Novel tunable materials for resistive protection of gaseous detectors from room temperature to 90 K

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On behalf of:
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Background

Needs in detectors with HV

- spark-quenching
- adjusting the charge-induction profile from moving charges to improve space resolution in tracking detectors
- reducing local charging-up

Solution –> resistive materials

- Too conductive -> problem not solved
- Too resistive -> charging-up + field deformation

Objective

- Find a suitable material for spark-quenching operating at LAr temperature -> candidates: DLC, Fe_2O_3/YSZ ceramics

Right range of surface/bulk resistivity: 10-10^4 Mohm / sq – 10^9 - 10^{12} Ω·cm

-Characterize such materials + behavior with temperature

see S. Leardini et al., Nucl. Instr. Meth. A 1049 (2023) 168104 for DLC and
L. Olano-Vegas et al., Front. Detect. Sci. Technol. Volume 1 (2023) for ceramics

- Operate them in a detector

*see A. Tesi et al, Eur. Phys. J. C **83**, 979 (2023) and*
A. Tesi, S. Leardini et al., JINST 19 P02019 (2024)

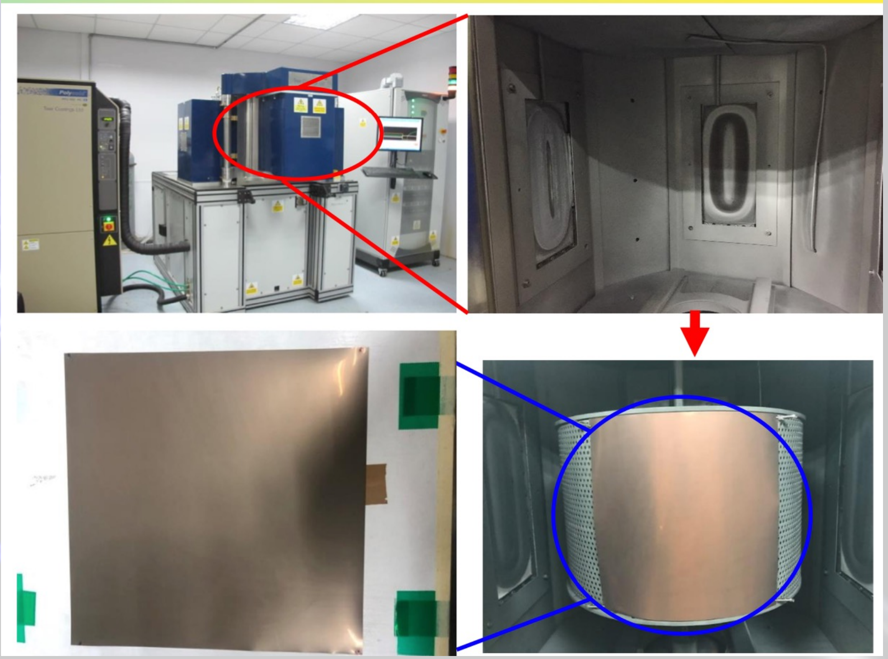
DLC characterization

- DLC produced at the University of Science and Technology of China

-Deposition through magnetron sputtering

-Procedure: - substrate kept in oven @ 70ºC
- surface cleaned with ethanol
- vacuum @ 10^{-5} mbar
- deposition (20-60 min)

- Six different ~ 10 x 10 cm samples with kapton substrate (named A-F)

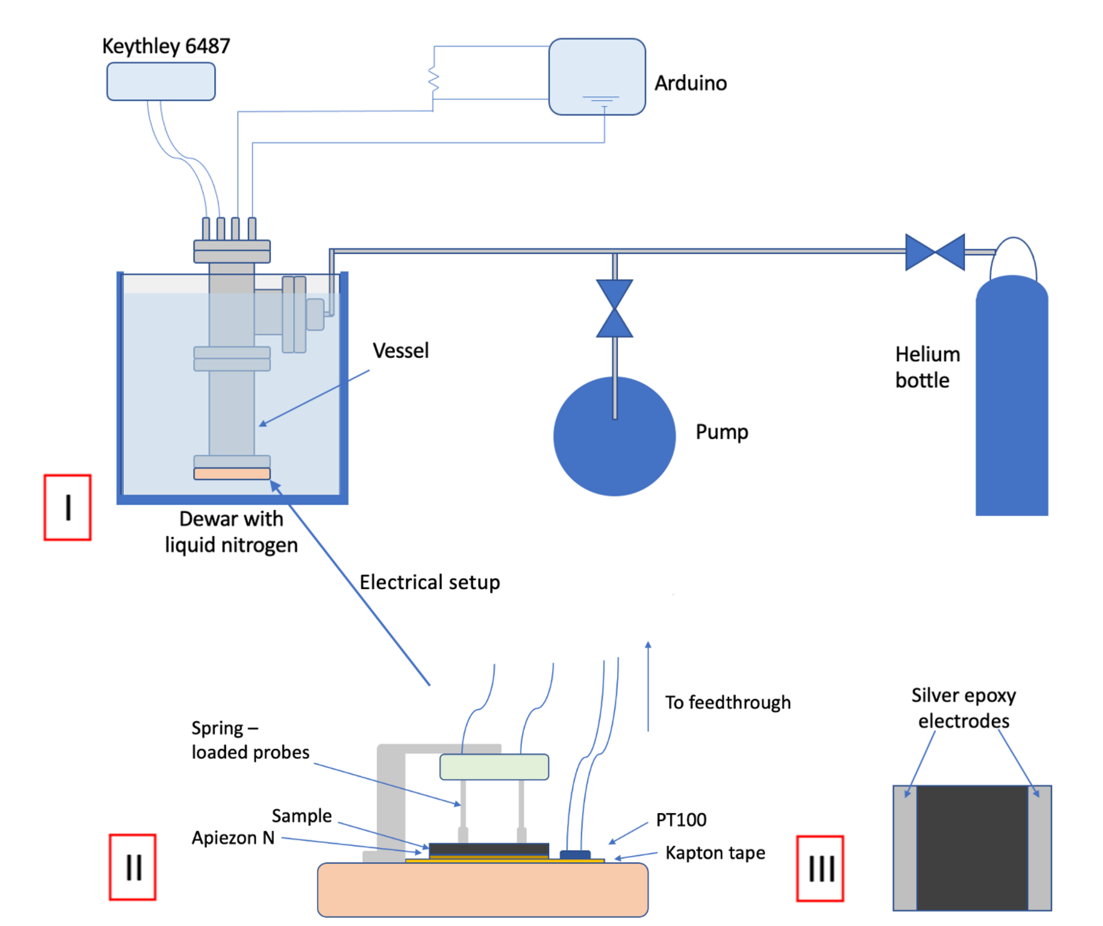


From talk by Yi Zhou:
https://indico.cern.ch/event/852331/contributions/4611238/attachments/2367150/4042458/Resistive%20Detectors%20with%20DLC.pdf

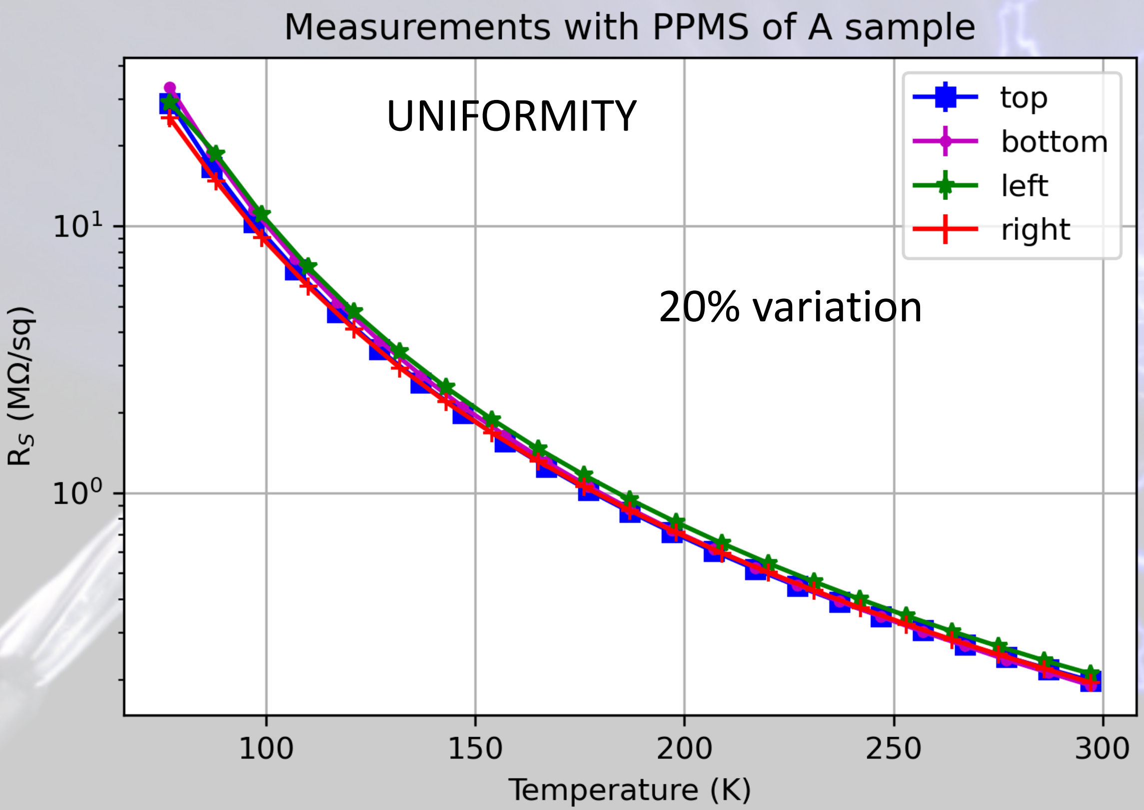
Cryogenic setup

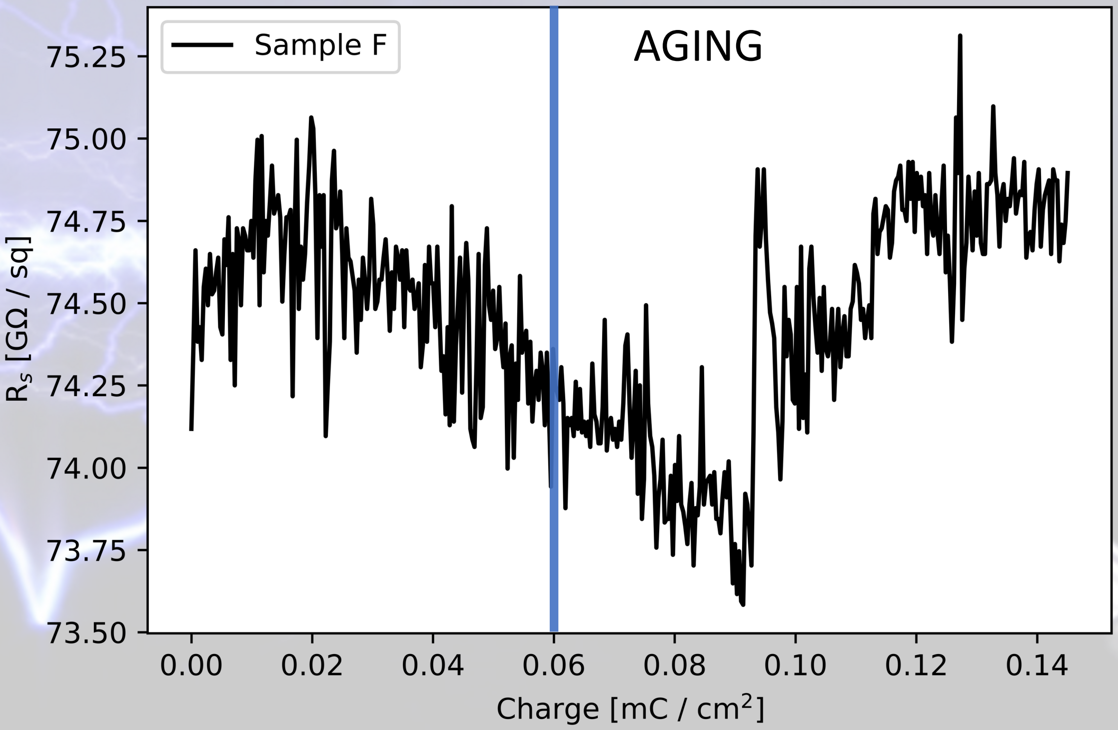
Home- made cryostat

Able to measure all the range of resistivities



Uniformity and aging



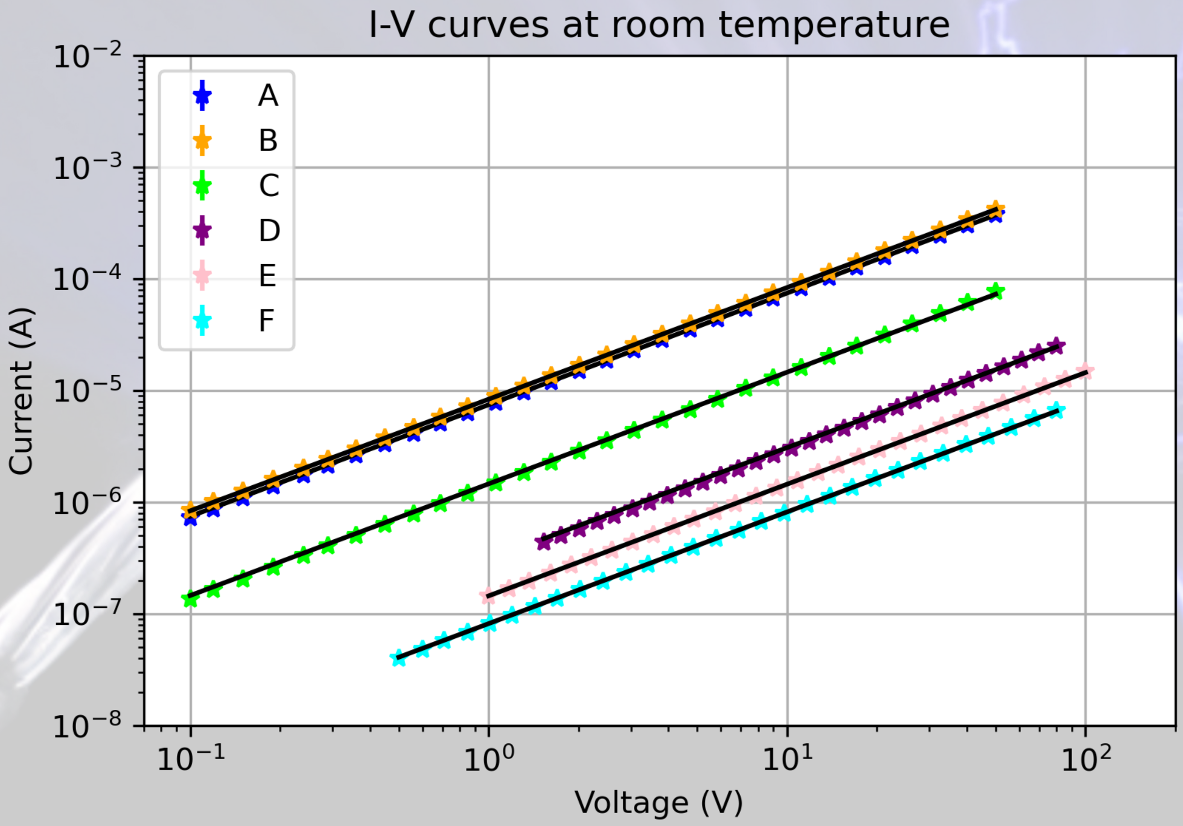


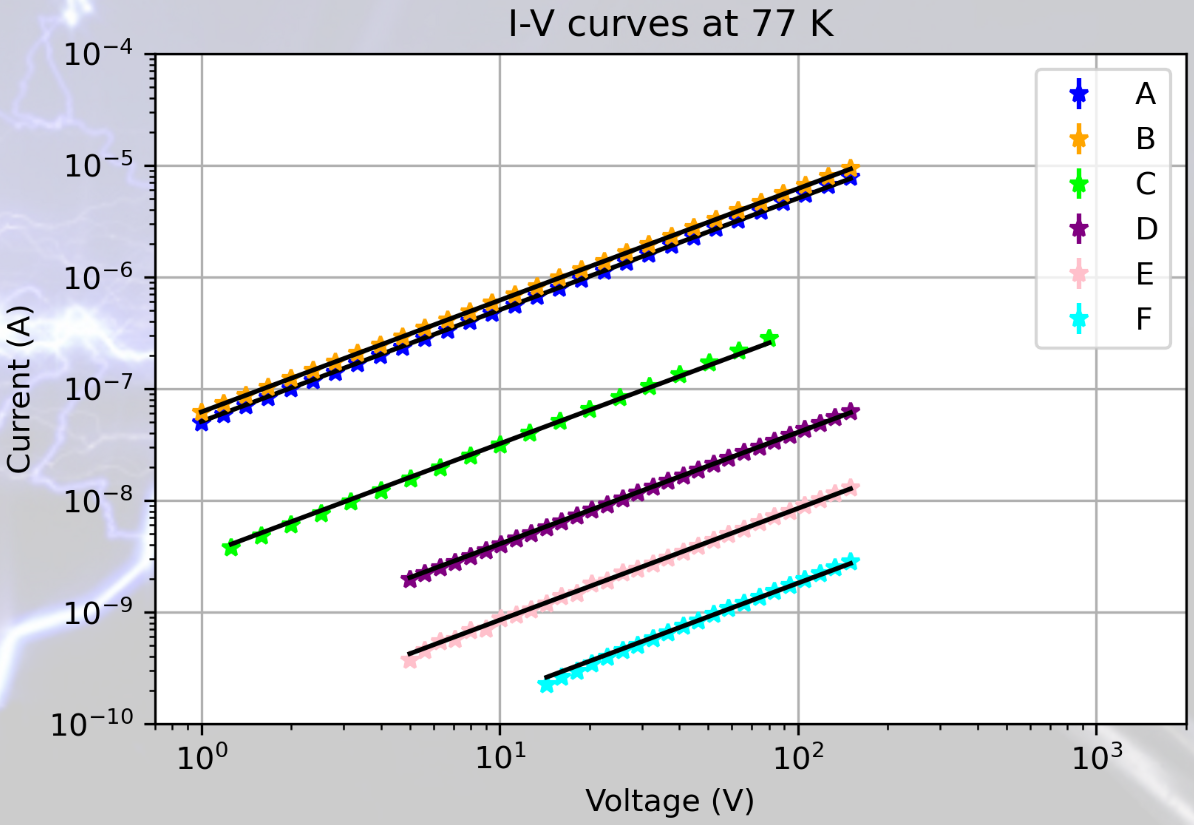
-RT : no aging effect after transporting > 2 C / cm^2

-LN : < 2% variations

-DUNE Far Detector (assuming ^{39}Ar background, gain =100): 60.5 µC/cm^2 in 10 years

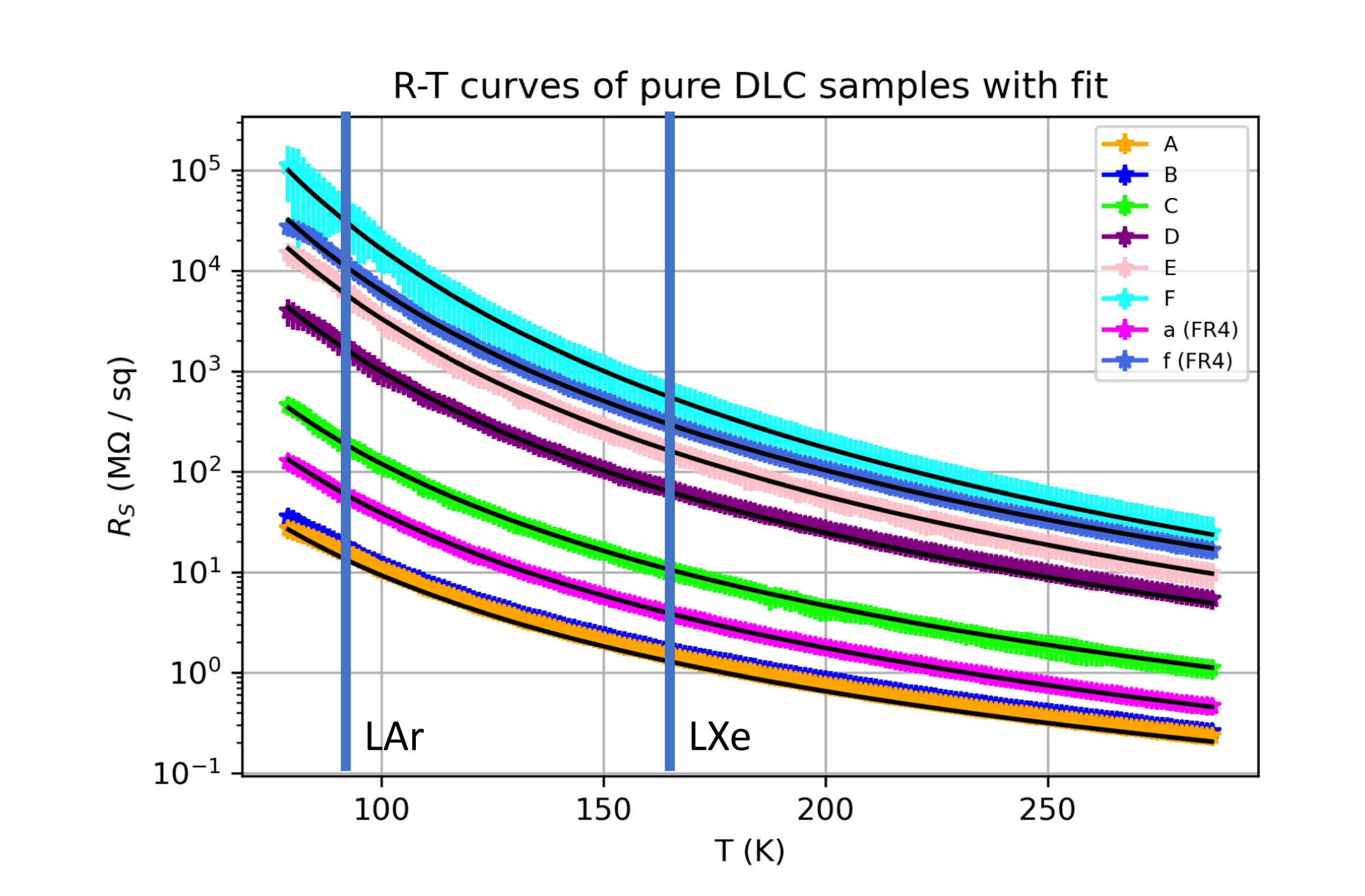
Linearity





All samples linear both at RT and 77K

R-T curves



$$R = R_{300} * \exp\left(\left(\frac{T_0}{T}\right)^a - \left(\frac{T_0}{300}\right)^a\right)$$

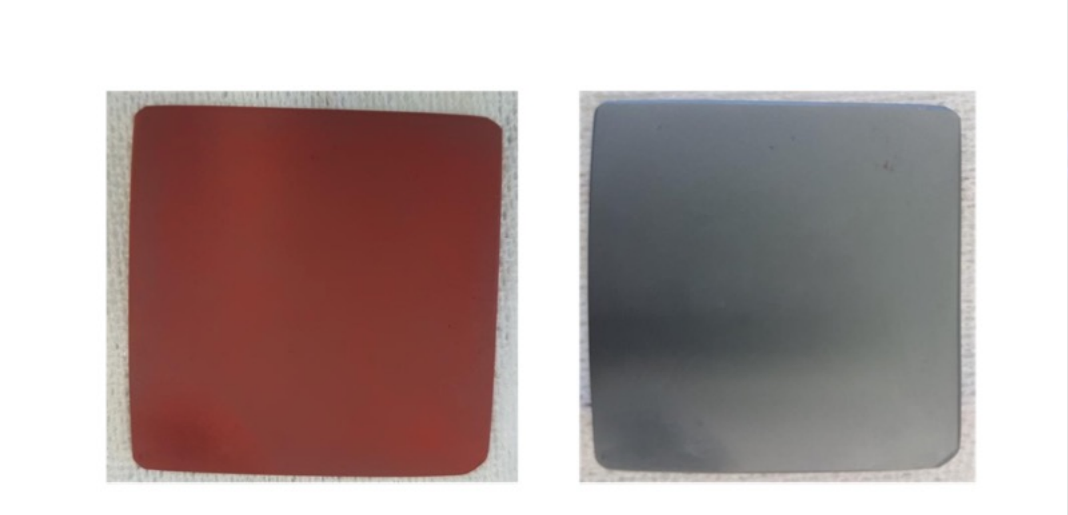
a = 1/3 for resistance over the surface

(see B. I. Shklovskii, A. L. Efros, ”Electronic Properties of Doped Semiconductors”, Springer, Berlin (1984) and N. F. Mott, ”Metal Insulator Transition”, Taylor & Francis, London (1974).

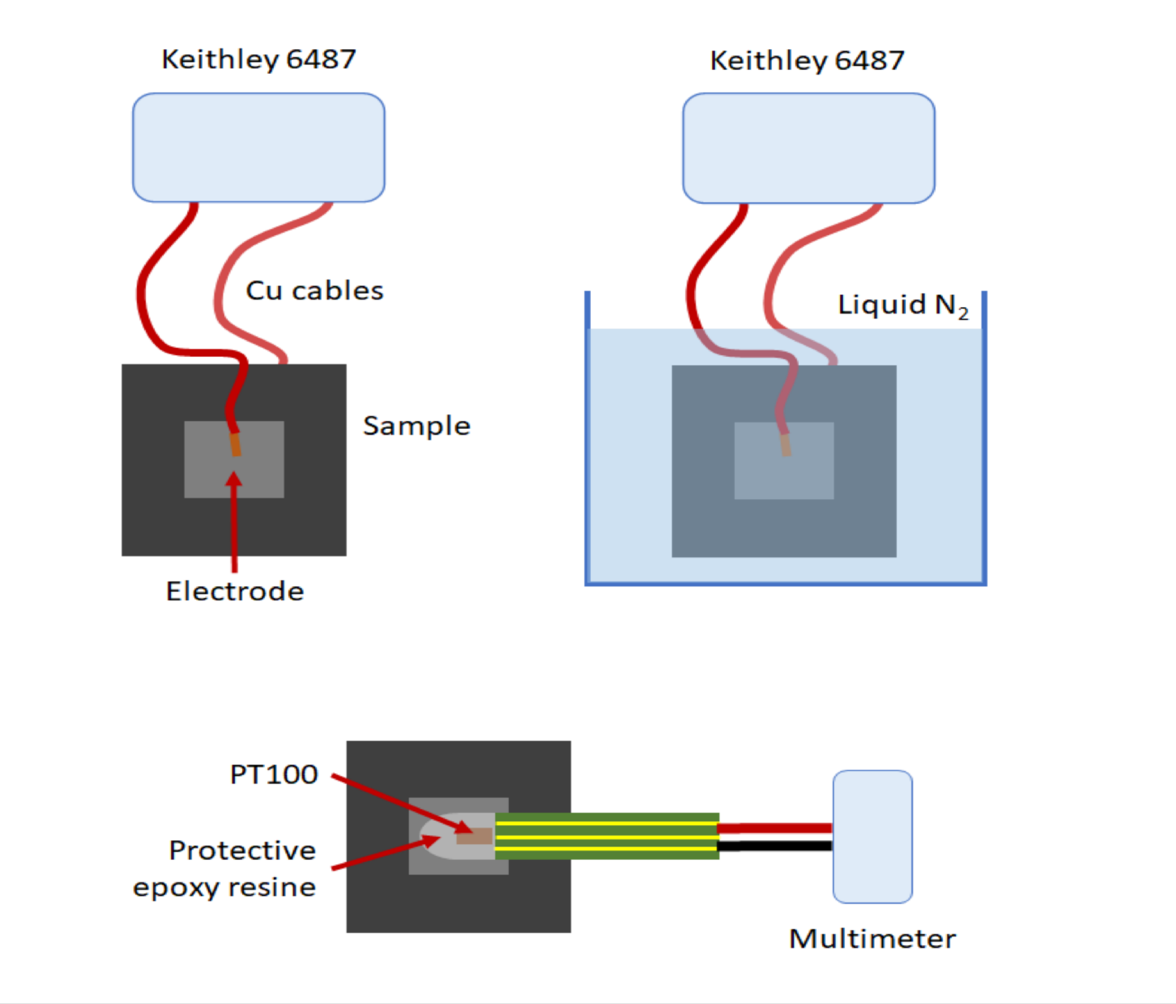
Ceramics characterization

- Fe_2O_3/YSZ ceramics produced at Ceramics Institute of Galicia

- Made by slip casting, possible to produce samples with different concentrations of Fe_2O_3



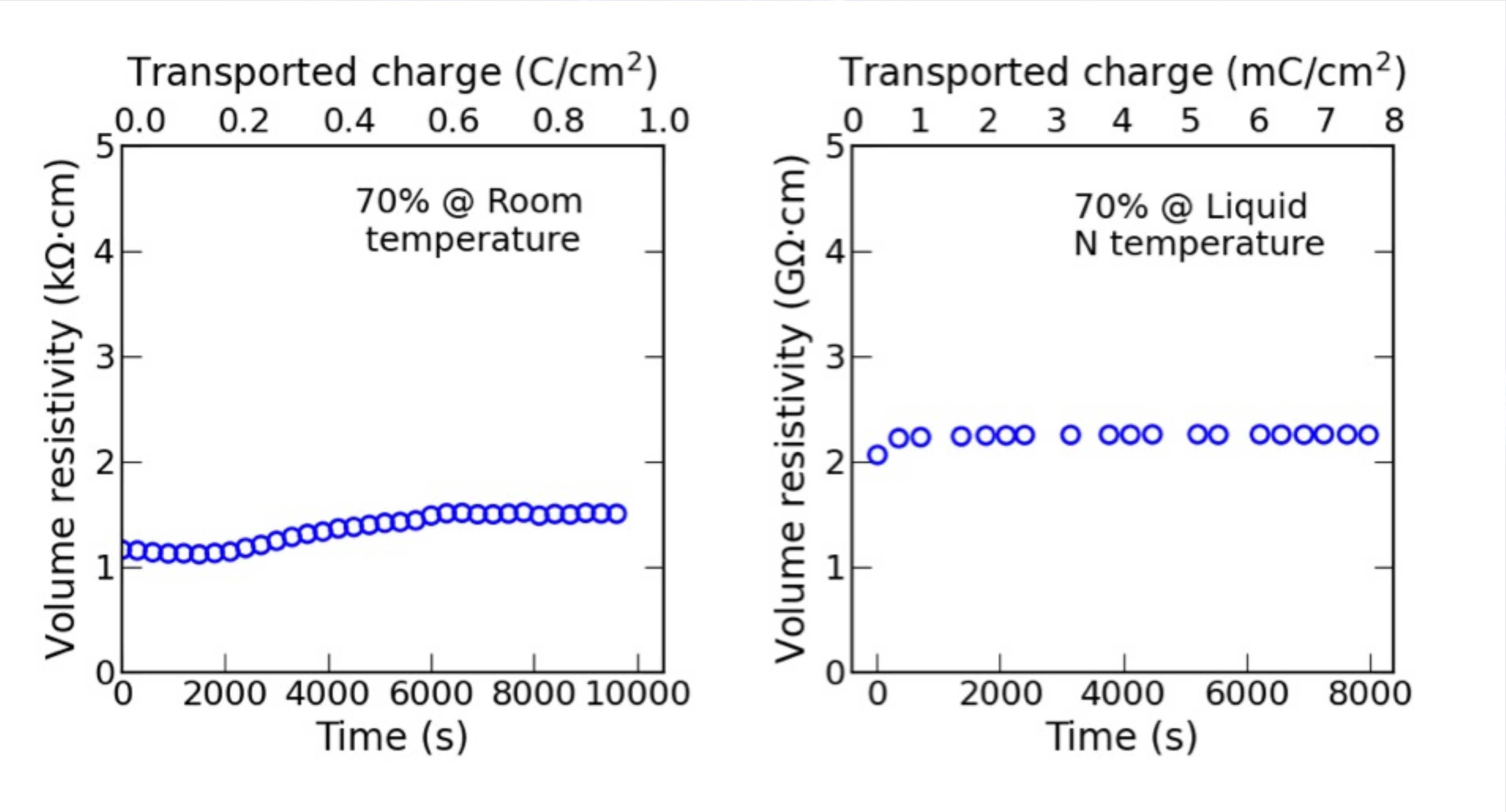
Experimental setup



Studied samples with concentrations of Fe_2O_3 in the range 30% - 100%

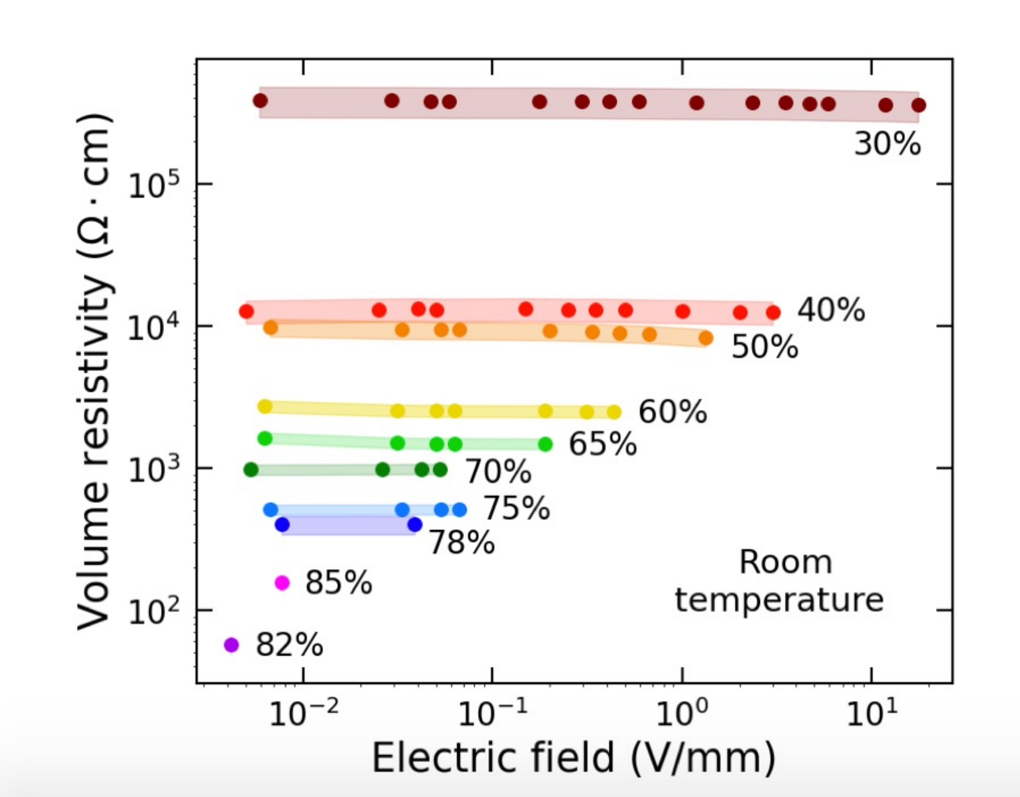
Characterized behavior with respect to E field, temperature, time

Aging test

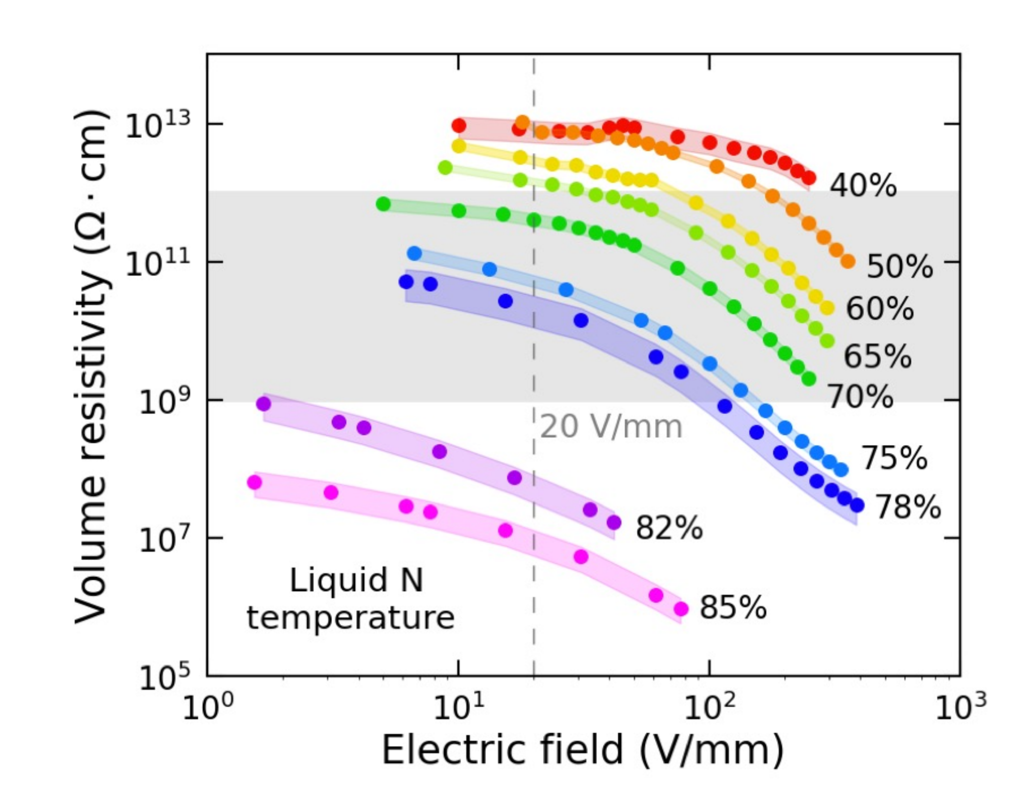


Transported charge (C/cm²)
0.0
0.2
0.4
0.6
0.8
1.0
70% @ Room temperature
Volume resistivity (kΩ·cm)
0
1
2
3
4
5
0
2000
4000
6000
8000
10000
Time (s)
Transported charge (mC/cm²)
0
1
2
3
4
5
6
7
8
70% @ Liquid N temperature
Volume resistivity (GΩ·cm)
0
1
2
3
4
5
0
2000
4000
6000
8000
Time (s)

Linearity

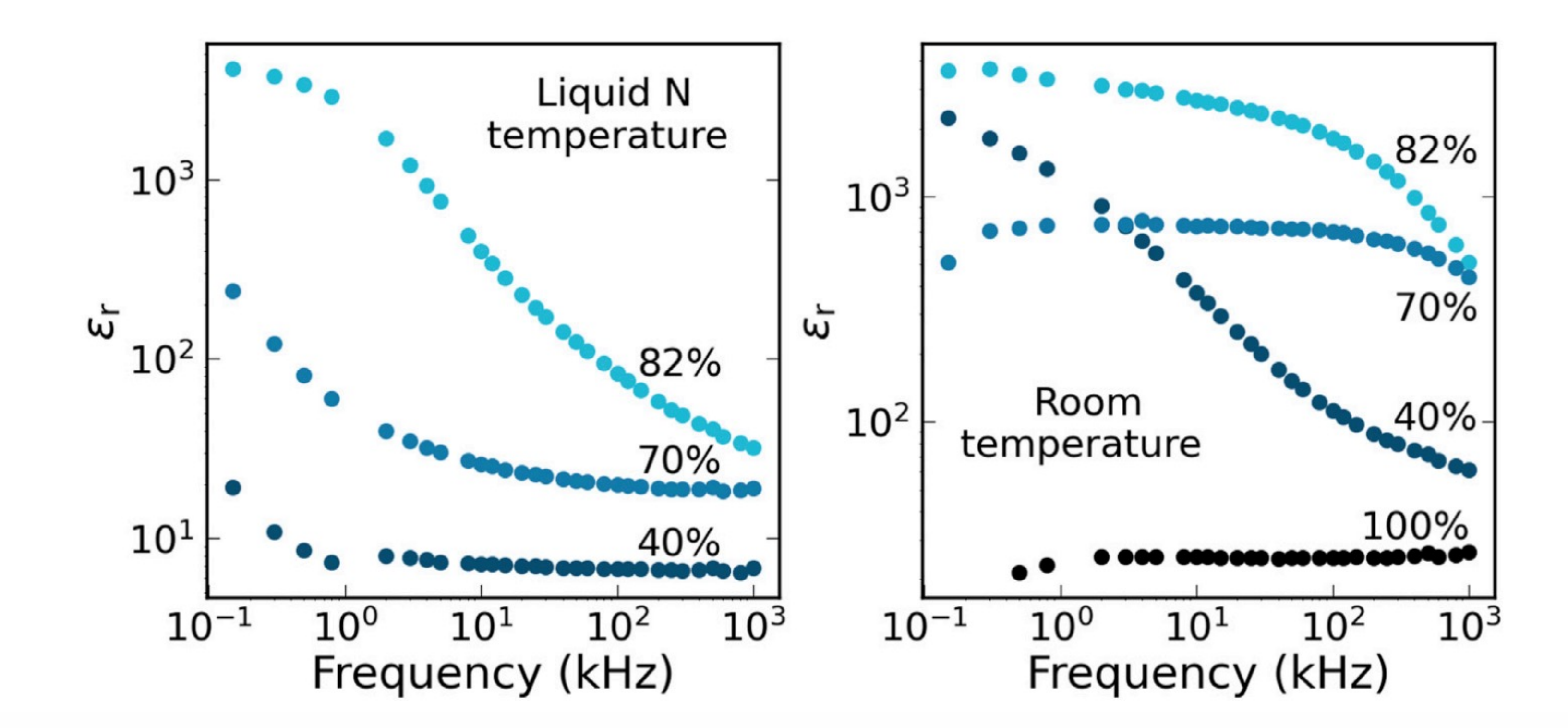


Volume resistivity (Ω · cm)
Electric field (V/mm)
30%
40%
50%
60%
65%
70%
75%
78%
85%
82%
Room temperature



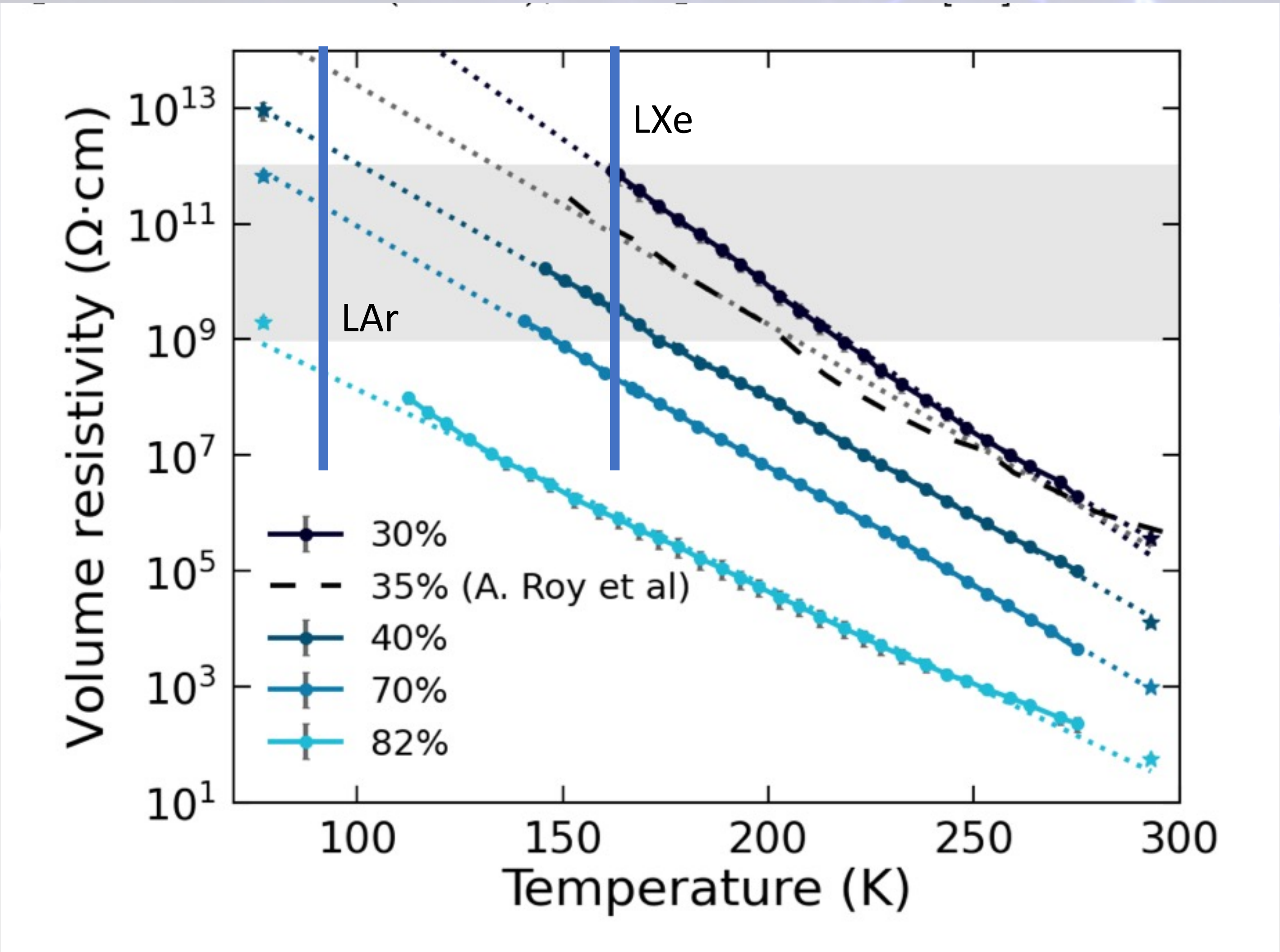
Volume resistivity (Ω · cm)
Electric field (V/mm)
20 V/mm
40%
50%
60%
65%
70%
75%
78%
82%
85%
Liquid N temperature

Impedance spectroscopy



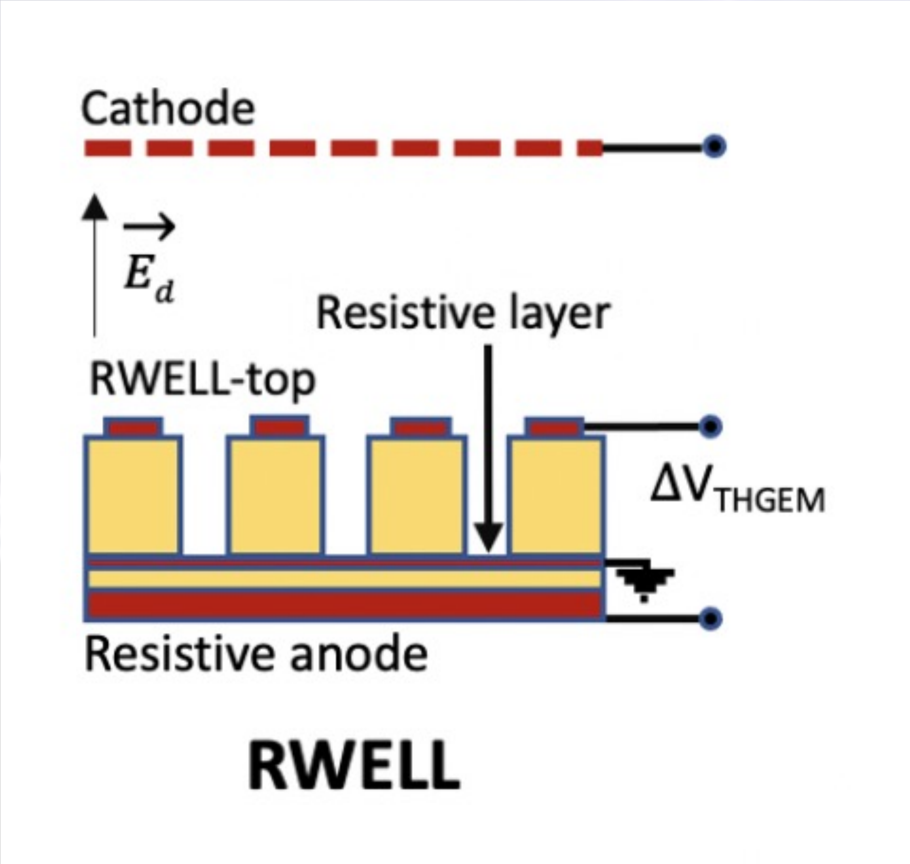
Thorough study being performed at CFM (Basque Country)

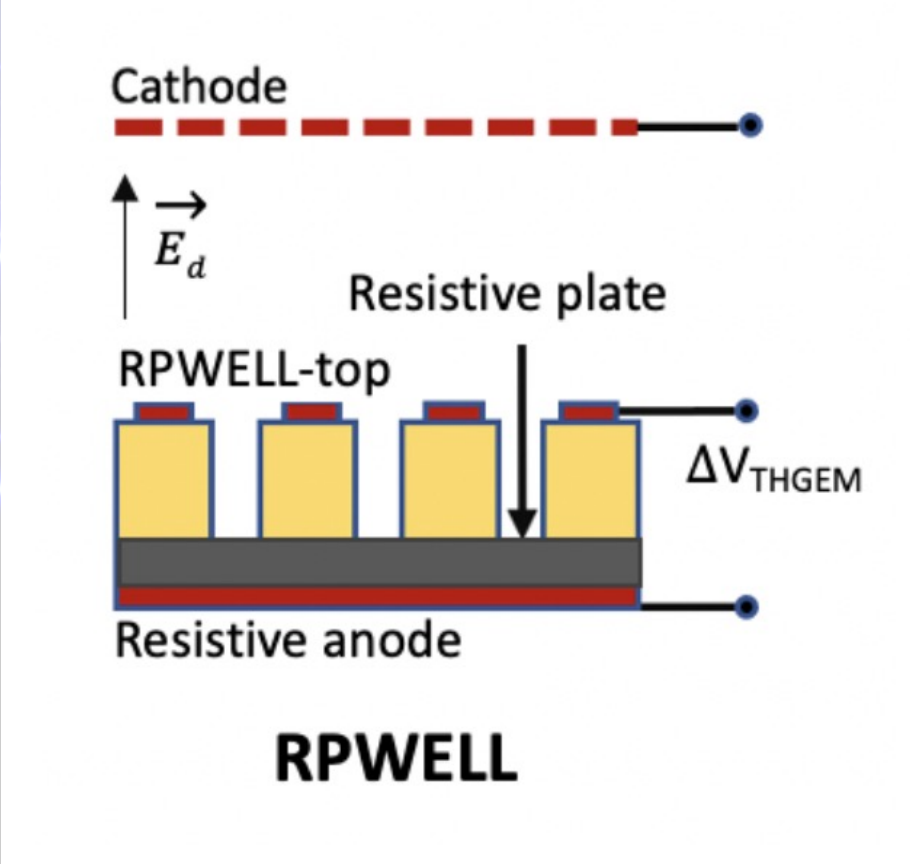
R-T curve



Concentrations of Fe_2O_3 that yield right bulk resistivity @90K:
65% - 80%

Test in detector @ WIS: R(P)-WELL

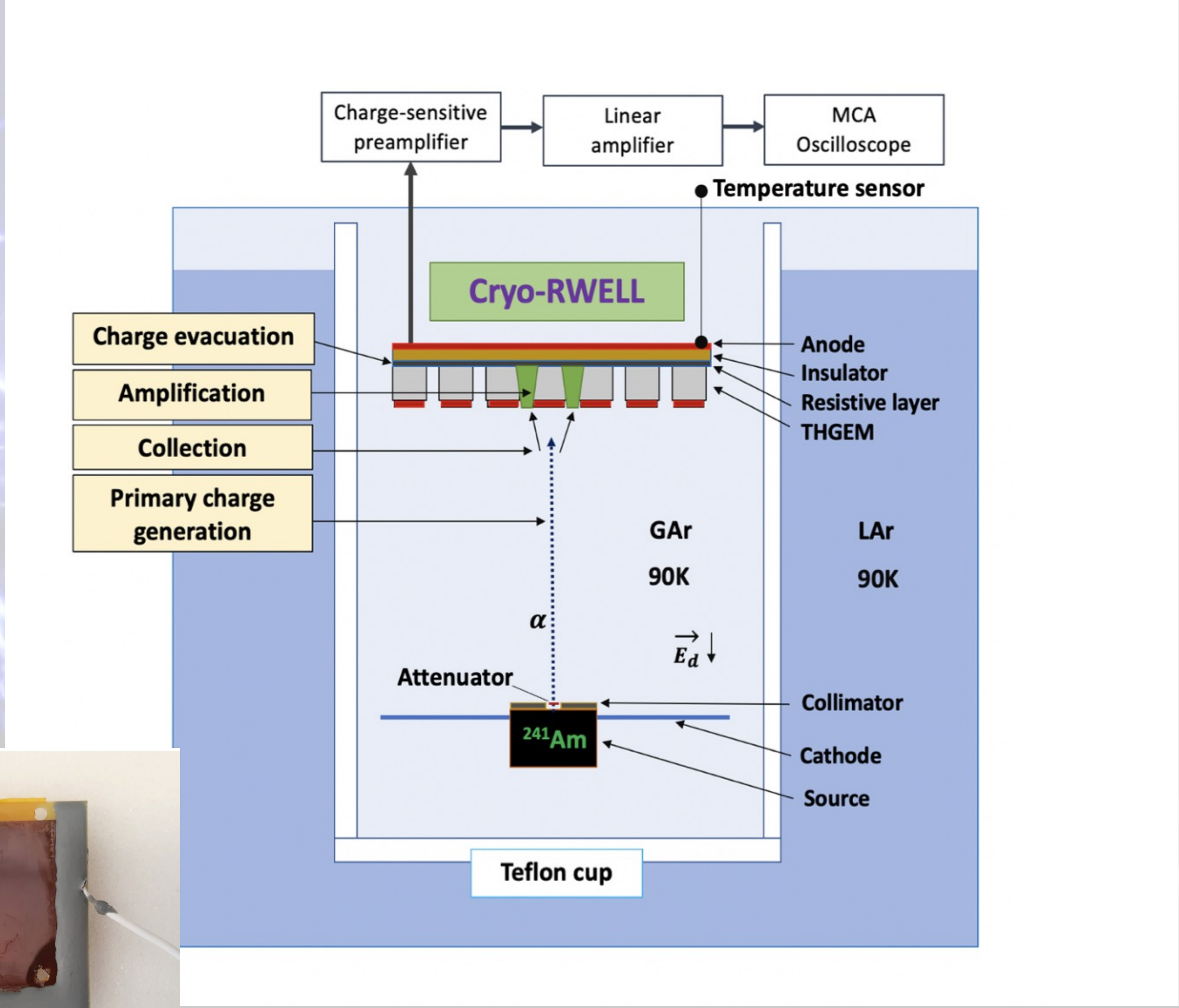


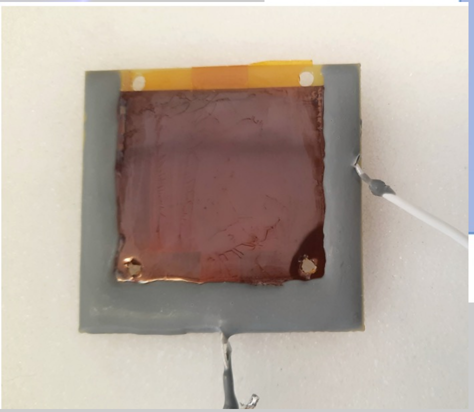


Test in detector: setup

- Attenuated and collimated alpha source
- Drift region 15 mm, 500 V/cm
- 0.8 mm THGEM
- DLC fixed to a PCB board with electrically-insulating cryogenic epoxy, ceramics also with conductive epoxy

- Assembly inserted in a teflon cup, in saturated argon vapour (90K, 1.2 bar)





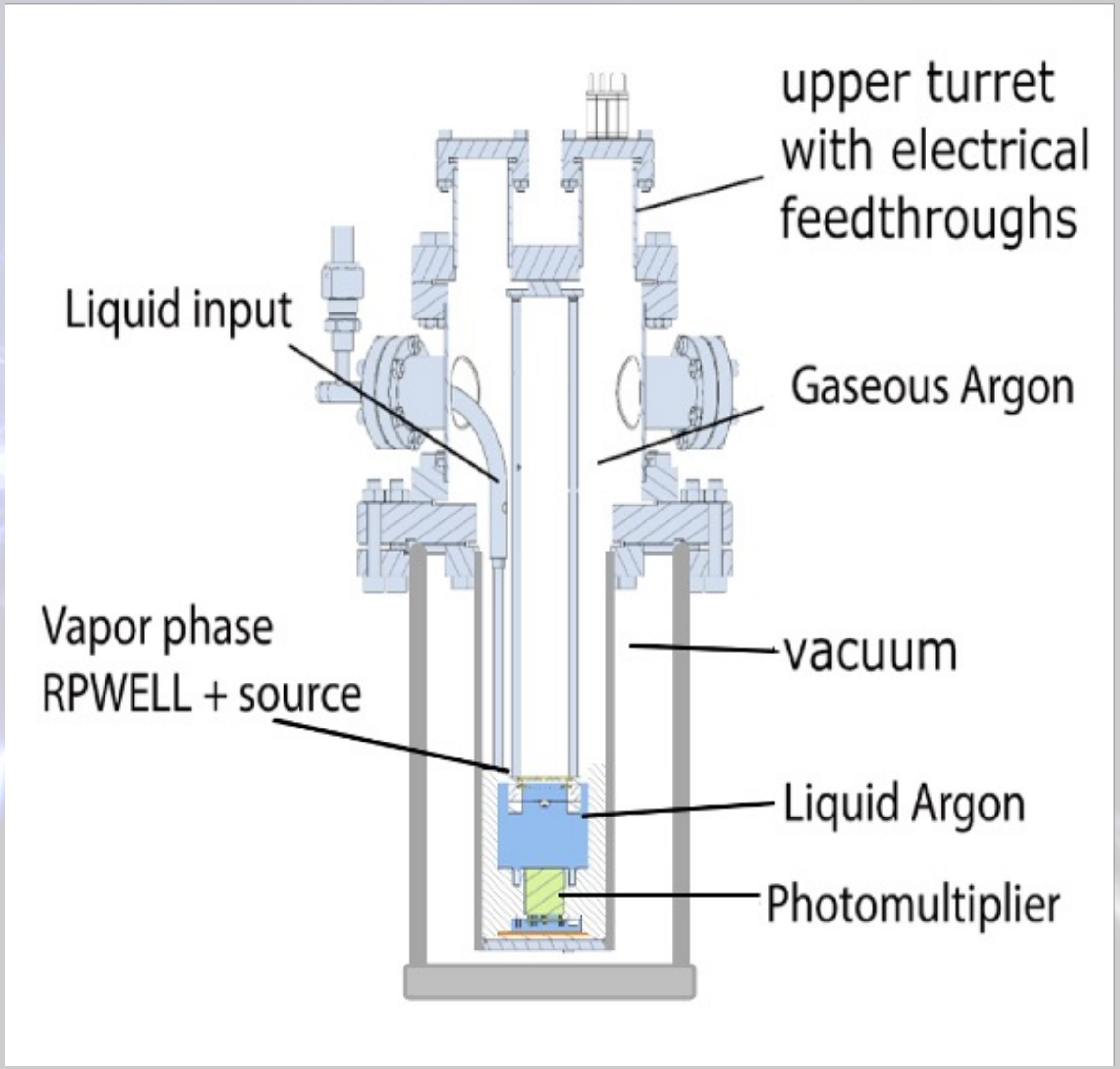
Test in detector: setup -2

High purity:

- pumped down to 10^{-4} mbar before filling

- Argon circulated through hot getter during operation

Liquid extraction → Evaporation → Hot getter → Cryocooler → Liquid to the vessel → Liquid extraction



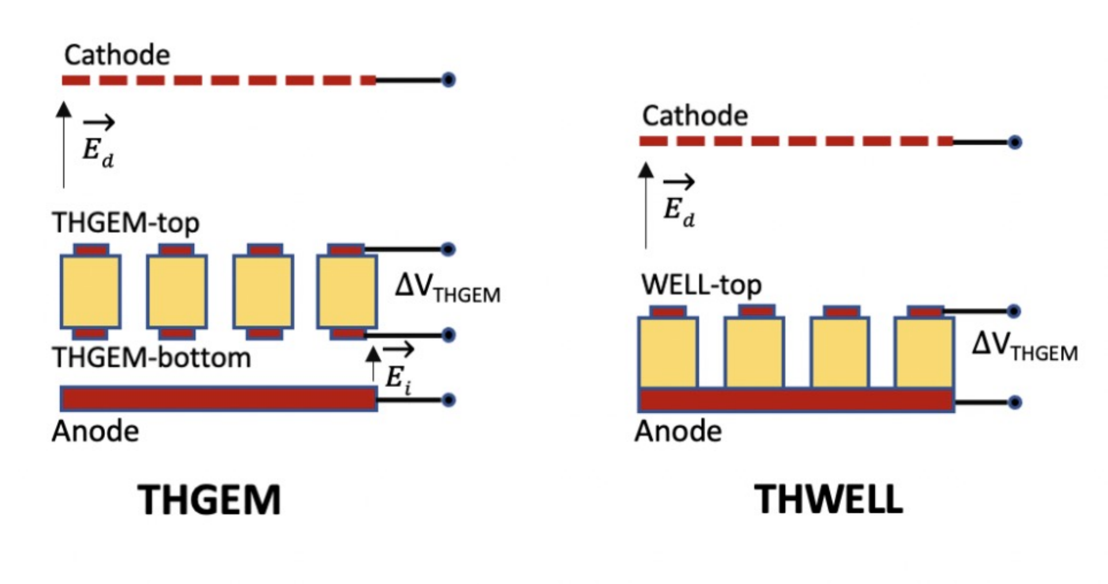
Starting point: unprotected structures

THGEM and THWELL ->

-same experimental conditions

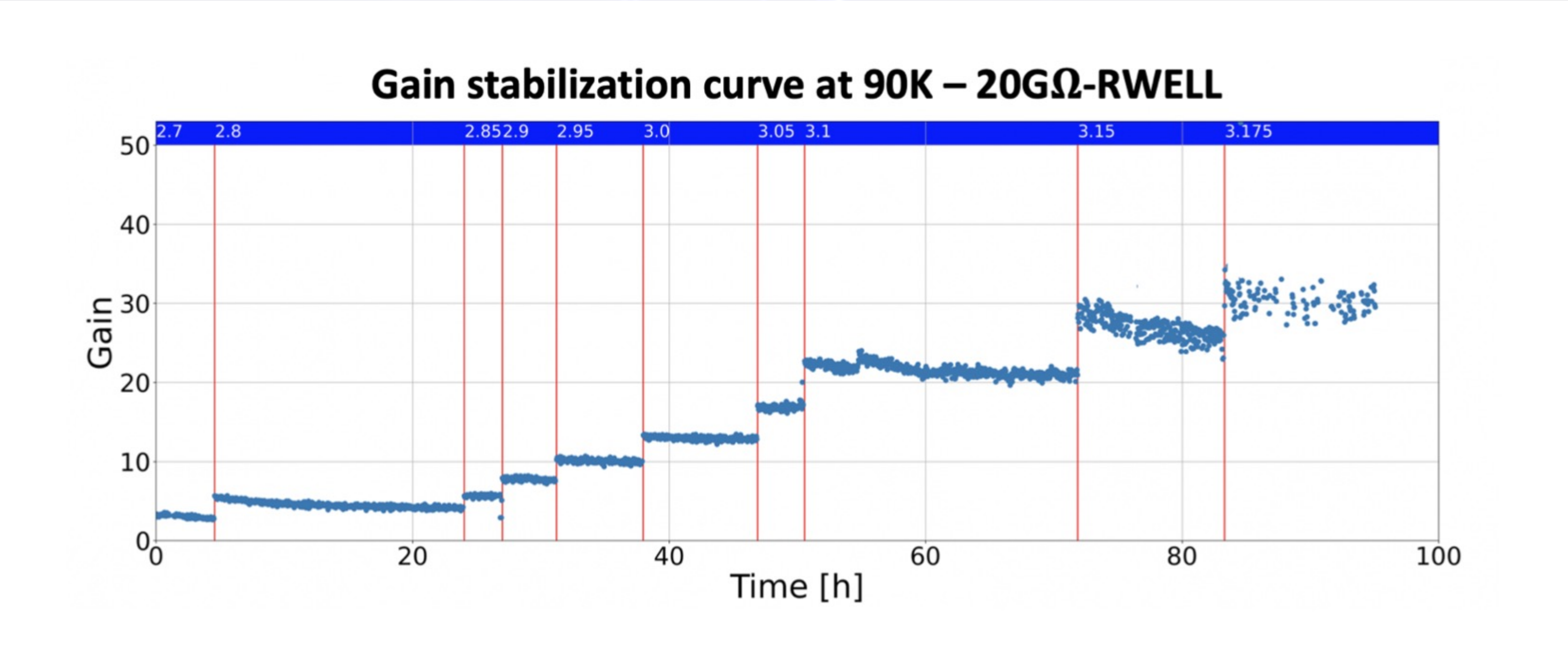
-single discharge makes stable gain operation impossible,
power supplies had to be restarted

- max gain 6 and 8 respectively

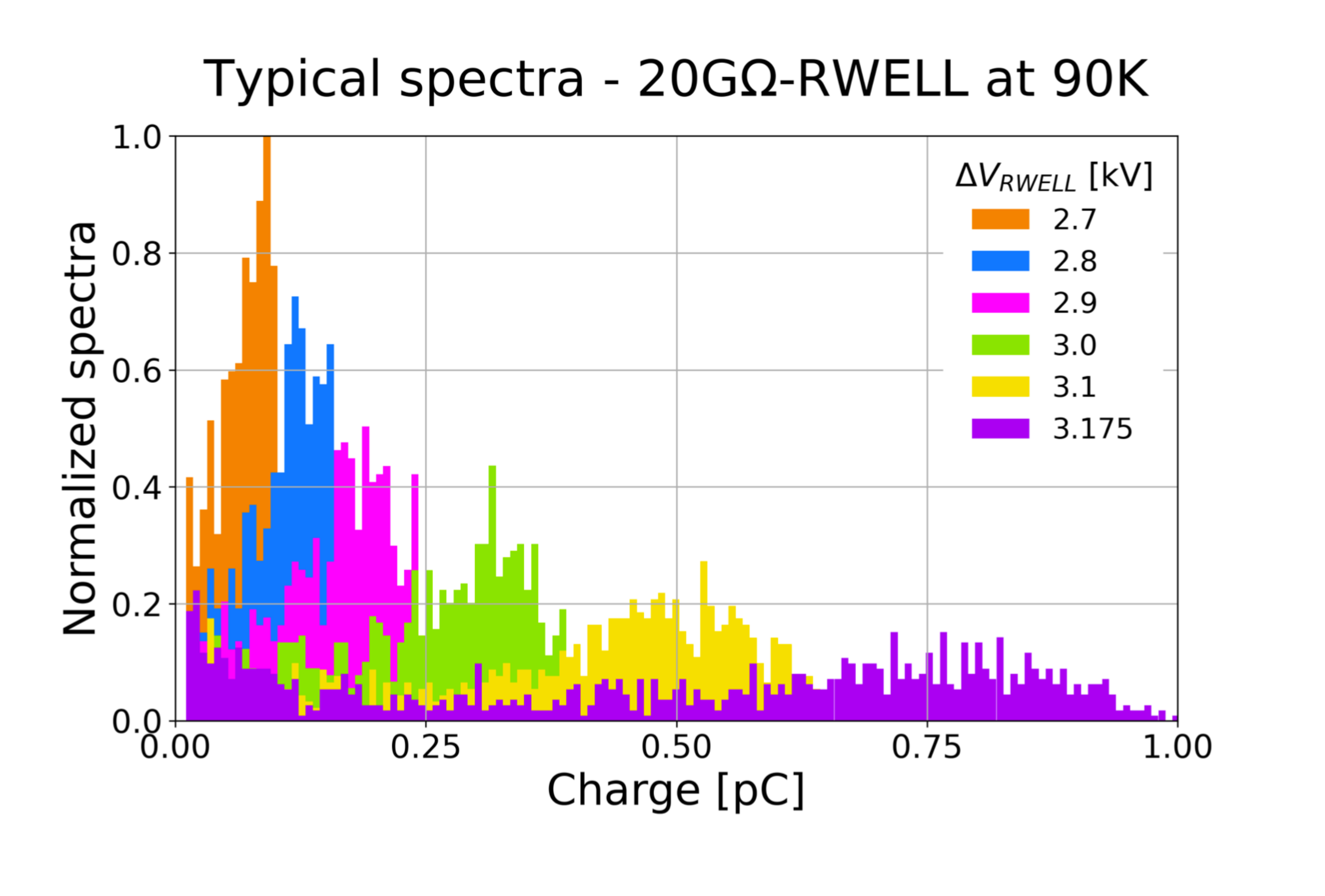


$$G_{Eff} = \frac{P_{Amplif}}{P_{Coll}}$$

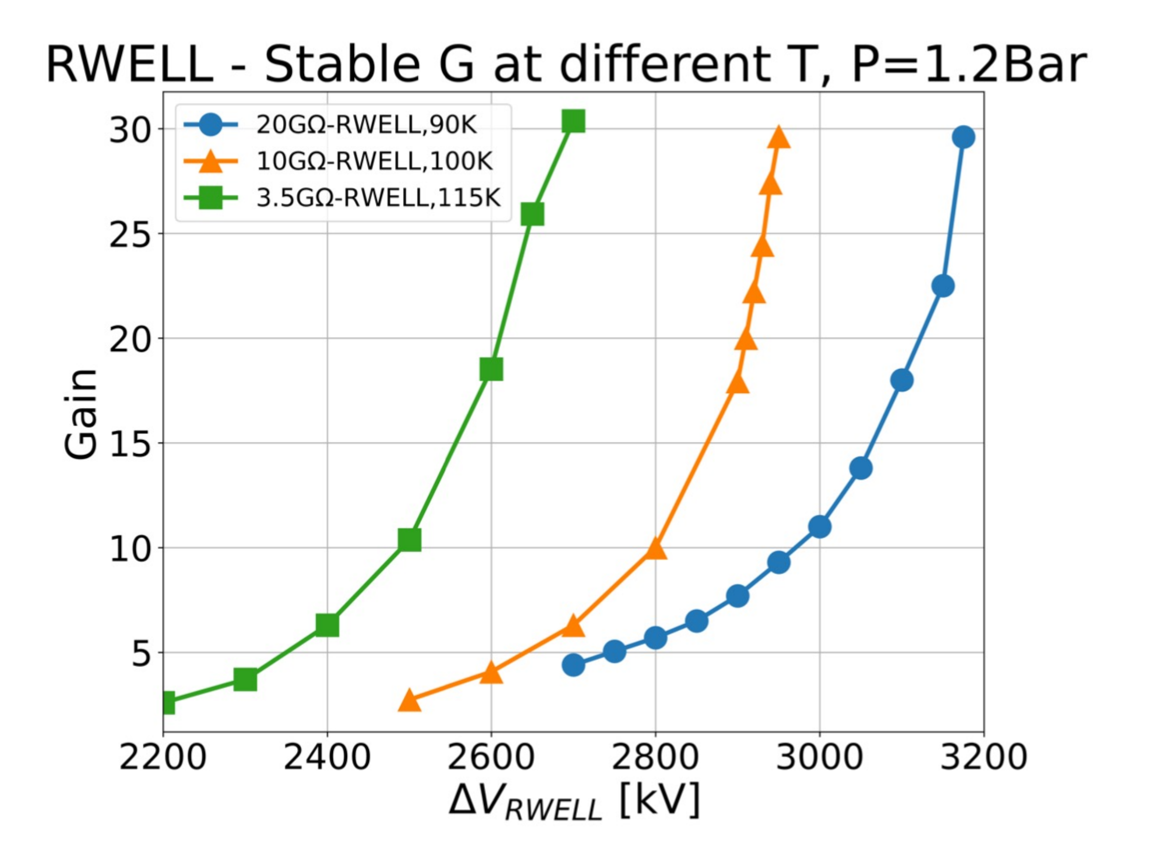
RWELL: gain curve

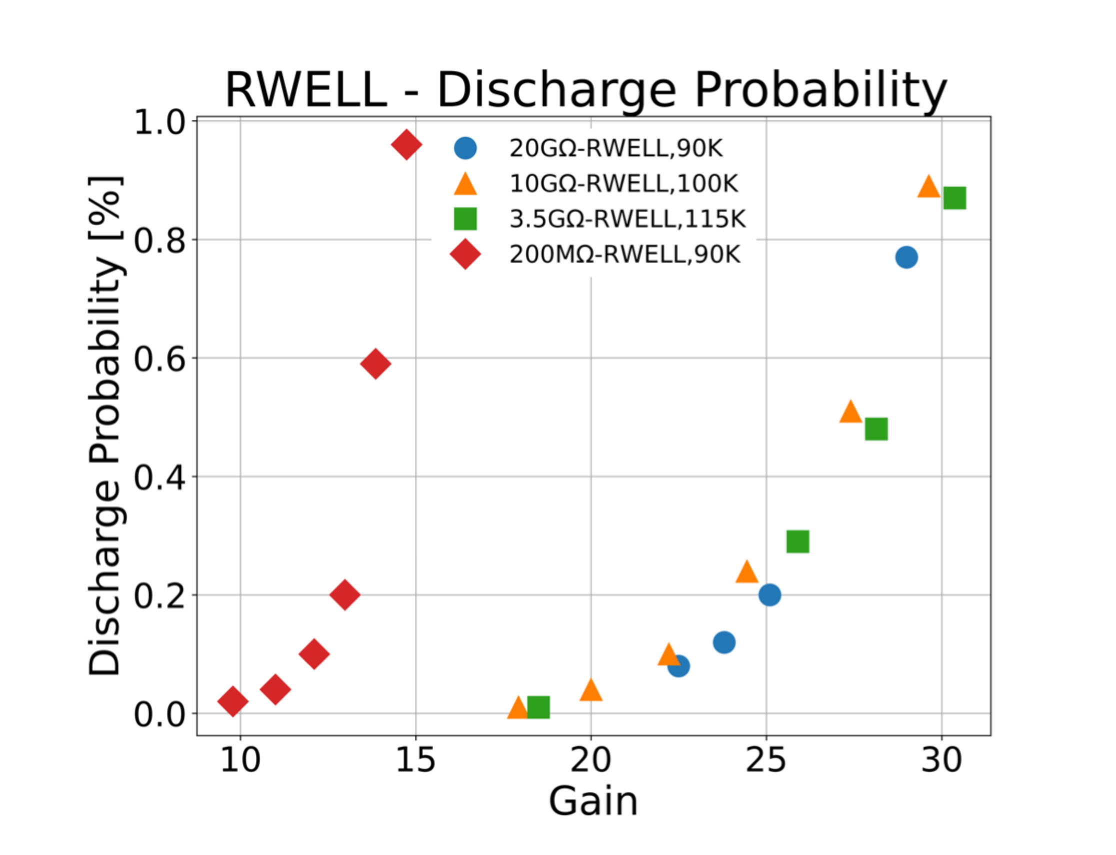


RWELL: spectra

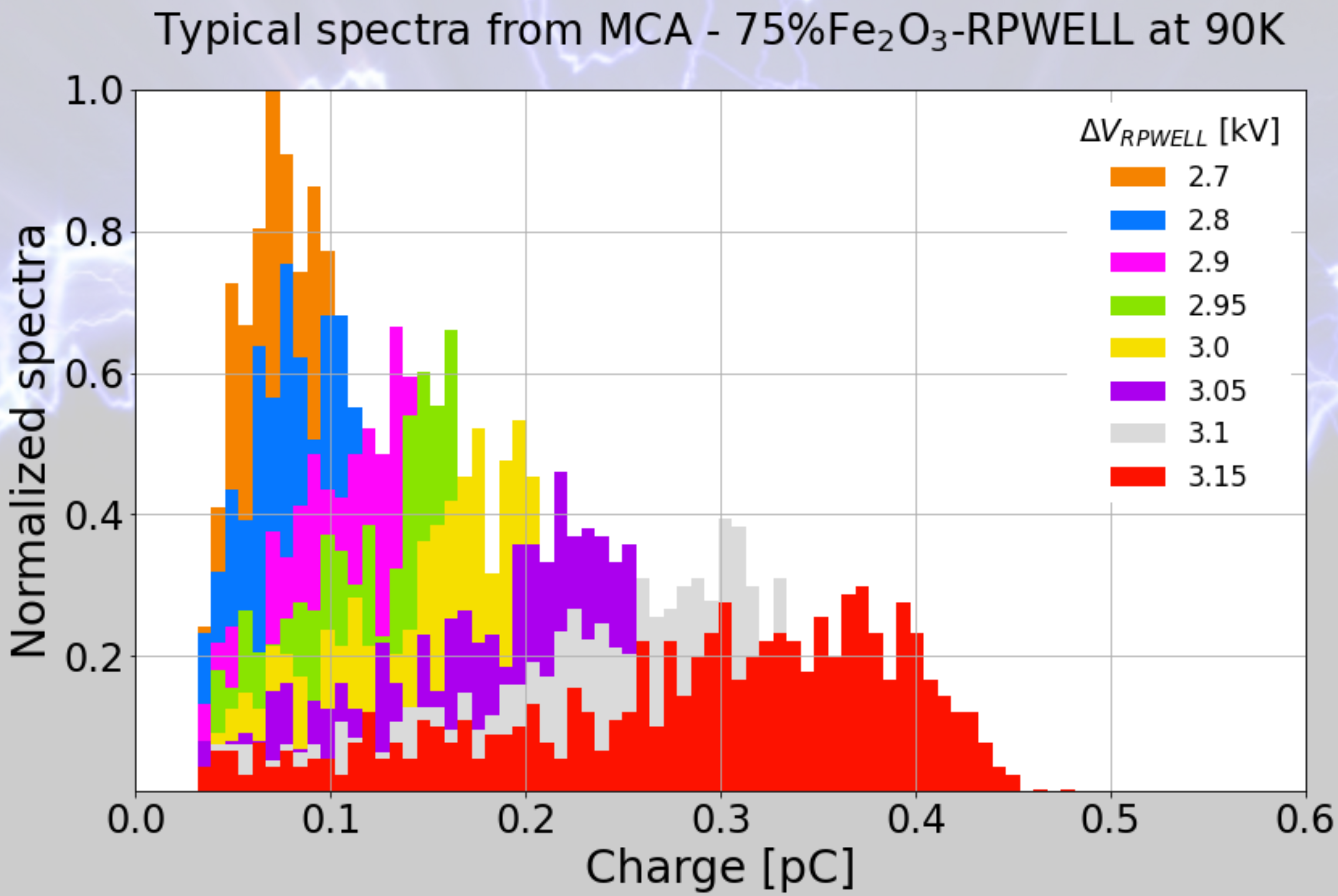


RWELL: comparison

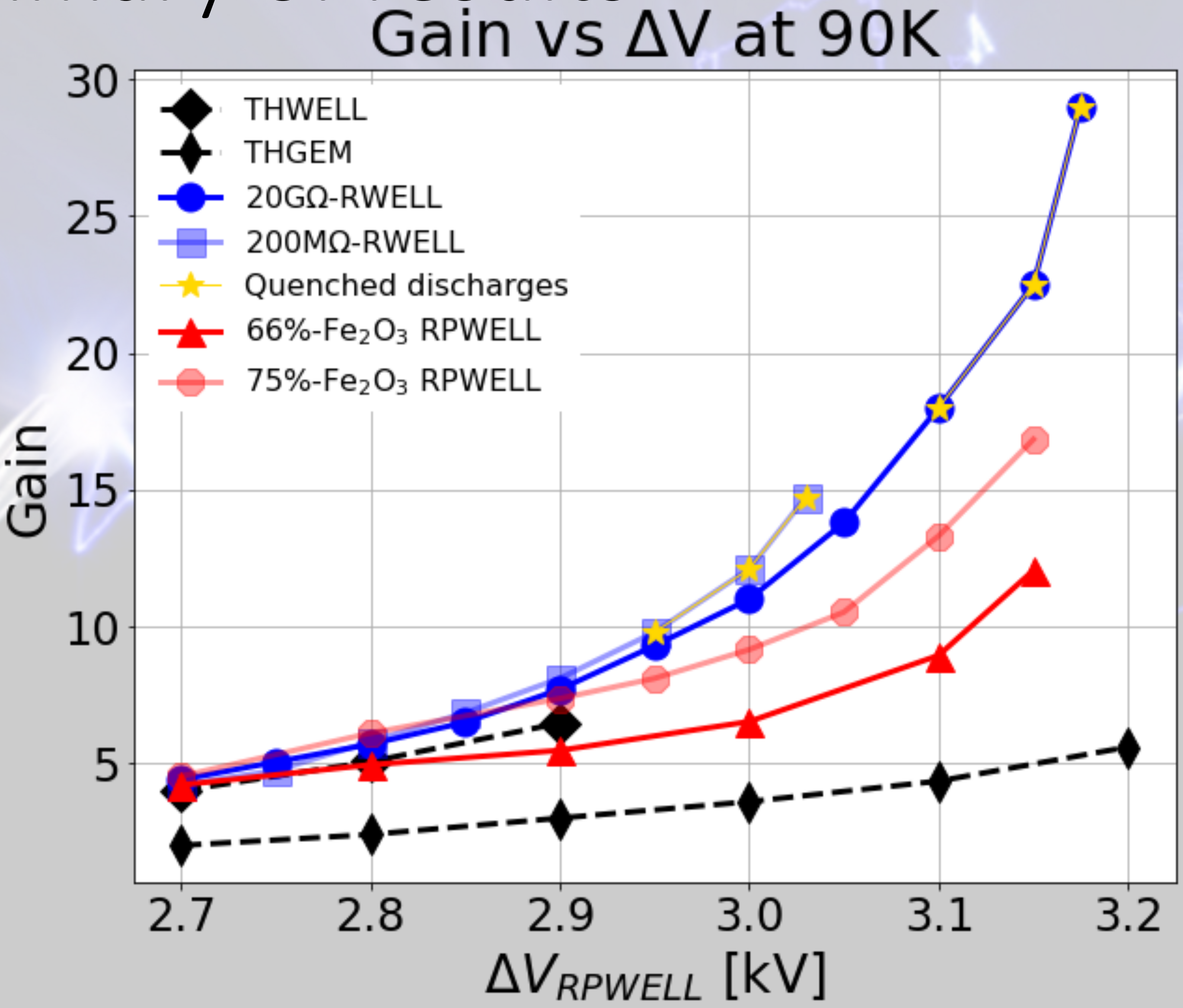




RPWELL: spectra

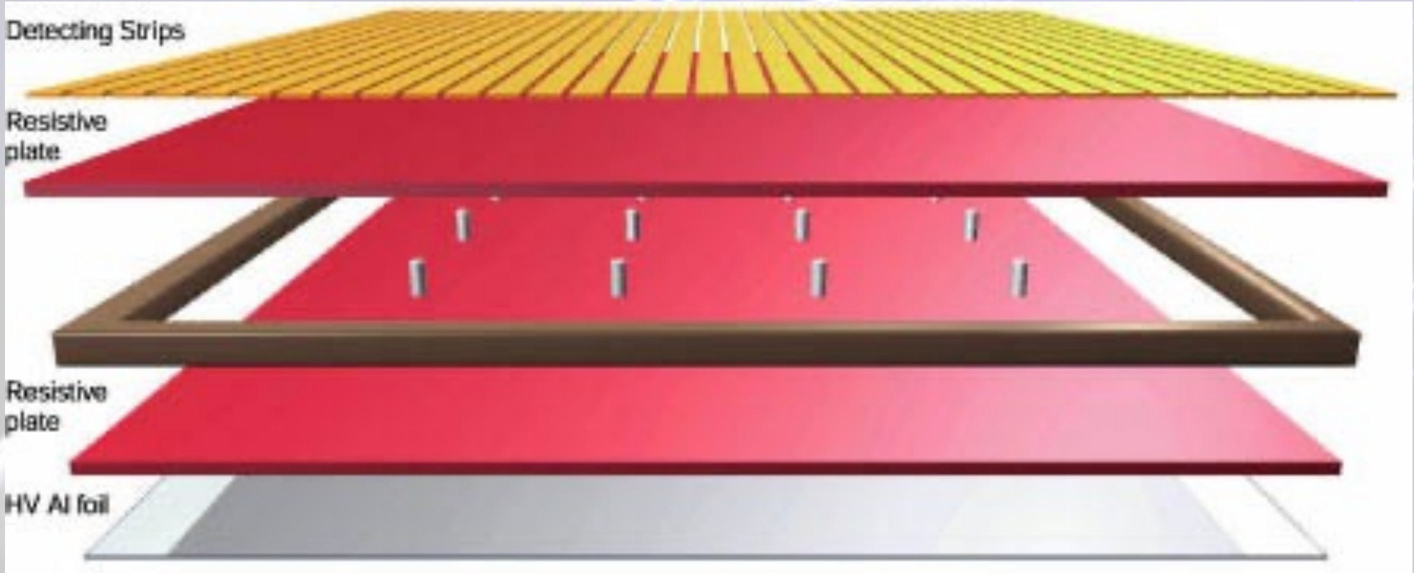


Summary of results



All operated in pure gas!

And what about RPCs?



From CMS experiment website

DLC and ceramics have **<u>tunable</u>** resistivity:

-> possible to produce samples in right range for RT operation

-> compatible with RPC-based detectors

Conclusions

- DLCs and Fe_2O_3/YSZ display good properties to use them as resistive protection for detectors that operate at cryogenic temperature

- A Fe_2O_3/YSZ ceramics was successfully operated in Ne/5%CH_4 atmosphere at LXe temperature (see A. Roy *et al* 2019 *JINST* **14** P10014)

-We managed to operate a detector in LAr (90 K) with DLC layers, obtaining a maximum stable gain of 30 with a 20 Gohm/sq sample

- We managed to operate the detector in LAr with two different ceramics samples, having 75% and 65% Fe_2O_3 concentration, obtaining a maximum stable gain of 16

- Thanks to the possibility of tuning resistivity (changing thickness for DLCs, Fe_2O_3 concentration for ceramics), the materials can be operated in a wide range of temperatures, including room temperature. This is in principle compatible with RPC-based detectors.

Thanks for your attention!

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