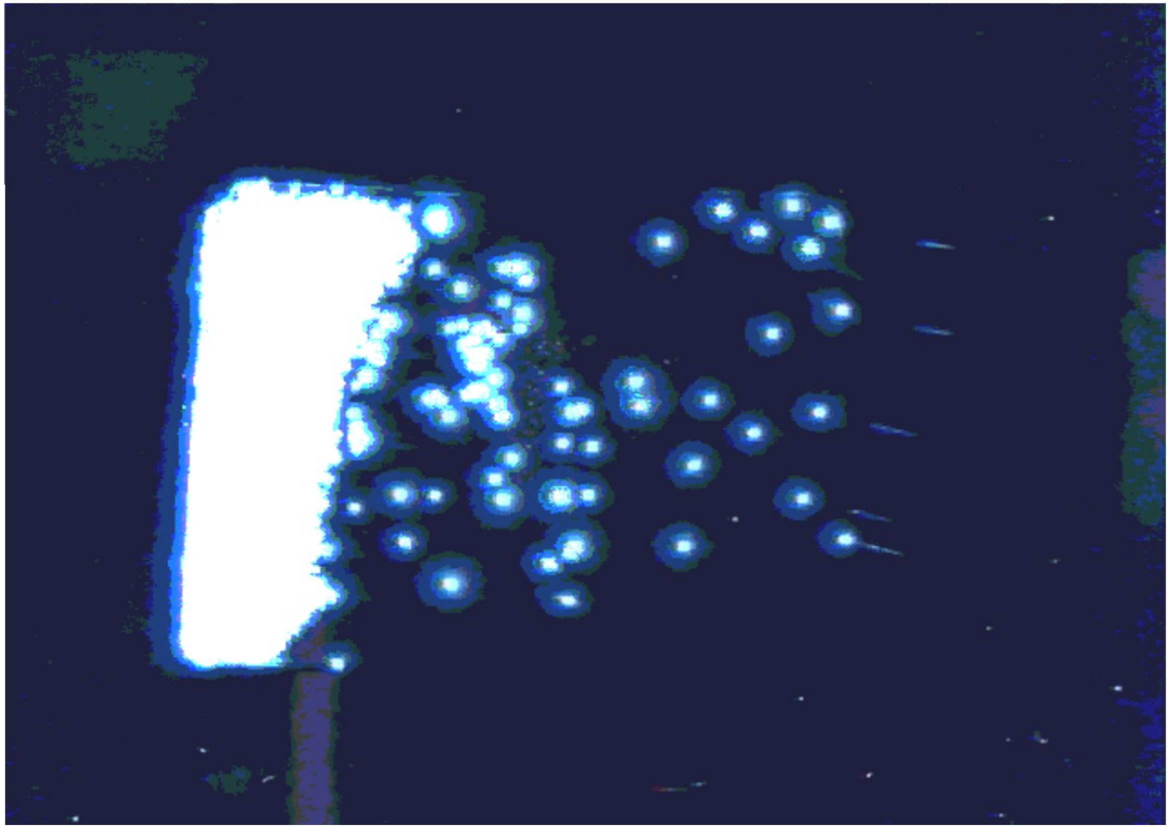


- operated double framed GEM under extreme conditions with protective circuit
- recorded about 30,000 discharges
- towards the end deterioration of performance, constant current
- physical damage to the GEM observed, details are under study





Repetition of the test (about 150,000 discharges)



- About 150,000 discharges.
- Stage of testing the protective circuit

Assumption

Stable chemical compounds

CuO

Cu2O

- Oxidation takes place faster on higher temperature
- We assume that dark spots appear due to local heating up by a discharge
- Oxide layer may serve as protective coverage

Copper oxides are semiconductors

Effect of post-annealing on the properties of copper oxide thin films obtained from the oxidation of evaporated metallic copper

V. Figueiredo [a], E. Elangovan [a,*], G. Gonçalves [a], P. Barquinha [a], L. Pereira [a], N. Franco [b], E. Alves [b], R. Martins [a], E. Fortunato [a]

[a] *Materials Science Department, CENIMAT-I3N and CEMOP-UNINOVA, FCT-UNL, Campus de Caparica, 2829-516 Caparica, Portugal*
[b] *LFI, Dep. Física, Instituto Tecnológico e Nuclear, EN10, 2686-953 Sacavém, Portugal*

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T (°C)	t (μm)	AVT (%)	Band gap (eV)	Carrier type	Resistivity		Mobility ($cm^2 V^{-1} s^{-1}$)	Carrier concentration (cm^{-3})
					R_{sh} (Ω/□)	ρ (Ω–cm)		
RT	0.15	0.1	–	n	0.29	3.51×10^{-6}	18.30	9.72×10^{22}
100	0.15	5.1	2.70	n	1.82	2.73×10^{-5}	6.11	3.75×10^{22}
200	0.17	65.6	3.02	p	6.37×10^{6}	108	1.56	3.69×10^{16}
250	0.17	49.4	2.57	p	1.48×10^{7}	251	1.27	1.95×10^{16}
300	0.17	38.0	2.85	p	3.24×10^{7}	551	0.21	5.45×10^{16}
350	0.18	44.4	2.03	n	1.07×10^{7}	192	0.26	1.25×10^{17}
400	0.18	43.0	2.79	n	3.22×10^{6}	58	0.22	4.98×10^{17}
450	0.18	36.4	2.80	n	1.73×10^{6}	31	0.28	7.19×10^{17}

T—annealing temperature; t—film thickness; AVT—average visible transmittance; R_{sh}—sheet resistivity; ρ—electrical resistivity.

- Cu: ~10^{-1} Ohm/cm^2
- Cu2O: ~10^{7} Ohm/cm^2
- Cu2O: ~10^{6} Ohm/cm^2
- It starts to accumulate mostly after 350 with high presents of air

Low temperature (<100 °C) deposited P-type cuprous oxide thin films: Importance of controlled oxygen and deposition energy

Flora M. Li [a,*], Rob Waddingham [a], William I. Milne [a], Andrew J. Flewitt [a], Stuart Speakman [b], James Dutson [c], Steve Wakeham [c], Mike Thwaites [c]

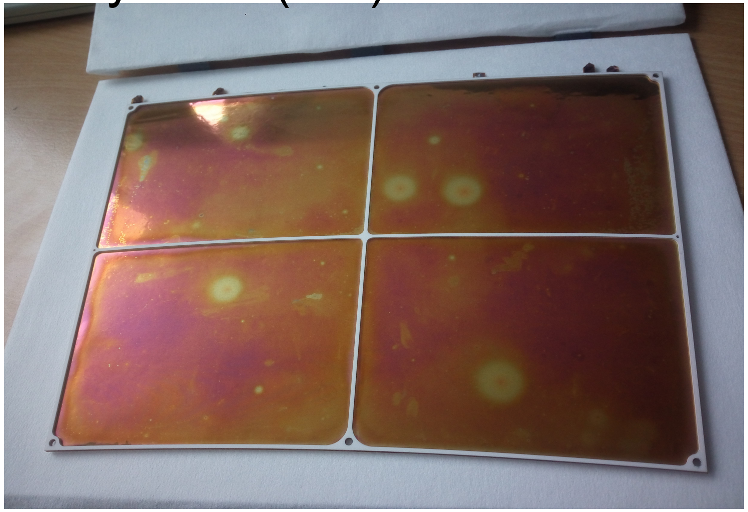
[a] *Electrical Engineering Division, Department of Engineering, University of Cambridge, Cambridge, CB3 0FA, UK*
[b] *3T Technologies Limited, 7 Chapel Drive, Little Waltham, Chelmsford, CM3 3LW, UK*
[c] *Plasma Quest Limited, Unit 1B Rose Estate, Osborn Way, Hook, Hampshire, RG27 9UT, UK*

Name	Molecular formula	IUPAC name	E_g (eV)	Resistivity (Ω-cm)	Type	Crystal structure	Appearance
Cuprous oxide	Cu_2O	Copper (I) oxide	2.0–2.6	10^3–10^8	P	Cubic	Yellow/Red, semi-transparent
Cupric oxide	CuO	Copper (II) oxide	1.2–1.6	0.01–1	N/P	Monoclinic	Darker colour

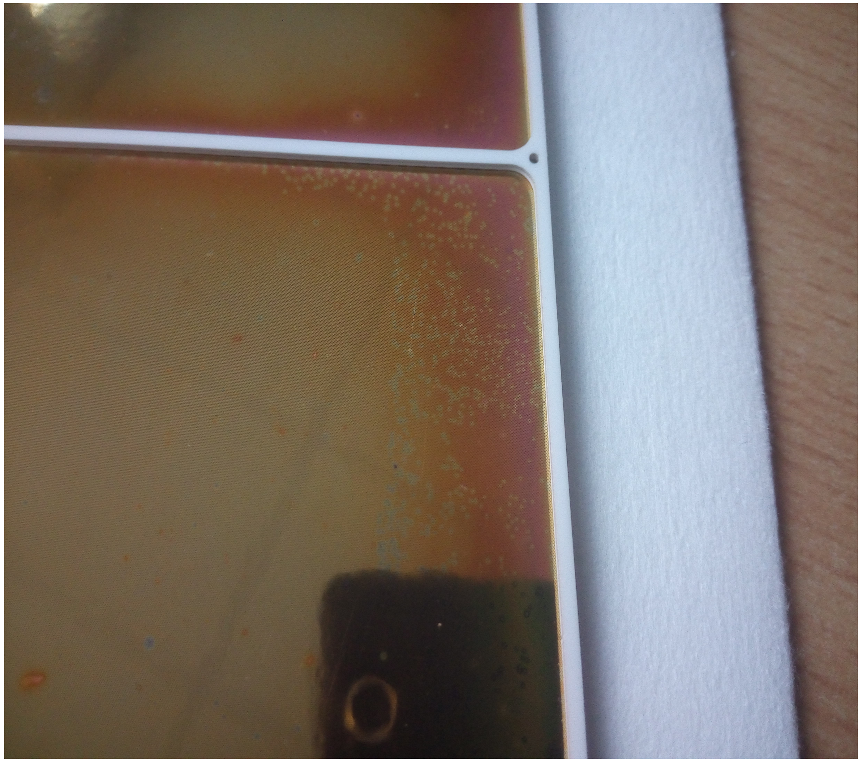
We try to grow oxide layer (3 hours at 200C)

- Presumably covered with bigger percentage of CuO(black)

- Presumably covered mostly by Cu_2O(red)



- Presumably trace of previous sparks



- Two 4-working sectors example is stable after >10,000 discharges each
- Gain tests are needed.

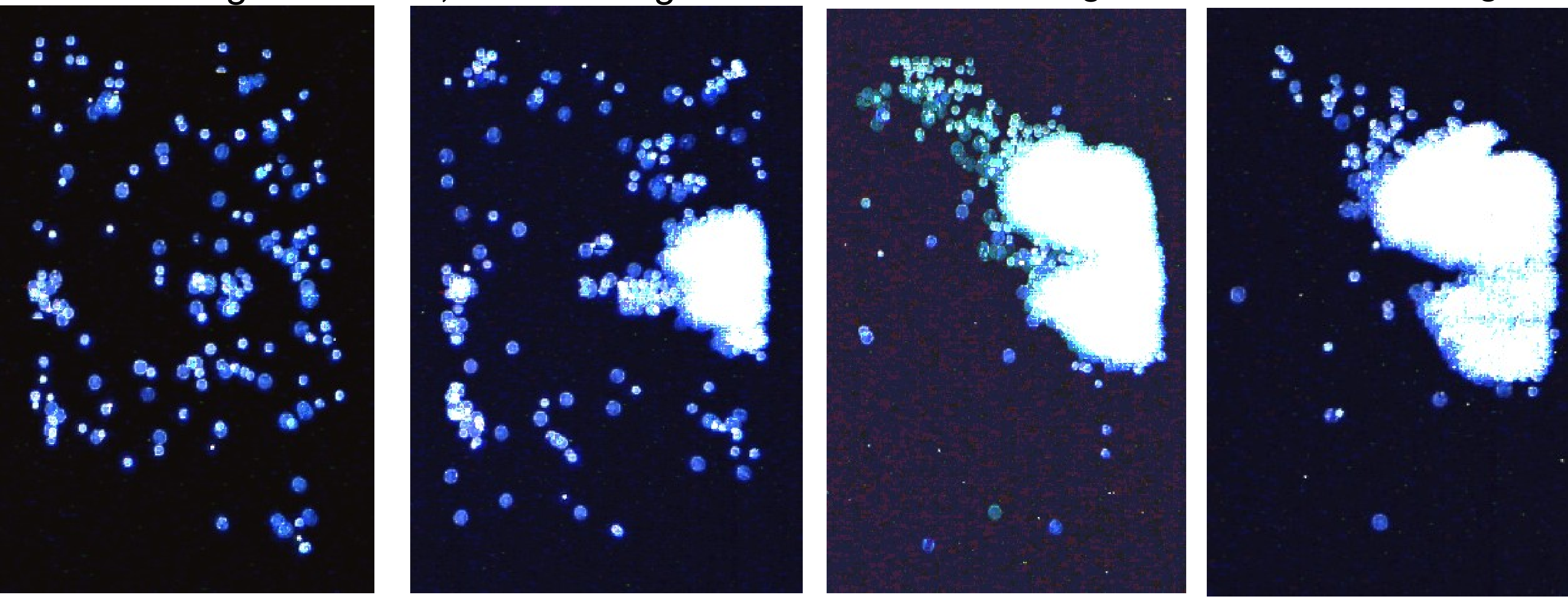
Intermediate conclusions (III)

- Theoretically and practically we see that oxide layer serve as a protection against destructive discharges
- There are two Oxide type CuO and Cu_2O. At least theoretically Cu_2O is preferable due to significantly bigger surface resistivity
- Gain studies and oxidation parameters tuning are needed

Discharge topology

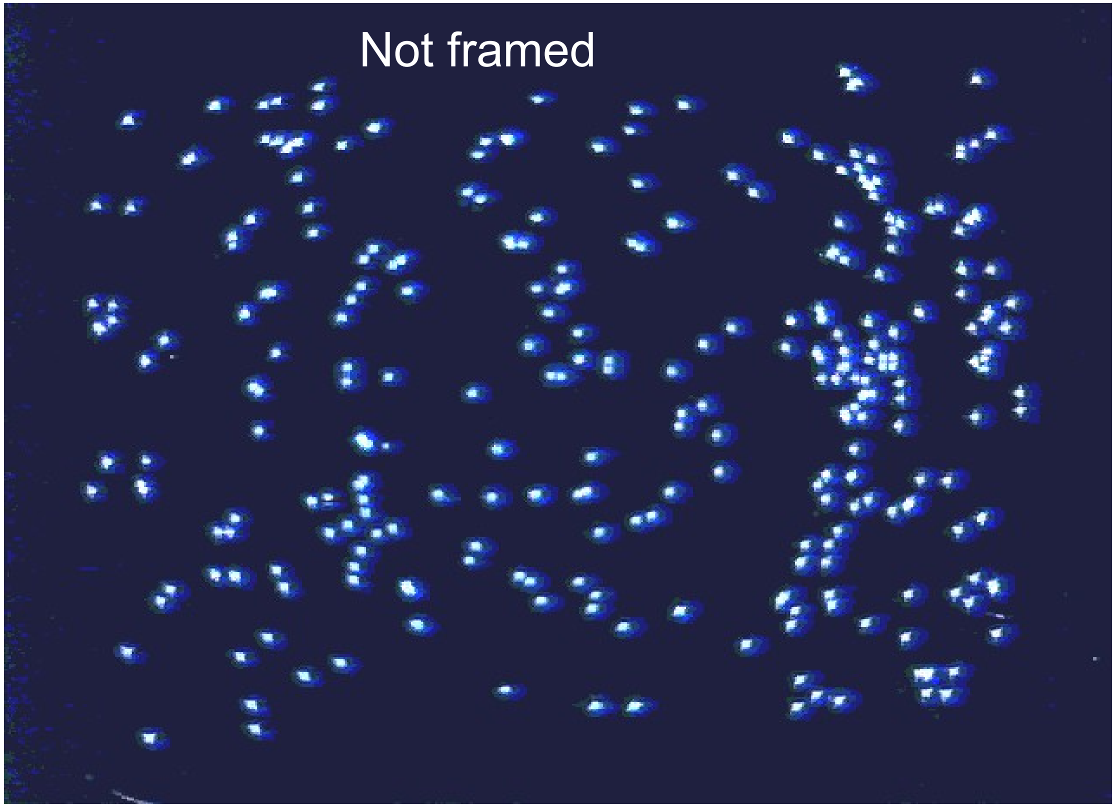
Discharge area evolution

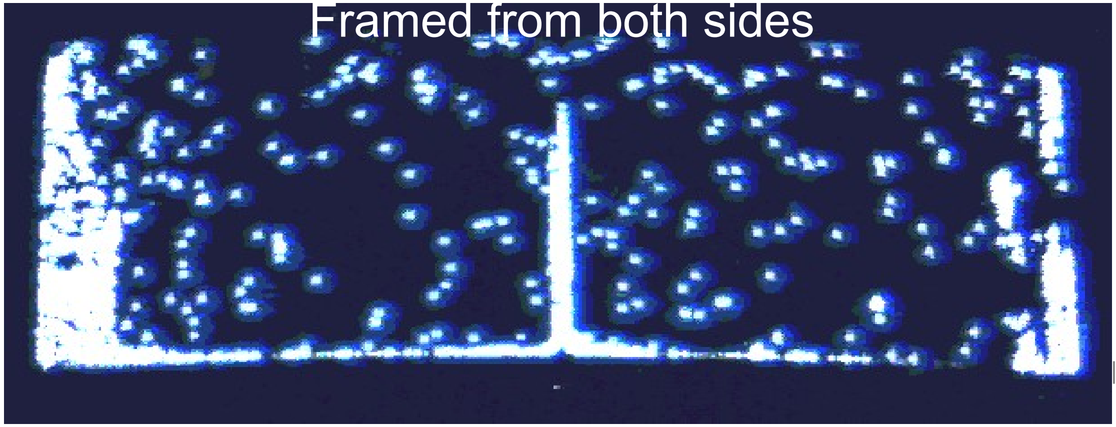
200 Discharges | 40,000 discharges | 162,000 discharges | 40,000 discharges

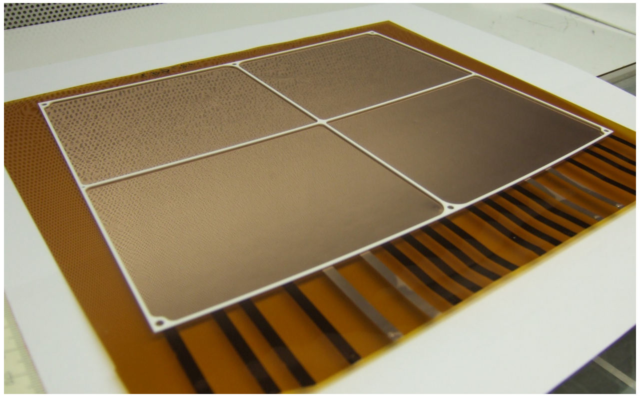


- Discharge area after 5k-10k discharges start to be located in some certain place
- This place start to be oxided (presumably)
- This spots tends to grow

Impact of the Module Mechanics





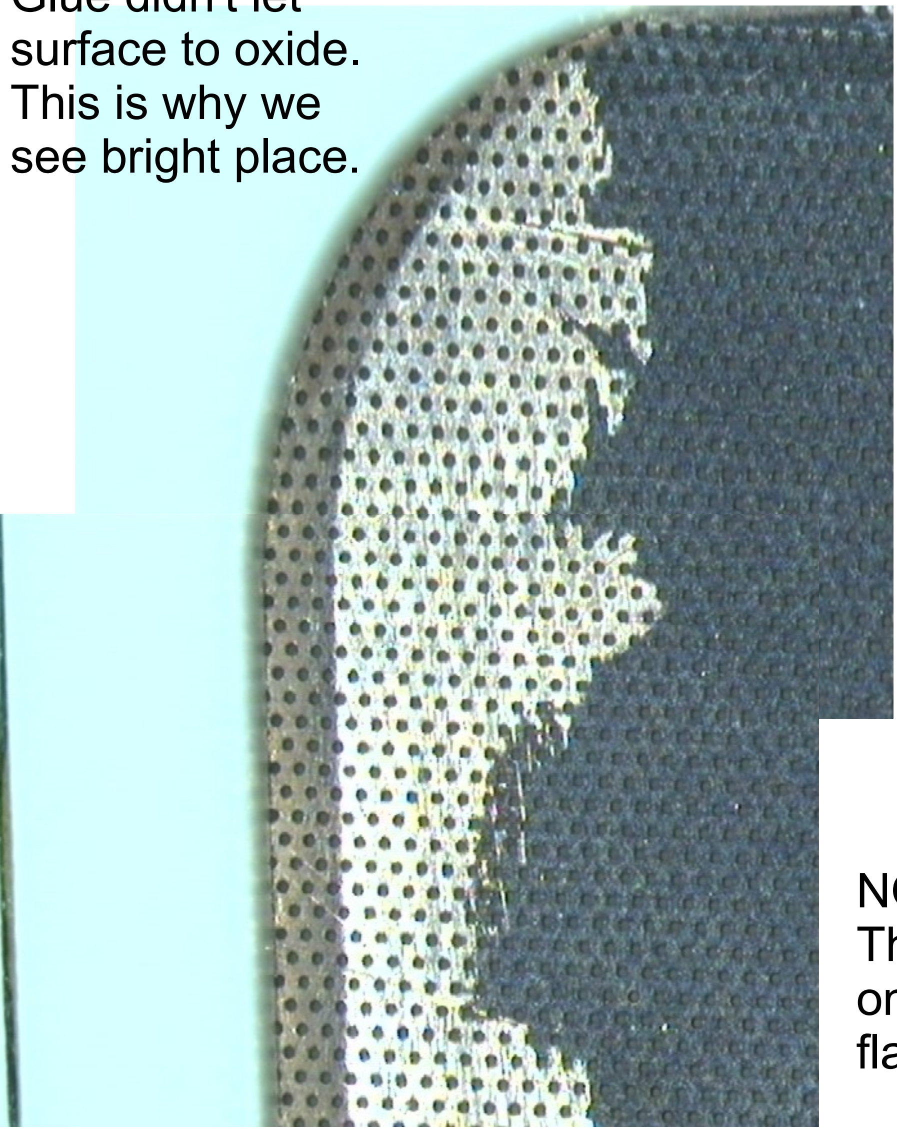


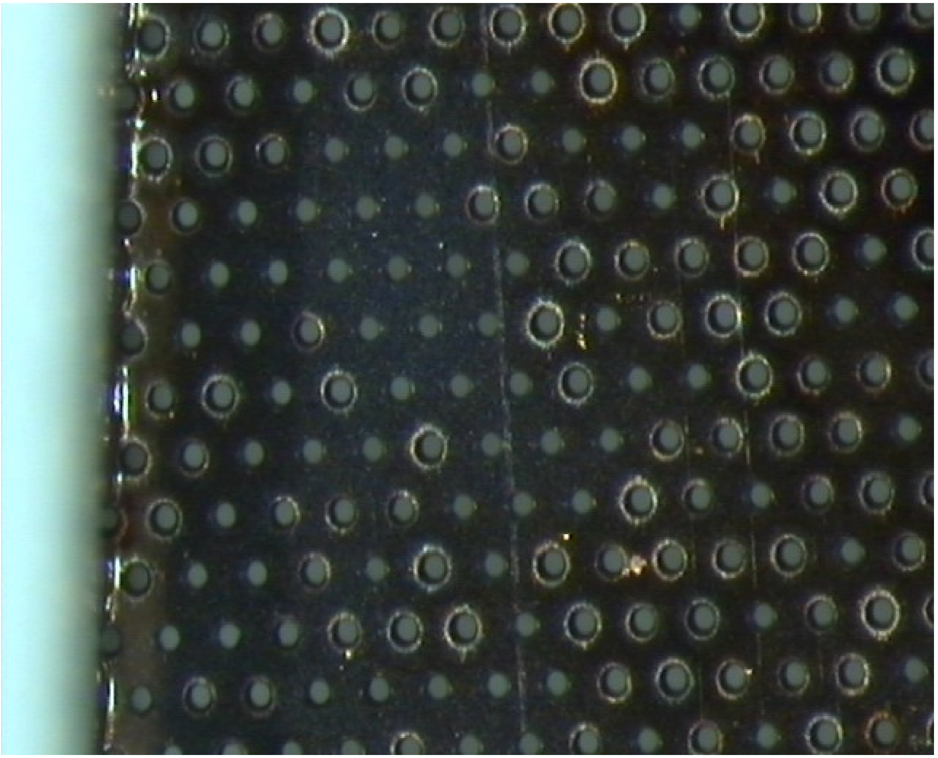
- Unframed GEM.
- 247 events at 620 V for 20 hours. **4 Sectors**

- Framed from both sides
- 2503 events at 600 V for 24 hours. 2 Sectors

Potential Glue spot and less fried GEM

Glue didn't let surface to oxide. This is why we see bright place.





NOTE!
The surface not as dark and not as bright as on the picture. This happened due to direct flash of microscope light.

Intermediate conclusions (IV)

- We see that after 5k-10k discharges more or less uniformly distributed discharge places start to dominate near dark spotted places
- Glue spill + frame/hole overlapping attracts discharges and reduce voltage breakdown threshold. Modifications has been already done.

Types of shorts

Types of shorts between GEM plates

<5 Ohm	1-20 kOhm	>1 MOhm
Not healable by us By applying huge current (~0.8A) may go to second column	Not healable by us May go to high resistive state by applying current (1-5 mA). But still not healable.	Healable by: - applying low current for long time - high current (~20 uA) for a short time - good cleaning

Summary

- We haven't found charge sharing between sectors in electrical approach.
- Discharges is full. Close to 100%
- Dependence of destruction on voltage(discharge energy) in a broad range has not been found

---

- We see observe multiple discharges (30-150 ns time difference) triggered by oscillations that has been created by primary discharge
- We see evidence that introducing a filter (damper) can significantly reduce the multiple discharge rate
- We can see pure charge transfer time about 50 ns, but it is not clear how comparable is it with plasma channel lifetime

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- Theoretically and practically we see that oxide layer serve as a protection against destructive discharges. Further studies are needed

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- Glue spill + frame/hole overlapping attracts discharges and reduce voltage breakdown threshold. Modifications has been already done

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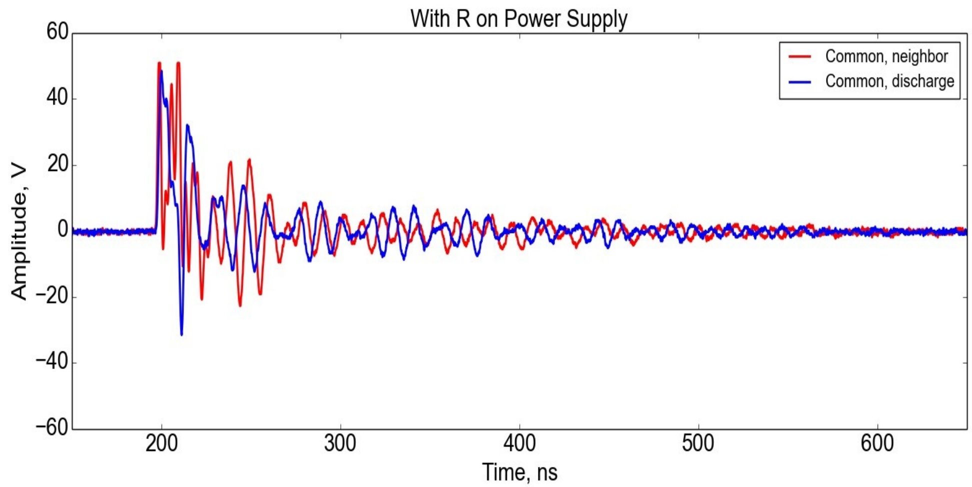
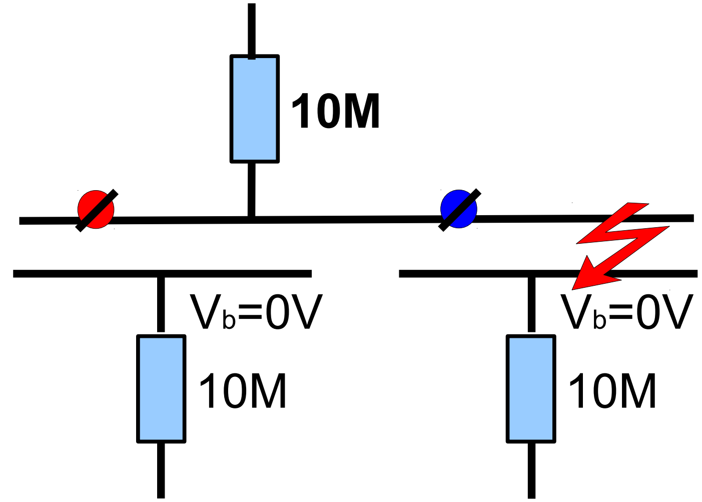
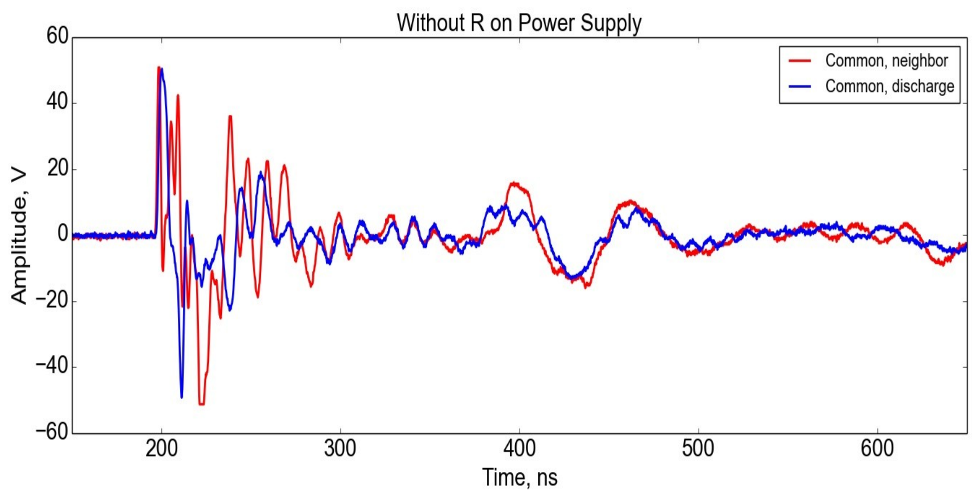
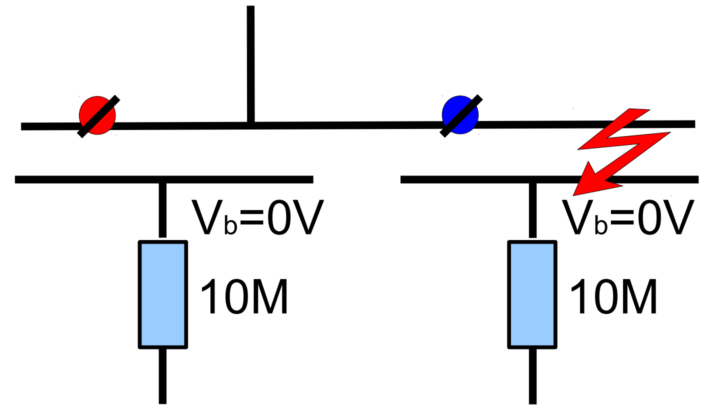
- Shorts are not the same and likely have a different nature

Behavior of common sides



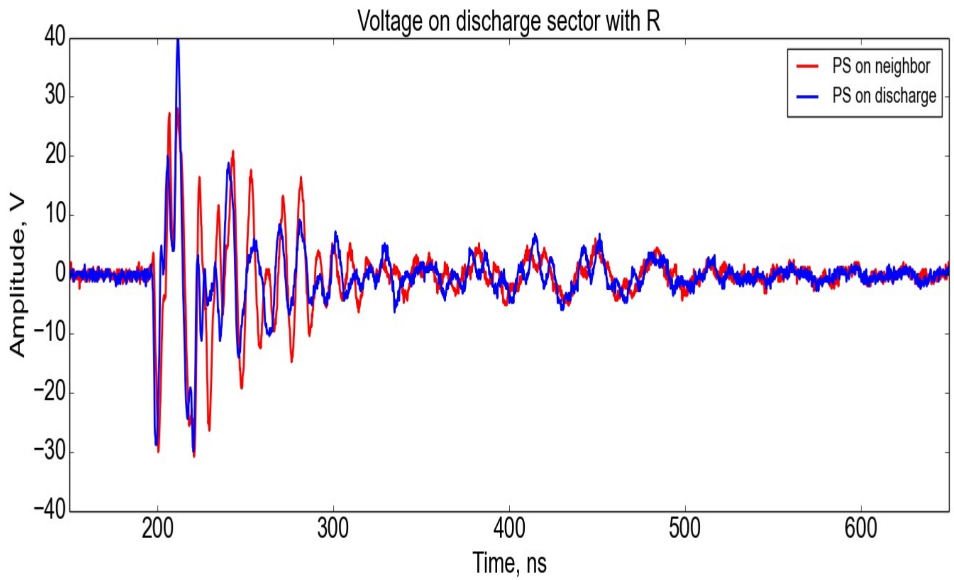


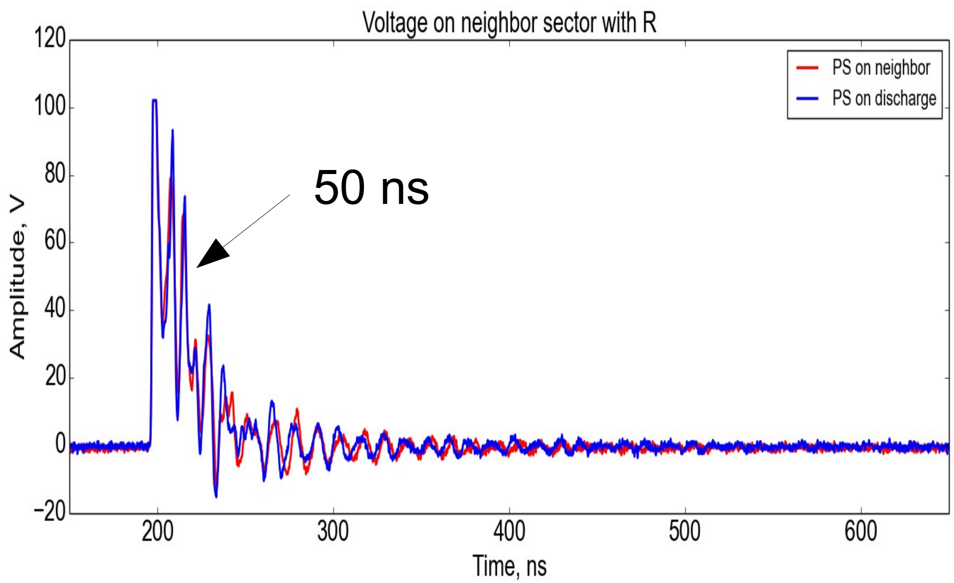


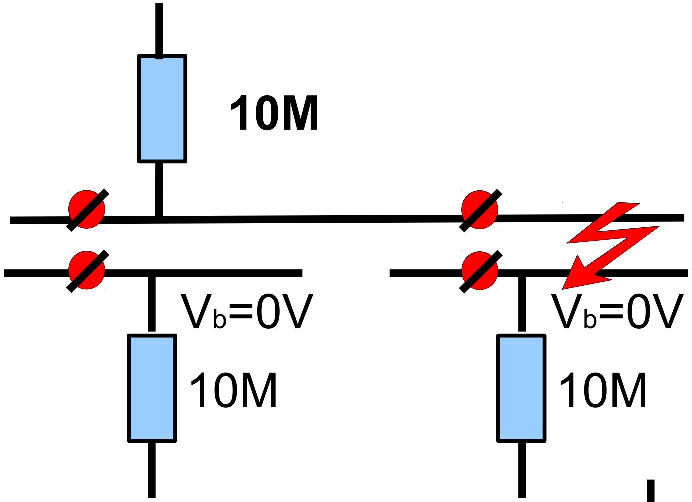


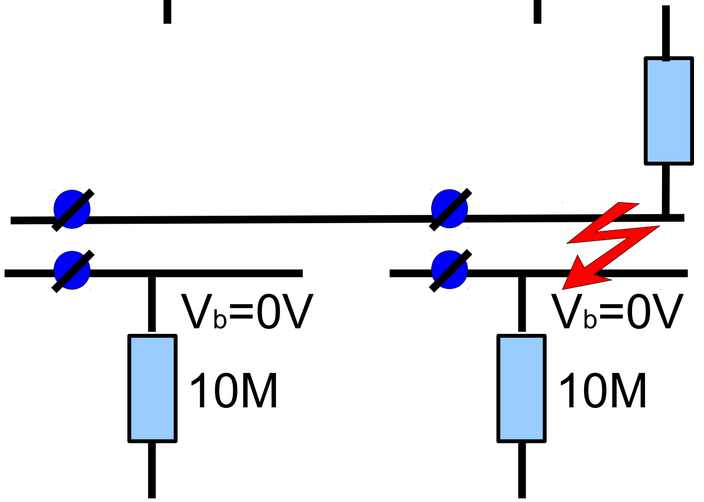
Common side behaviors are not the same despite the fact that they are connected. For both cases: with R and without.

Power Supply position influence



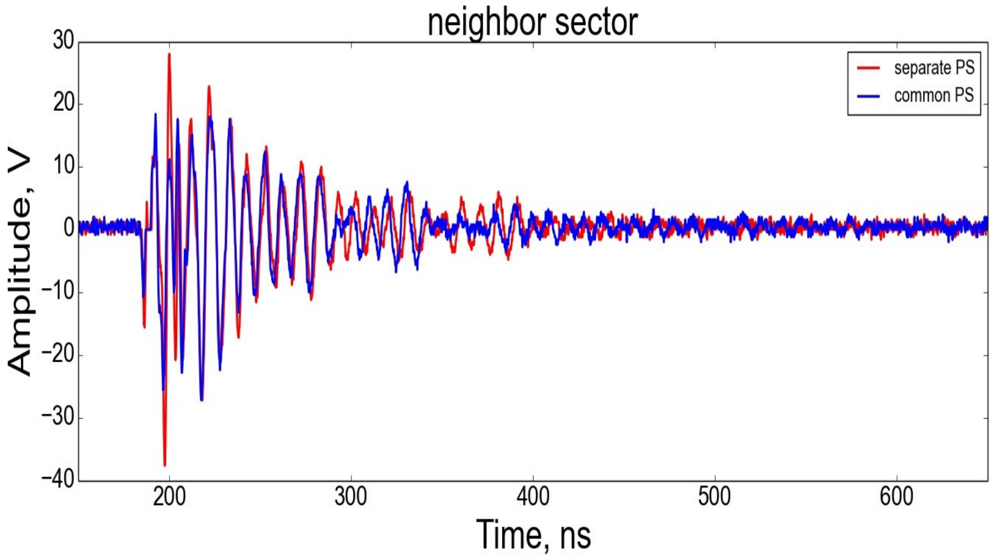


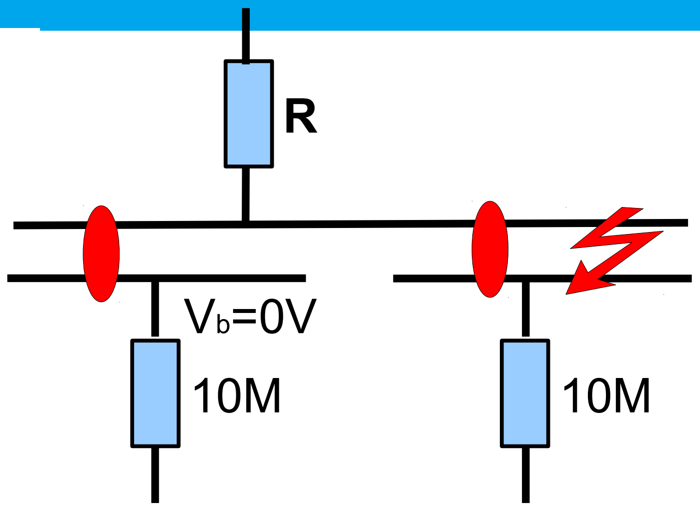


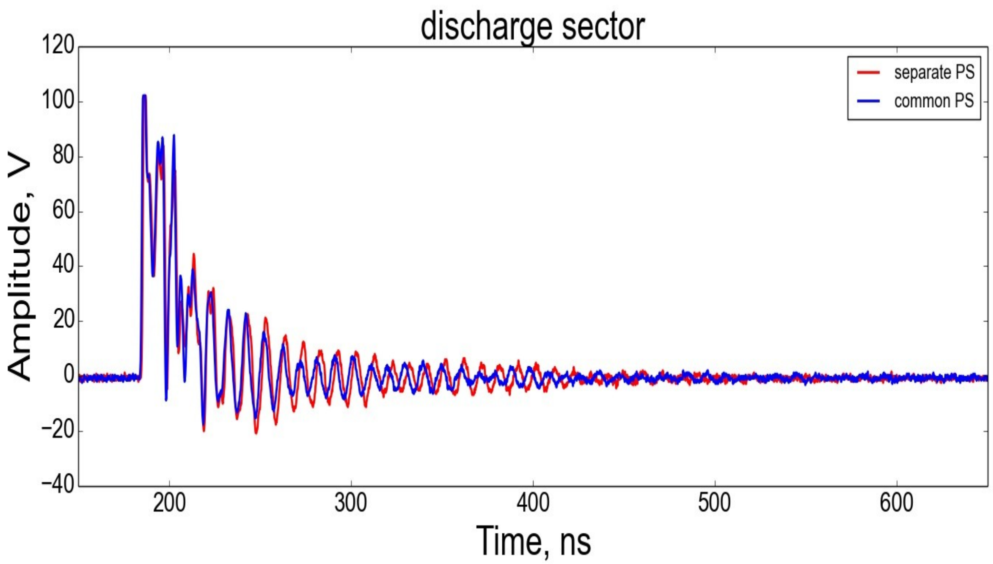


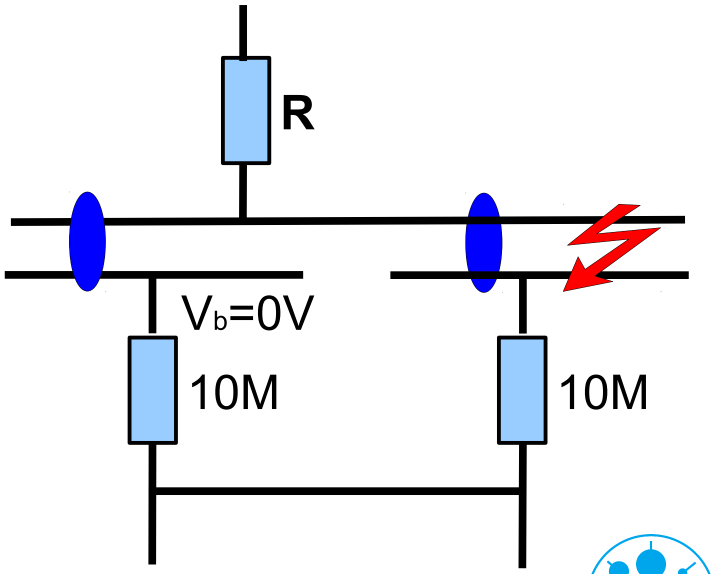
Position of PS towards discharge sector also shows dependency

Influence of Power Supply separation

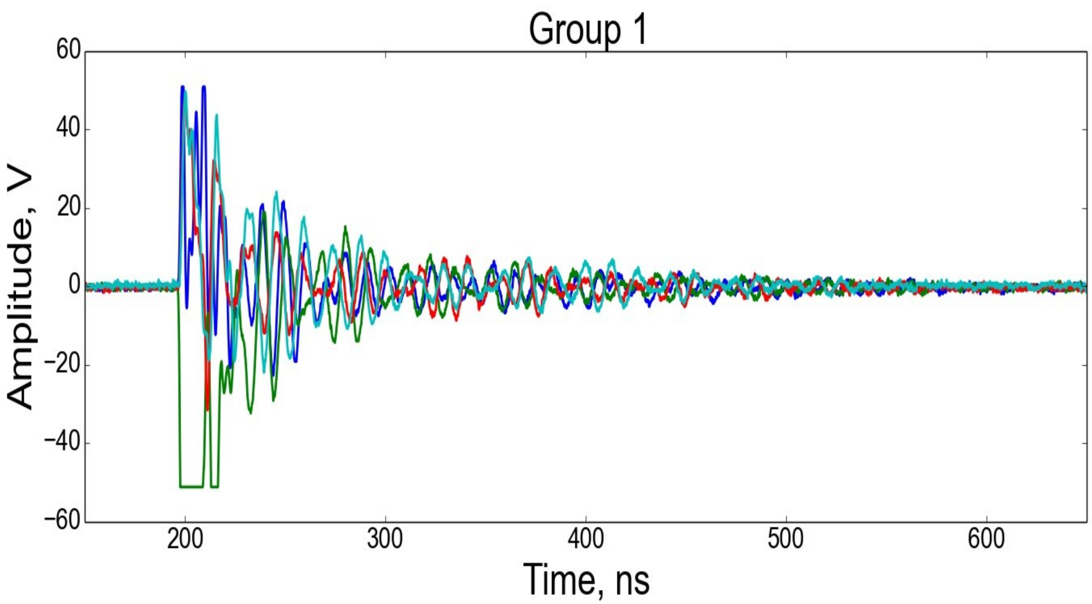


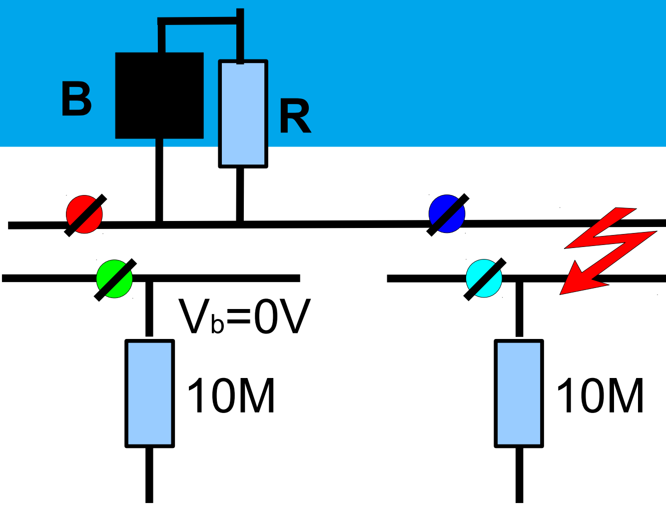




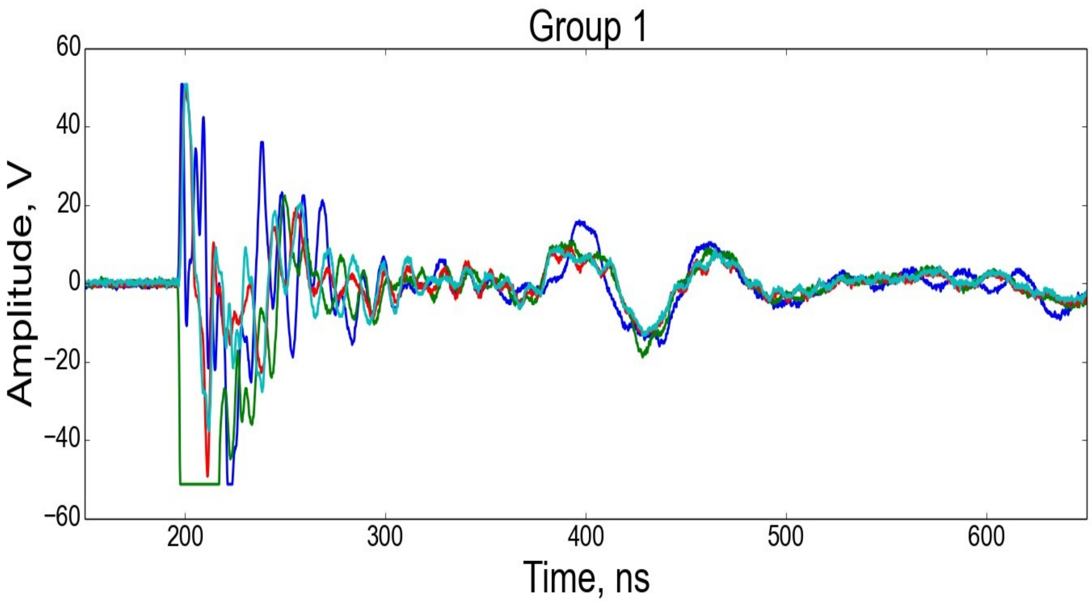


Potential profiles families





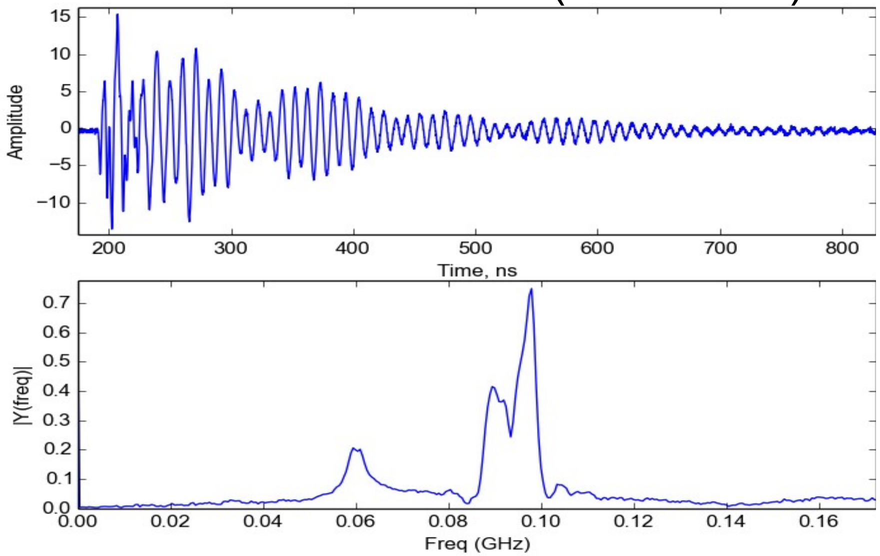
R=10M, B=0,
R=10M, B=10n to GND
R=0, B=10nF to GND
R=10M, B=100p1k to PWR
R=10M, B=100p1k to GND



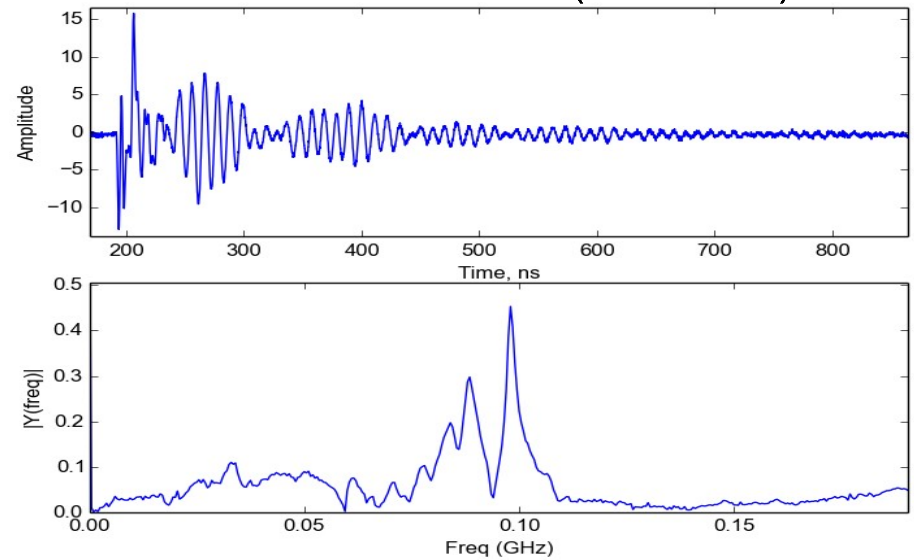
R=0, B=0
R=0, B=10nF to PWR
R=10M,B=10nF to PWR
R=0, B=100pF1kOhm to PWR
R=0, B=100pF1kOhm to GND

Fourier transformation

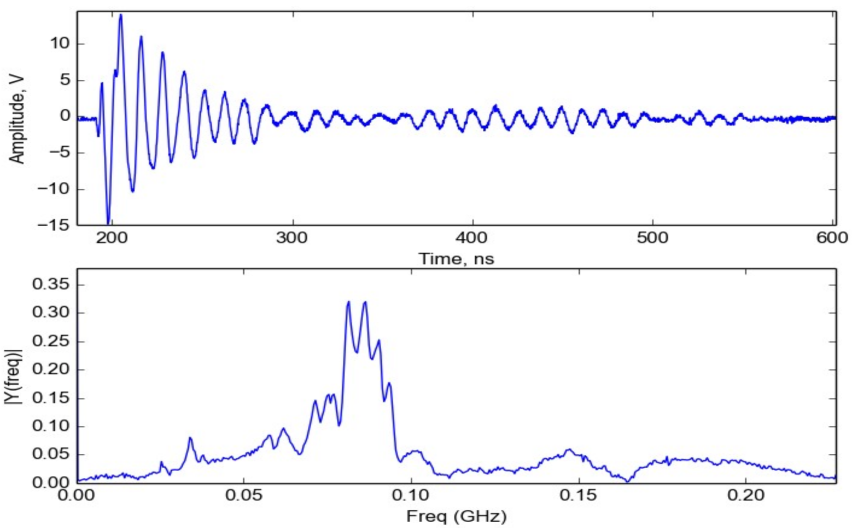
Common electrode (~22x18cm)



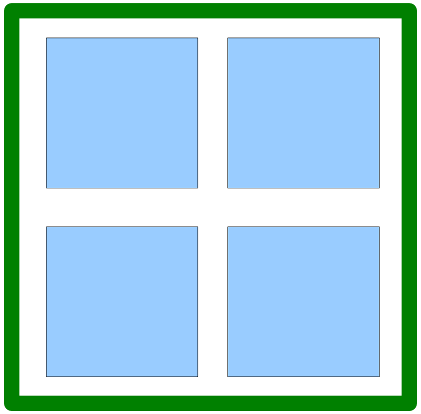
Sector electrode (~11x9cm)



10x10cm GEM

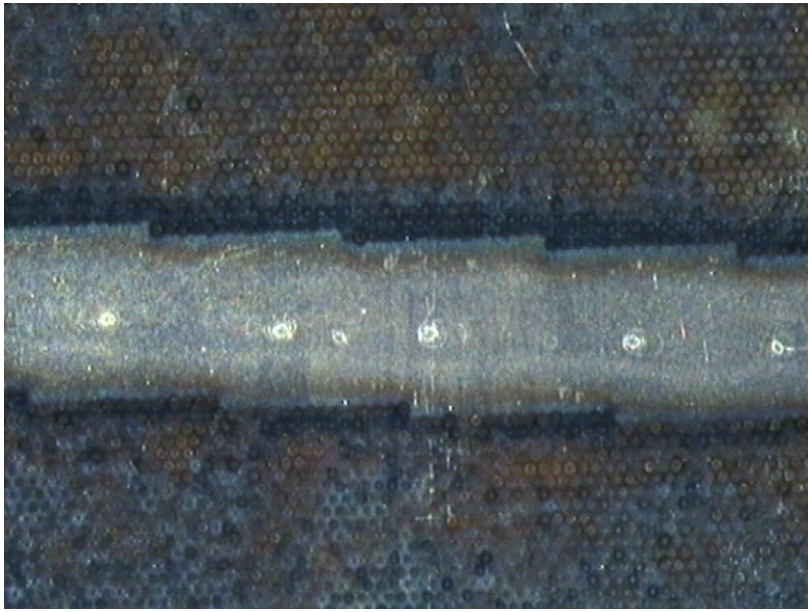


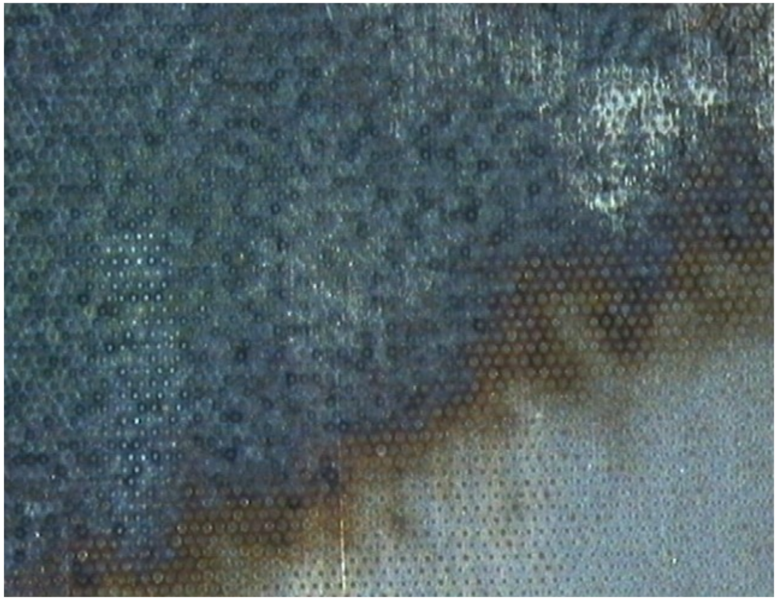
- TDS 3054b
- 500MHz bandwidth
- 5GS/s
- 50Ohm load
- 100x attenuatior
- Multiple modes for single sector
- Low frequency for common

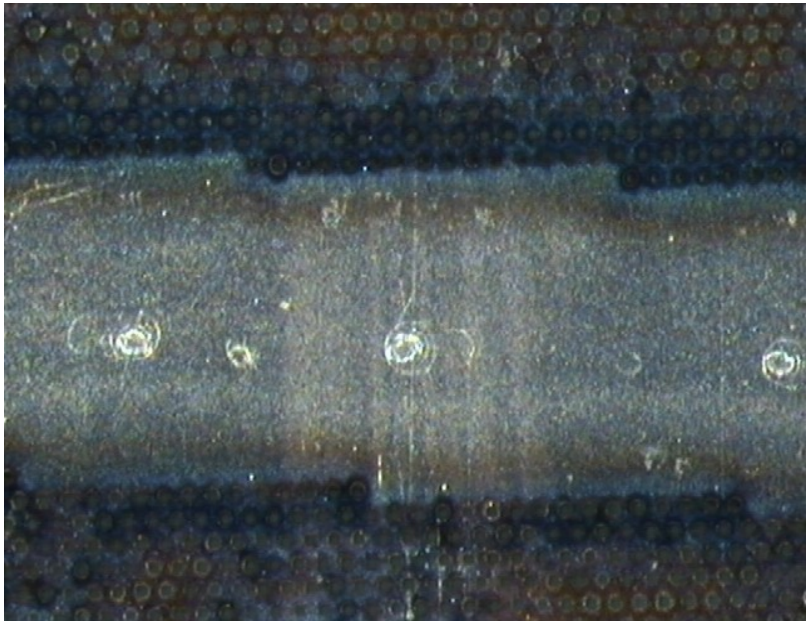


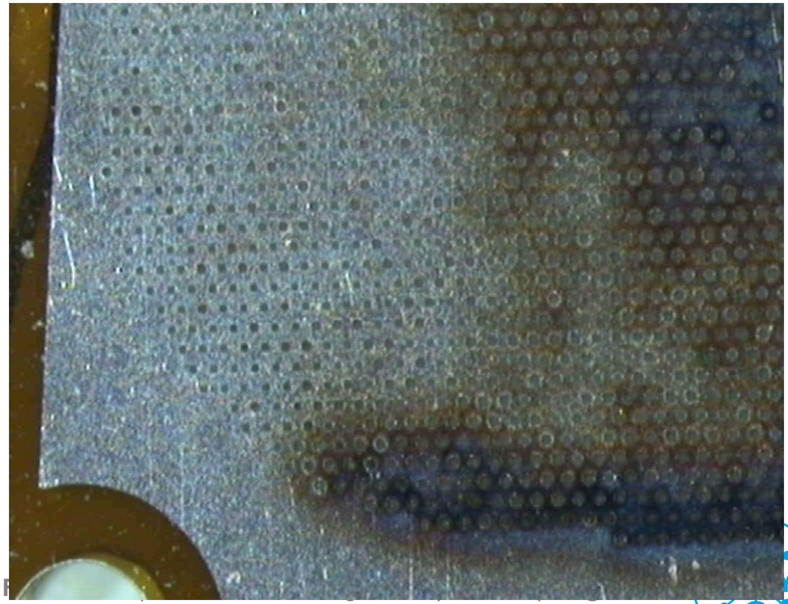
- **Oscillation profile for common electrode and sector is not the same**

About 250kEvents. Last Burned GEM

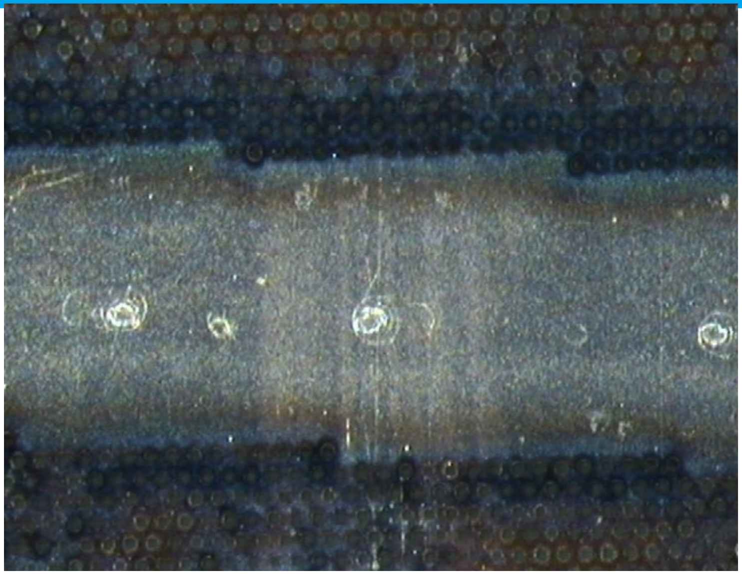


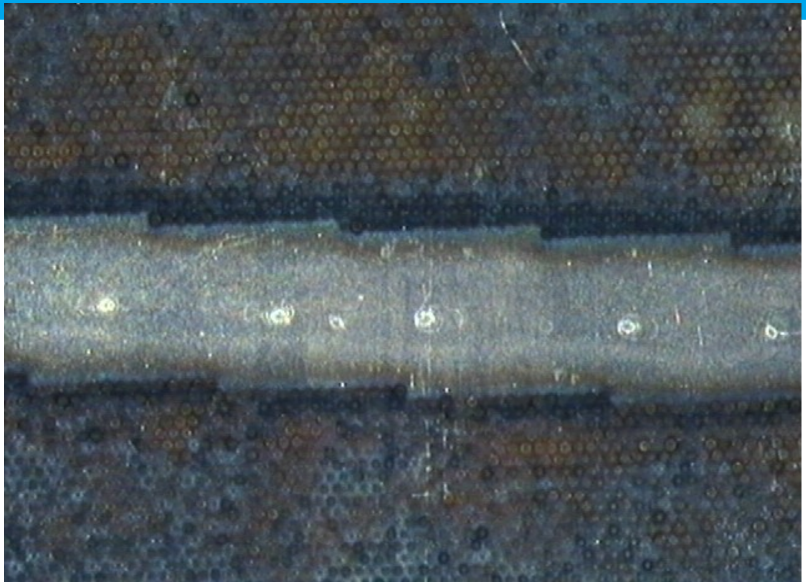


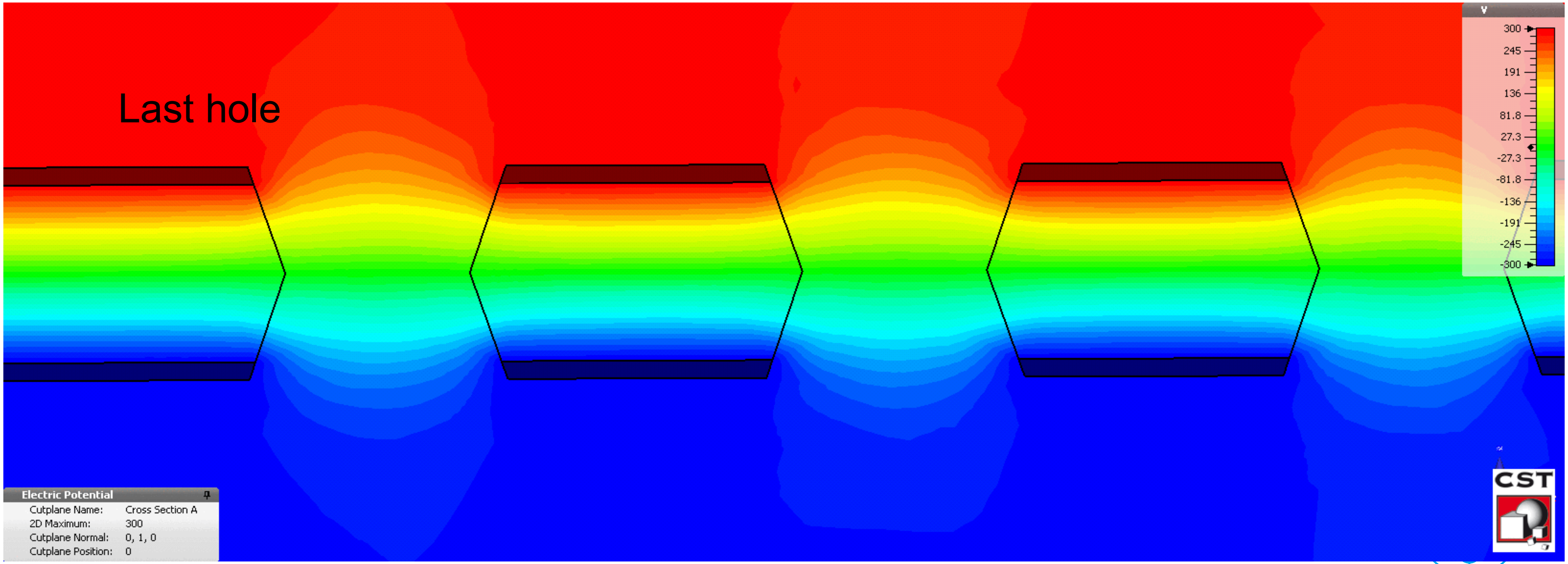




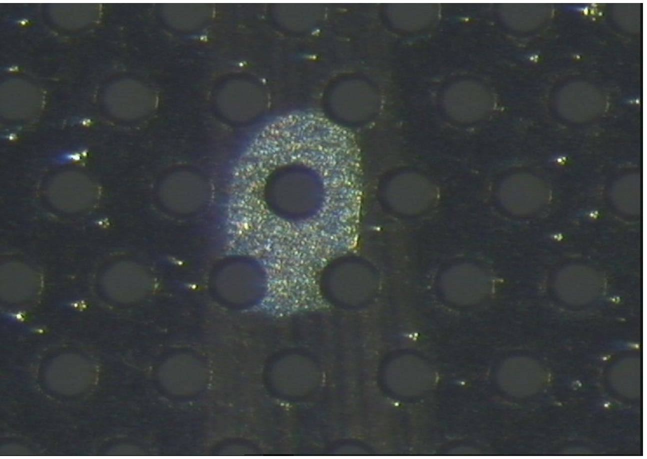
No evidence of field influence. CST

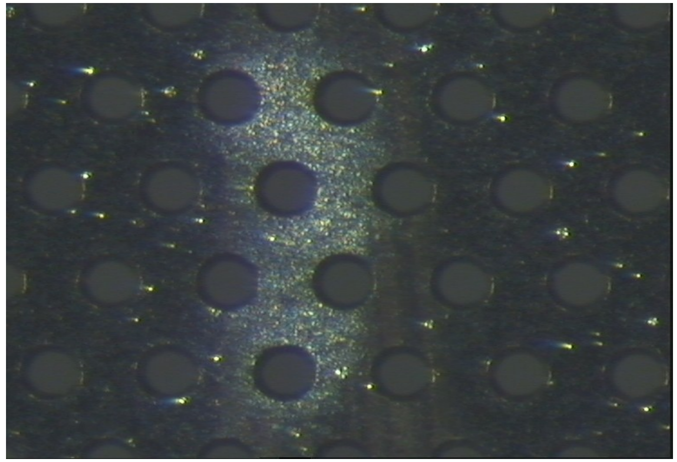


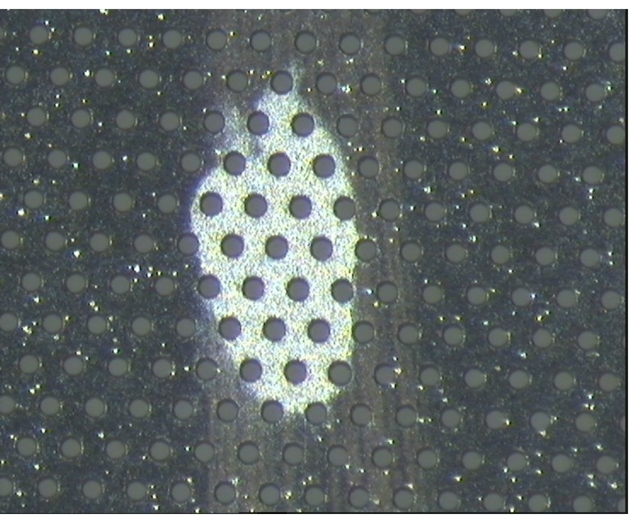


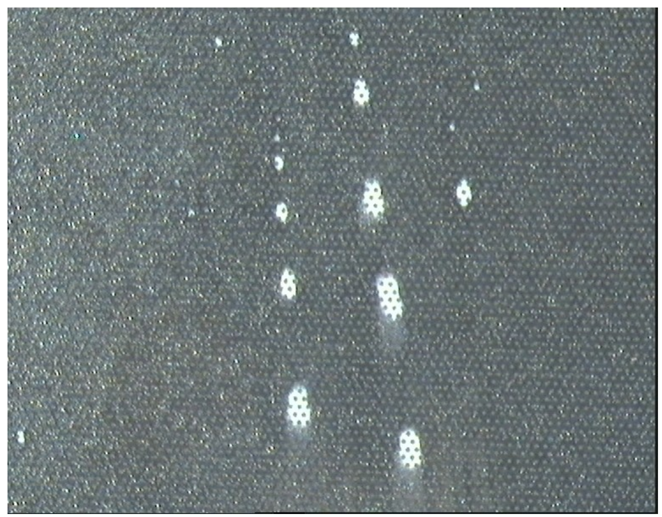


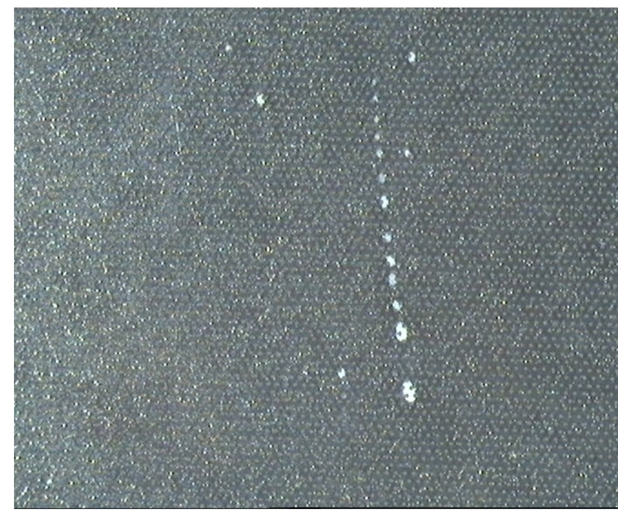
Bright spots



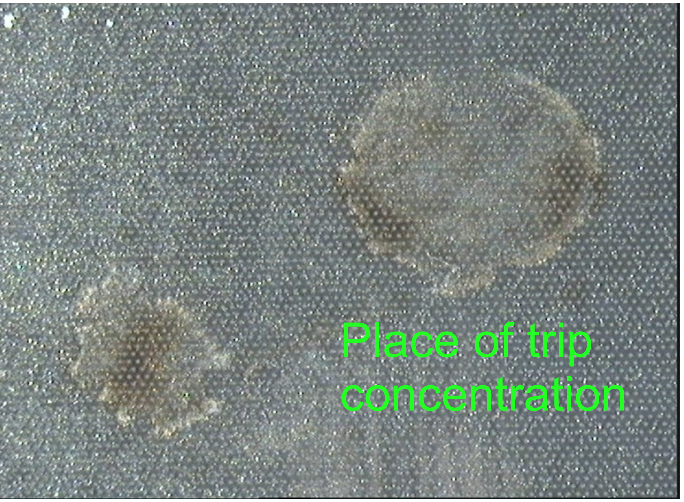


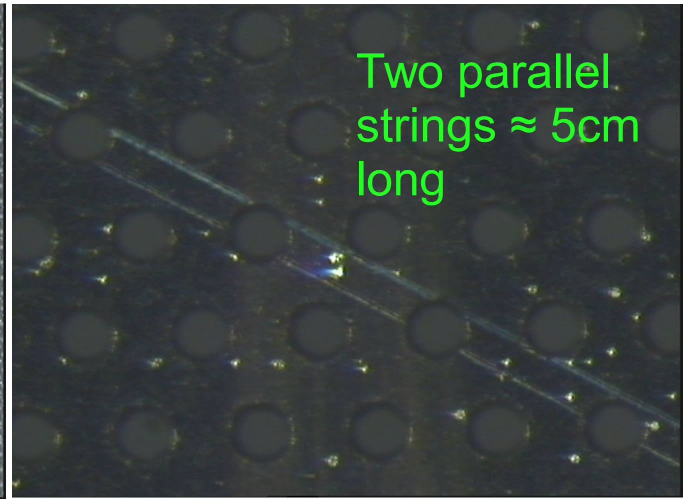


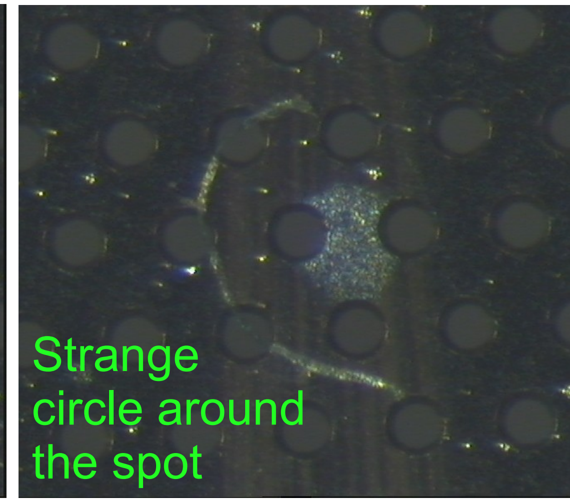


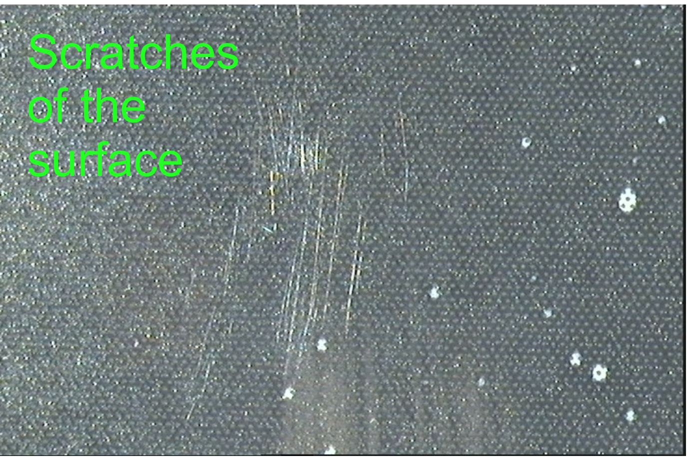


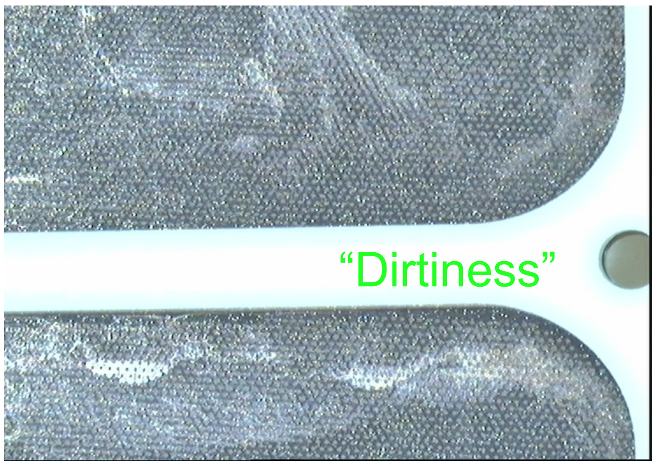
Other imperfections

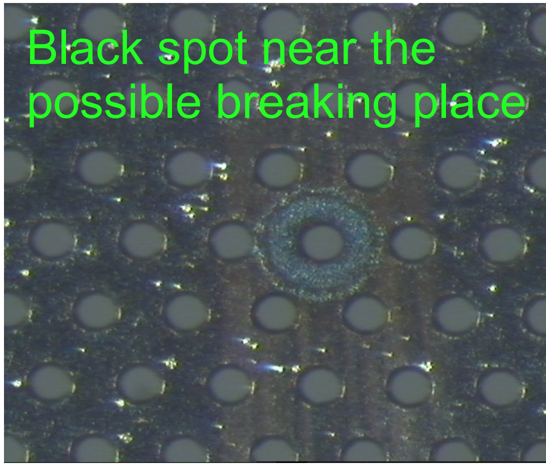




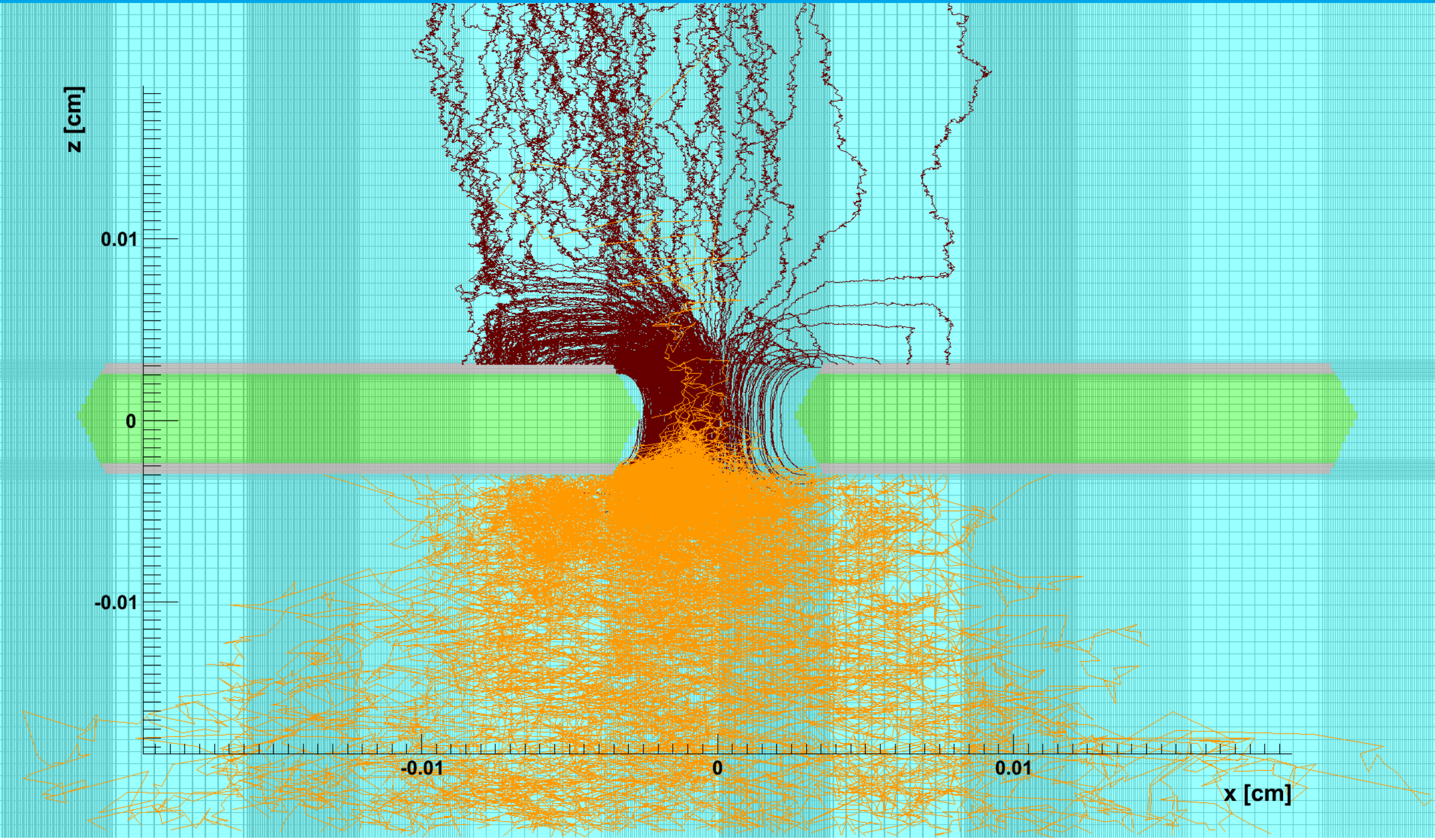








Gas Electron Multipliers (GEM) simulations



DESY