Cryogenic Resistive-WELL :
high gain with quenched discharges

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Scope – Generic R&D

- What are the desiderata for a readout to be innovative in the context of large-volume noble liquid DP-TPCs? (and in particular, in LAr)
  - Cost-effective ✓ LEM
  - Robustness ✓ LEM
  - Reach high gain at stable operation ✗ ✗ LEM

- Testing new concepts
  1. Bubble-asisstted LHM – Ref.1
  2. Bubble-free LHM – Ref.2
  3. Floating Hole Multiplier – Ref. 3
  4. **RWELL – this talk**
  5. RPWELL – next project

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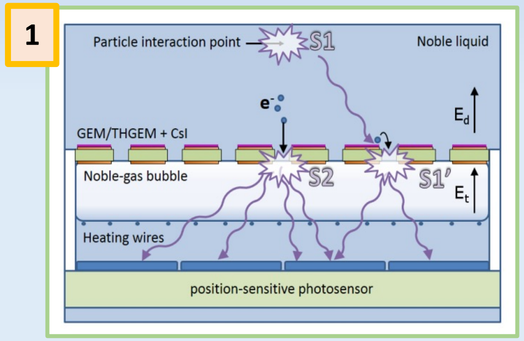

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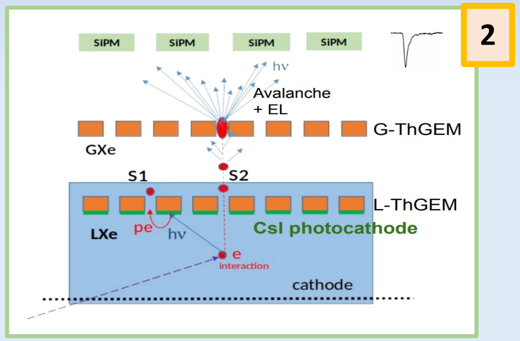

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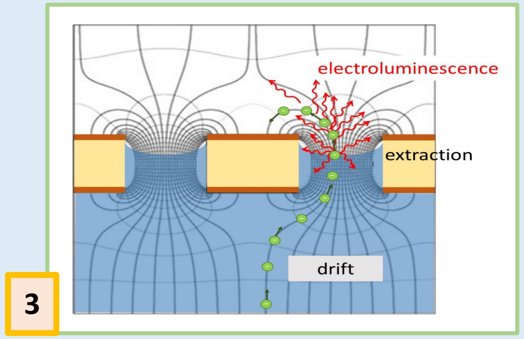

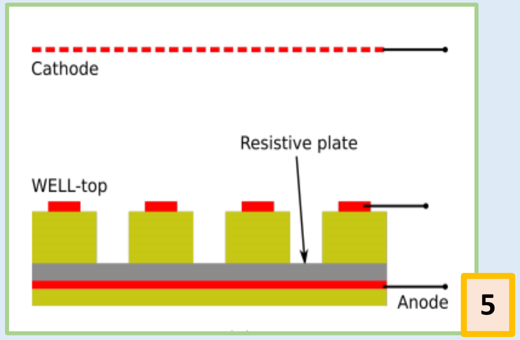

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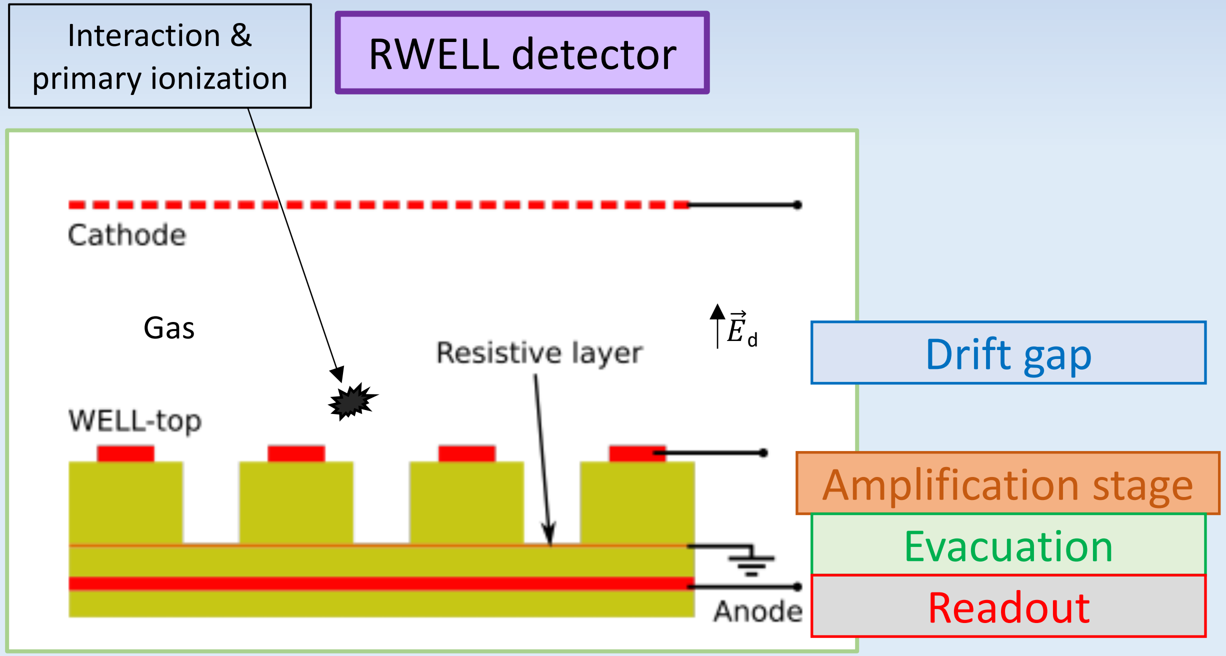
1) https://arxiv.org/pdf/1912.10698.pdf

2) https://events.camk.edu.pl/event/47/contributions/377/attachments/126/281/LIDINE-2022%20The%20Bubble-Free%20Liquid%20Hole-Multiplier-v2.pdf

3) https://events.camk.edu.pl/event/47/contributions/379/attachments/122/275/LIDINE2022_Chepel_presentation%20.pdf

The RWELL concept



Interaction & primary ionization

RWELL detector

Drift gap

Amplification stage

Evacuation

Readout

Typical resistivity used at RT – 10MΩ/sq

Structure:

- Single-sided THGEM electrode
- Coupling to readout anode via a thin resistive layer deposited on an insulator
- Amplification field defined by ΔV_{RWELL}
- Drift region created by a cathode (mesh)

Operation principles:

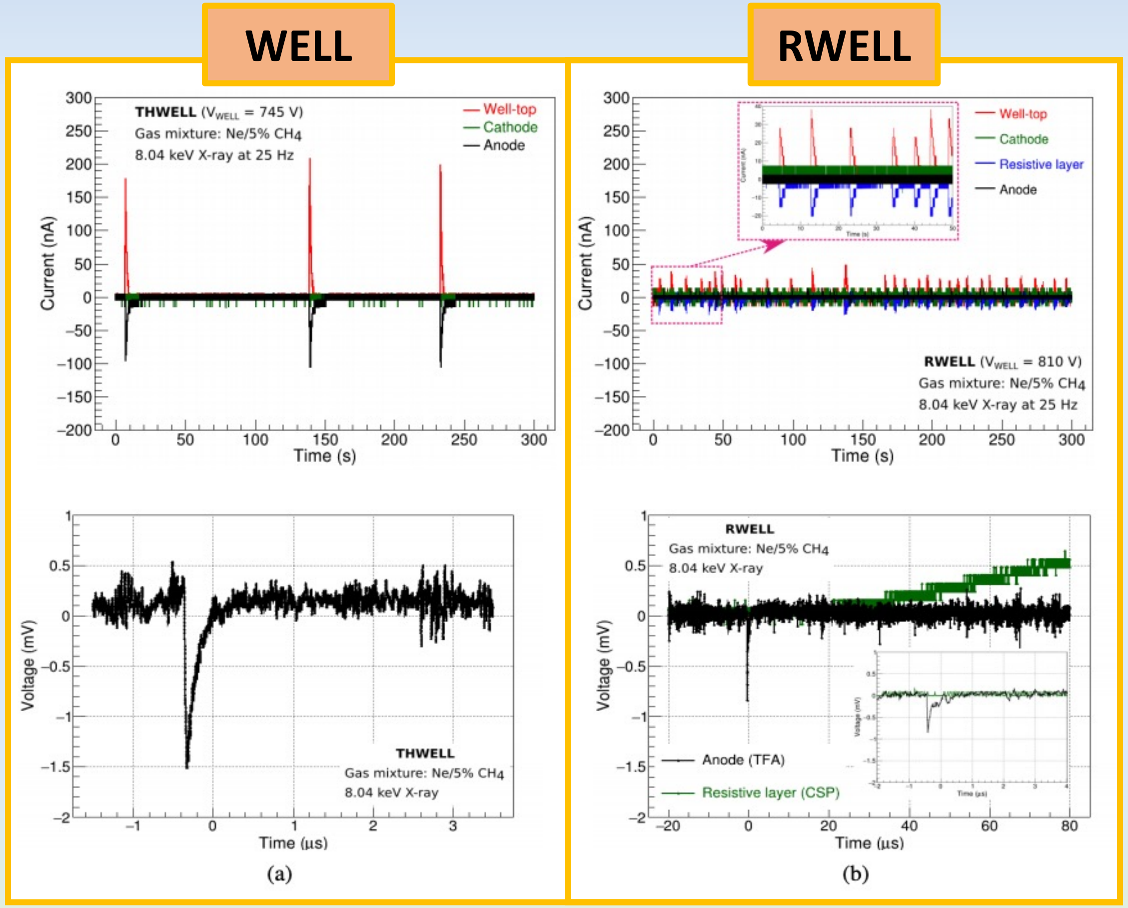
- Primary electrons generated in the drift gap
- Drift into the amplification stage and undergo charge avalanche multiplication
- Charge evacuation to ground via the resistive layer
- Signals induction on the readout anode by the movement of charges (electrons and ions).

L. Arazi et al., Laboratory studies of THGEM-based WELL structures with resistive anodes, https://arxiv.org/abs/1310.6183

RWELL – advantages at RT

Advantage of RL:

- ✓ protect the multiplier, its anode, and the readout electronics from discharge damages;
- ✓ minimize dead-time effects following a discharge.



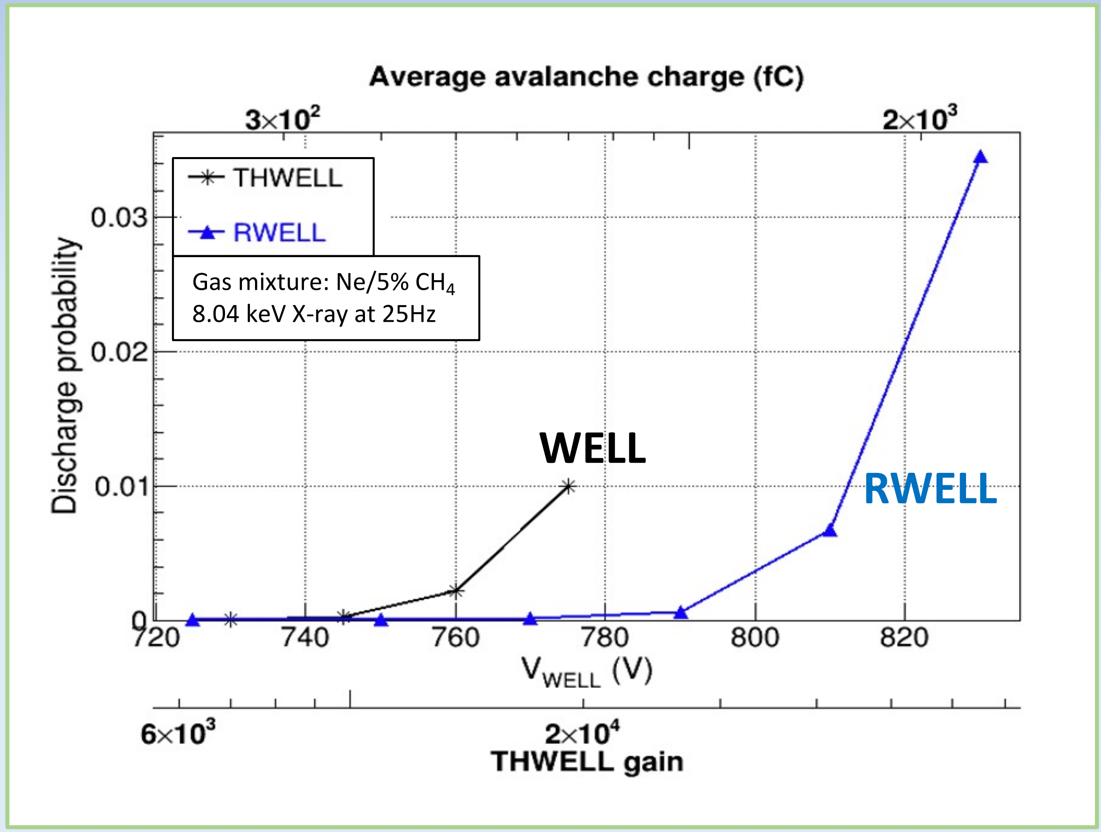
Observations

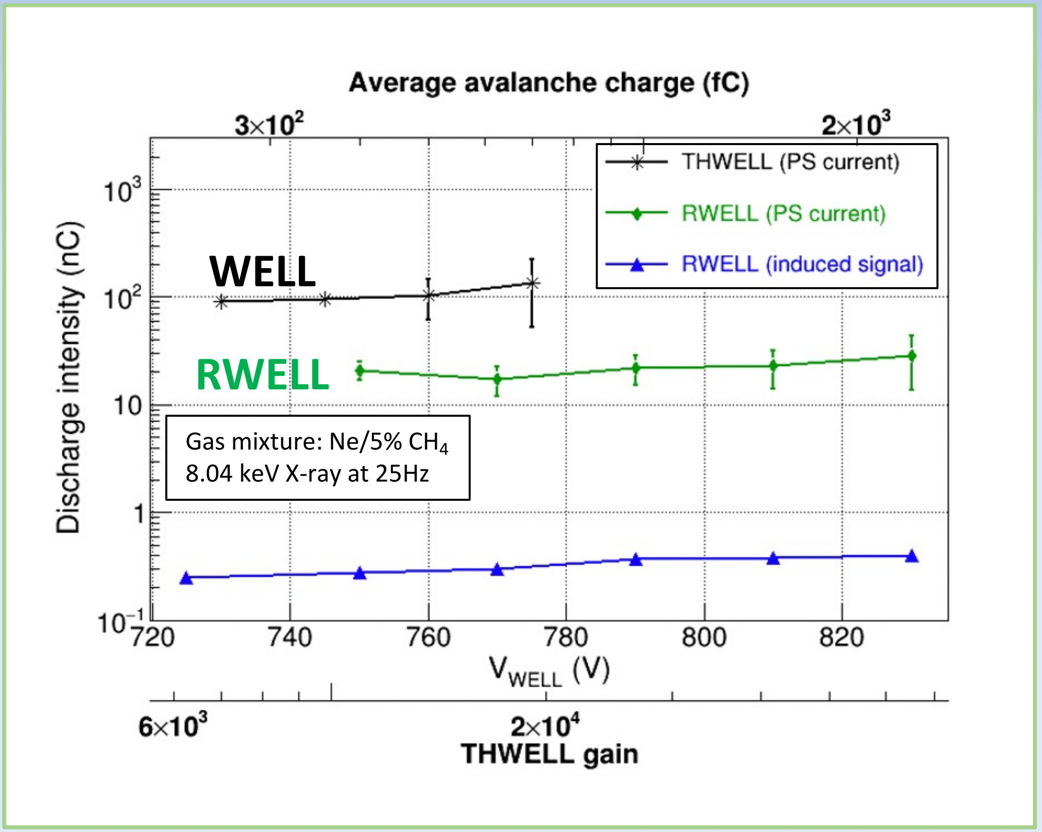
1) Discharge in RWELL are quenched: when the gas breakdown occurs, a huge amount of charge is accumulated inside the hole and it is able to reduce the local electric field. This results in a quenching of the discharge energy;

2) A voltage drop is observed: it is caused by the charge movement within the resistive layer and depends on the rate.

A. Jash et al., Electrical breakdown in Thick-GEM based WELL detectors, https://iopscience.iop.org/article/10.1088/1748-0221/17/11/P11004/meta

Discharge probability & Energy quenching at RT

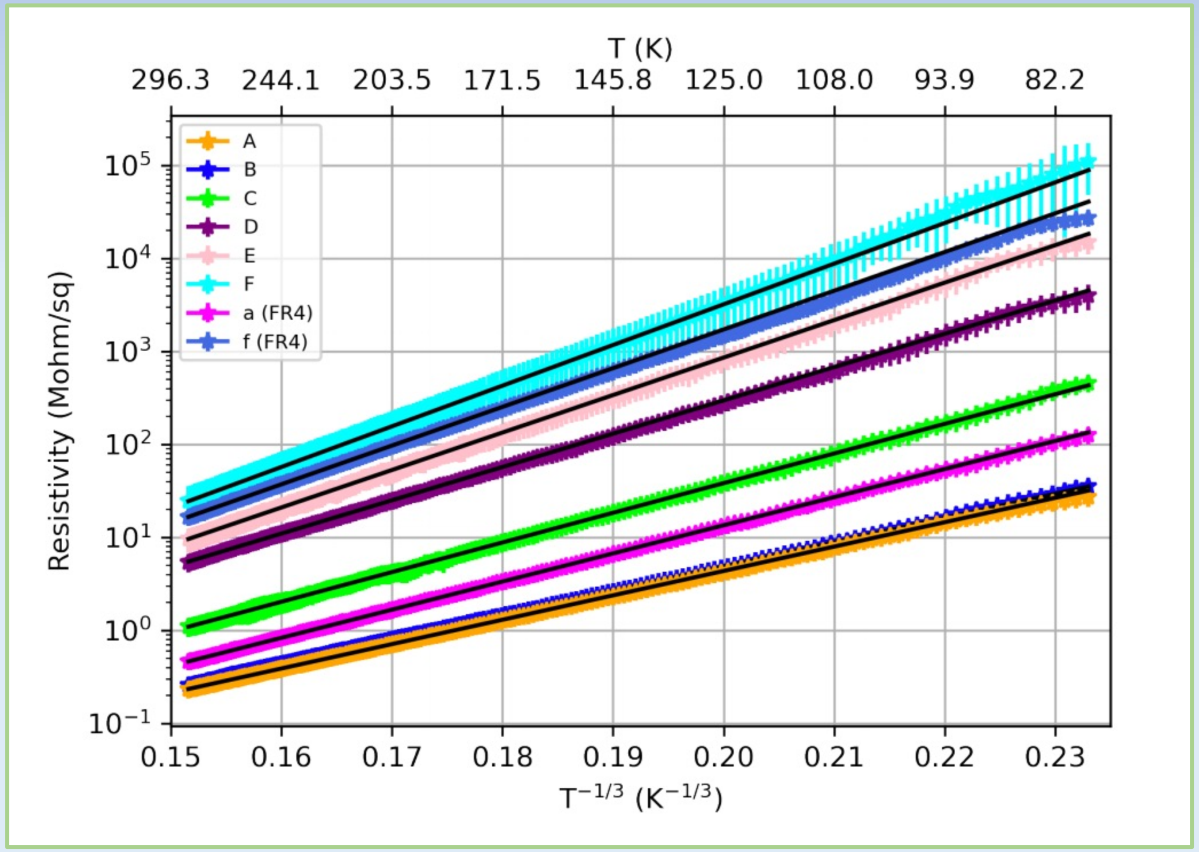




Discharge probability doesn’t improve significantly but discharge energy yes – discharge quenching factor ≈70

A. Jash et al., Electrical breakdown in Thick-GEM based WELL detectors, https://iopscience.iop.org/article/10.1088/1748-0221/17/11/P11004/meta

Resistive layer for cryogenic temperatures



R_S as a function of $T^{-1/3}$ (lower x-axis) and T (upper x-axis) in a logarithmic representation

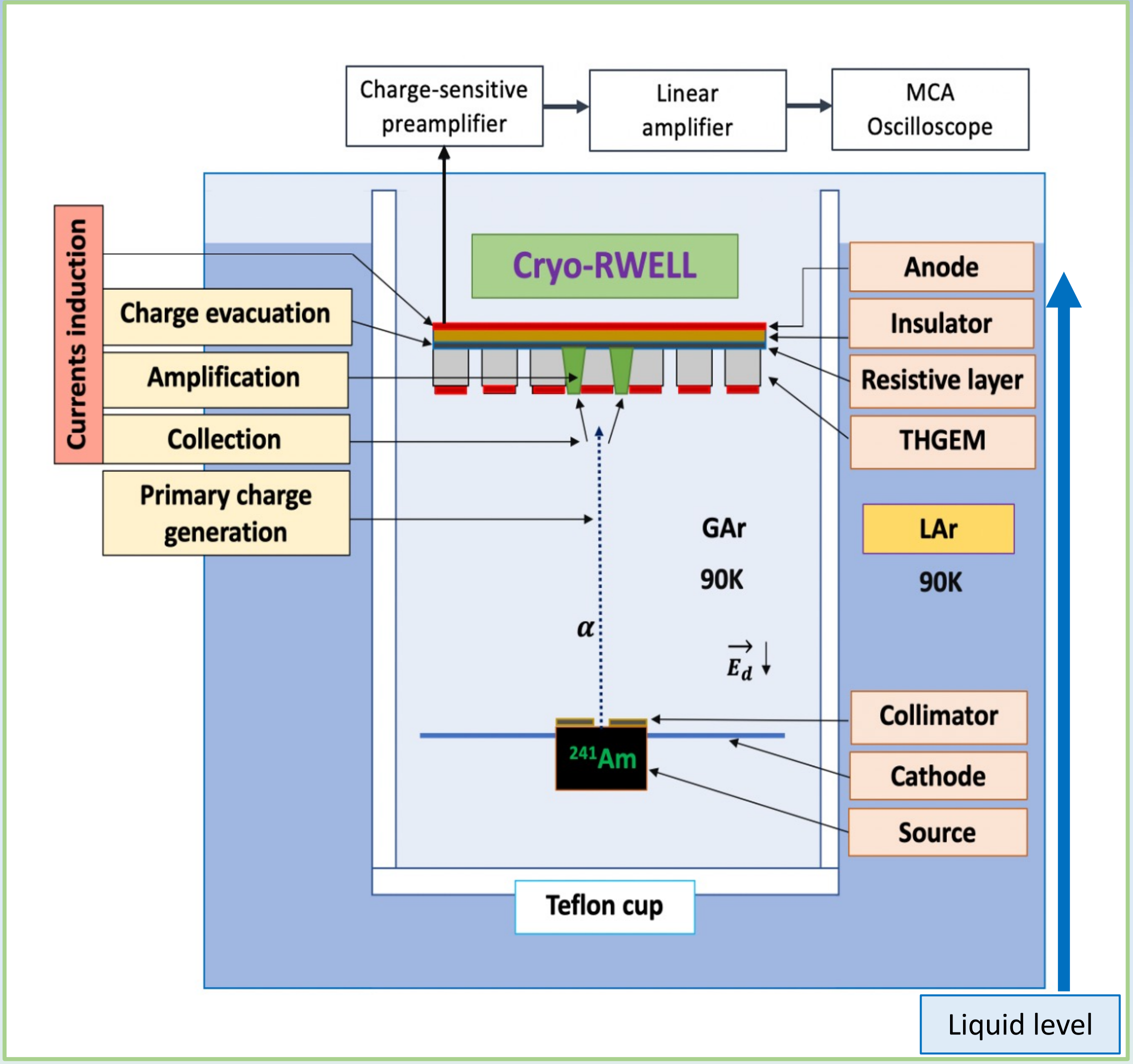
- A characterization of diamond-like carbon (DLC) coatings at cryogenic temperatures was produced;
- DLC layers possess a tunable electrical resistivity;
- Good behaviour of DLC layers:
  - linearity (ohmic)
  - surface uniformity
  - stability with time and transported charge
  - low chemical reactivity
  - tolerance to radiation
- Exponential dependence on T

↓

They can be a good option for a cryo-RWELL

S. Leardini et al., Diamond-like carbon coatings for cryogenic operation of particle detectors, https://arxiv.org/abs/2209.15509

Small TPC setup



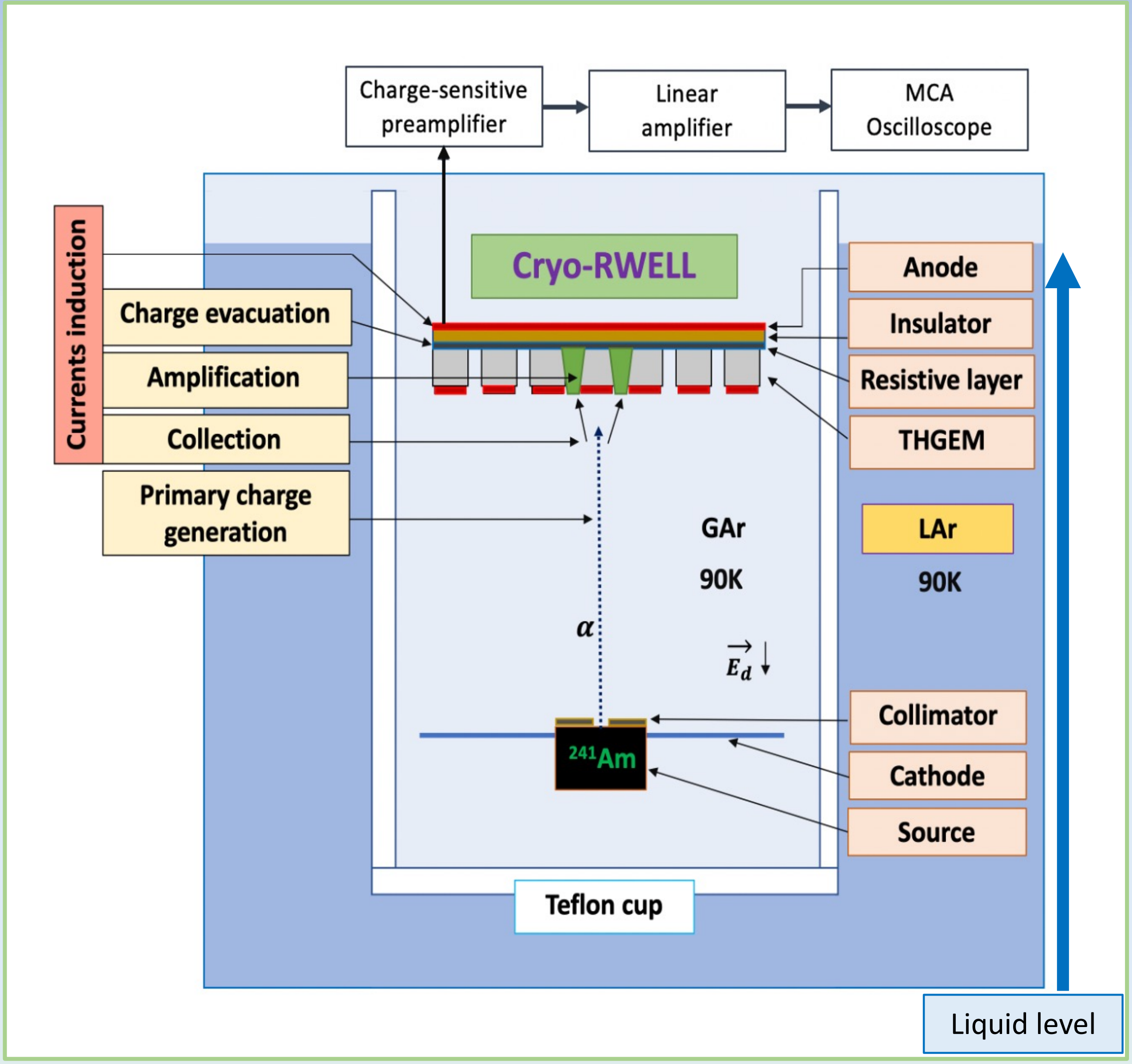
SETUP

- Single-sided THGEM= 0.8 mm thick, 3x3cm^2
- 15mm drift gap, E_d = 0.5kV/cm
- DLC layer – 200MΩ/sq, 20GΩ/cm^2 at 90K
- 5.5 Mev Am source (10Hz)

- Attenuation + Collimation
- 4MeV alpha in gaseous argon
- Number of primaries ~ 10^5

The system is equipped with an RGA to measure residual contamination, Ar is 99.999% pure and constantly recirculated through with a purifier (SAES/Entegris) [<1ppb].

Setup - Properties



SIGNAL SHAPE CONSIDERATIONS

- Track perpendicular to the detector plane
- Track lenghts about 10 mm
- Most energy (30%) deposited in the Bragg peak

Drift

- V_e = 2mm/μs at 100K, 1.3Bar
- Δt_{drift} ~5-7μs

Multiplication at 35kV/cm

- V_e = 30 mm/us -> 350ns
- V_i = 0.14 mm/us -> 3.5us (Ar^{++}) < 7us < 14us (Ar_2^+)

- signal shape dominated by different time constants

HW Ellis, *Atom.Data Nucl.Data Tabl.* 22 179-217
Y. Kalkan *et al* 2015 *JINST* **10** P07004

Operations and measurements methodology

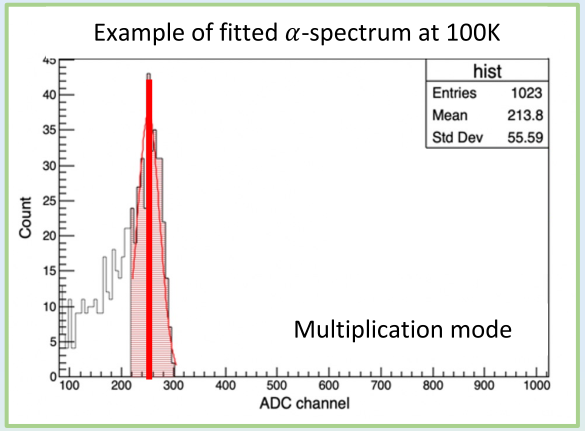
- The RWELL was operated at 3 different temperatures – 90K, 100K , 115K; P = 1.2 Bar;
- The measurements were performed recording signals in the following way:

1) DETECTOR | PREAMPLIFIER | AMPLIFIER | MCA

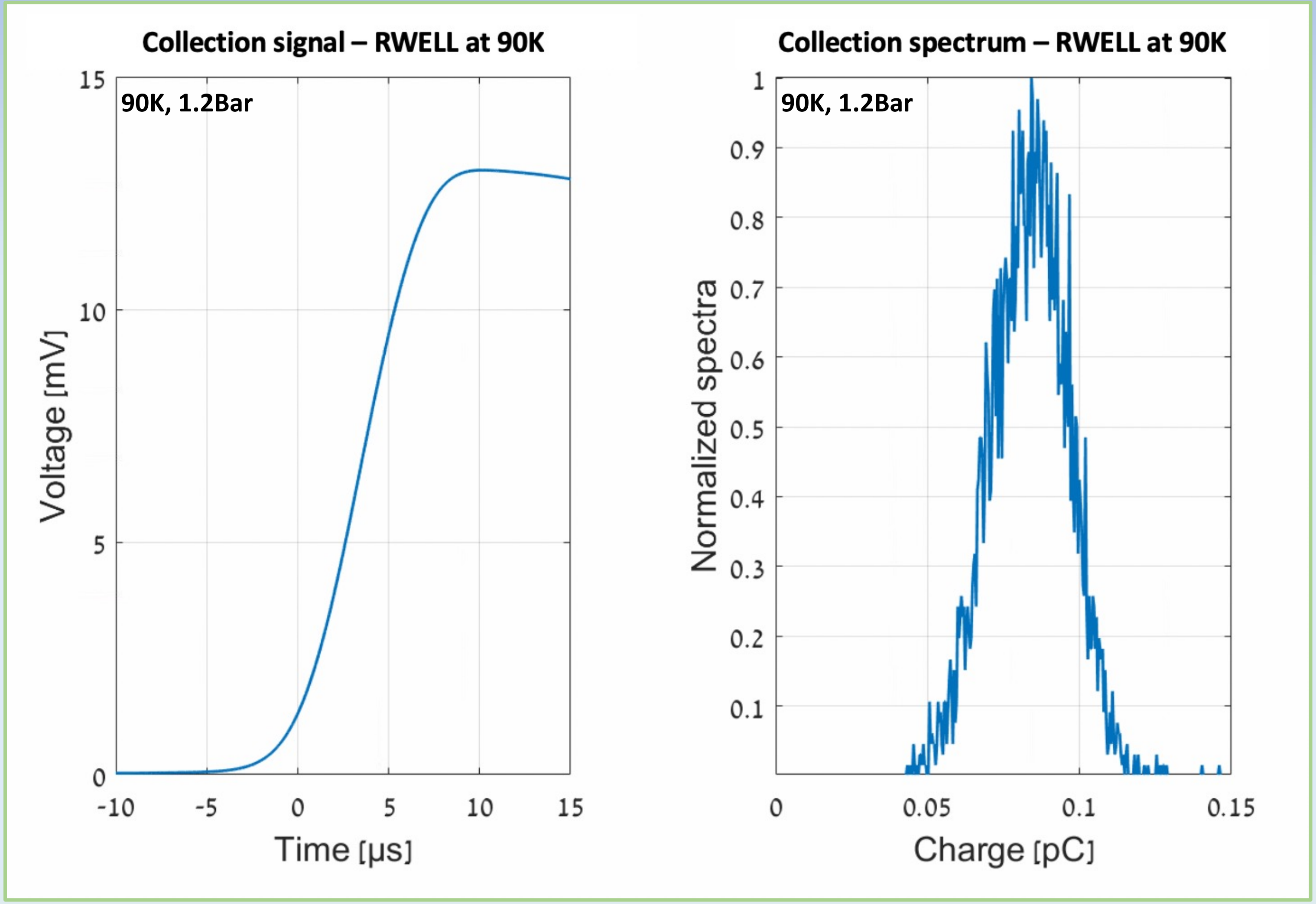
2) DETECTOR | PREAMPLIFIER | OSCILLOSCOPE | Data Analysis

$$G_i = \frac{P_i^{Multiplication}}{P_i^{Collection}}$$

- Detector gain stabilization for several hours before recording waveforms;
- **Gain was computed selecting the main peak from the energy spectrum and normalizing it over collection peak**: the latter represents the primary charge deposited in the drift region above the detector operated in ‘ionization chamber mode’


Example of fitted α-spectrum at 100K

Collection – Signals & Spectra



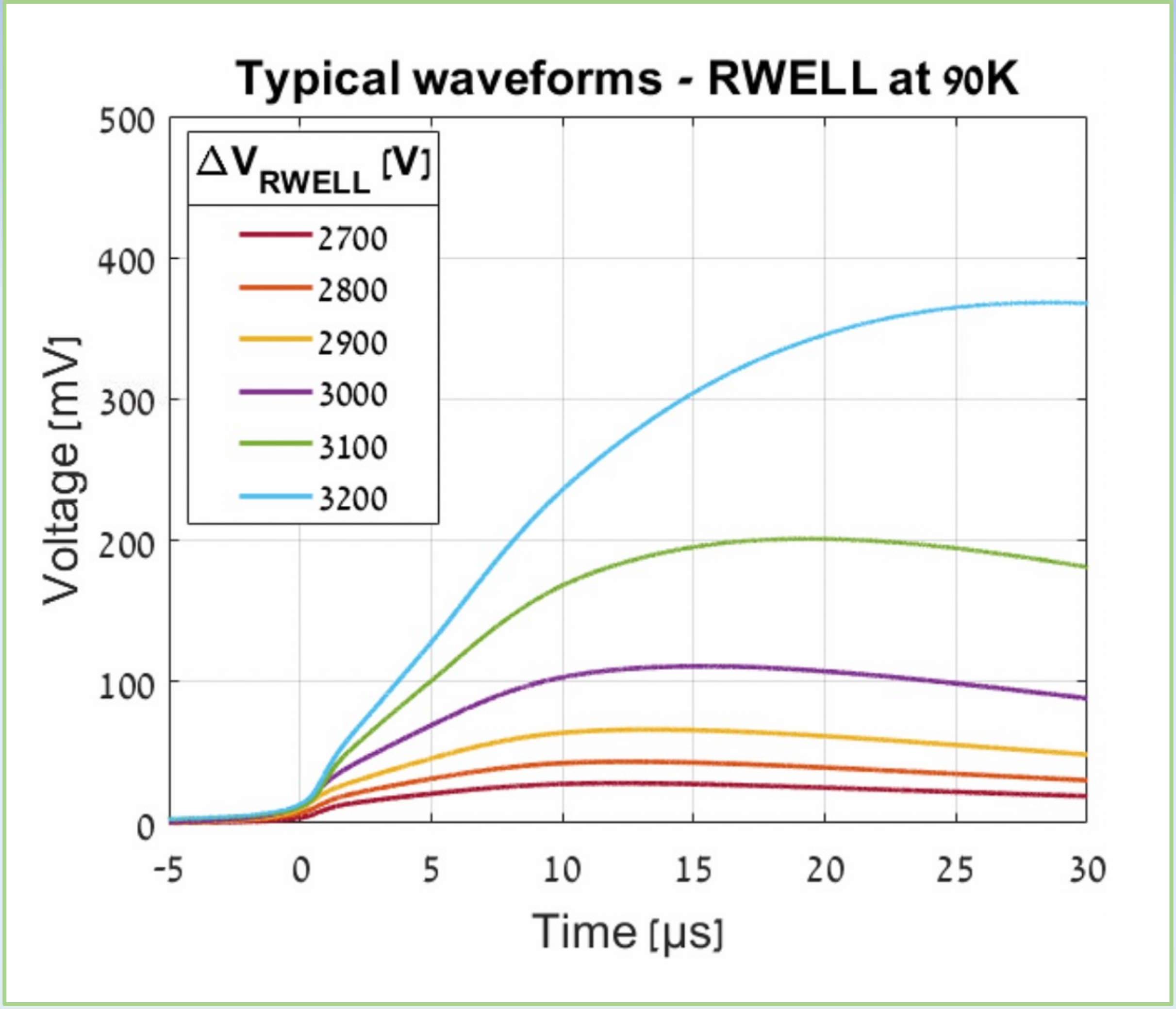
Collection signal – RWELL at 90K

Collection spectrum – RWELL at 90K

- Collection signals and spectra were recorded from the RWELL top;
- Electric drift field E_d = 0.5kV/cm (or 1kV/cm);
- Voltage across the RWELL ΔV_{RWELL} =0V;

- 1k-waveforms per acquisition;
- Risetime ~ 7µs.

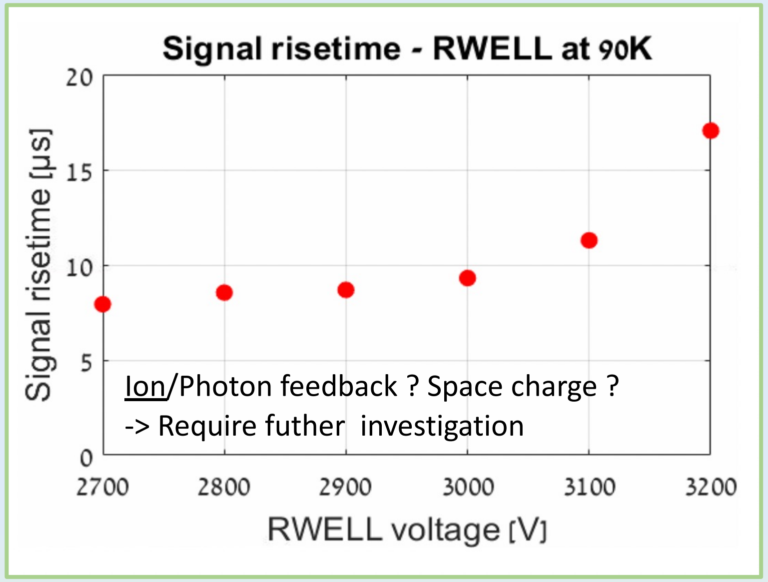
Amplification waveforms at 90K



- Average amplification waveforms were computed averaging over 1k waveforms, aligned and cleaned from noise.

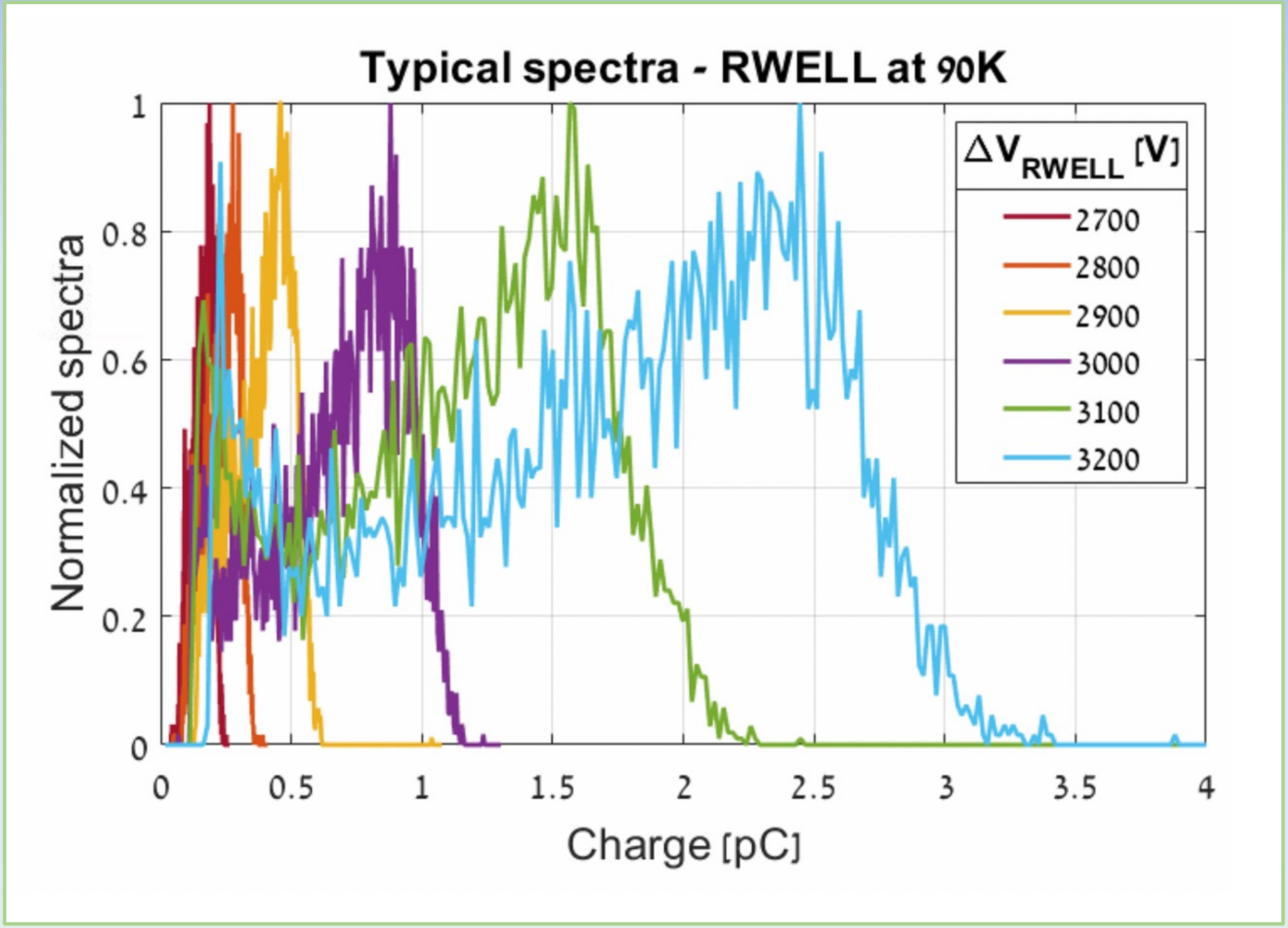
Observations

- Several components
  - Fast 1-2 µs, Slow, Other ?
- Risetime elongation as function of V_{RWELL}



Ion/Photon feedback ? Space charge ?
-> Require futher investigation

Spectra evolution at 90K

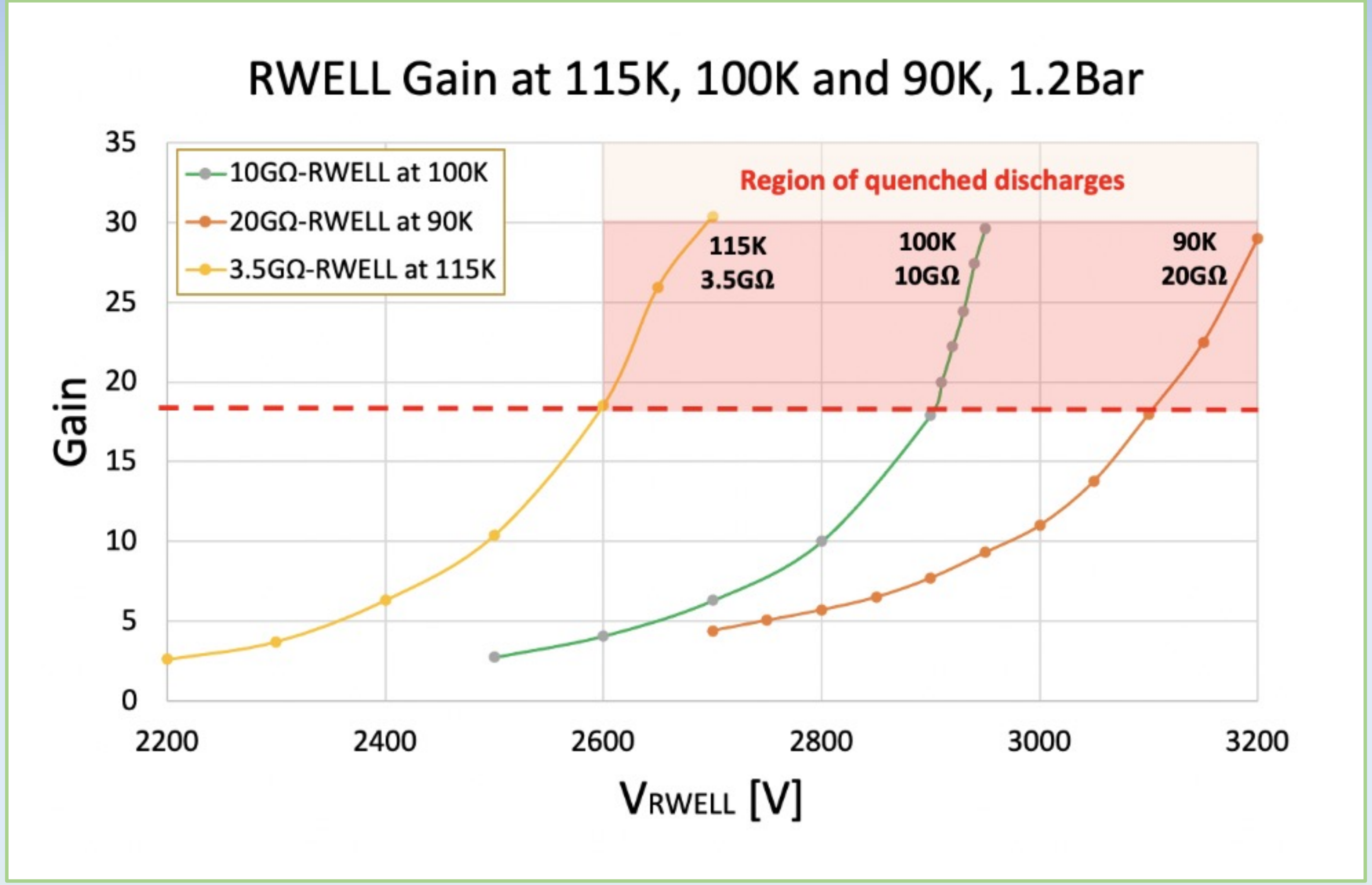


- 5k waveforms in each spectrum
- Each entry corresponds to the peak of the signal

Observations

- As expected, amplification increases with V_{RWELL}
- Shape conservation – peak + low energy tail

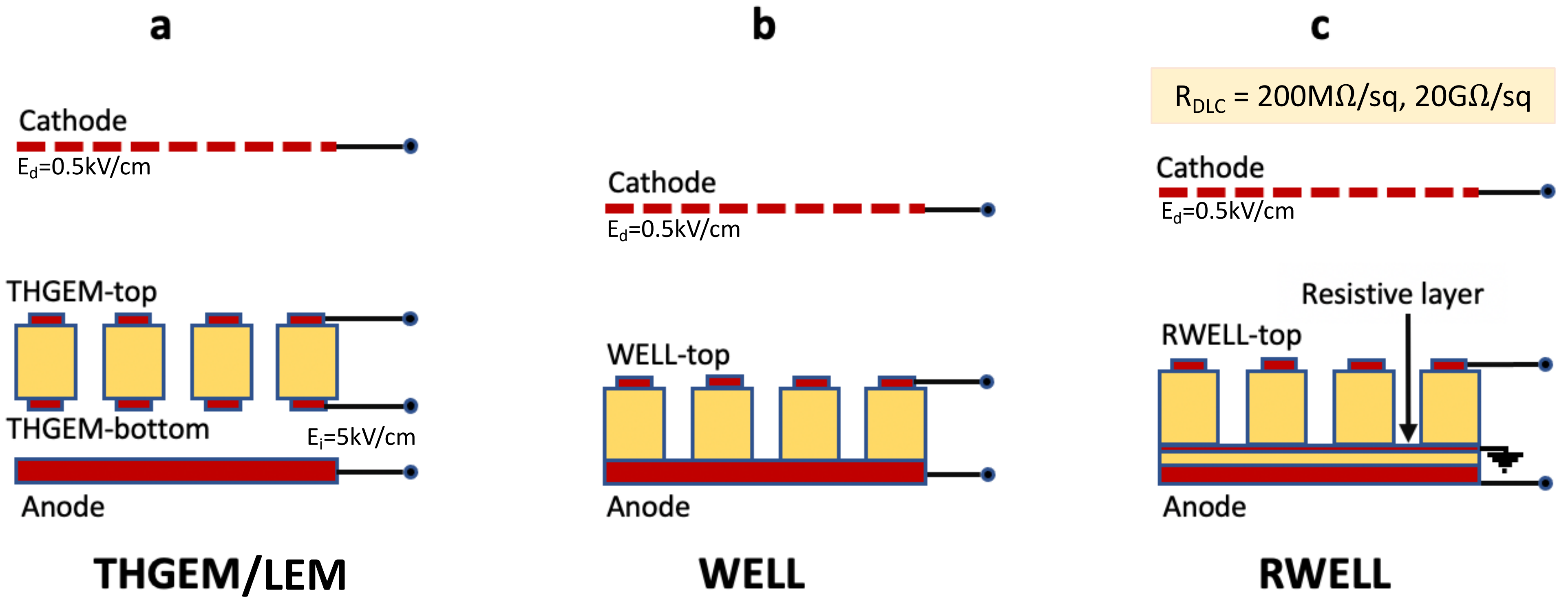
Gain at different temperatures



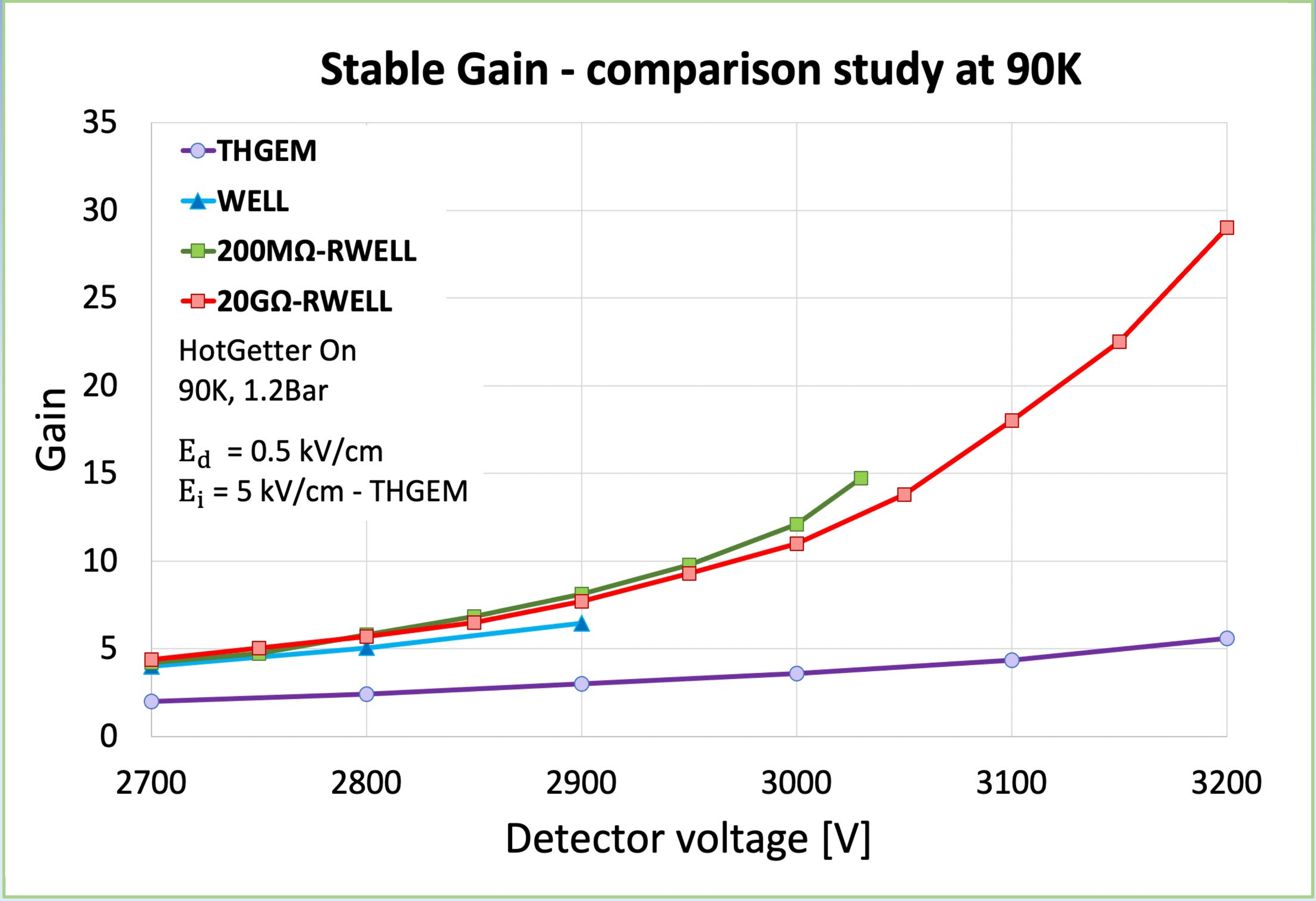
Observations

- Max achievable stable gain G=30 at 90K,1.2 Bar with a resistance of 20GΩ;
- After gas extraction, the detector was stabilized first at 100K, 1.2 Bar with a resistance of 10GΩ and subsequently at 115K, 1.2Bar with a resistance of 3.5GΩ. Also in these two configurations, G=30.
- Above G=18, quenched discharges were observed.

Comparative study



Is the RWELL advantegeous over WELL/THGEM??

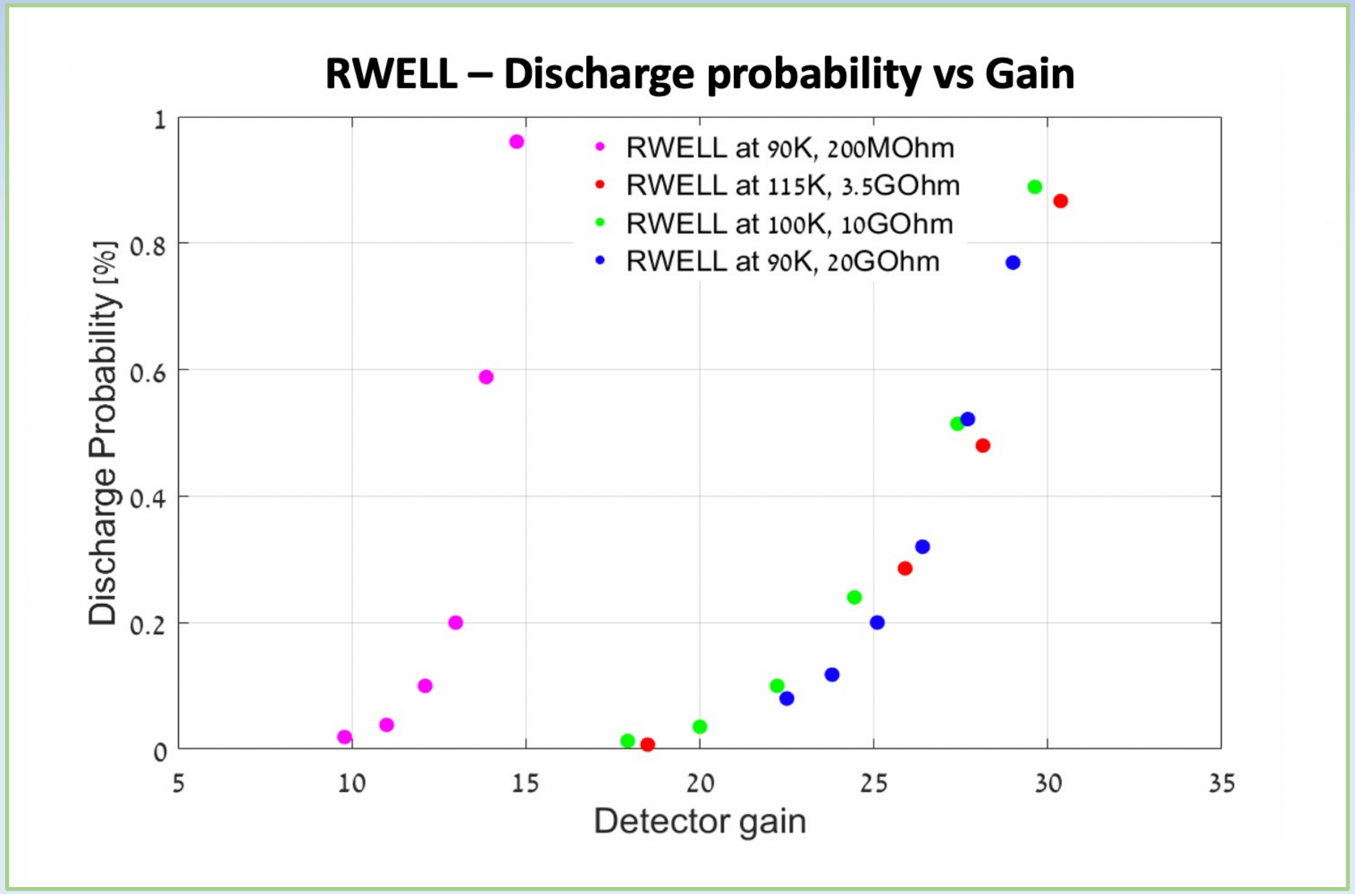


Detector	20GΩ-RWELL	200MΩ-RWELL	WELL	THGEM
Max stable G	30	15	8	6

Observations

- RWELL vs WELL/THGEM:
  - higher stable gain
  - Presence of non-destructive discharges;
- **200MΩ-RWELL:** quenched discharges in the gain range 10<G<15;
- **20GΩ-RWELL:** quenched discharges were observed in the gain range 18<G<30 without any significant effect on the detector operation;
- WELL and THGEM discharges were single events able to induce a full detector paralysis and damages to the electronic modules.

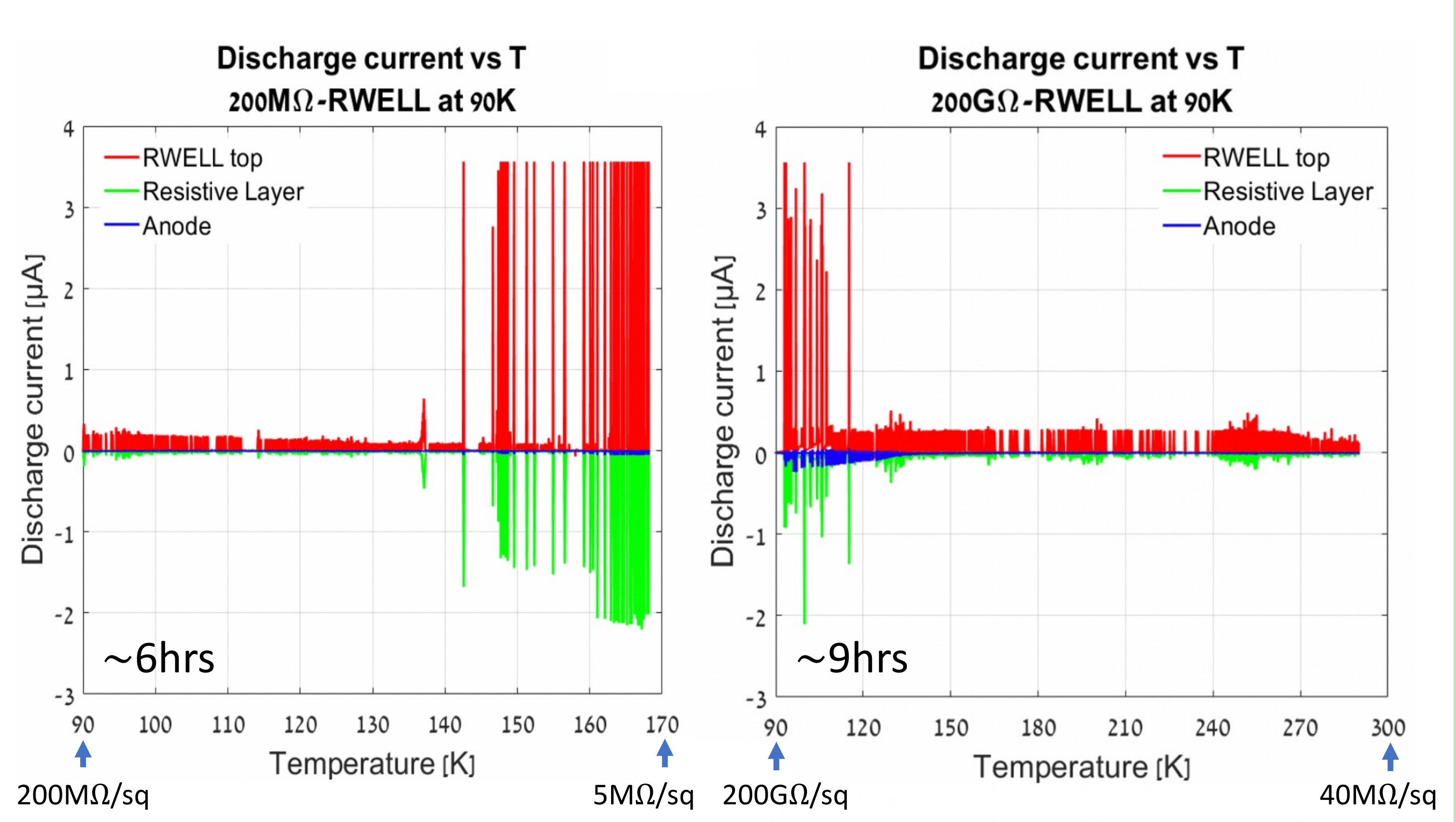
Discharge probability



$$P_d = \frac{N}{R * T}$$

- Discharge probability P_d accounts for the number of discharges produced by an event in a single unit of time. According to the formula:
  - N = number of discharges recorded by the current monitor
  - R = source rate
  - T = elapsed time
- $P_d \approx 1\%$ is achieved at the maximal voltage for all the three case.

Temperature (Resistivity) scan



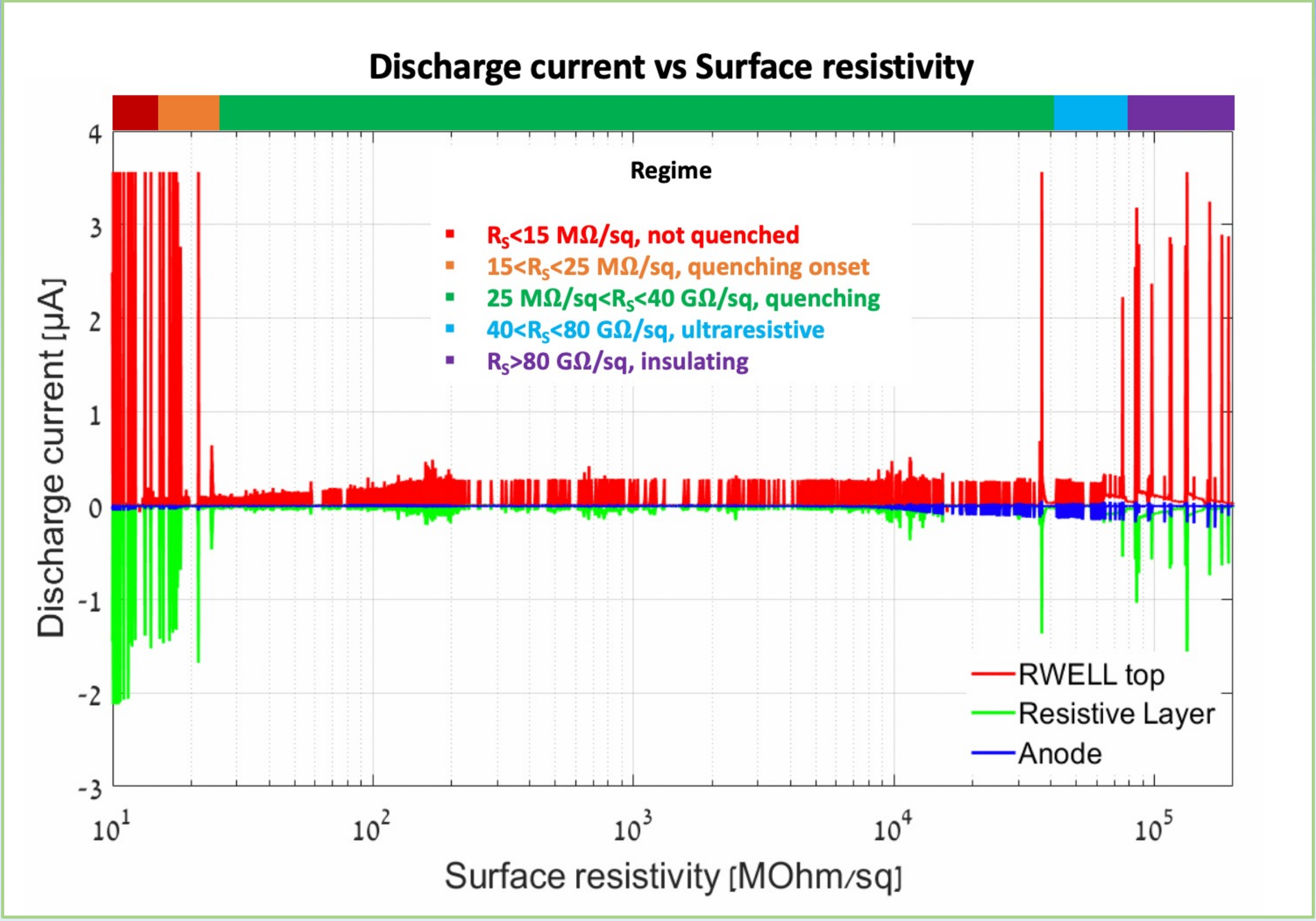
V_{BD}=3.01kV	V_{BD}=2.08kV	V_{BD}=4.01kV	V_{BD}=1.65kV

V_{BD} = voltage in the proximity of the breakdown point, $V_{BD} = f(\varrho(T))$, with ϱ=gas density, P~ ϱT

Measurements of discharge currents

- Two detectors were investigated: a 200MΩ-RWELL and 200GΩ-RWELL at 90K;
- Isobaric warming-up – T: 90K -> 298K, P=1.2Bar
- Record PS currents from RWELL top, RL and anode;
- Detector was operated in discharge mode;
- Quenching factor: ~15

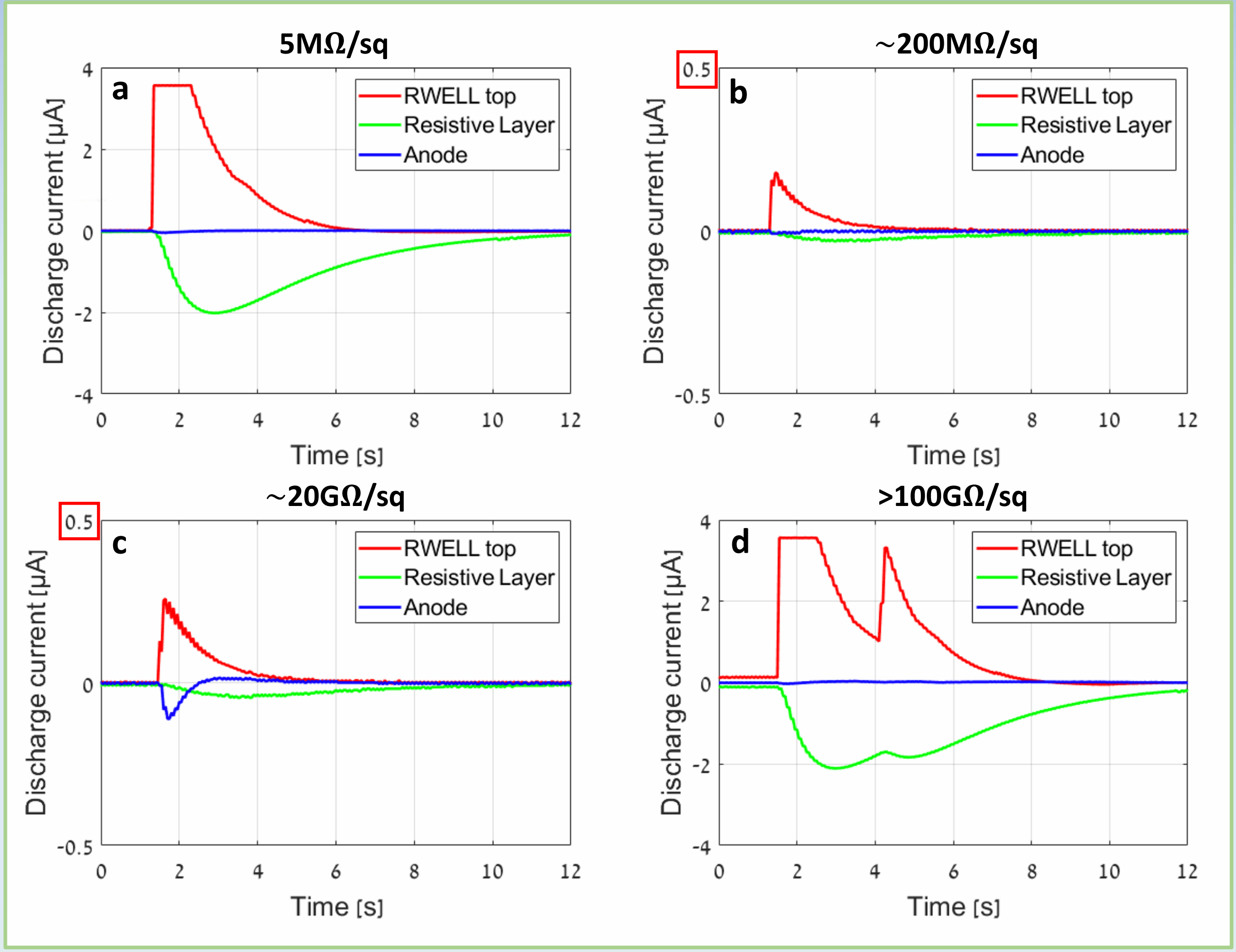
Let's combine the plots: T[K] -> R[MΩ/sq]



Observations

- Surface resistivity controls the nature of the discharges in the detector;
- Presence of different quenching regimes
  - i. Non-quenching
  - ii. Quenching
  - iii. Insulating
- Quenching factor: ~15

Nature of the discharges



Observations

a) Non-quenched discharges saturate the current monitor and cause a full tripping to the detector;

b) For 15M Ω/sq <R<10 GΩ/sq, discharge is visible from the RWELL top and the RL;

c) For 10<R<50 GΩ/sq, an induced discharge on the anode becomes visible;

d) For R>100 GΩ/sq, the material is too resistive: presence of constant currents on the electrodes and non-quenche/piled-up discharges.

Summary & Outlook

- ❑**RWELL was operated at 90K, 1.2Bar in purified argon up to a stable gain of 30 (20GΩ/sq), 15 (200MΩ/sq)**
  - ▪ Gain increased exponentially with voltage
  - ▪ Signal risetime elongation at high operation voltages – requires better modelling of the signal formation processes (ion/photon feedback?)
  - ▪ **Discharges are quenched** – discharge quenching factor ≥15
  - ▪ Discharge probability was limited to 1% at the maximum gain
- ❑**RWELL achieved a higher stable gain relative to WELL/THGEM at 90K, 1.2Bar**
- ❑**Investigation of the physics of the discharges in the presence of a resistive layer**

- **NEXT: Resistive-Plate WELL (RPWELL) at 90K**

Thanks for your attention!

Q&A

Backup