New resistive-protected MPGD structures for cryogenic conditions, results from operation in Ar at 90K

Sara Leardini

IGFAE Instituto Galego de Física de Altas Enerxías

USC Universidade de Santiago de Compostela

Weizmann Institute of Science

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 https://arxiv.org/pdf/2305.12899.pdf for ceramics)

- Operate them in a detector (see https://arxiv.org/abs/2304.04044 + upcoming papers in near future!)

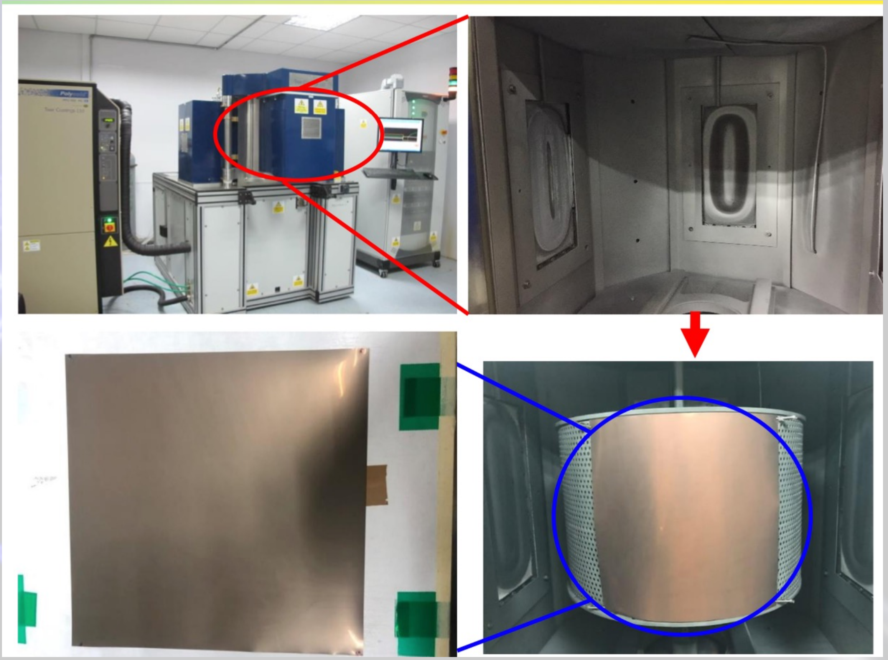
DLC characterization

- 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)

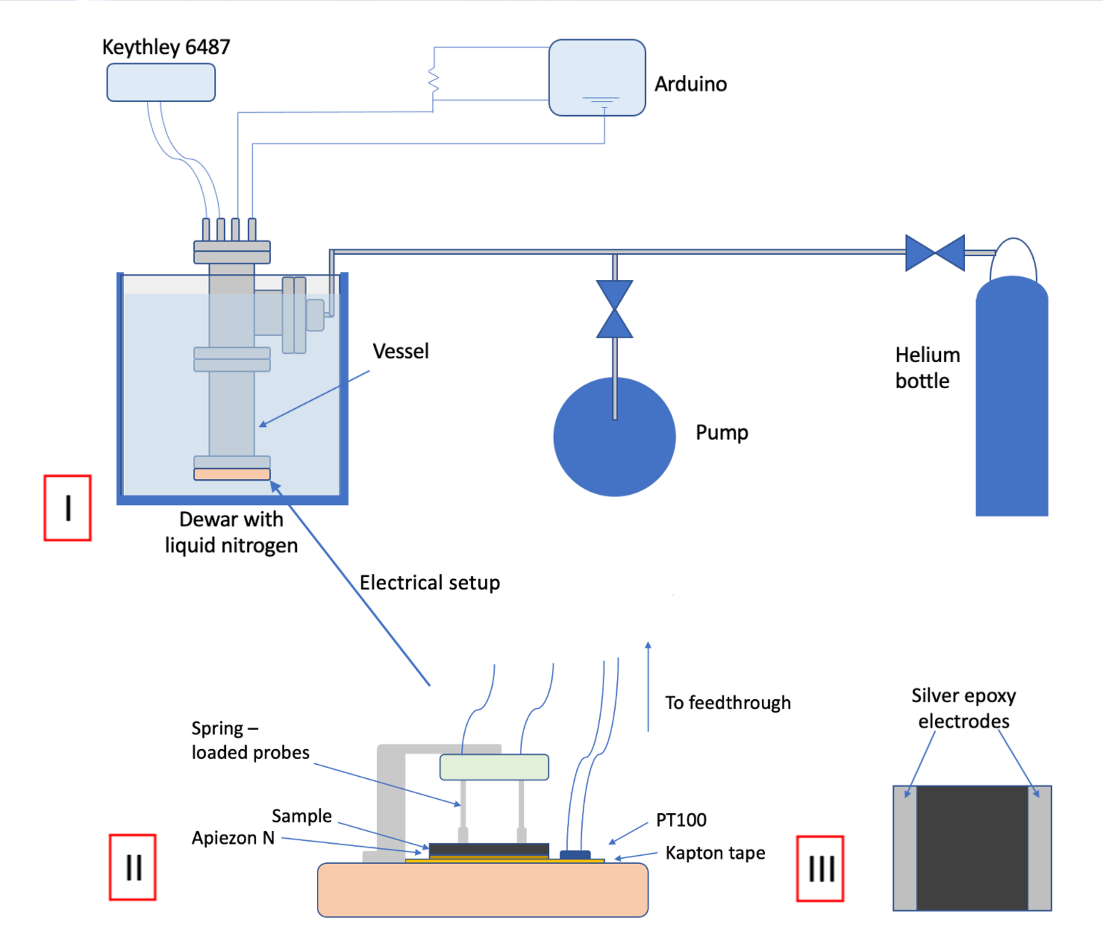


From talk by Yi Zhou:
https://indico.cern.ch/event/852331/contributions/4611238/attachments/2367150/4042458/Resistive%20Detectors%20with%20DLC.pdf

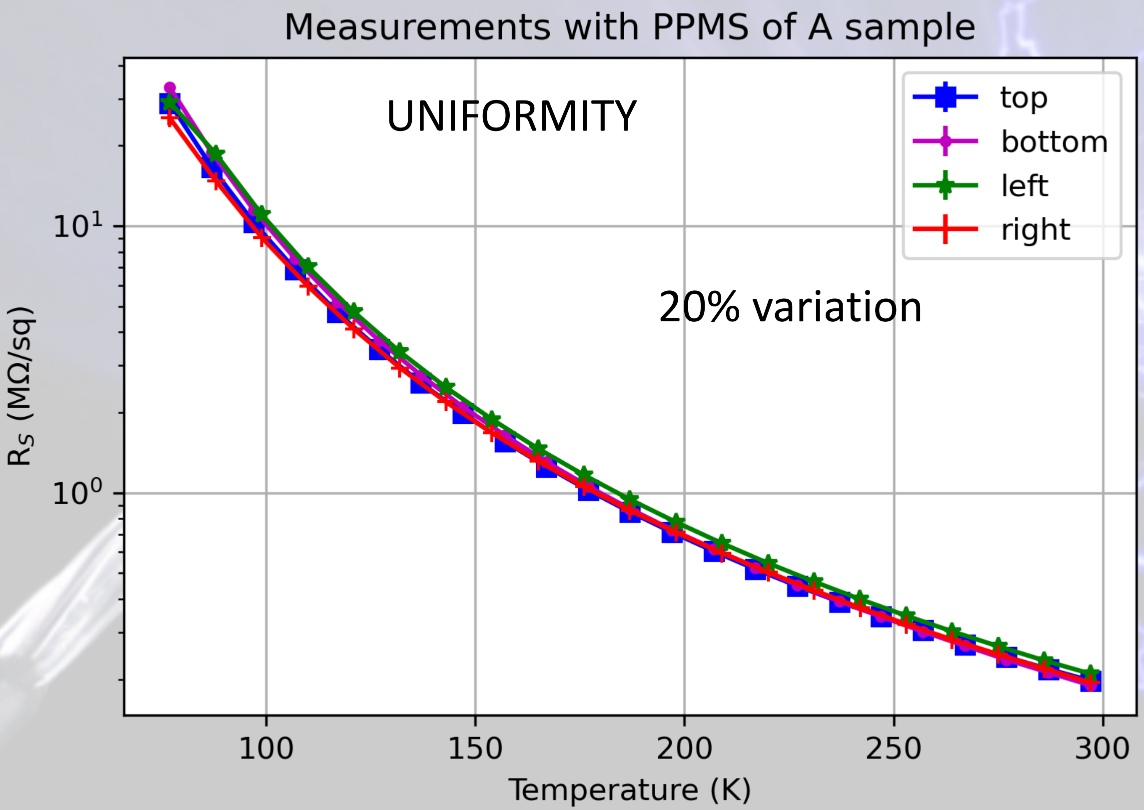
Cryogenic setup

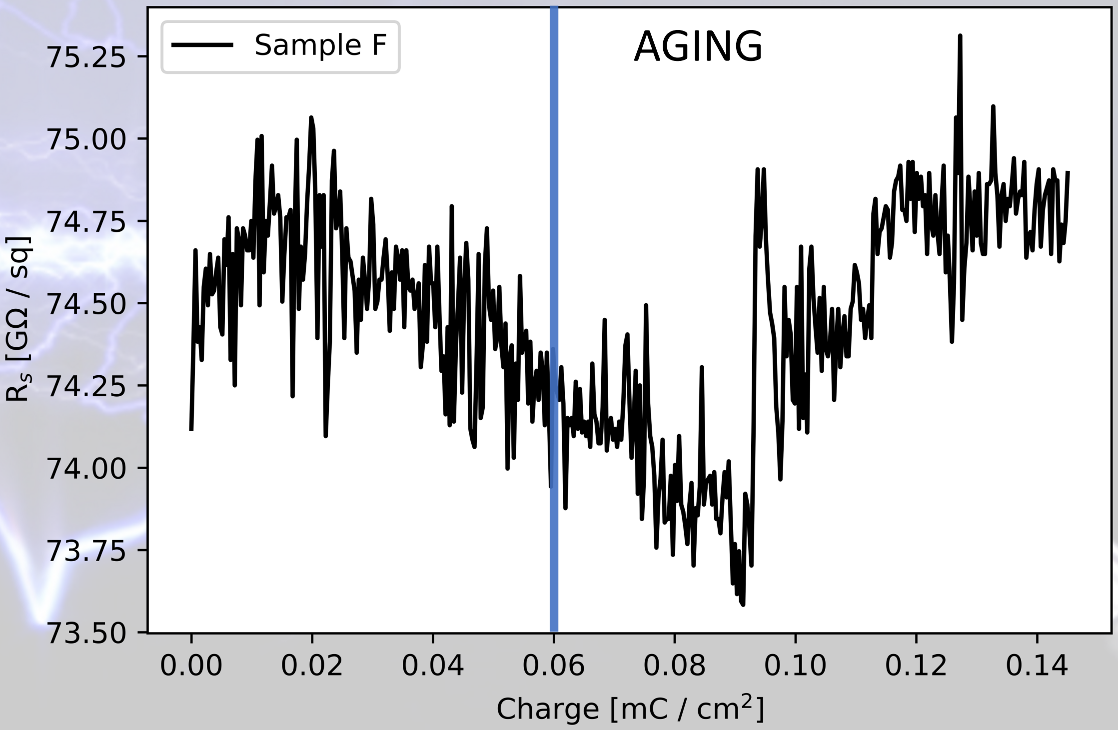
Home- made cryostat

Able to measure all the range of resistivities



Uniformity and aging



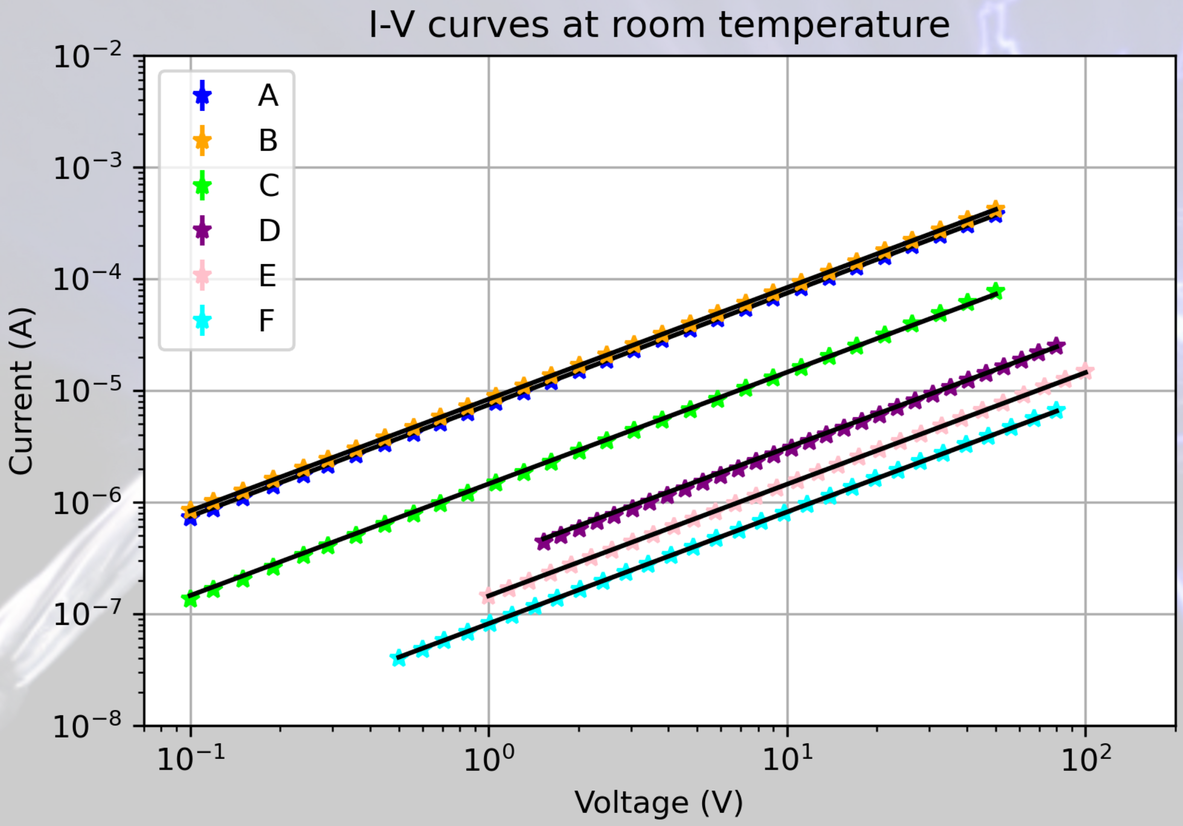


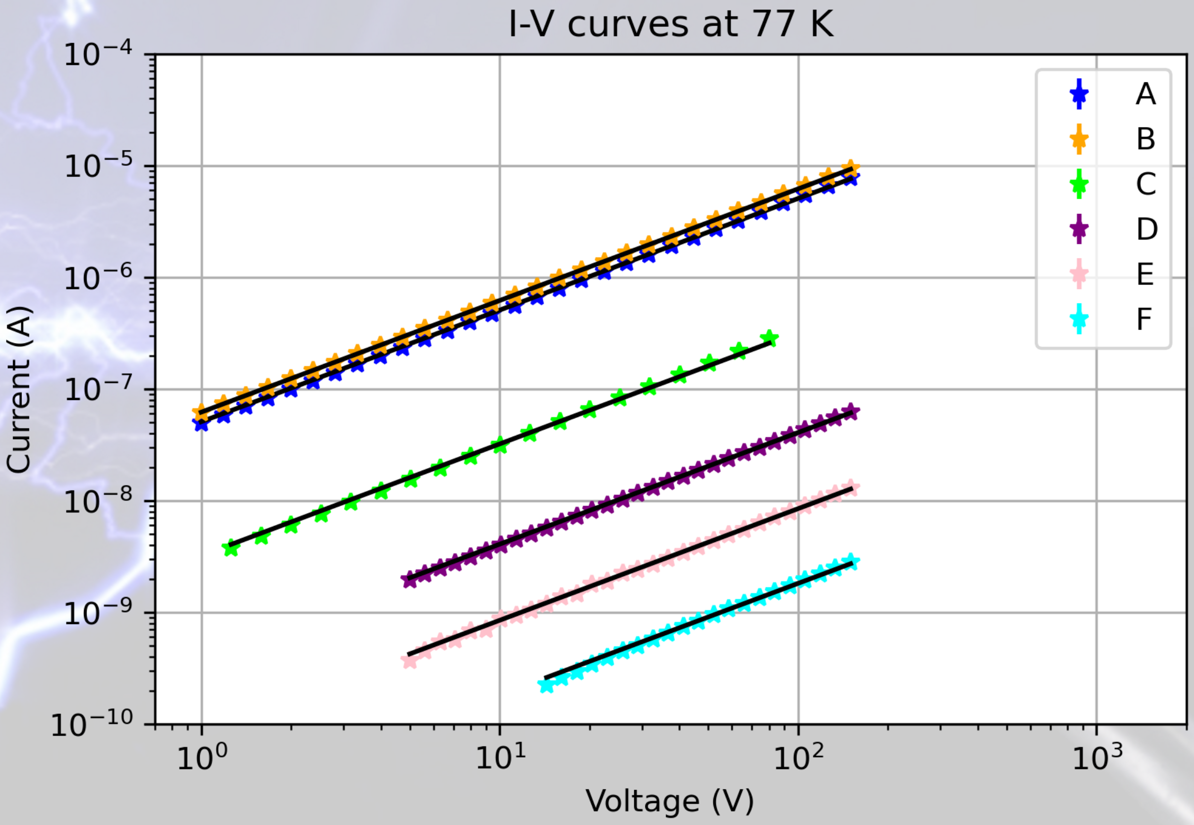
-RT : no aging effect after transporting > 2 C / cm^2

-LN : < 2% variations

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

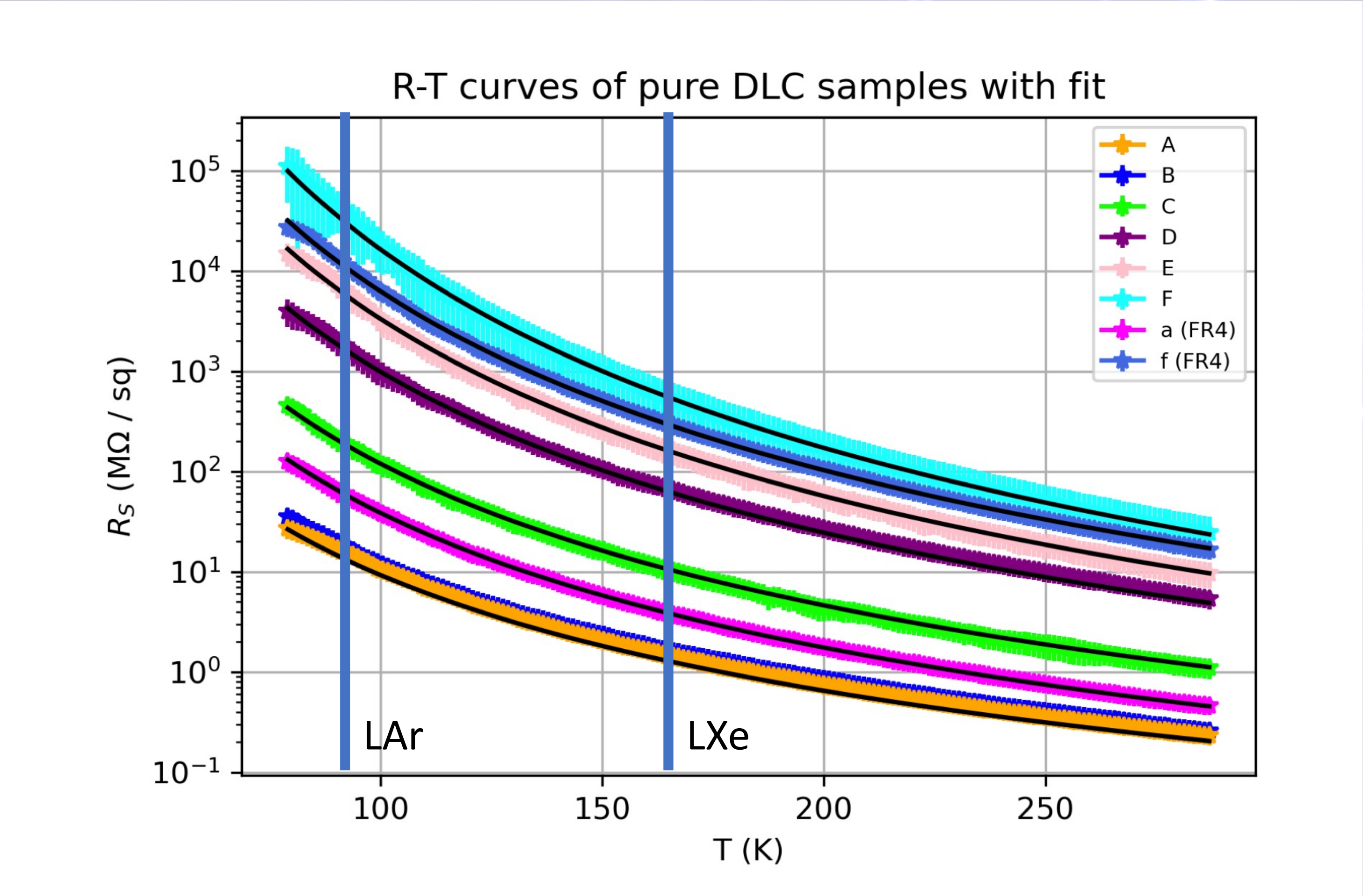
Linearity





All samples linear both at RT and 77K

R-T curves



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

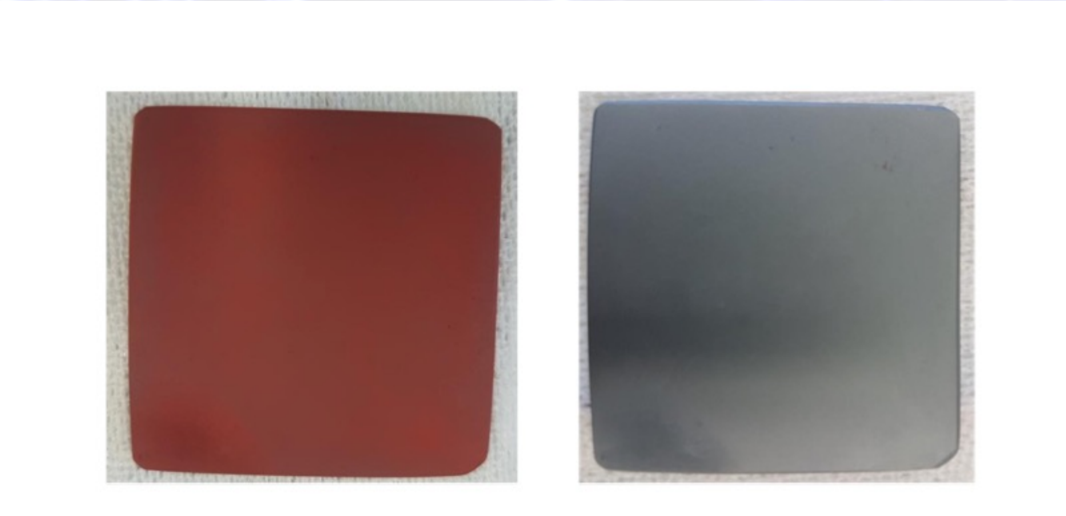
a = 1/3 for resistance over the surface

(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).

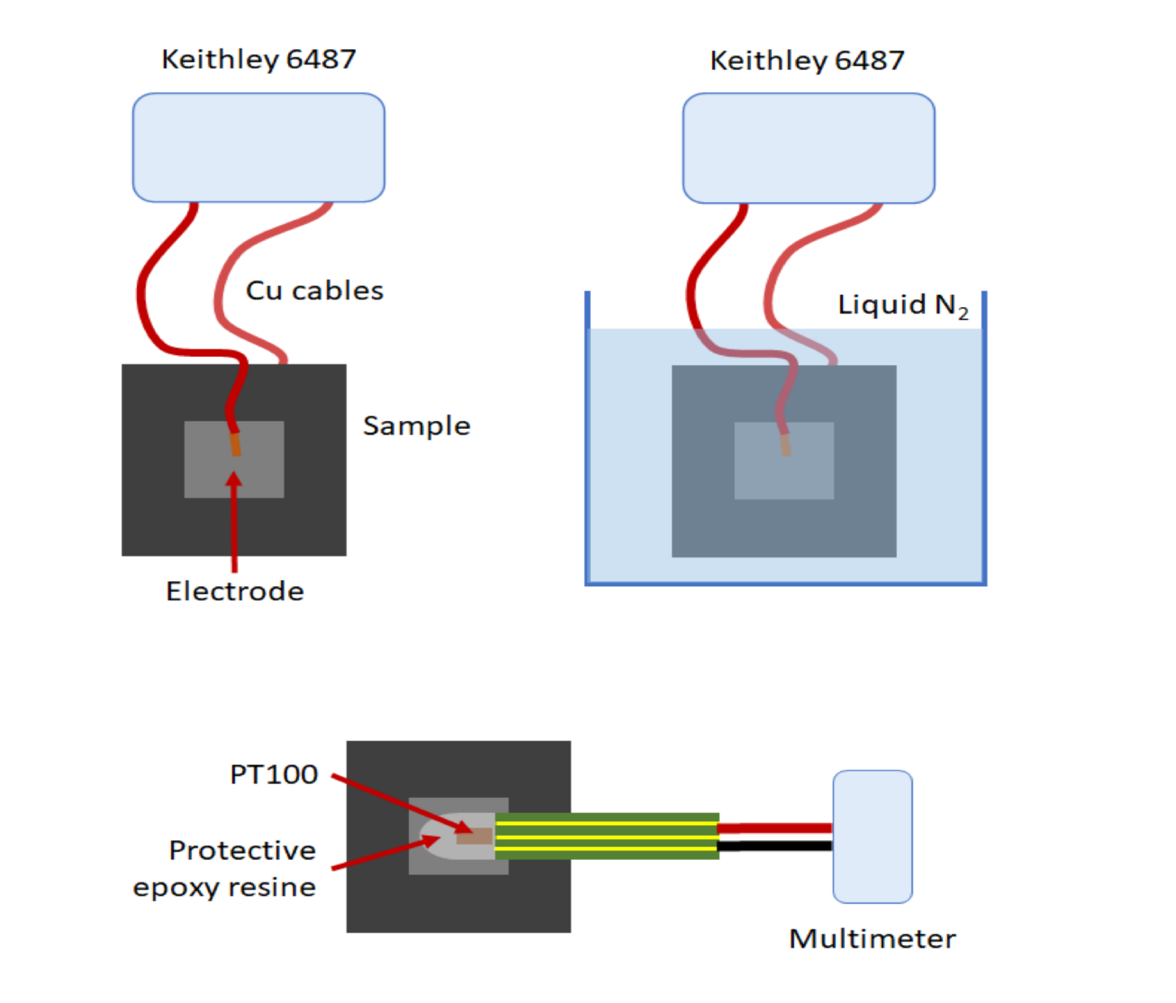
Ceramics characterization

- 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



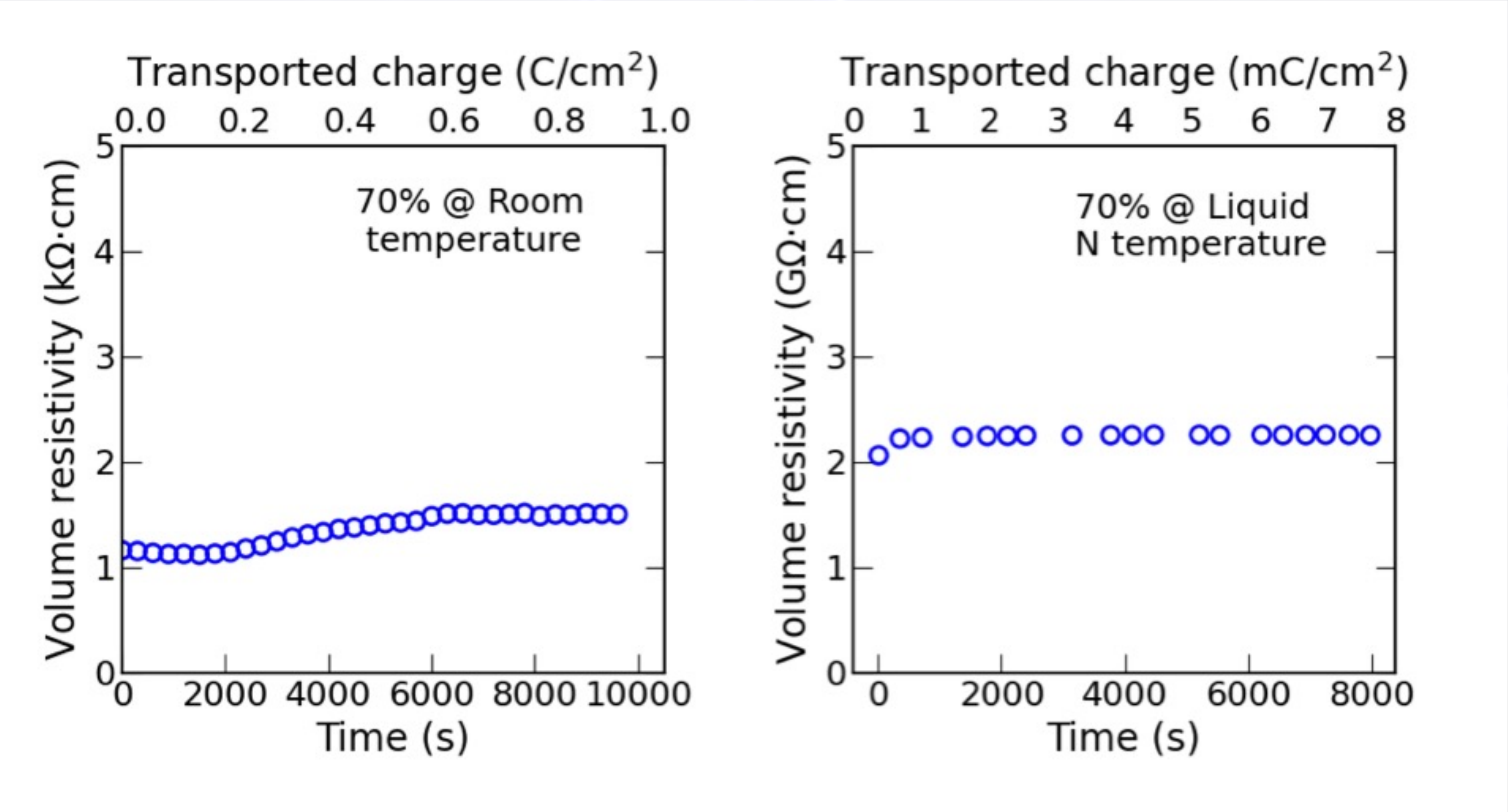
Experimental setup



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

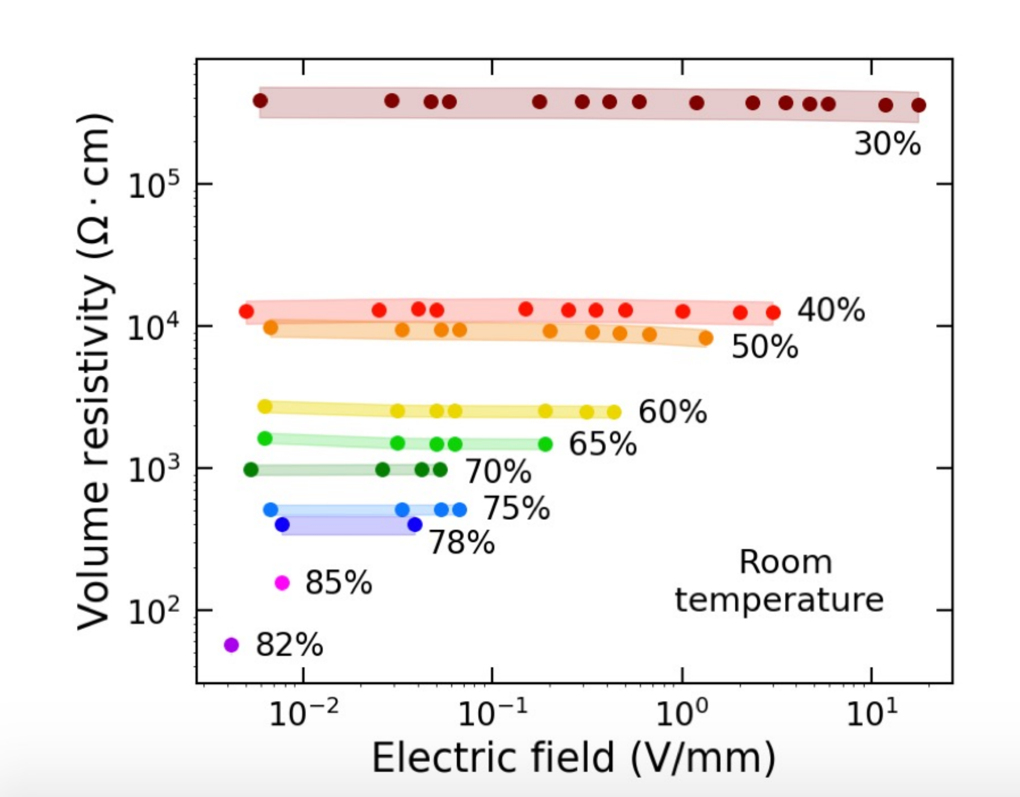
Characterized behavior with respect to E field, temperature, time

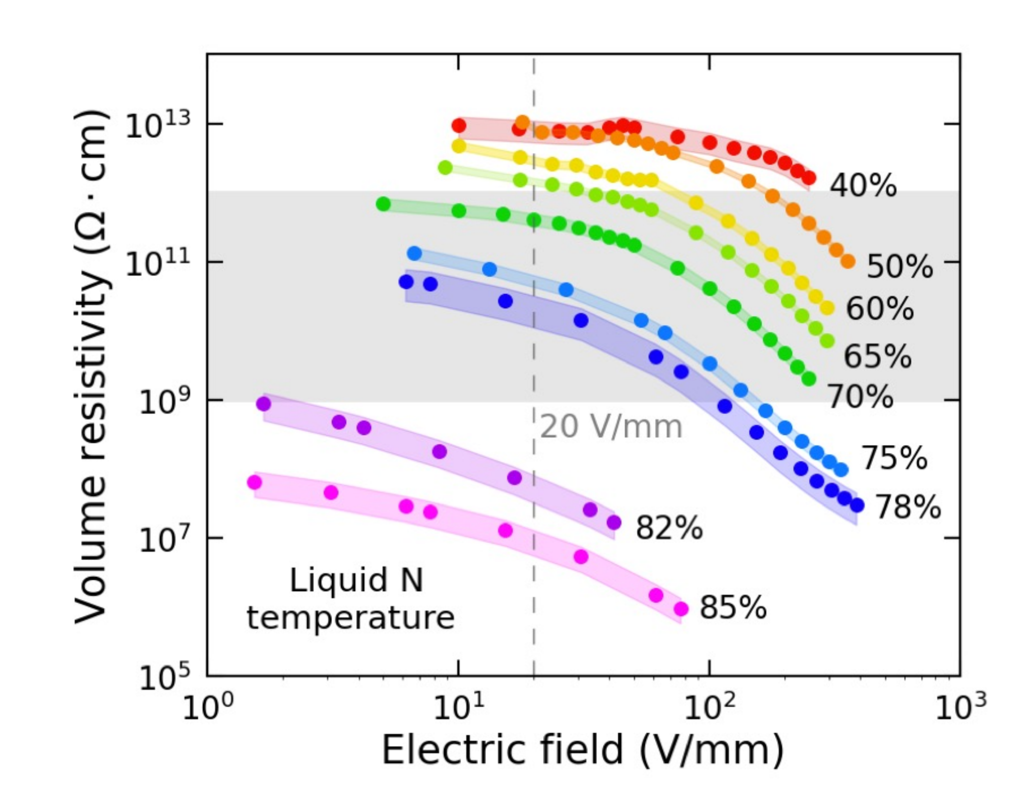
Aging test



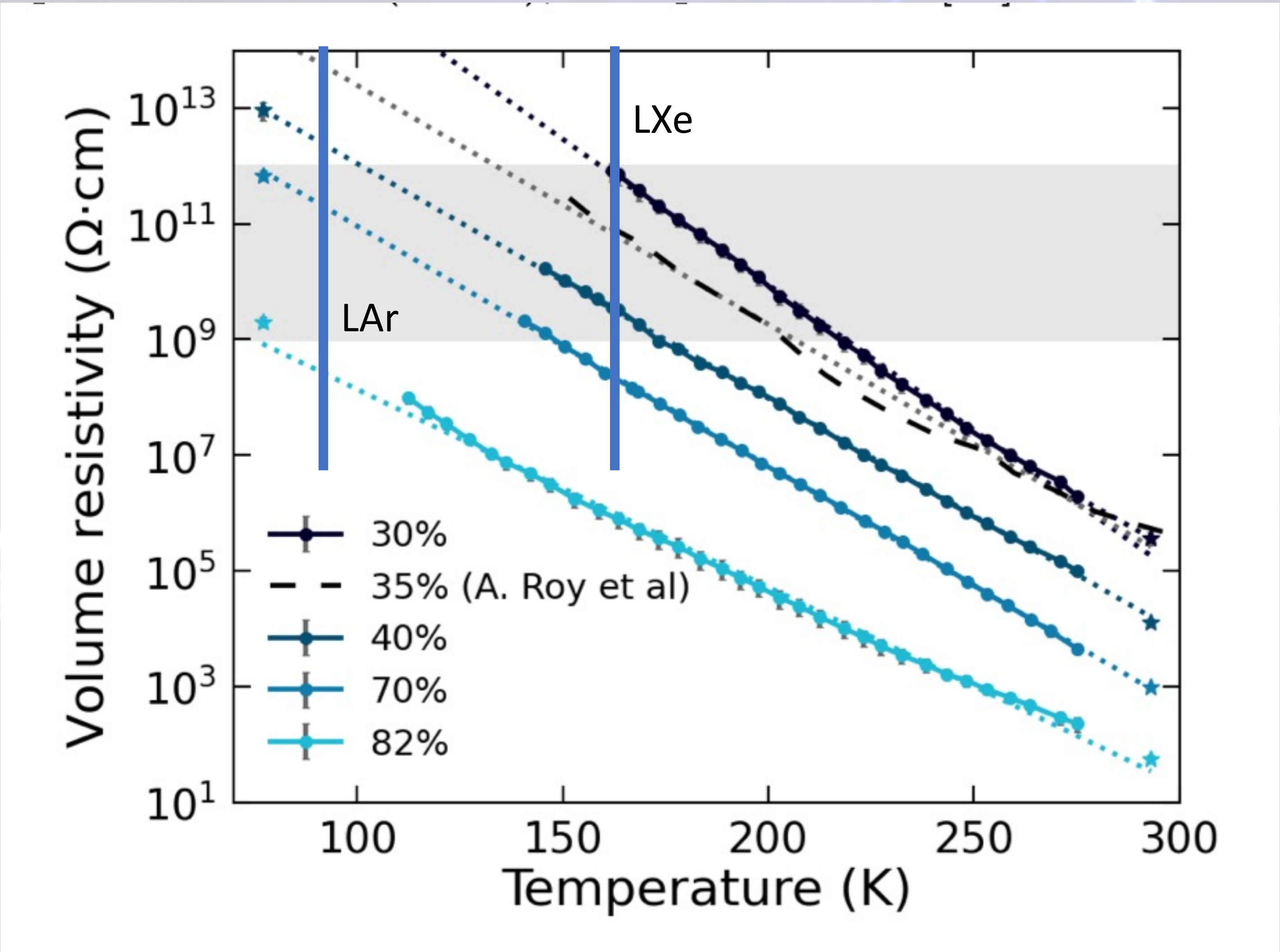
Transported charge (C/cm²)
0.0 0.2 0.4 0.6 0.8 1.0
70% @ Room temperature
Volume resistivity (kΩ·cm)
0 1 2 3 4 5
0 2000 4000 6000 8000 10000
Time (s)
Transported charge (mC/cm²)
0 1 2 3 4 5 6 7 8
70% @ Liquid N temperature
Volume resistivity (GΩ·cm)
0 1 2 3 4 5
0 2000 4000 6000 8000
Time (s)

Linearity


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

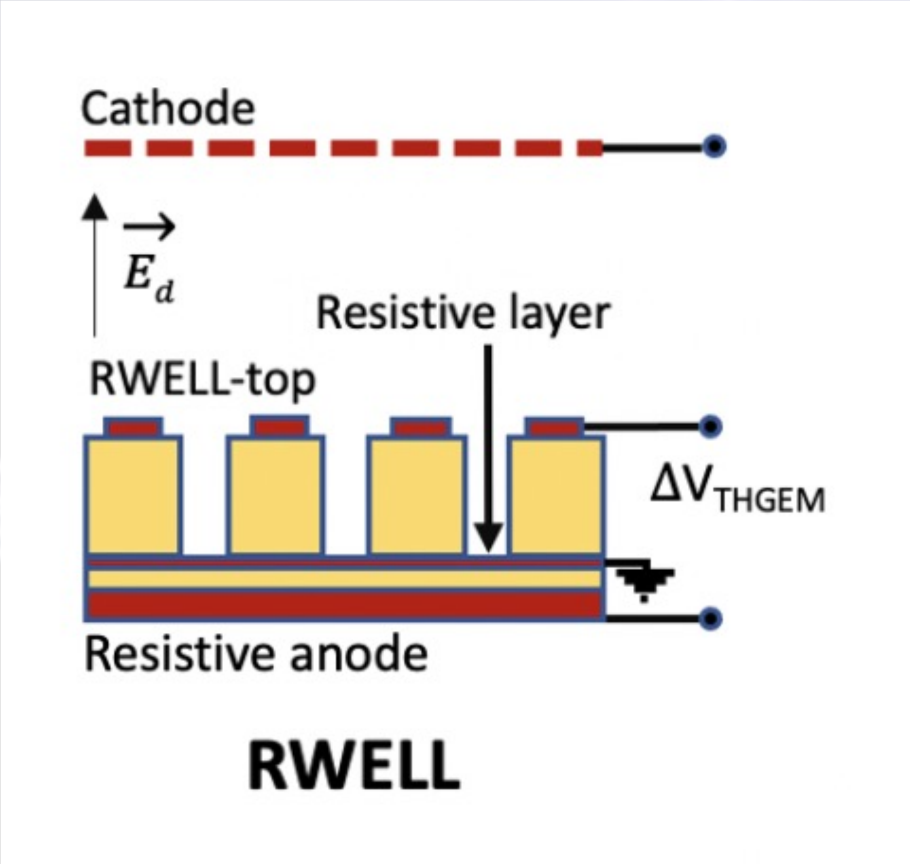

Volume resistivity (Ω·cm)
Electric field (V/mm)
20 V/mm
40%
50%
60%
65%
70%
75%
78%
82%
85%
Liquid N temperature

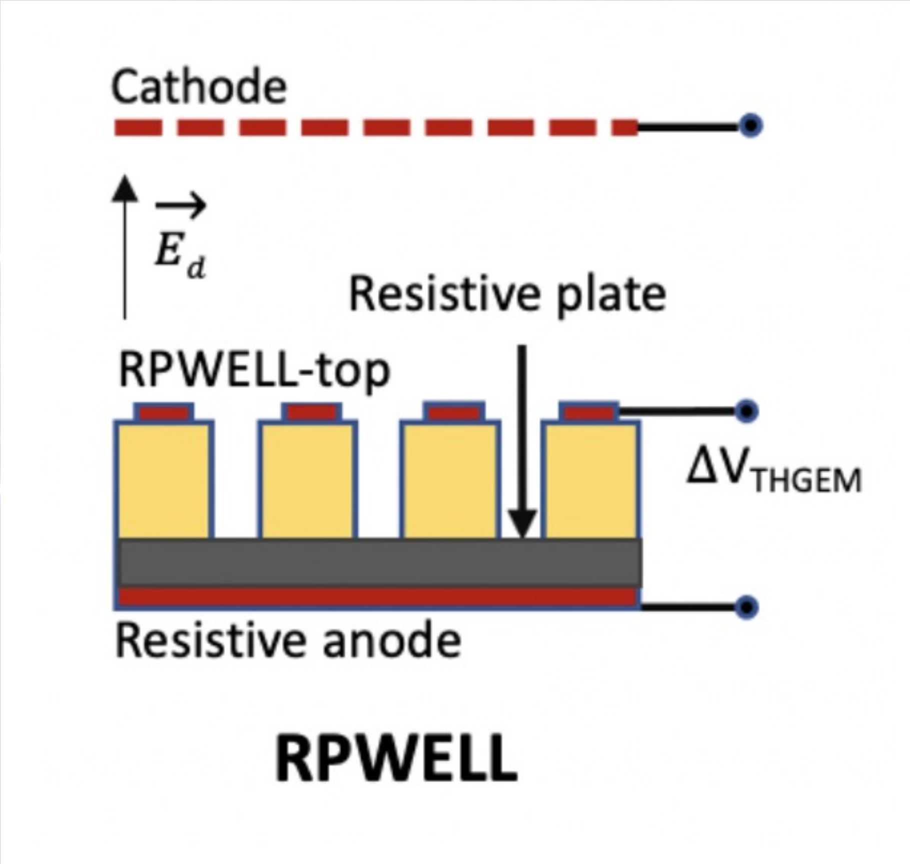
R-T curve



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

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

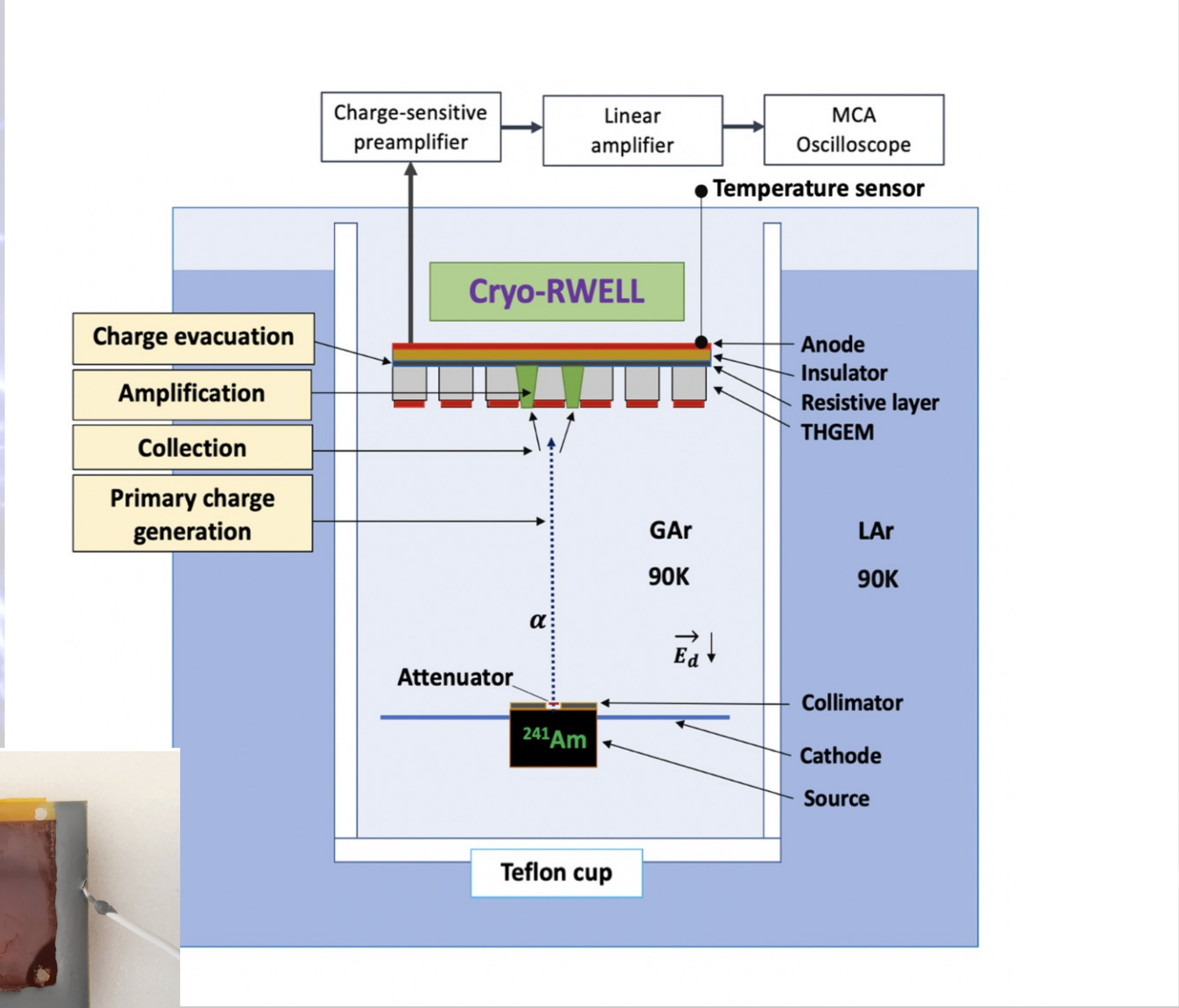


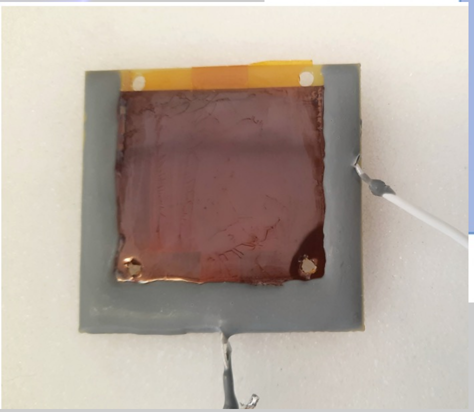


Test in detector: setup

- 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)



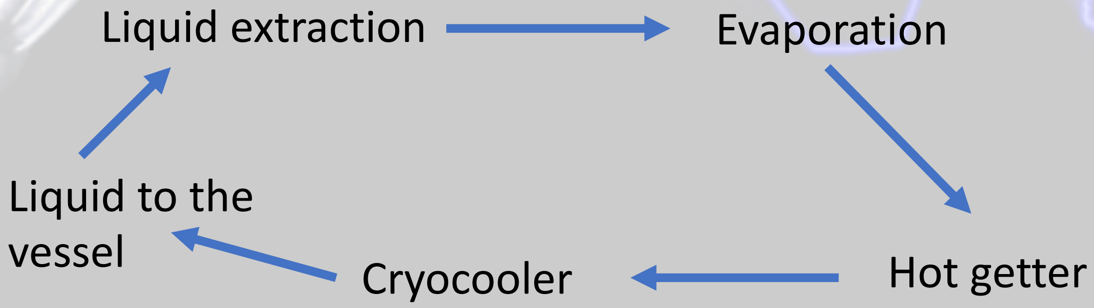


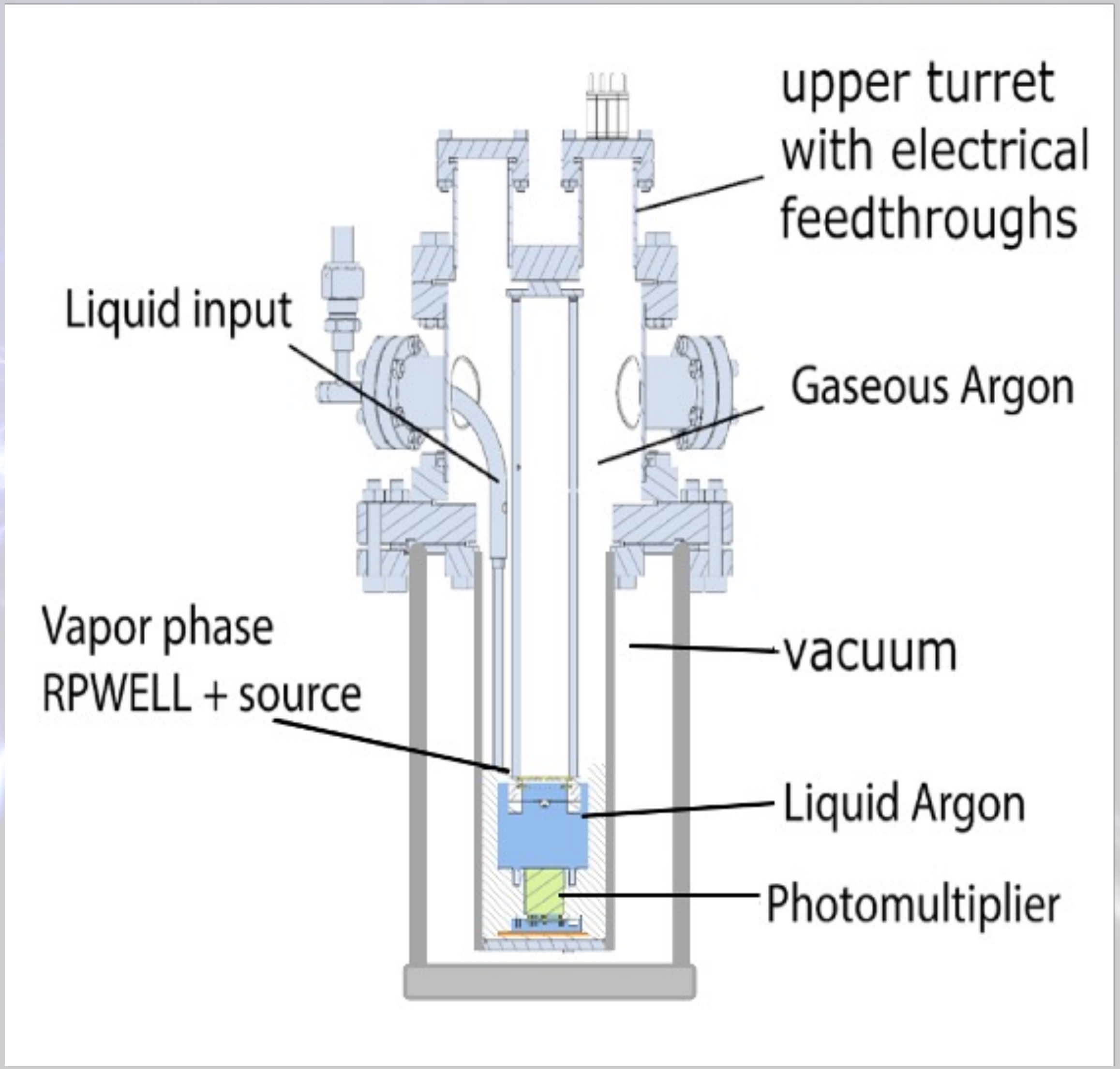
Test in detector: setup -2

High purity:

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

- Argon circulated through hot getter during operation





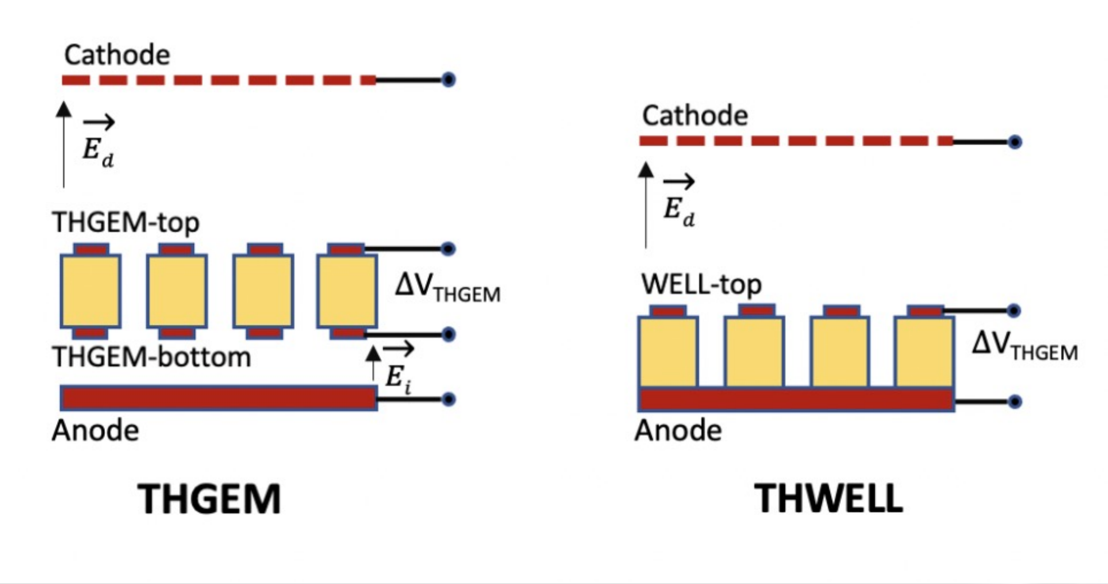
Starting point: unprotected structures

THGEM and THWELL ->

-same experimental conditions

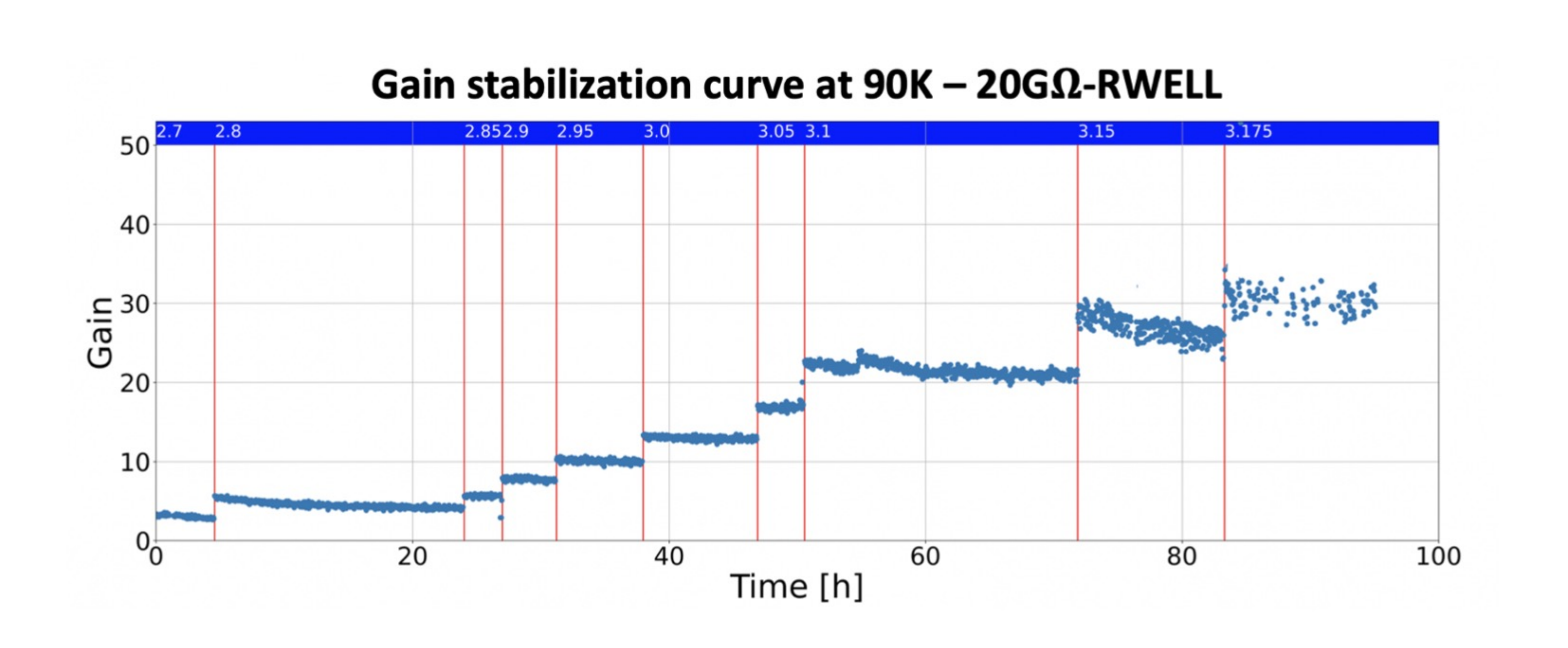
-single discharge makes stable gain operation impossible,
power supplies had to be restarted

- max gain 6 and 8 respectively

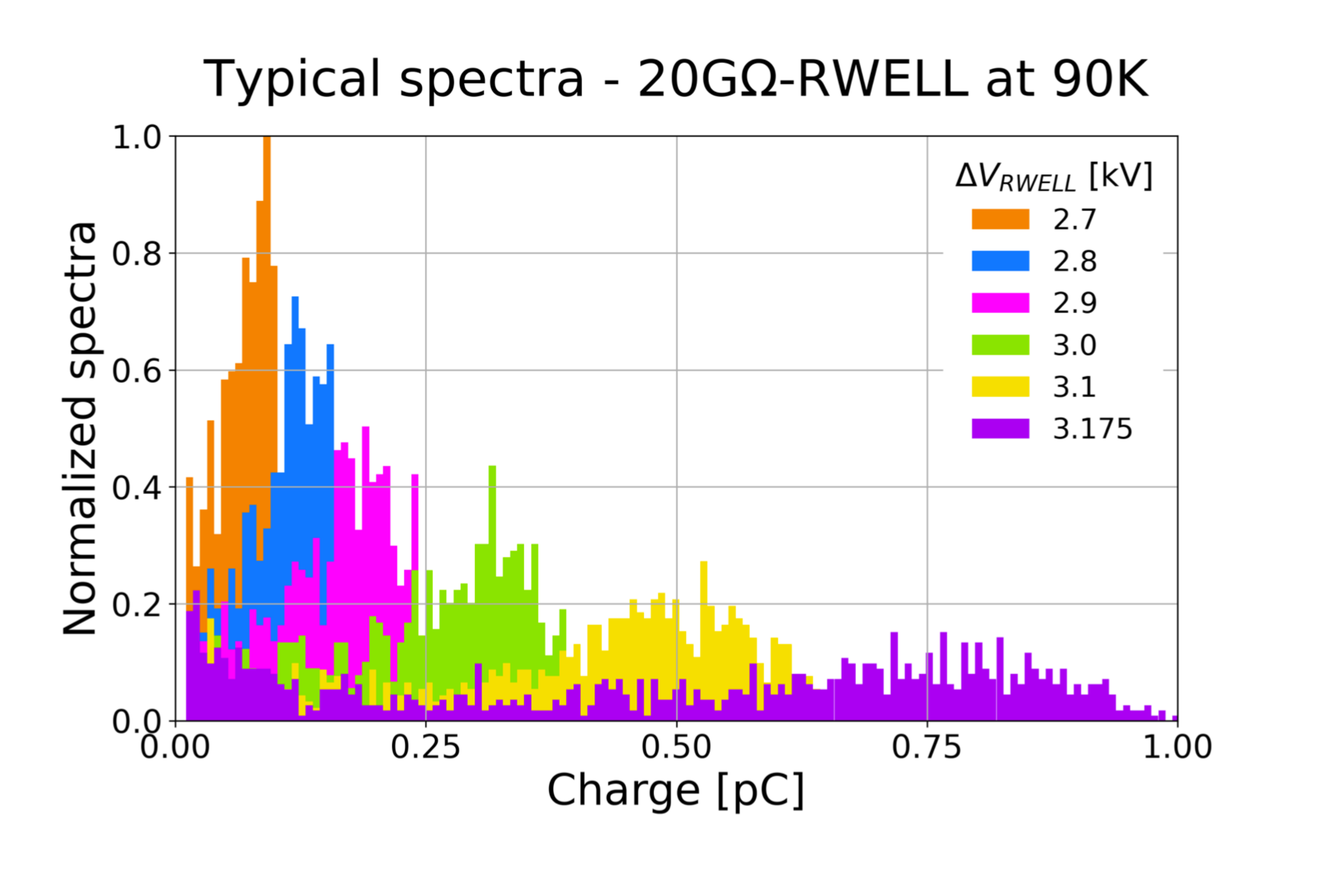


$$G_{Eff} = \frac{P_{Amplif}}{P_{Coll}}$$

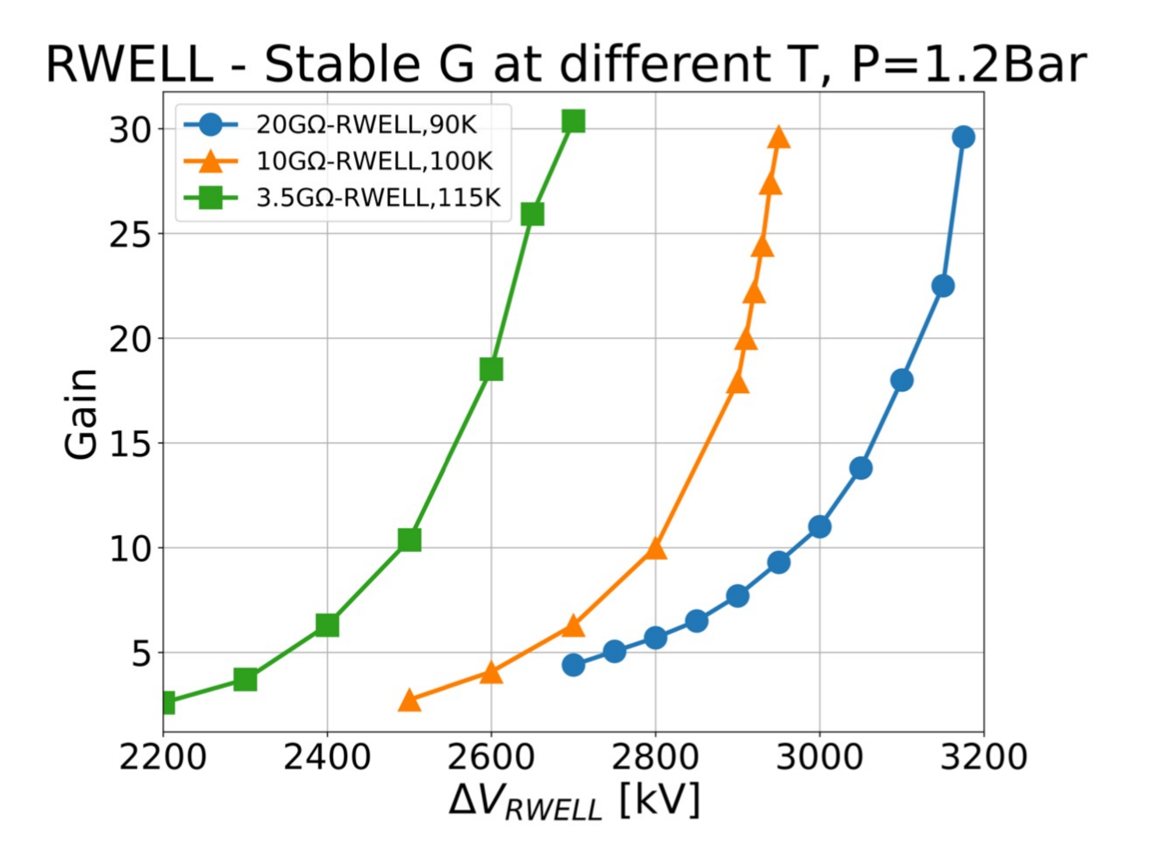
RWELL: gain curve

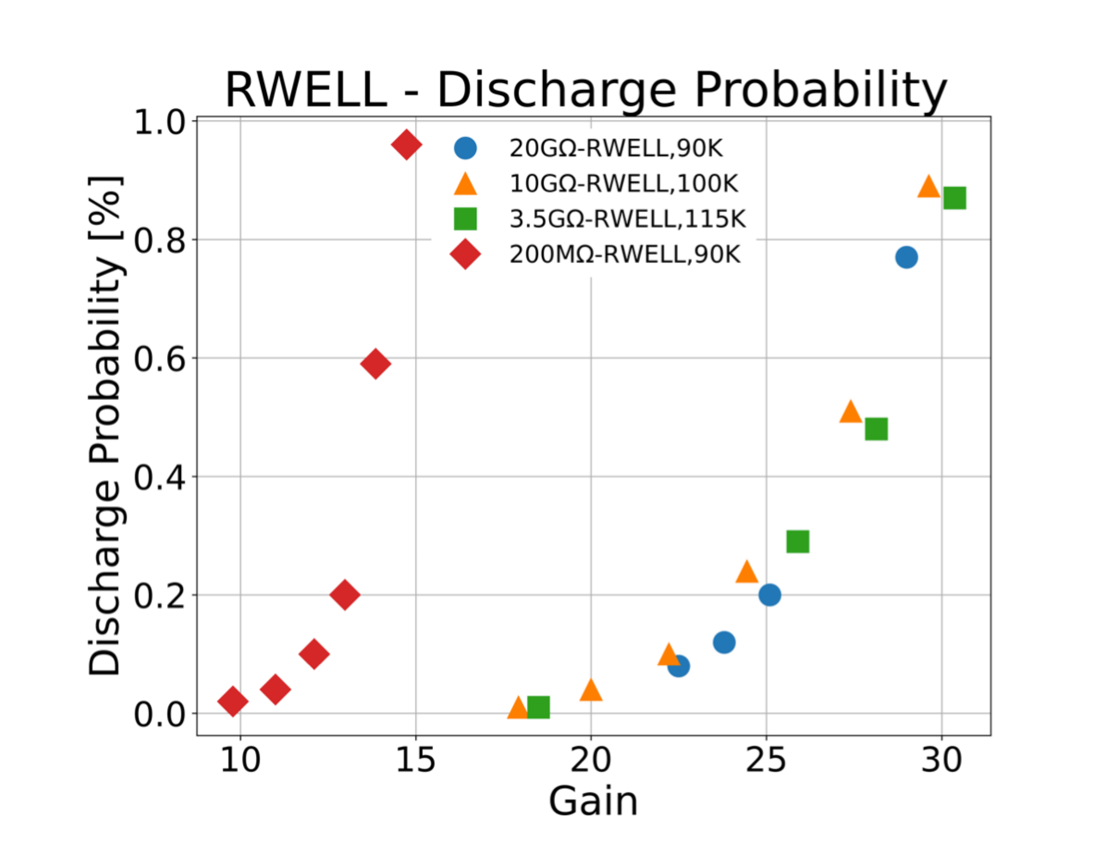


RWELL: spectra

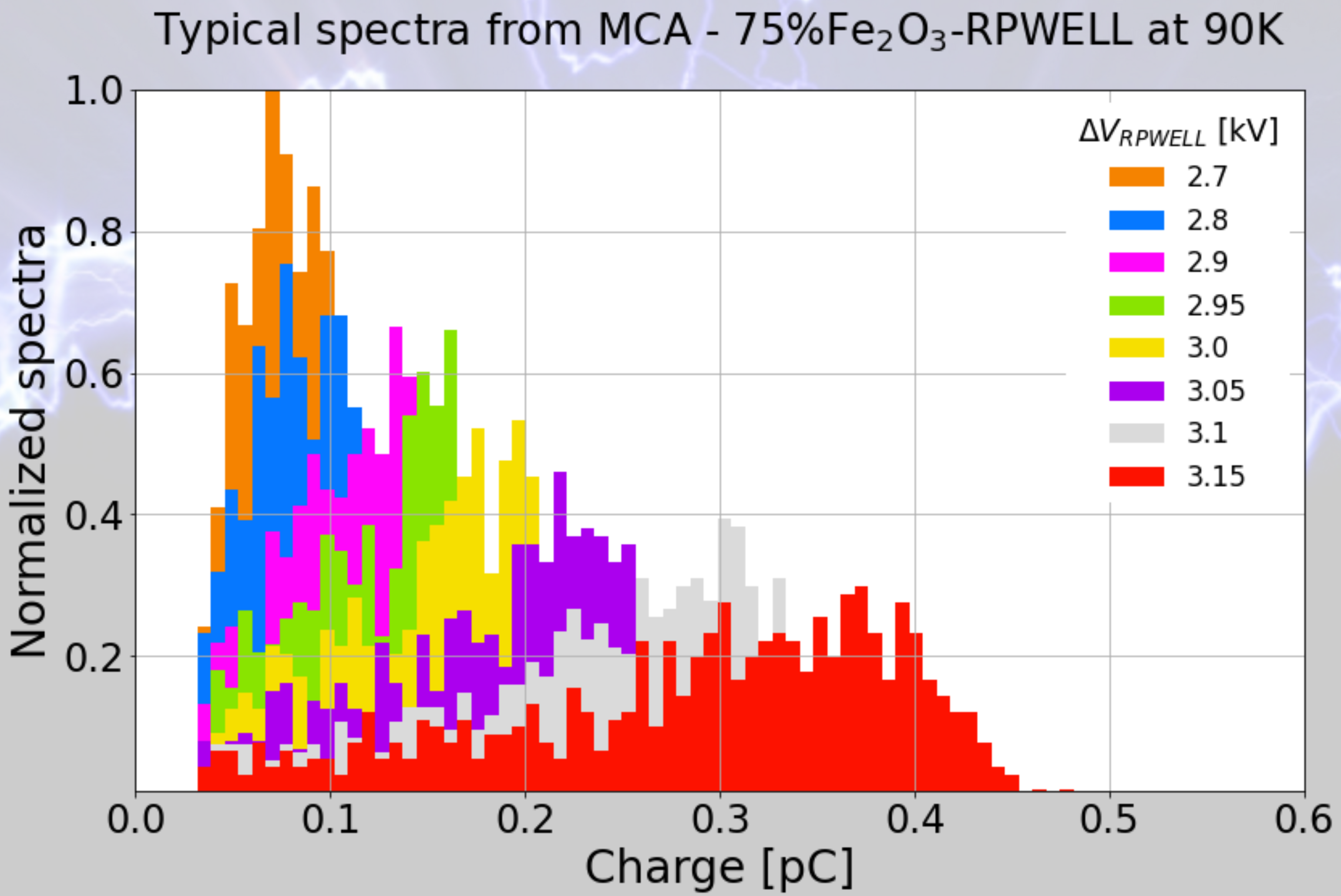


RWELL: comparison

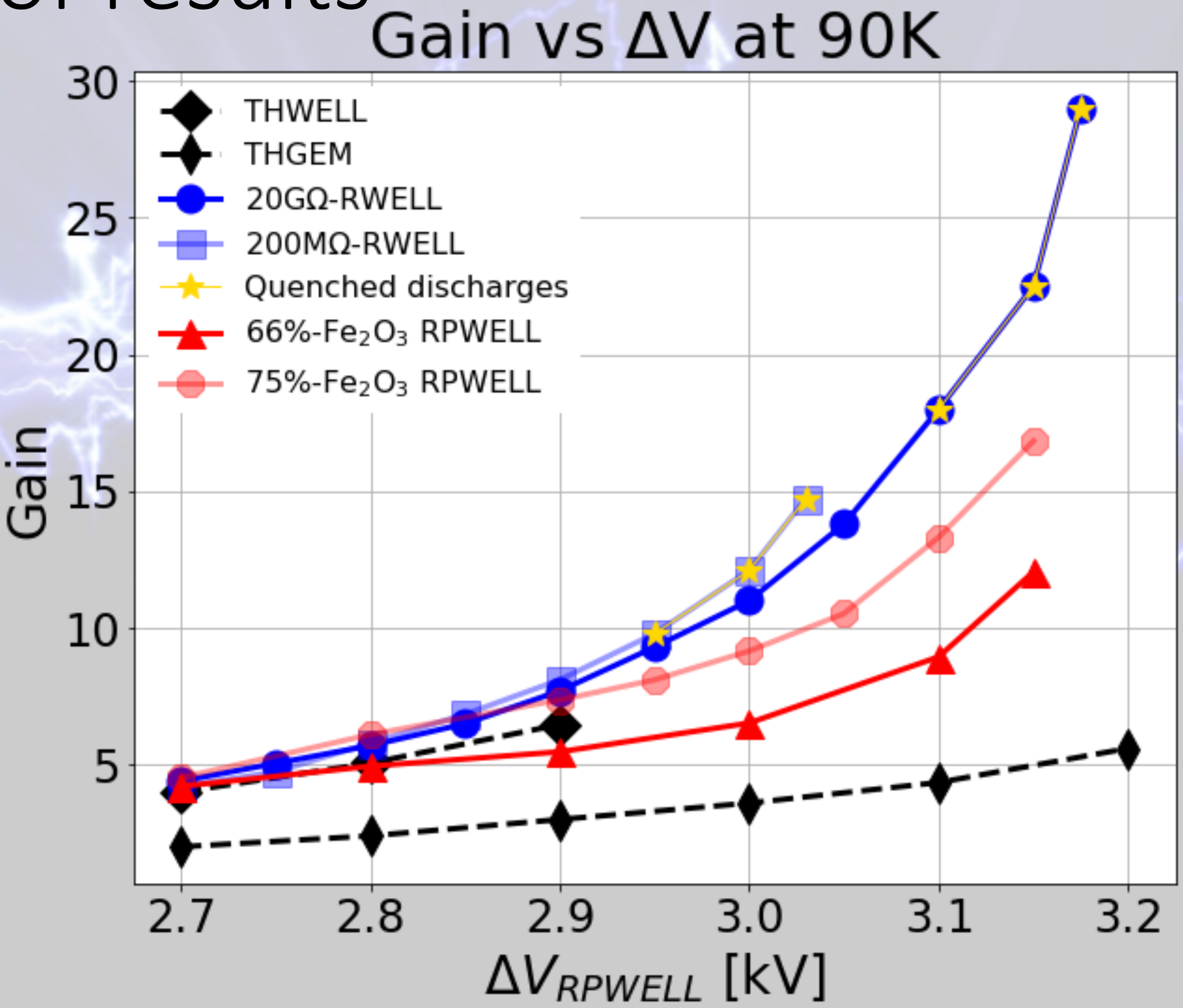




RPWELL: spectra



Summary of results



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 at 90 K with DLC layers, obtaining a maximum stable gain of 30 with a 20 Gohm/sq sample

- We managed to operate the detector with two different ceramics samples, having 75% and 65% Fe2O3 concentration, obtaining a maximum stable gain of 16

Detector	$\mathbf{V}_{\text{Max}}$ **[kV]**	$\mathbf{G}_{\text{Max}}$	$\mathbf{P}_d\|_{\text{G}_{\text{Max}}}$
75%Fe_2O_3-RPWELL	3.15	16	0
65%Fe_2O_3-RPWELL	3.15	12	0
20G$\Omega/\square$-RWELL	3.175	30	~1 %
200M$\Omega/\square$-RWELL	3.025	15	~1 %
THWELL	2.9	8	0
THGEM	3.2	6	0

Thanks for your attention!