Discharges and their effect in WELL detectors with and without resistive anodes

Based on: *JINST **17** (2022) P11004*
*NIM A **1045** (2023) 167540*

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WEIZMANN INSTITUTE OF SCIENCE

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OUTLINE

- WELL detectors & discharges
- Effect of discharges on RPWELL gain

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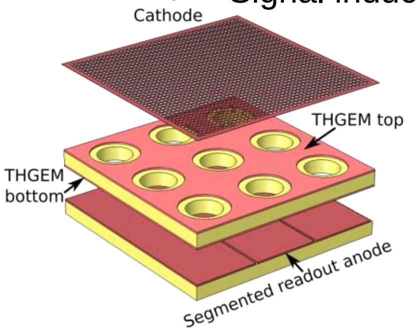
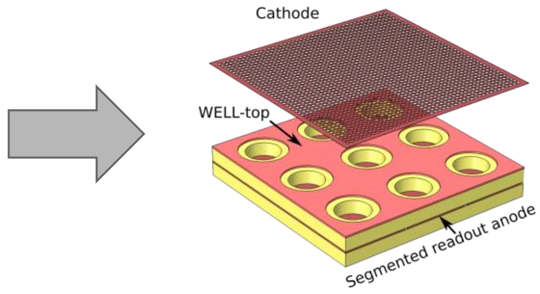
- Effect of discharges on RPWELL gain

Thick-GEM and WELL detectors

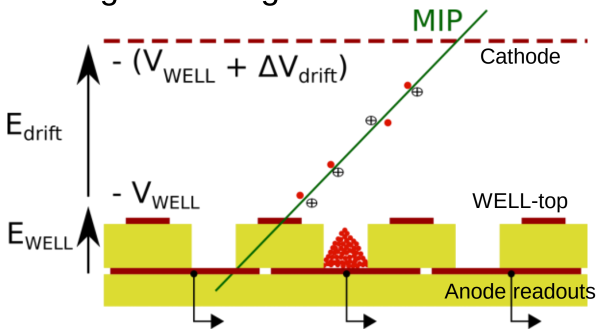
- A Thick-GEM (THGEM) is about 10-fold larger than a Gas Electron Multiplier (GEM).
  - Thickness ~0.5 mm, hole diameter ~0.5 mm (0.1 mm rim), 1 mm pitch.
- **Thick-GEM configuration:** A double-faced THGEM electrode assembled with an induction gap.
- **WELL configuration:** A single-faced THGEM electrode coupled to the readout plane. No induction gap.
  - Primary ionization in the drift gap. Charge multiplication inside the holes.
  - Signal induction on the anode readouts due to movement of charges in the gaseous medium.



THGEM configuration in 3D



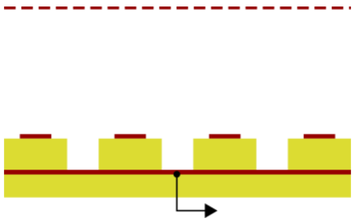
WELL configuration in 3D



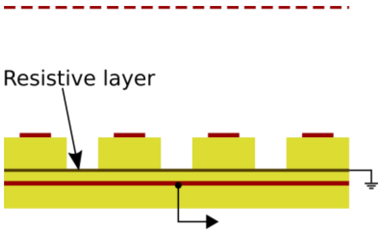
Working principle of WELL detector

Tested configurations

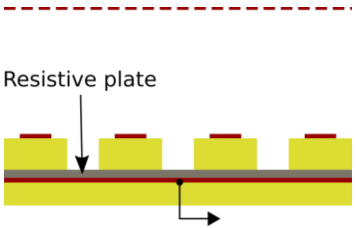
- **THWELL:** THGEM electrode directly coupled to a readout anode.
- **RWELL**: THGEM electrode coupled to anode through a resistive layer providing lateral charge evacuation.
  - Graphite sprayed on 0.9 mm FR4. Surface resistivity = 16 MΩ/□. One edge connected to ground.
- **RPWELL**: THGEM coupled to anode via a resistive material. Charge evacuation via the bulk.
  - 0.7 mm thick LRS glass (ρ=2×10^{10} Ωcm) conductively attaches the anode and THGEM foil.



Thick WELL (THWELL).



Resistive WELL (RWELL).



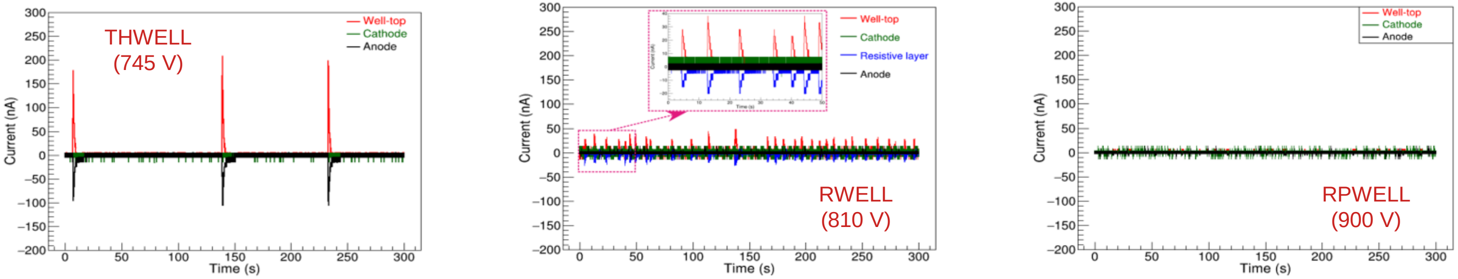
Resistive Plate WELL (RPWELL)

FR4 thickness	0.4 mm	**Hole dia.**	0.5 mm	E_{drift}	0.5 kV/cm	**Gas mixture**	Ne/5% CH_4
Drift gap	3 mm	**Rim**	0.1 mm	E_{WELL}	15-30 kV/cm	**X-ray collimation**	0.5 mm

Discharge id through current measurement

Ref: *A. Jash et. al, JINST **17** (2022) P11004*

- The currents supplied to the electrodes are monitored.

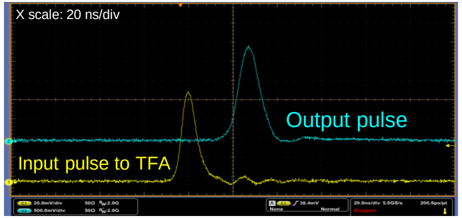


Monitored currents supplied to the electrodes in the investigated detector configurations.

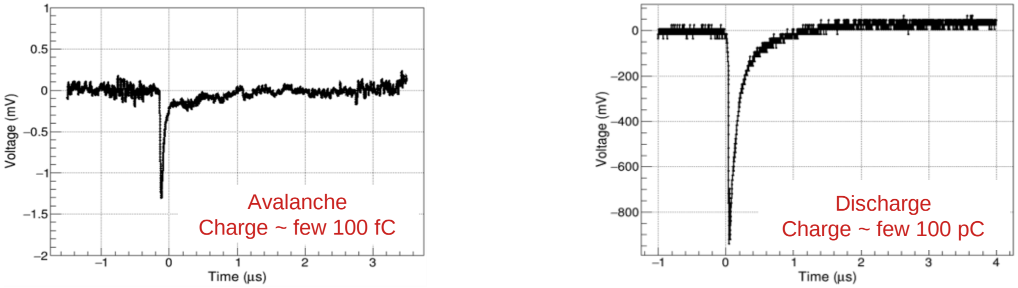
- In presence of a discharge: sudden change in current between a pair of electrodes. Polarity of the spikes indicate direction of current flow.
  - **THWELL**: intense (~200 nA) discharges between WELL-top and anode.
  - **RWELL**: quenched (~40 nA) discharges between WELL-top and graphite layer.
- **RPWELL**: no current fluctuation visible (instrument resolution = 5 nA).

Discharge id through pulse monitoring

Ref: *A. Jash et. al, JINST **17** (2022) P11004*



- Anode pulses recorded on oscilloscope after a Timing Filter amplifier.
  - Int. time = 10 ns, diff. time = 150 μs : minimum pulse shaping.
- **THWELL**: saturated pulses.
- **RWELL**: large pulses (~3 orders of magnitude larger than avalanche case) appear on anode, correlated with the current spikes from the WELL-top and graphite layer.
- **RPWELL**: large pulses correlated with sub-nA current fluctuation on WELL-top.

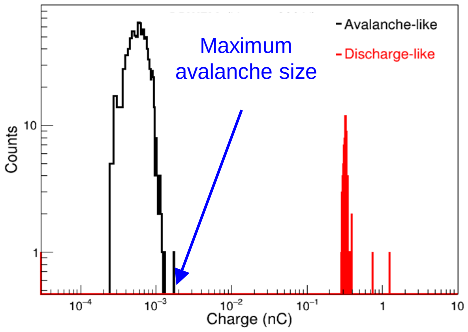


Induced pulses on RPWELL anode after Timing filter amplifier.

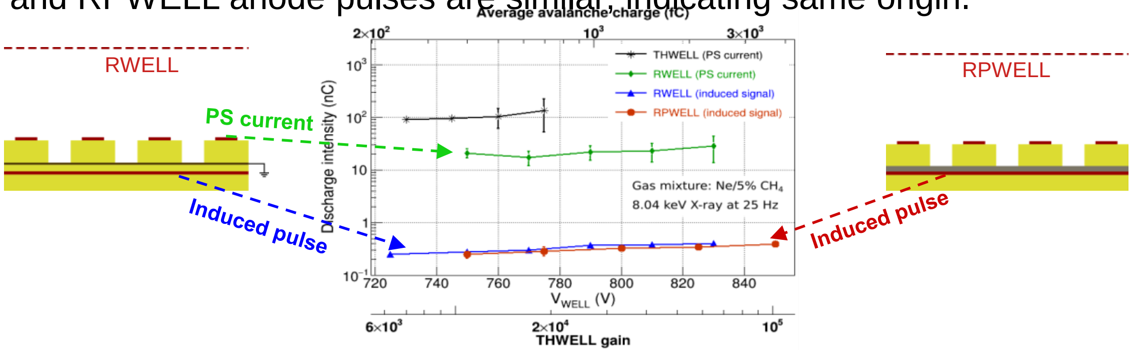
Discharge id through pulse monitoring

Ref: *A. Jash et. al, JINST **17** (2022) P11004*

- Pulse height calibrated to charge.
- The endpoint of avalanche charge distribution corresponds to a few 10^6 electrons.
- In RWELL, the discharge intensity from induced anode pulses is 100 times lower than that from WELL-top current spikes.
    - Two different mechanisms.
- Discharge intensity from RWELL and RPWELL anode pulses are similar, indicating same origin.



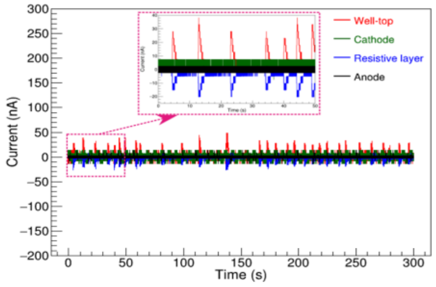
Combined distribution of charges induced on RPWELL anode in avalanche and discharge modes.

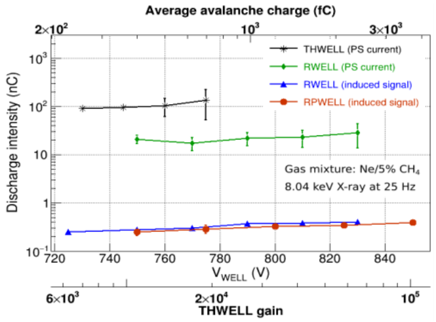


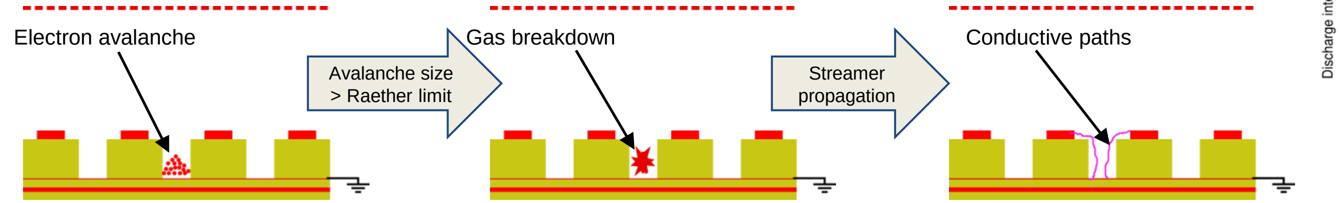
Variation of discharge intensity with applied voltage across WELL and the corresponding avalanche charge

The discharge phenomenon

- Stage 1: avalanche size crossing the Raether limit (few 10^6 e-) breaks down the gaseous medium.
- Stage 2: streamer propagation inducing **~few 100 pC** charge on anode.
  - Visible only in resistive configurations.
- Stage 3: streamers connect nearby electrodes at different potential.
  - Discharge of the involved capacitor.
    - Large current flow in THWELL, RWELL.
    - Suppressed in RPWELL.







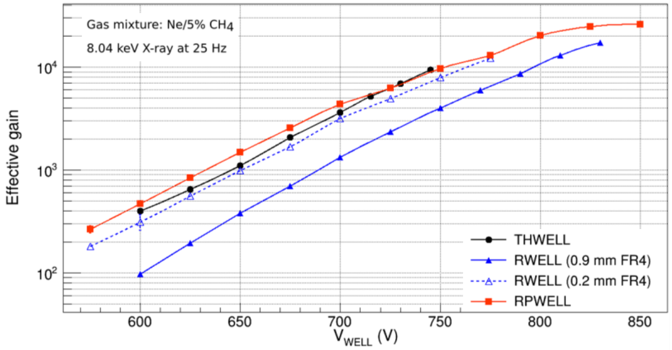
Hundreds of fC induced signal on anode. Hundreds of pC induced signal on anode. Current flow between the short electrodes.

OUTLINE

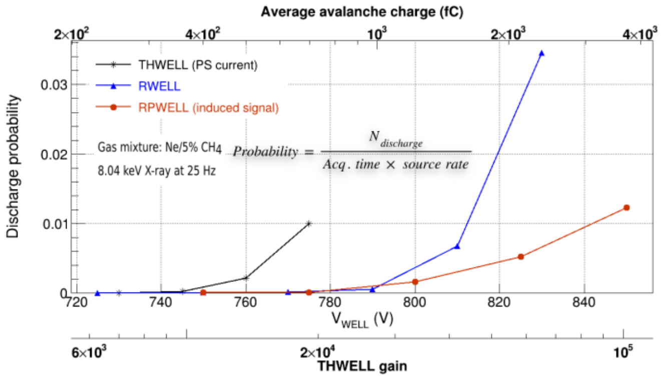
- WELL detectors & discharges
- **Effect of discharges on RPWELL gain**

Effect of discharges (gas breakdown) on RPWELL gain

- **RPWELL**:
  - Effective gain > 10^4 for 8.04 keV X-ray.
  - Readout protection. No capacitor discharge.
  - Lower probability for gas breakdown.
- **Goal:** find effect of gas breakdown on RPWELL gain.
  - as a function of distance, time, detector properties.
- **Challenges:** discharges occur randomly in time, space.
  - produce discharges at a known, localized region, at a known time.
- **Solution:** forced gas breakdown at one region by producing a charge greater than Raether limit.



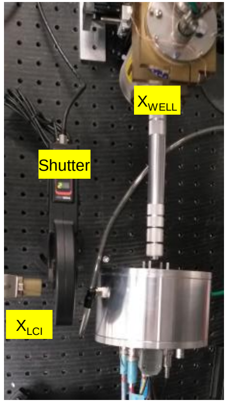
Effective gain vs applied bias across WELL.

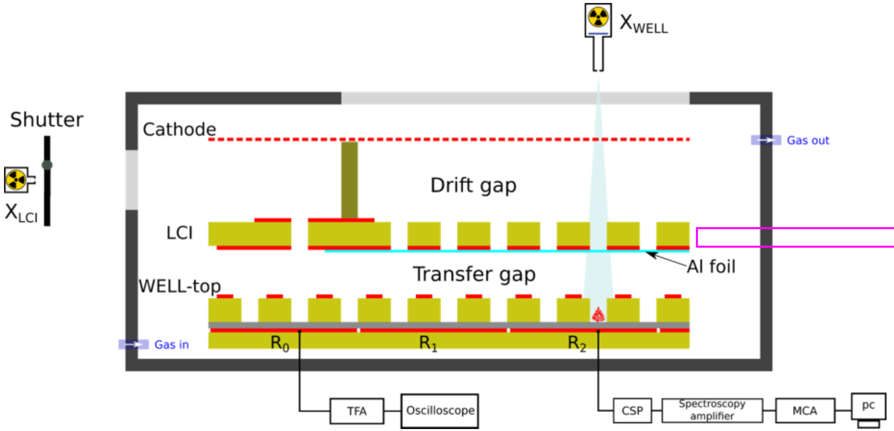


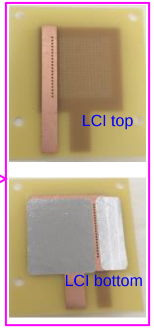
Variation of discharge probability with the applied voltage.

Experimental setup

- A pre-amplification stage to insert large charge locally
  - a localized charge injector (LCI) with open row of holes coinciding with the position of a readout strip, R_0 (the intended discharge location).
  - A low-rate X-ray source, X_{LCI} (Fe^{55}) controlled by a shutter, positioned to irradiate from one side.
- RPWELL biased to operate near discharge regime for a high rate X-ray source, X_{WELL}(Cu-target X-ray tube, 0.5 mm collimation).



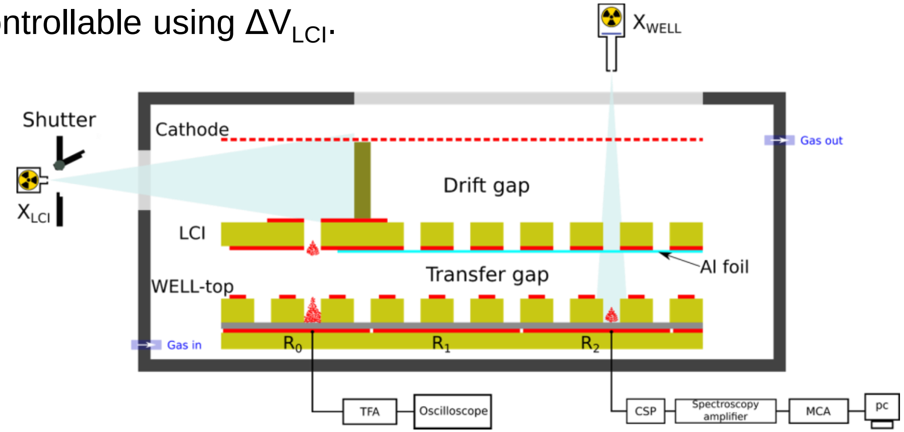




Experimental setup (not to scale): shutter OFF

Methodology

- Opening the shutter produces gas breakdown inside the WELL hole on top of R_0:
  - X_{LCI} creates primary ionization in the top gap. Charge, Q_{LCI} enters the LCI hole.
  - Charge multiplication in LCI. Gain (G_{LCI}) decided by ΔV_{LCI}.
  - When total charge ($Q_{LCI} \times G_{LCI} \times G_{WELL}$) crosses the Raether limit, gas breaks down.
    - Identified as larges pulses from R_0.
    - Rate controllable using ΔV_{LCI}.

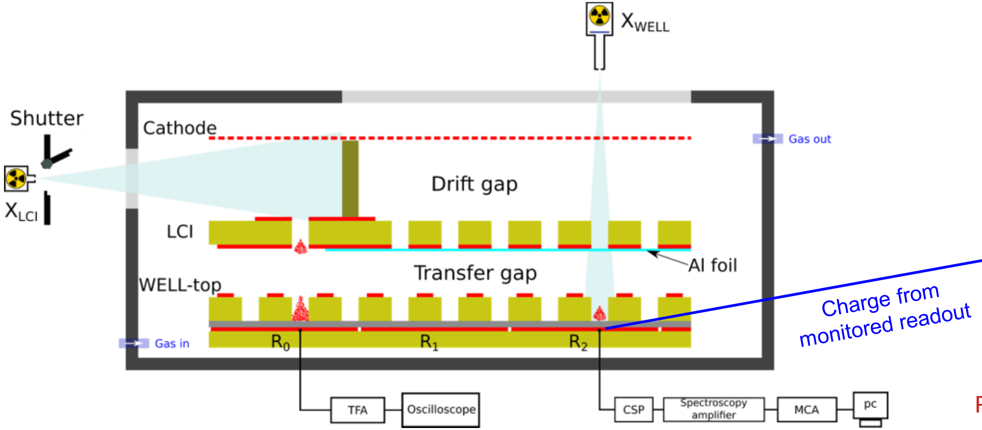


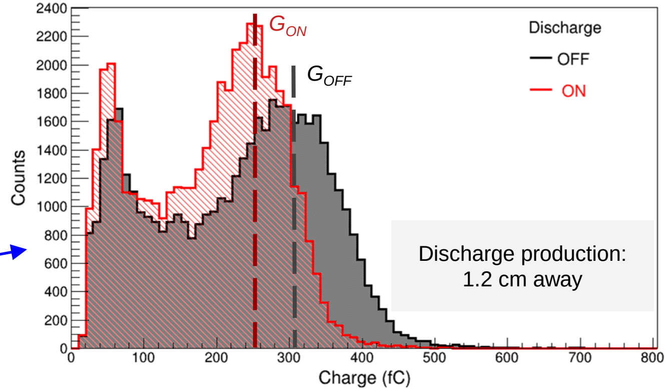
Experimental setup (not to scale): shutter ON

Methodology

- Find the effect of discharges on the RPWELL gain by monitoring the charge spectrum produced by X_{WELL}.
  - Change X_{WELL} position to quantify the effect as a function of distance.
- Detector gain calculated from Gaussian fit of the photopeak.
- Production of multiple discharges reduces RPWELL gain at regions away from R_0.

$$Gain\ drop\ (\%) = \frac{G_{OFF} - G_{ON}}{G_{OFF}} \times 100$$

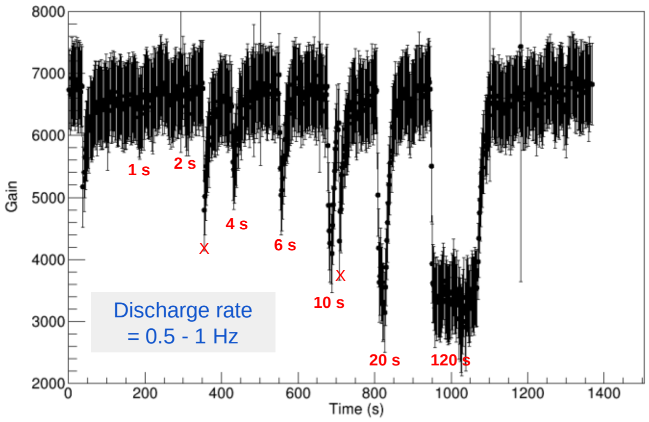




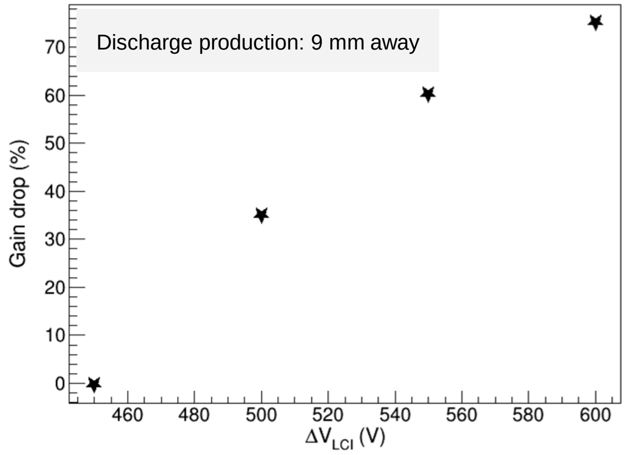
RPWELL charge spectra with X_{WELL} irradiating a region 1 cm away from R_0.

Result

- A single discharge has no effect on the gain.
- To see an effect we need multiple discharges over a short period.
  - Shutter kept ON for different durations.
- Amount of gain drop increases with the duration of discharge period (shutter ON).
- Gain drop increases with ΔV_{LCI} (higher discharge rate).



RPWELL gain variation for different shutter opening times.

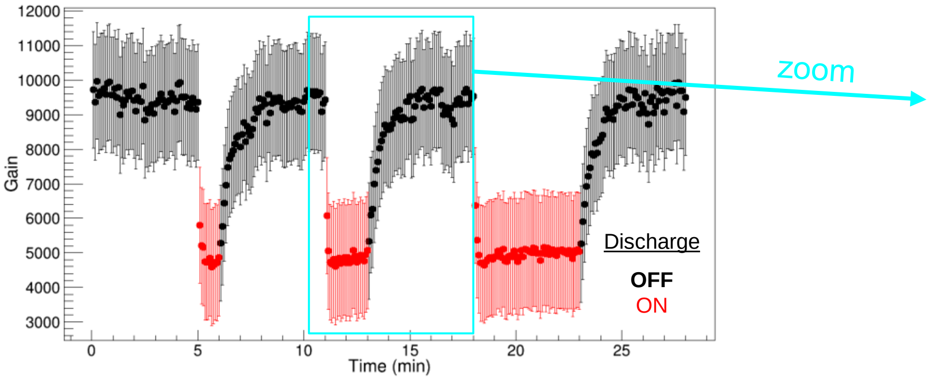


RPWELL relative gain drop as a function of voltage across the LCI.

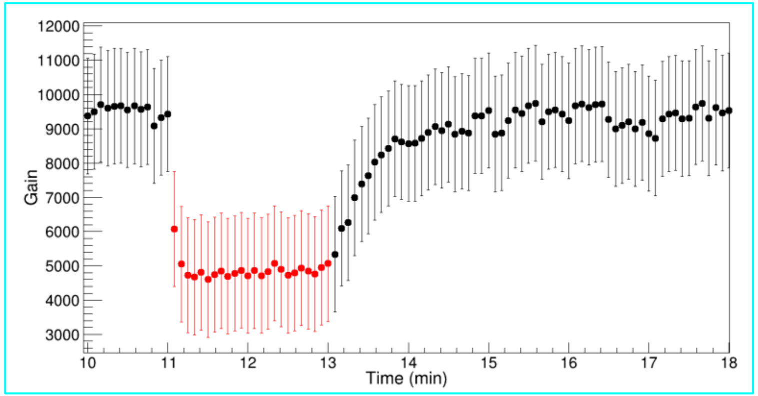
Result

Ref: *A. Jash et. al, NIM A* ***1045*** *(2023) 167540*

- Repeated spectra acquisition (acq. time = 5 sec) from RPWELL in a cycle of discharge OFF and ON:
  - Different durations of discharge period.
  - Discharge production: 6 mm away.



Gain variation in a cycle of discharges OFF and ON.



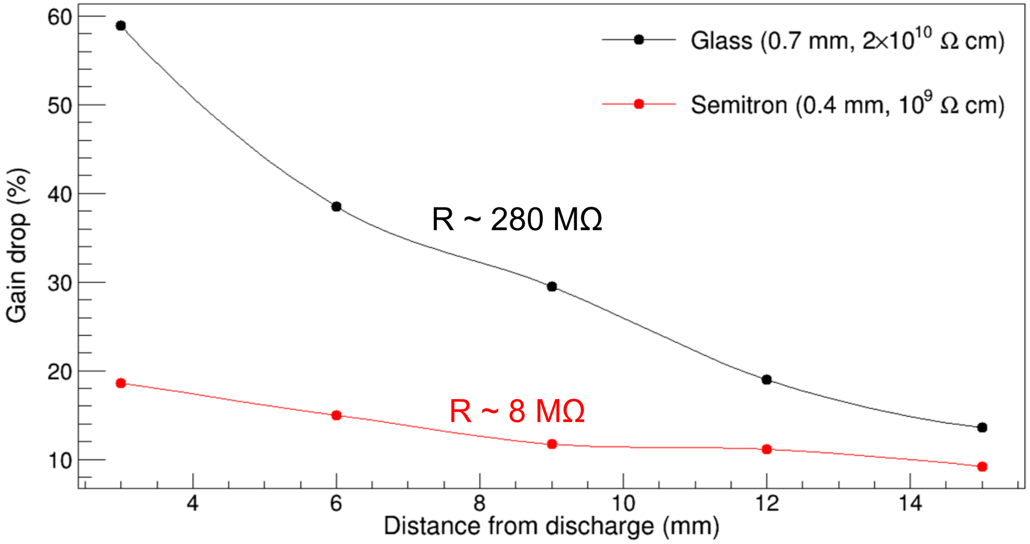
Zoomed area showing the fall and recovery times.

- Gain drop occurs within acquisition time (~ **5 seconds**).
- The recovery time is about **1 minute**.
  - Longer than anticipated from simple R-C calculation for the RP (~10 ms).

Result

Ref: *A. Jash et. al, NIM A* ***1045*** *(2023) 167540*

- Gain drop decreases with distance from discharge production point.
  - Effect present throughout the area of the investigated detector (1.5 cm).
- It increases with resistance of the used RP.



Relative gain drop vs distance from discharge production point for different resistive plates.

Summary

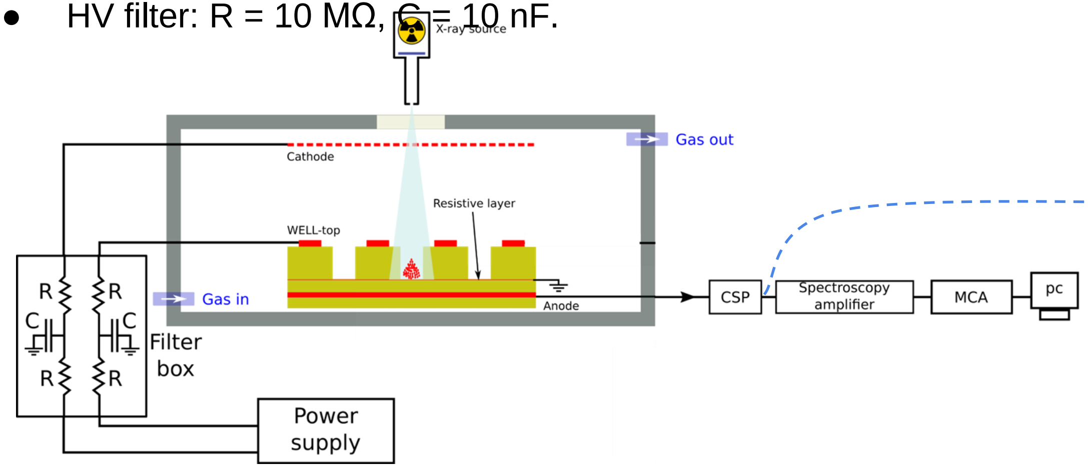
- Gas breakdown occurs in all the three detectors, with or without resistive components.
    - May evolve into a capacitor discharge if the streamer can connect electrodes at different potentials.
    - Readout isolation using resistive layer helps to protect it.
- Their appearance inside an RPWELL reduces its gain (not observed for a single discharge).
    - Increases with rate.
    - Decreases with distance.
    - Increases with resistance of the used RP.
- Recovery time ~ 1 min ± 5 s. Does not seem to depend on the distance.
    - Yet to understand.
- The **gain drop vanished** when we used a **segmented** resistive plate.
- **No gain drop** was observed in THWELL, the **non-resistive** variant.
- Simulation in progress.

Thank you

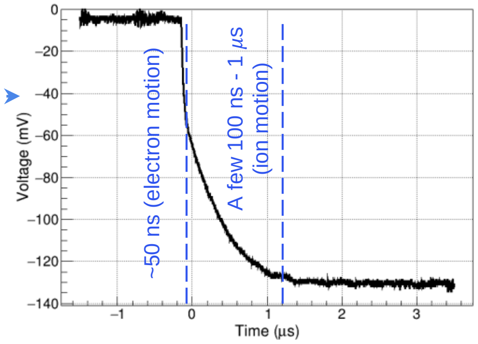
BACKUP

Gain measurement: Experimental setup

- **Gas mixture**: Ne/5%CH_4.
- **Source**: Cu-target X-ray generator (E_γ=8.04 keV) 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 (ADC).
- HV filter: R = 10 MΩ, C = 10 nF.



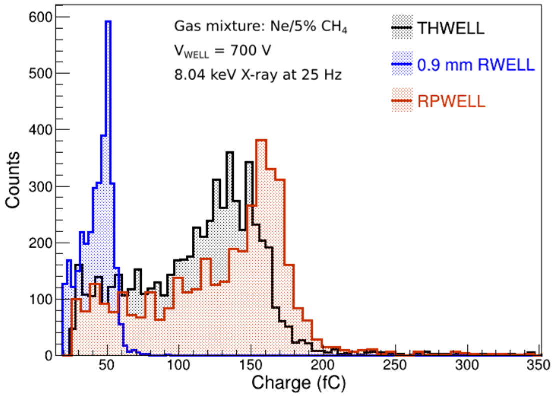
Experimental setup for the basic characterization.



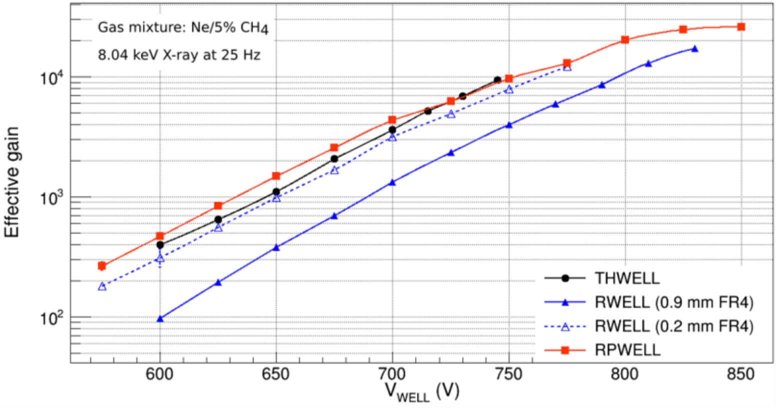
A typical CSP pulse from anode.

Spectra and gain curves

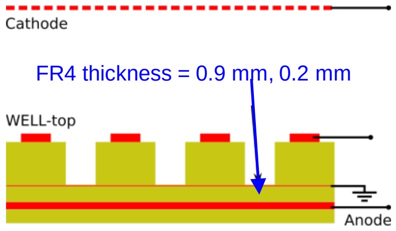
- Effective gain = peak position of calibrated MCA spectrum/primary charge (= 229 e^- from HEED [1]).
- Lower effective gain in RWELL due to presence of 0.9 mm FR4 (lower weighting field) [2].
- In RPWELL, the presence of the resistive plate does not affect the effective gain (same observation at [3]).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



MCA spectra of the detectors.



Effective gain vs applied bias across THGEM.



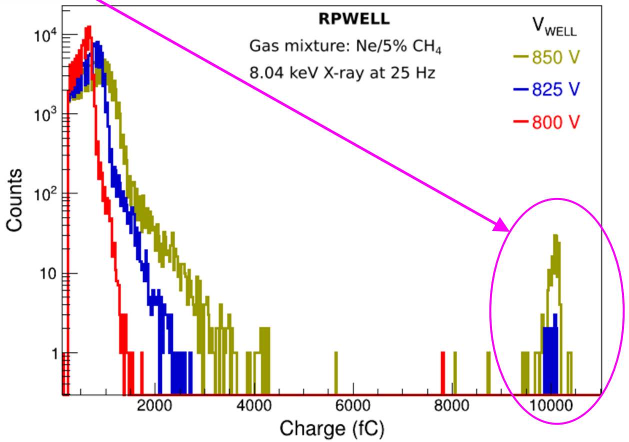
[1] I.B. Smirnov, Nucl. Instr. Meth. A, 554 (2005) 474.

[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.

A closer look at RPWELL

- RPWELL was reported as discharge free in the past [3-6].
- Observations in RPWELL around its maximum allowed voltage:
    - A sub-nA to a few nA current fluctuation from the WELL-top, on the power-supply screen.
    - Saturation of CSP pulses giving rise to saturated events in MCA.
        - Frequency increases with voltage.
- CSP measurements provide limited information.

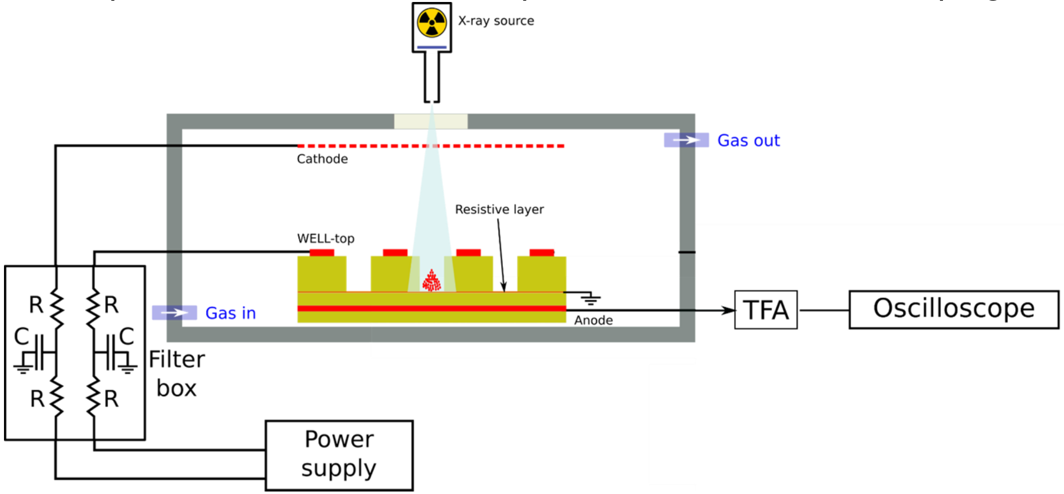


Saturation of RPWELL MCA spectra around its maximum achievable gain.

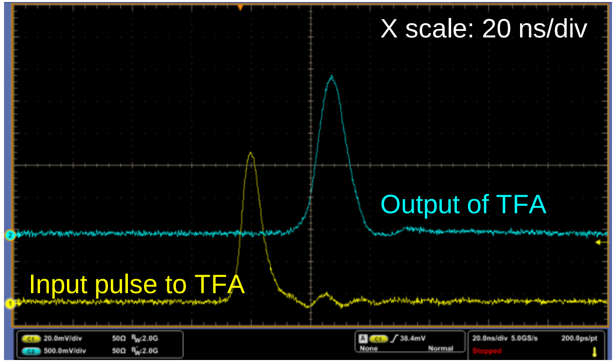
[3] A. Rubin et al., JINST 8 (2013) P11004.
[4] L. Moleri et. al, Nucl. Instr. Meth. A 845 (2017) 262.
[5] S. Bressler et. al, JINST 11 (2016) P01005.
[6] S. Bressler et. al, JINST 8 (2013) C12012.

Discharge id from pulses: experimental setup

- Replacing the standard readout chain:
  - Anode → Timing-filter amplifier (TFA) → Oscilloscope.
    - TFA (ORTEC 474): integration time = 10 ns, differentiation time = 150 μs, variable amplification. ±1 V input and ±5 V output ranges.
- Reproduction of raw detector pulses with a minimum shaping.



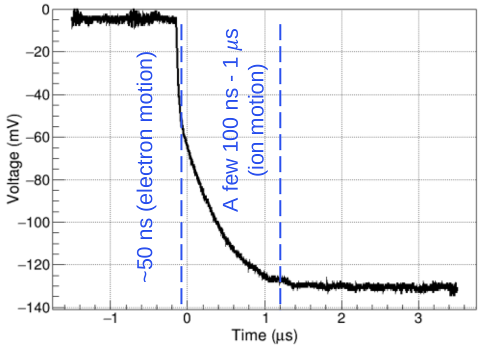
Experimental setup for discharge identification by pulse monitoring.



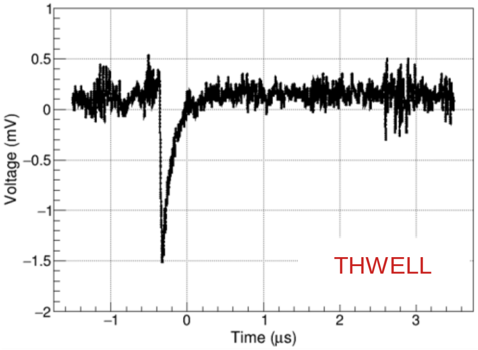
Response of TFA to a fast pulse.

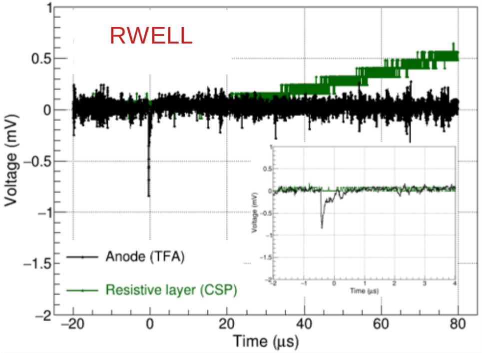
Avalanche-like pulses

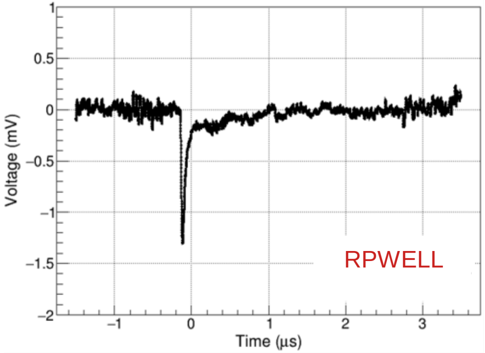
- Amplitude ~ few mV, corresponding to a charge of hundreds of fC.
- Signal shape (correlated with the CSP pulse shape):
    - ~50 ns falling edge due to electron motion.
    - Hundreds of ns tail due to ion motion.
- In RWELL, an additional slow-rising pulse was measured on the resistive layer due to the evacuating charges.



Integrated pulse after CSP.

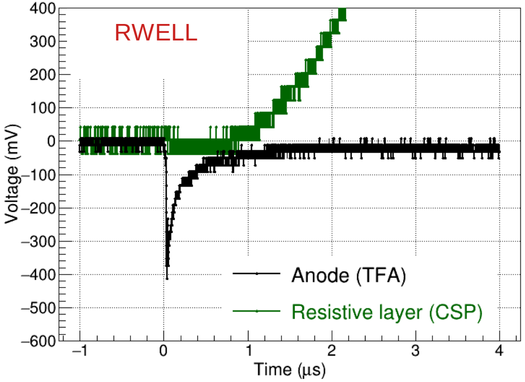


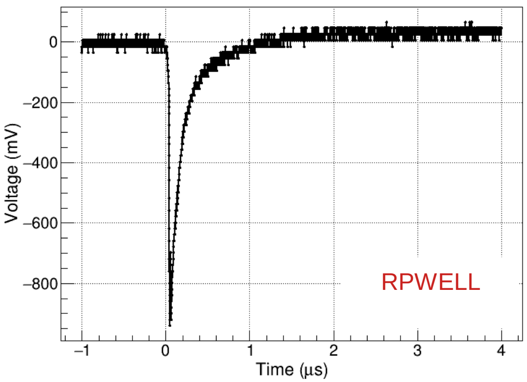




Discharge-like pulses

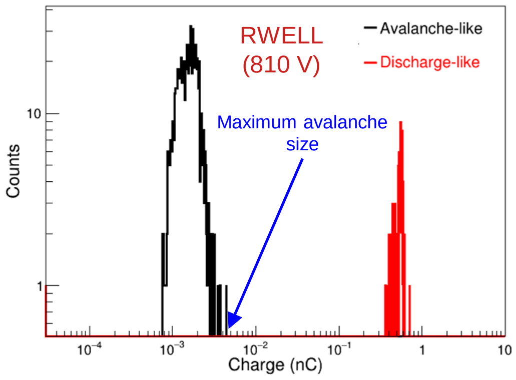
- THWELL: saturation of TFA.
- RWELL & RPWELL: large pulses (hundreds of mV) appear on anode.
- RWELL: **large pulses correlated with current spikes** from WELL-top and resistive layer.
- RPWELL: large pulses correlated with the sub-nA fluctuation on the current supplied to WELL-top.
  - Not always,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

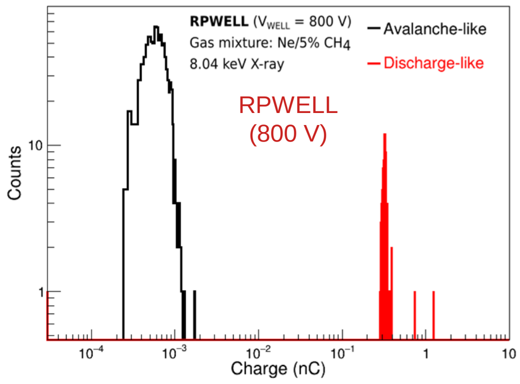


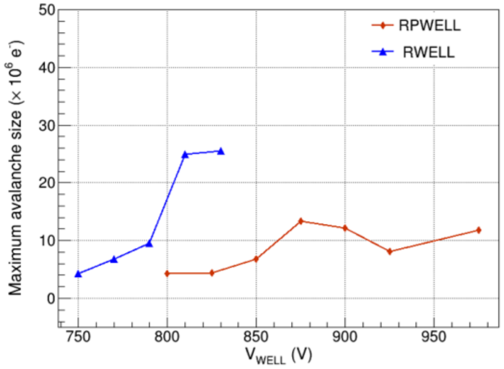


A critical charge limit

- Recording of avalanche-like and discharge-like pulses.
- Pulse height calibrated to charge [7].
- A combined distribution of those charges.
- Maximum avalanche size ~ a few **10^6 e^-**, similar to the Raether limit reported for MPGDs.
- Average induced charge due to a discharge is **minimum 2 orders of magnitude higher** than that due to avalanche.





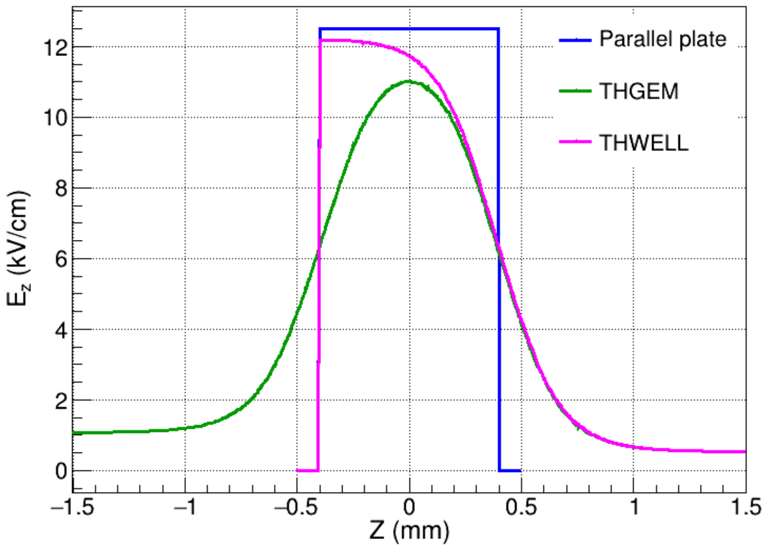


Variation of critical charge limit with applied voltage.

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

Electric field comparison

- Field comparison for 0.8 mm thick THGEM foil (0.5 mm diameter holes with 0.1 mm wide rim) for 1000 V across it.
- The peak field value is higher in THWELL than in THGEM. THWELL field varies rapidly with thickness.



Electric field variation along the thickness of the multipliers.