Recent Advances with RPWELL detectors: Physics and potential applications

A. Roy\textsuperscript{1,2}, L. Arazi\textsuperscript{1}, P. Bhattacharya\textsuperscript{2}, A. Breskin\textsuperscript{2}, S. Bressler\textsuperscript{2}, E. Erdal\textsuperscript{2}, I. Israelashvili\textsuperscript{3}, L. Moleri\textsuperscript{2,4}, D. Shaked-Renous\textsuperscript{2}, A. Tesi\textsuperscript{2}

\textsuperscript{1} Ben Gurion University
\textsuperscript{2} Weizmann Institute of Science
\textsuperscript{3} Negev Nuclear Research Centre
\textsuperscript{4} Technion - Israel Institute of Technology

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The Resistive-Plate WELL (RPWELL): a robust single-element detector

- Single-sided THGEM
- Coupled to segmented readout through material of high bulk resistivity ($10^9 - 10^{12} \, \Omega \, cm$)
- Combining MPGD and RPC concepts

**Features:**

**Discharge-free operation** (Gain $10^4 - 10^7$)
- With Ne- and Ar-based gas mixtures
- Broad dynamic range: MIPs ($\mu$, $\pi$); x-rays, UV-photons
- Low avg. pad multiplicity at High efficiency
- Up to 50x50 cm$^2$ RPWELL prototypes tested
- Gain stabilization mechanisms studied
- Moderate counting rates ($\sim 10^4$ Hz/cm$^2$)
- Sub-mm localization resolution ($\sigma \sim 280 \, \mu m$)
Motivation

Applications requiring **cost-effective large-area detectors with moderate spatial resolution**.

Single-stage **sampling elements** for (Semi) Digital Hadronic Calorimeter – **(S)DHCAL** - Up to 50x50 cm² RPWELL prototypes *(Talk by Dan Shaked Renous)*. [arXiv:1904.05545v1](https://arxiv.org/abs/1904.05545v1)

Single- & double-stage **RPWELL-based detectors** - potential candidates for **UV-photon detection @ Room Temperature (RT)**
With high dynamic range and detection efficiency

**Cryogenic RPWELL-based detectors** at LXe & LAr Temperatures (T) →
- UV-photon detection in noble-liquid detectors with **Cryogenic Gaseous Photomultipliers (GPM)**; neutrino physics, Dark Matter & other rare-event searches, fast-neutron and Gamma-imaging.
- **Charge multipliers in dual-phase noble-gas detectors**: investigating possible operation at higher stable gain relative to LEM (Large Electron Multipliers).
- **Immediate challenge → Resistive materials** of $\rho = 10^9 - 10^{12} \Omega$-cm bulk resistivity @ LXe & LAr T.
Single-stage sampling elements for (Semi) Digital Hadronic Calorimeter – (S)DHCAL

Physics requirements:
- High detection efficiency
- Low pad multiplicity
- Moderate rate capability
- Stability over wide dynamic range

Reached DHCAL requirements with RPWELL
- 98% efficiency
- Multiplicity 1.2
- No efficiency loss up to $10^4$ Hz/cm$^2$
- Stable operation in high intensity pion beam – No discharge over $10^8$ events
- Total thickness ~ 5 mm w/o electronics
- Use of Argon gas – Low cost, high # of PEs, low diffusion

Meet DHCAL requirement for a single sampling element

JINST (2016) P09013 ; JINST (2016) P01005
Double-stage RPWELL-based detectors -- potential candidates for UV-photon detection @ RT
RPWELL–based 2-stage UV-photon detector (RT)

MOTIVATION: enhanced Polya distributions ➔ increase efficiency for single photons (e.g. in RICH)

RT UV photon detection with MPGD for RICH
Recent example: COMPASS RICH-1

J. Agarwala et al., NIM A (2019),
https://doi.org/10.1016/j.nima.2019.01.058
(Micromegas +THGEM based)

Get Signal pulse-height distribution with peaked Polya distribution

➔ Better signal-to-noise ratio (compared to an exponential distribution)
➔ Increased single photon detection efficiency

\[ P(N_e) = \frac{(1+\theta)^{1+\theta} (N_e)^\theta}{T(1+\theta)} \exp\left[-(1+\theta)\frac{N_e}{\bar{N}_e}\right] \]  

where \( \bar{N}_e \) is the mean gain and \( \theta \) the Polya parameter which gives the relative gain variance \( f \):

\[ f = \left( \frac{\sigma_{N_e}}{N_e} \right)^2 = \frac{1}{1+\theta} \]

Byrne J, NIM A 74 (1969) 291-296
RPWELL–based 2-stage UV-photon detector (RT)

- Double Stage RPWELL – high dynamic range of gain
- Clear Polya distribution, improves with higher gain
- Stable operation up to high gain

Detector parameters:
- 5 mm Drift Gap; 2 mm Transfer gap
- 0.6 mm thick CsI-coated Double-sided THGEM
- 0.4 mm thick Single-sided THGEM
- 0.4 mm thick Semitron as RP
- Source: Hg Lamp
- Gas: Ne/5%CH₄

Single Electron Spectrum Evolution, $\Delta V_{RP} = 500 – 775V$

- Drift Field = 0 V/cm
- Transfer Field = 500 V/cm

Gas: Ne/CH₄ 95/5
$\Delta V_{THGEM} = 700 V$

Counts

Electrons
RPWELL–based 2-Stage UV-photon Detector (RT) - Effects of Gain and $\theta$

- The spectra were fitted with $P(N_e, \theta)$
- Efficiency estimated numerically - from the fitted spectrum
- Electronics threshold $\sim10^4$ electrons $\rightarrow$ Detecting single electrons ($\theta \sim 0.2$) with $> 90\%$ efficiency

**Observed Gas Mixture dependence**

- $\theta$ parameter vs $Gain$, $Efficiency(e)$ & % ($CH_4$) in Ne
- **Observation**: Increase in $CH_4$ $\rightarrow$ lower $\theta$ at same gain
- Preliminary - Stable UV detection ($\varepsilon>90\%$) under 6 keV X-ray background.
- **Ongoing measurements**: lower gains, Ar-mixtures & background rate dependence
Cryogenic-RP WELL

In collaboration with:

Carlos Pecharromán (Instituto de Ciencia de Materiales de Madrid, ICMM)
Miguel Morales (University of Santiago de Compostela, USC) and
Diego Gonzalez Diaz (University of Santiago de Compostela, USC)

Thanks!
## Challenges for low-T operation: Resistive-plate materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Source</th>
<th>Volume Resistivity ($\rho$) @ RT</th>
<th>Resistivity as f(T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semitron ESD 225 (Acetal based)</td>
<td>Quadrant Plastics USA</td>
<td>$1.5 \times 10^9$ Ω-cm</td>
<td>Quenches discharges completely at RT. $\rho$ increases exponentially with decreasing T. Investigated with small RPWELL prototypes</td>
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<tr>
<td>Low Resistivity Silicate (LRS) Glass</td>
<td>Prof. Wang Yi; Tsinghua University, China</td>
<td>$2 \times 10^{10}$ Ω-cm</td>
<td>Quenches discharges completely at RT. $\rho$ increases exponentially with decreasing T. Investigated @ RT with up to 50x50 cm$^2$ RPWELL</td>
</tr>
<tr>
<td>Ferrite Ceramics</td>
<td>C Pecharromán, M Morales et al, ICMM/CSIC, Spain</td>
<td>$\sim 10^5$ - $10^7$ Ω-cm</td>
<td>$\rho$ increases exponentially with decreasing T but tunable. Investigated in RPWELL down to 150K</td>
</tr>
</tbody>
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Other Resistive materials tested → **Fail to quench Discharges @ RT and/or low T**:

1. **Tivar EC (UHMW-PE) & Tivar ESD (UHMW-PE)** -> Prof. Jerry Vavra, SLAC, $\rho \sim 10^6$ – $10^7$ Ω-cm, constant as f(T); $\rho$ too low - fails to quench discharges.
2. **(PTFE + 1.5% Carbon)** -> 3M, USA, $\rho \sim 10^7$ - $10^8$ Ω-cm (function of Carbon content); constant as f(T); $\rho$ too low - fails to quench discharges.
3. **Araldite + Graphite** (Graphite % from 15-30 %) -> Fabricated @WIS, $\rho \sim 10^8$ - $10^{14}$ Ω-cm. Fails to quench discharges.
4. **Si-based Ceramics** -> Prof. Lothar Naumann, HZDR, Germany, $\rho \sim 10^8$ Ω-cm. $\rho$ too low @ RT increases exponentially with decreasing T, unsuitable @low T.
The Resistive Plate - Fe Ceramics

- Resistive materials range $\rho \sim 10^9 - 10^{12} \, \Omega \cdot \text{cm}$ (LXe & LAr T’s)

- Semitron & LRS Glass (suitable @ RT) $\rho > 10^{14} \, \Omega \cdot \text{cm}$ around 200K.

- Fe-Ceramics - robust ceramic composites with tunable electrical properties (C Pecharromán, M Morales et al; 2013 JINST 8 P01022)

- Sample S24 : $\rho \sim 10^{11} \, \Omega \cdot \text{cm}$ @ LXe Temp (measured in controlled conditions).

- Preliminary $\rho$ measurements down to LAr T. Promising results with ZN80

- Dedicated experiments ongoing @ USC, Spain and WIS to understand the behavior.
First Fe-Ceramic RPWELL @ LXe T

- First proof of discharge-free RPWELL detector operation at 163K !!

- Fe-Ceramic RPWELL tested in Ne/5%CH$_4$ at RT & low T in LN$_2$ + ethanol bath down to 160 K ($\rho \sim 10^{11}$ $\Omega$-cm)

- Detector investigated with X-rays & single UV-photons (RPWELL without/with CsI photocathode)

Fe Ceramic RPWELL compared to THWELL (same THGEM, but with standard Cu anode)
Single-stage Cryo-RPWELL – first results @ 163K

Discharge-free RPWELL operation up to $\sim 10^4$ gain with X-rays, and $\sim 10^5$ with single UV-photons (without CsI) @ 163K
Discharge behavior at 163K:

RPWELL → Discharge-free operation upto $10^4$ gain. ~5nA discharges @ gain > $10^4$. THWELL → ~200nA discharges! Onset of discharges around $10^3$ gain (850V). Unstable @ $10^4$ gain. Regular discharges.
2-stage THGEM+ Cryo-RPWELL – first results @ 163K

Detector parameters:
- 5 mm Drift gap; 2 mm Transfer gap
- 0.6 mm thick CsI-coated Double-sided THGEM
- 0.4 mm thick Single-sided THGEM
- 2.1 mm thick Fe ceramic as RP
- Source: H₂ discharge lamp

2-stage THGEM + Cryo-RPWELL (Ne/5%CH₄) →
Gain >10⁵ with X-rays @ RT and 163K
Gain >10⁶ with single UV photons @ RT and
Gain ~10⁶ @ 163K
2-stage THGEM+ Cryo-RPWELL – first results @ 163K

Gain $\approx 1.2 \times 10^5$; $\Delta V_{RP} = 875$ V; $\Delta V_{TH} = 800$ V

FWHM ~ 14%

Ne/5\%CH$_4$ 163K

Pulse height spectra of double-stage detector with X-rays; $T = 163$K

$\Delta V_{RP} = 750$ V; $\Delta V_{TH} = 900$ V; Gain $\approx 2.5 \times 10^6$

Single UV photons, 163K, w/o CsI

Clear Polya distributions obtained @ $T = 163$K with the double-stage detector with Single UV-photons

A. Roy – Advances with RPWELL

MPGD 2019, La Rochelle May 5-10, 2019

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Cryo-RP WELL based noble liquid detectors -- Investigating possible enhancement of maximum achievable stable detector gain in ultrapure Ar vapor
Cryo-RP WELL charge multipliers in dual-phase noble-gas detectors

Dedicated LAr cryostat @ WIS – WISArD (Weizmann Institute Argon detector)

Breakdown of Fe-Ceramic RPWELL vs THWELL (Fe-Ceramic -> $\rho \sim 10^6$-$10^7$ $\Omega$-cm @ RT):

- **200-300K** – No difference in breakdown voltages -> Fe-Ceramic $\rho$ inadequate to quench discharges!

- **$T < 200K$** --> $\rho \sim 10^9$ $\Omega$-cm ➔ Effect of RP clearly seen. **Higher RPWELL Breakdown Voltages.**

Preliminary Breakdown Voltage Measurements

![Graph showing preliminary breakdown voltage measurements for Standard WELL and RPWELL at various temperatures.]
Summary & Outlook

- **Resistive material – main challenge → Fe-Ceramics suitable at 163K.** Promising results for LAr (~87K).
  
  *Ongoing:* Detailed investigations @ USC and WIS

- **UV detectors @ RT → 2-stage CsI-THGEM + RPWELL.**
  
  - Clear Polya distributions in Ne/5%CH₄.
  - Single-photon detection efficiency >90%.
  
  → potential candidate for UV-photon detection.
  
  *Ongoing:* efficiency vs background, Single-stage RPWELL, other gases & quenchers (Ar, CF₄, etc).

- **Cryogenic RPWELL @ 163K → Single-stage RPWELL (Ne/5%CH₄)**
  
  - Gain ~10⁴ with X-rays, and ~10⁵ with single UV-photons.
  - Discharge quenching at 163K: RPWELL ~5nA vs THWELL ~200nA!

- **RPWELL-based Cryogenic Gaseous Photomultipliers (GPM) @ 163K → 2-stage THGEM + RPWELL (Ne/5%CH₄)**
  
  - Gain >10⁵ with x-rays and ~10⁶ with single UV photons. Clear Polya distributions.
  
  *Ongoing:* 2-stage CsI-THGEM + RPWELL; 10cm diameter cryo-GPM; Photon Detection Efficiency.

- **Cryo-RPWELL charge multipliers in dual-phase Ar detectors →**
  
  Preliminary studies highlight role of RP at low T
  
  *Ongoing:* Tuning resistivity to LAr-T; gain with single-stage RPWELL in dual-phase Ar.
Thanks!!