Electrical breakdown in Thick-GEM based WELL detectors

(Based on arXiv:2204.09445**)**

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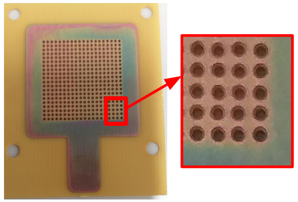
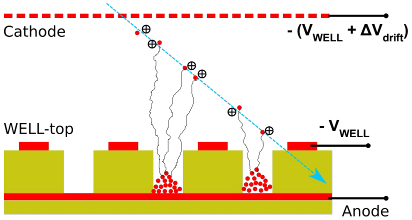
WELL concepts

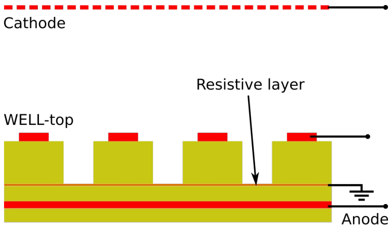
- **THWELL**: a single-faced THGEM foil coupled to a readout anode.
  - Another electrode, a few mm above THGEM acts as cathode.
  - Ionization induced primary electrons drift to the holes where they undergo charge avalanche.
- **RWELL**: THGEM coupled to anode through an insulating layer with resistive coating.
  - Charge evacuation to ground through the resistive layer.
- **RPWELL**: THGEM coupled to anode via a material of high bulk resistivity.
  - Charge evacuation to ground through the bulk of of the resistive plate.



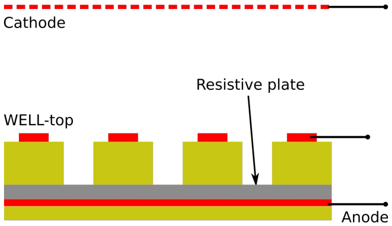
A 2 cm × 2 cm THGEM foil.



Thick WELL (THWELL).



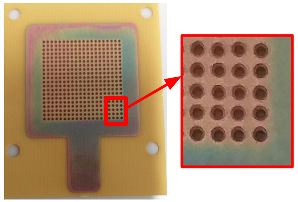
Resistive WELL (RWELL).



Resistive Plate WELL (RPWELL)

In this study

- **THWELL:**
  - Electrode**:** FR4 thickness = 0.4 mm, hole diameter = 0.5 mm, rim = 0.1 mm, hole pitch = 1 mm (square pattern).
  - Drift gap = 3 mm. E_{drift} = 0.5 kV/cm, E_{hole} = 15-30 kV/cm.
- **RWELL**: 0.9 mm thick FR4 coated with 16 MΩ/□ resistive graphite.
- **RPWELL**: 0.7 mm thick LRS glass (ρ=2×10^{10} Ω-cm).



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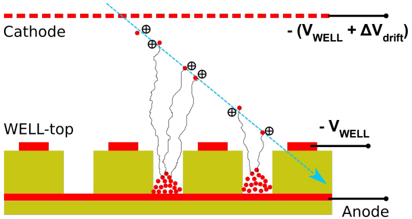
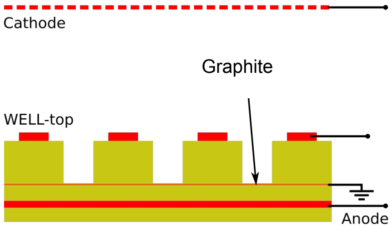
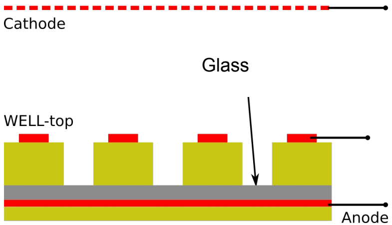


Thick WELL (THWELL).



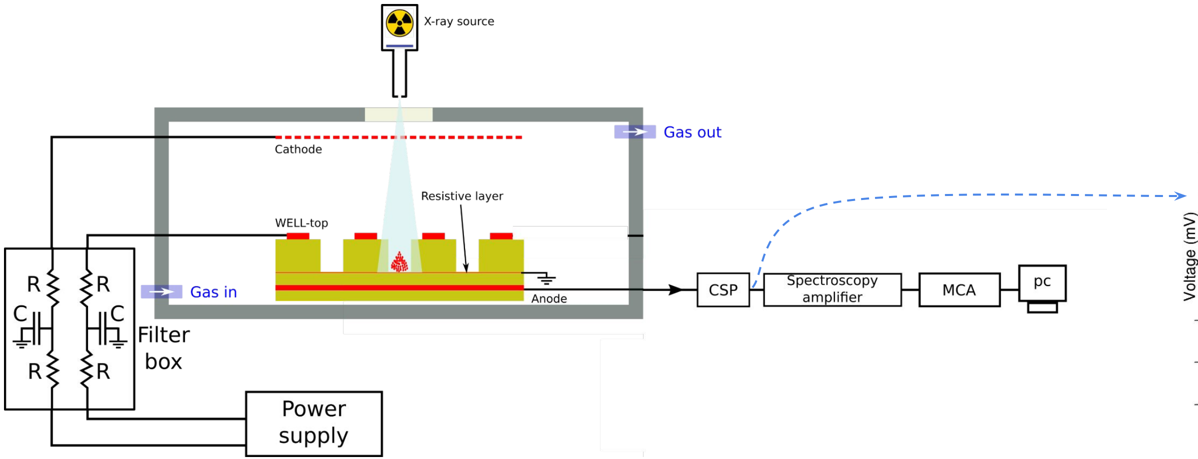
Resistive WELL (RWELL).



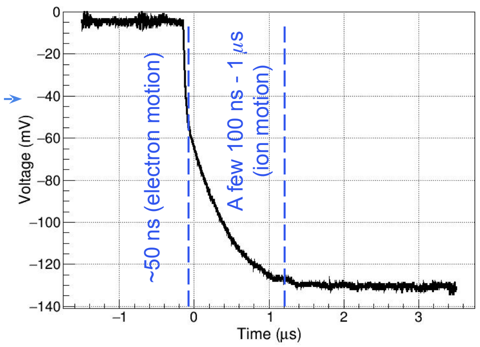
Resistive Plate WELL (RPWELL)

Experimental setup (1)

- **Gas mixture**: Ne/5%CH_4.
- **Source**: 8.04 keV X-ray with 0.5 mm collimation. Event rate ~ 25 Hz.
- Standard readout chain: anode → Charge-sensitive preamplifier (CSP) → Spectroscopic amplifier (2 μs shaping time) → Multi-channel analyzer.



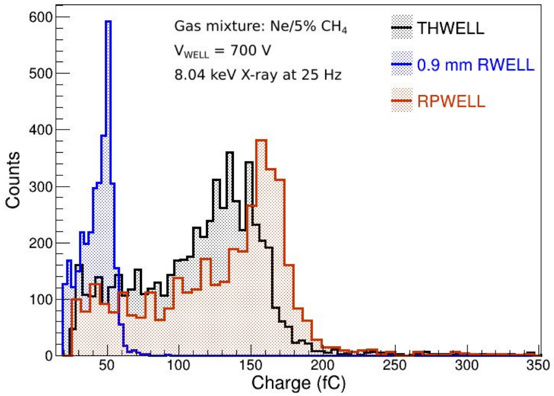
Experimental setup for the basic characterization.



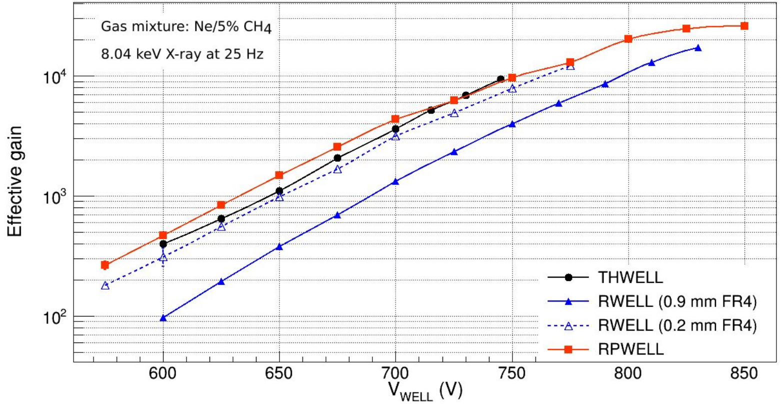
A typical CSP pulse from anode.

Spectra and gain curves

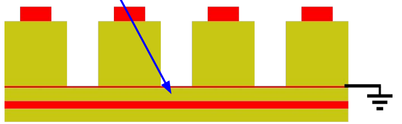
- Effective gain = peak position of calibrated MCA spectrum/primary charge (= 229 e^- from HEED [1]).
- Lower effective gain in gr-RWELL due to presence of 0.9 mm FR4 (lower weighting field) [2].
- In RPWELL, the presence of the resistive plate does not affect the effective gain (also at [3]).
  - Gain decreases at higher rate (in backup).
- Maximum achievable gain ~ 9500 (THWELL), 1.5×10^4 (gr-RWELL), 2.5×10^4 (RPWELL).



MCA spectra of the detectors.



Effective gain vs applied bias across THGEM.



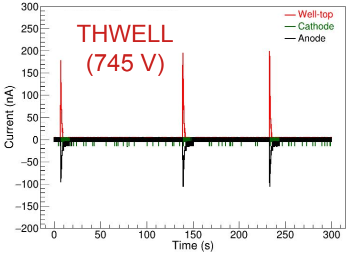
[1] I.B. Smirnov, Nucl. Instr. Meth. A, 554 (2005) 474.

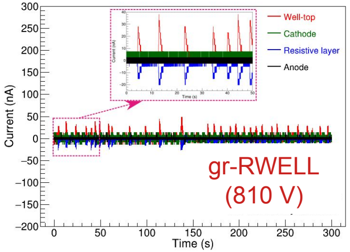
[2] W. Shockley, J. Appl. Phys. 9 (1938) 635.
S. Ramo, Proc. IRE 27 (1939) 584.

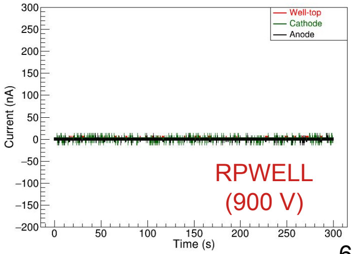
[3] A. Rubin et al., JINST 8 (2013) P11004.

Discharge id through current measurement

- Method:
  - Monitor the current supplied by the power supply to the electrodes.
  - A sudden increase in a given electrode indicating a discharge event involving this electrode.
  - Current polarity indicates the direction of the energy flow.
- Results:
  - THWELL: intense (~200 nA) discharges between WELL-top and anode.
  - gr-RWELL: quenched (~40 nA) discharges between WELL-top and graphite layer. No current (instrument sensitivity = 5 nA) on anode.
  - RPWELL: no current fluctuations.
- RPWELL was reported as discharge free in the past [3-6].



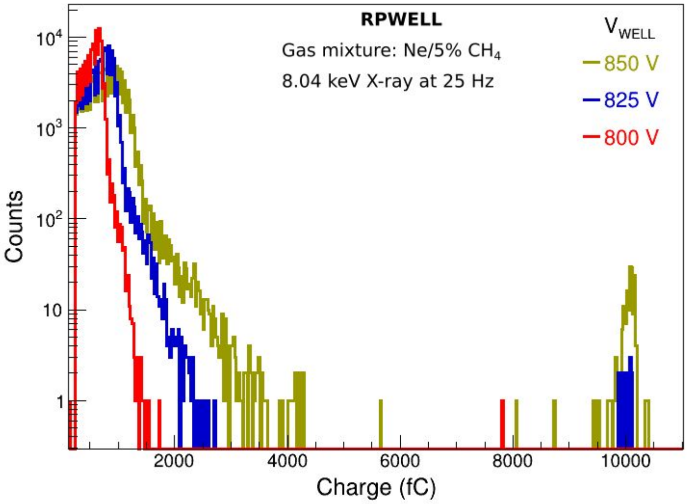




[3] A. Rubin et al., JINST 8 (2013) P11004.
[4] L. Moleri et. al, Nucl. Instr. Meth. A 845 (2017) 262.
[5] S. Bressler et. al, JINST 11 (2016) P01005.
[6] S. Bressler et. al, JINST 8 (2013) C12012.

Discharge id through pulse monitoring

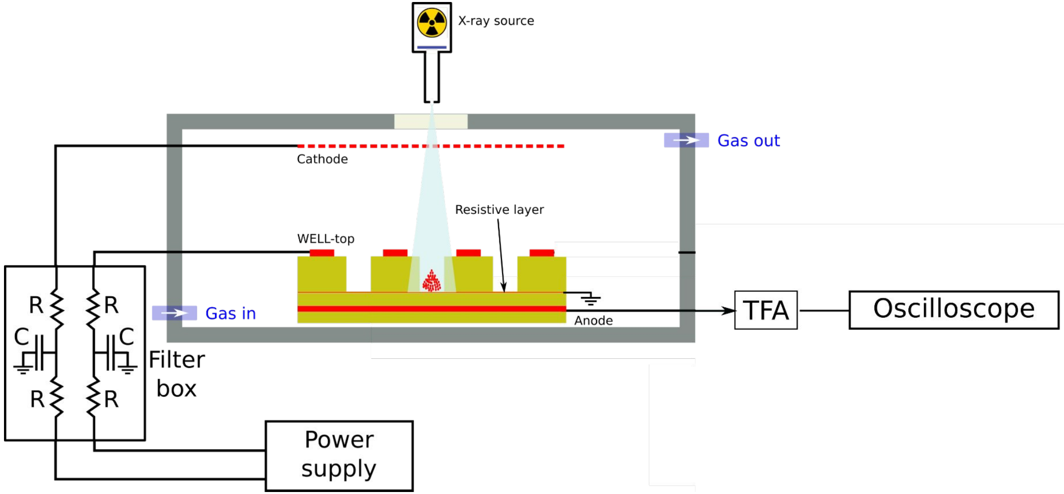
- A sub-nA to a few nA current fluctuation from WELL-top.
- Saturation of CSP pulses giving rise to saturated events in MCA.
  - Frequency increases with voltage.
- CSP measurements provide limited information.



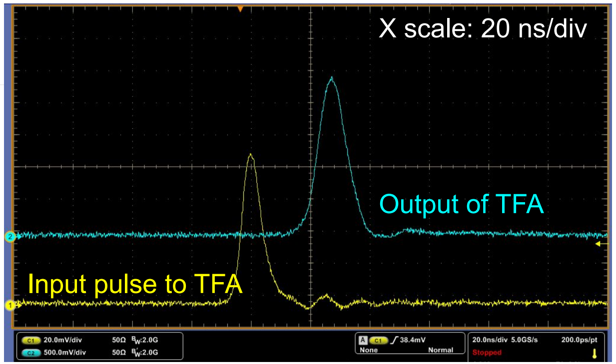
Saturation of RPWELL MCA spectra around its maximum achievable gain.

Experimental setup (2)

- Replacing the readout chain:
  - Anode → Timing-filter amplifier (TFA) → Oscilloscope.
    - TFA (ORTEC 474): integration time = 10 ns, differentiation time = 150 μs, variable amplification.
- Reproduction of raw detector pulses with a minimum shaping.



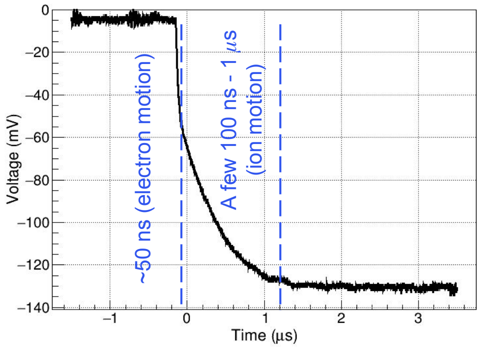
Experimental setup for discharge identification by pulse monitoring.



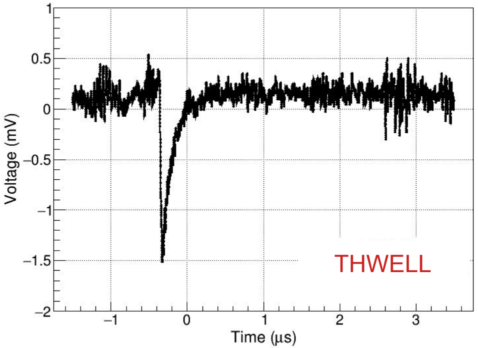
Response of TFA to a fast pulse.

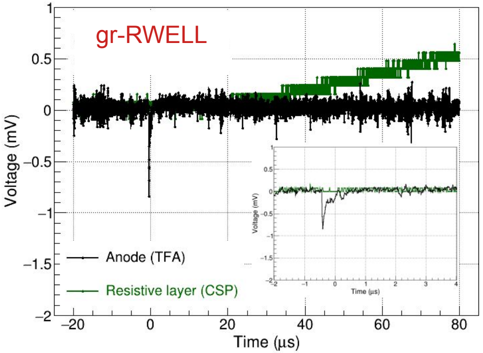
Avalanche-like pulses

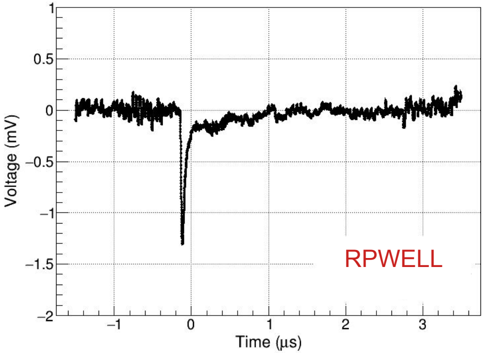
- Amplitude ~ few mV, corresponding to a charge of hundreds of fC.
- Signal shape (correlated with the CSP pulse shape):
  - ~50 ns falling edge due to electron motion.
  - Hundreds of ns tail due to ion motion.
- In RWELL, a slow-rising pulse measured on the resistive layer
  - Slow charge evacuation
  - Becomes pronounced after tenths of μs.



Integrated pulse after CSP.

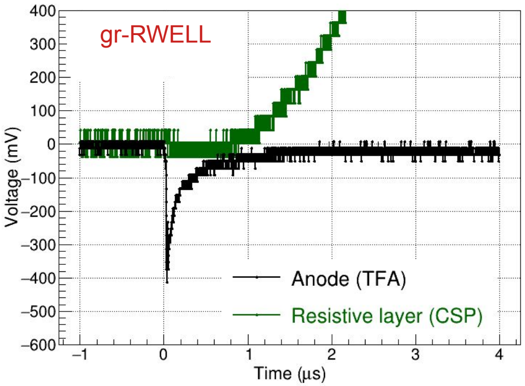


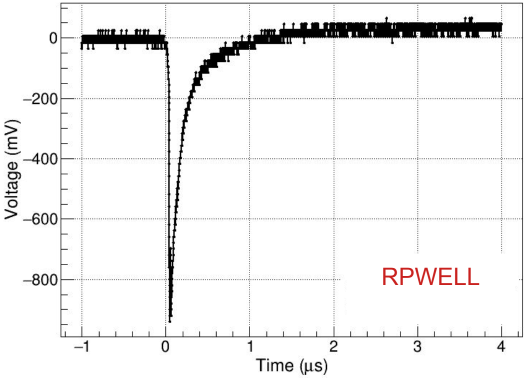




Discharge-like pulses

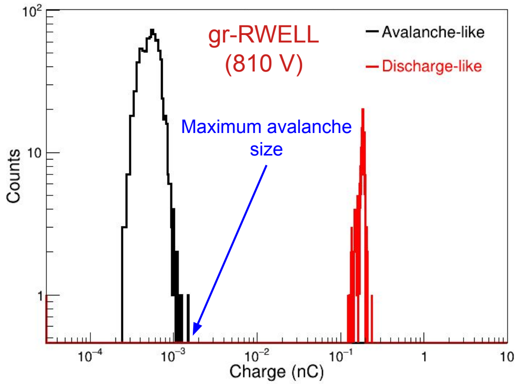
- THWELL: saturation of TFA.
- RWELL & RPWELL: large pulses (hundreds of mV) appear on anode.
- gr-RWELL: **large pulses correlated with current spikes** from WELL-top and resistive layer.
- RPWELL: large pulses correlated with the sub-nA fluctuation on the current supplied to WELL-top
    - Not always due to limited resolution of the power supply.

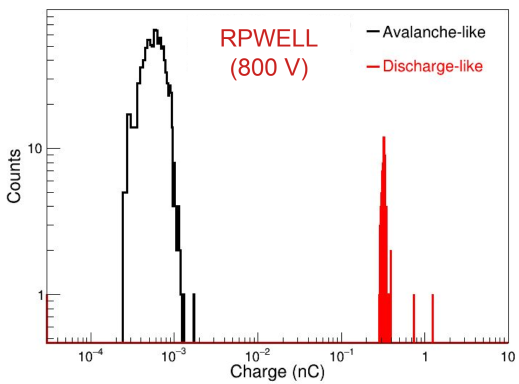


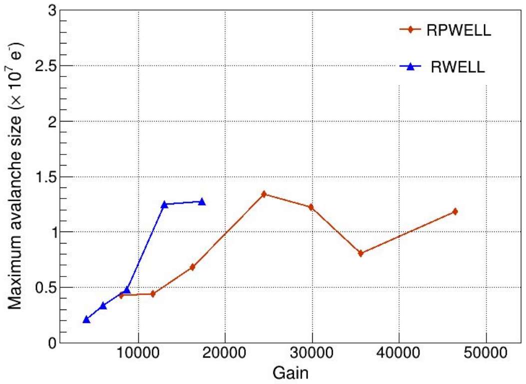


Raether limit

- Pulse recording in avalanche and discharge-modes.
- Pulse height calibrated to charge [7].
- Maximum avalanche size ~ **10^7 e^-**.
    - Independent of detector gain.





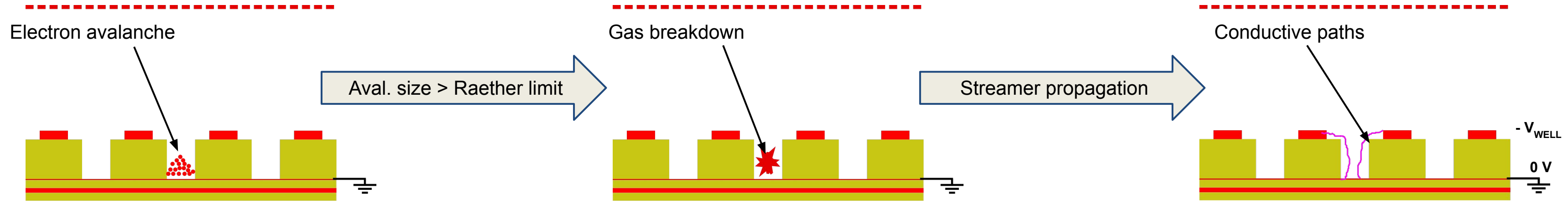


Maximum avalanche size vs detector gain

[7] L. Moleri et al., JINST 17 (2022) P02037.

The discharge phenomenon

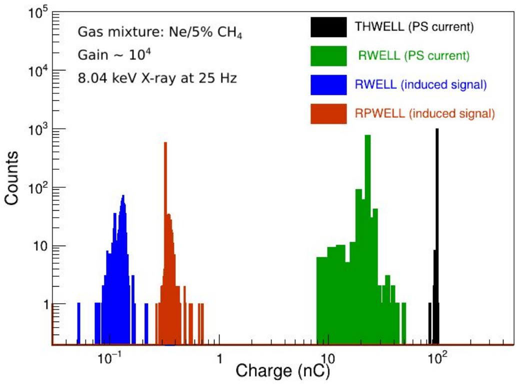
- Three phases:
  - Raether limit (10^7 e-) is crossed.
  - Streamer propagation forms a conductive path between the nearby electrodes of different potential.
  - Large flow of current between the shorted electrodes.
- THWELL: conductive path formed between the WELL-top and the anode at ground potential → large energy flow between the two.
- RWELL: conductive path formed between the WELL-top and ground via the resistive layer (16 MΩ/□) → energy flow is quenched.
- RPWELL: charge evacuation via bulk resistance (10^{10} Ω-cm). Discharge is extinguished.



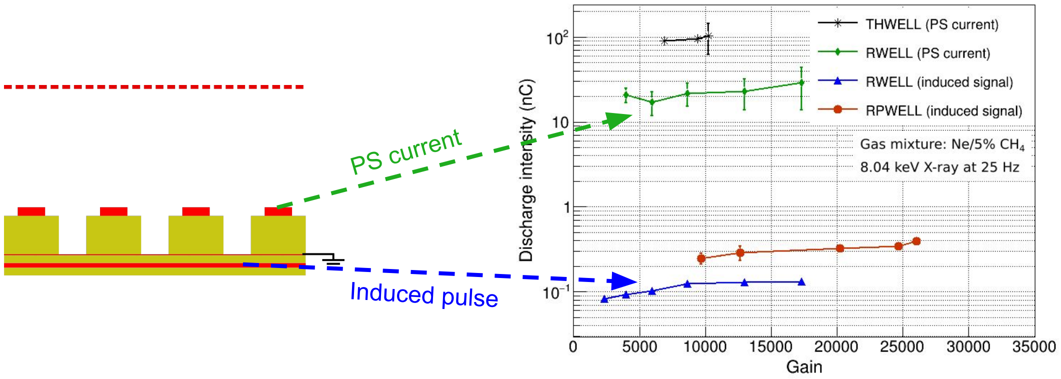
Hundreds of fC induced signal on anode.
Hundreds of pC induced signal on anode.
Current flow between the short electrodes.

Discharge intensity

- The charge corresponding to a discharge is defined as the discharge intensity.
    - Integration of the current spikes from WELL-top of THWELL and RWELL.
    - Calibration of the discharge-like pulses from anode of gr-RWELL and RPWELL.
- Order of magnitude difference in discharge intensity of gr-RWELL, from the two methods.
    - Suggesting two different mechanisms.
- Using resistive configurations, the readout anode is protected. It only sees the induced large pulses.



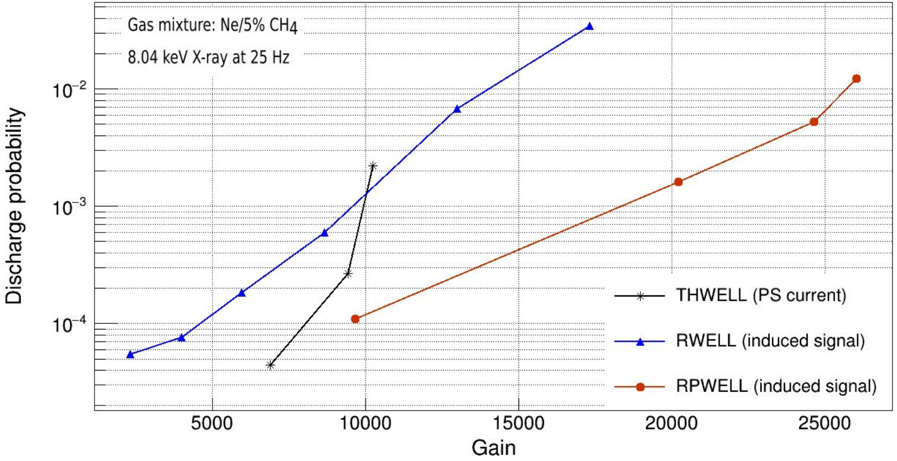
Distribution of charge of discharge events.



Variation of discharge intensity with detector gain.

Discharge probability

- Discharge probability = $N_{discharge}$ / (acquisition time ×source rate)
- Rises sharply for THWELL, moderately for RWELL, slowly for RPWELL.
    - Expecting similar probabilities.
- Detectors operable upto a maximum discharge probability around 10^{-2}.
    - Lower limit in THWELL.



Variation of discharge probability with the detector gain.

Summary

- Discharges occur in all the three detectors, with or without resistive components.
- In RWELL and RPWELL, the readout anode is decoupled from large energy flow.
- Effect of the weak discharges on the performance of RPWELL in under investigation.
- Observed two phenomena:
  - Gas breakdown inducing large pulses on the anode.
  - Discharge of the capacitor seen as current fluctuations (> 5 nA) on the power supply.
- Discharge identification via pulse monitoring can be a very useful tool if the discharges are very weak and not detectable by the power supply current.
- This method can also be used to estimate Raether limit for a detector configuration.

Thank you

BACKUP

RPWELL gain vs source rate

- Effective gain of RPWELL decreases with source rate.
- Using a model of voltage drop across a resistance, the effective resistance of the glass plate was estimated.
  - Falls within expected value for involvement of 1-2 holes in charge evacuation.