



Recent Advances with RPWELL detectors: Physics and potential applications

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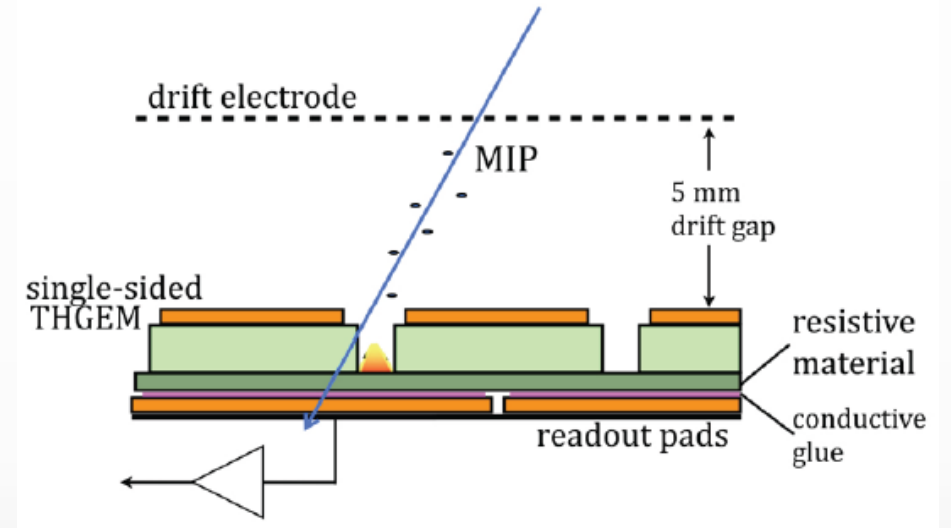
The Resistive-Plate WELL (RPWELL): a robust single-element detector

- Single-sided THGEM
- Coupled to segmented readout through material of high bulk resistivity ($10^9 - 10^{12} \Omega \text{ cm}$)
- 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 (μ, π); x-rays, UV-photons
- Low avg. pad multiplicity at High efficiency
- Up to $50 \times 50 \text{ cm}^2$ RPWELL prototypes tested
- Gain stabilization mechanisms studied
- Moderate counting rates ($\sim 10^4 \text{ Hz/cm}^2$)
- Sub-mm localization resolution ($\sigma \sim 280 \mu\text{m}$)



[2013 JINST 8 P11004](#)
[2016 JINST 11 P01005](#)
[2016 JINST 11 P09013](#)
[NIM A 845 \(2017\) 262 -265](#)
[2017 JINST 12 P10017](#)
[2017 JINST 12 P09036](#)
[arXiv:1904.05545v1](#)

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)

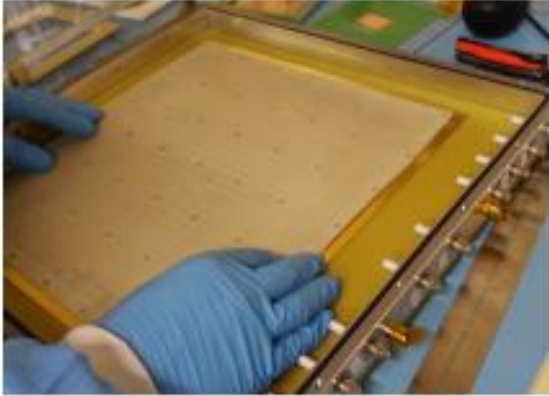
Single-& double-stage **RPWELL-based detectors** - potential candidates for **UV-photon detection @ Room Temperature (RT)**

With high dynamic range and detection efficiency

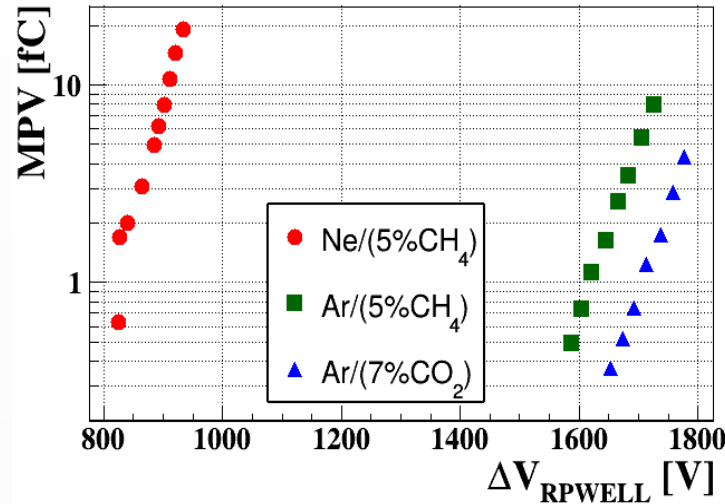
Cryogenic RPWELL-based detectors at LXe & LAr Temperatures (T) →

- 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 $\rho = 10^9 - 10^{12} \Omega\text{-cm}$ bulk resistivity @ LXe & LAr T.**

Single-stage sampling elements for (Semi) Digital Hadronic Calorimeter – (S)DHCAL



30x30 cm² RPWELL prototype



Physics requirements:

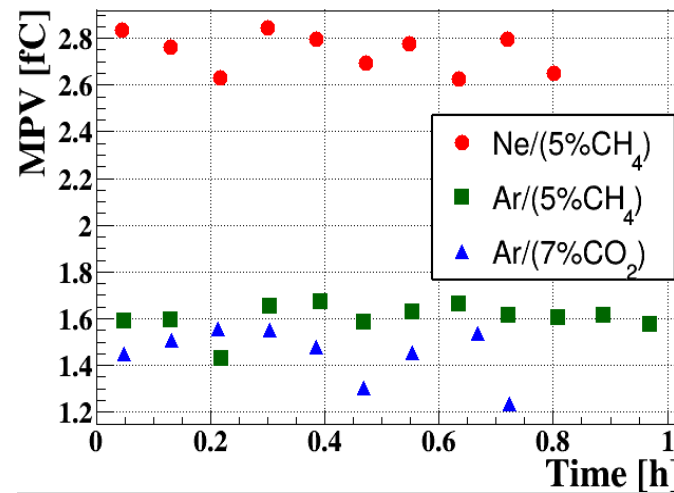
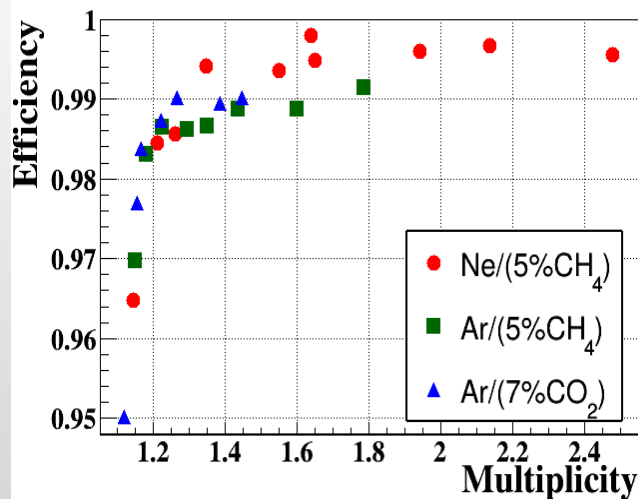
- High detection efficiency
- Low pad multiplicity
- Moderate rate capability
- Stability over wide dynamic range

Reached DHCAL requirements with RPWELL

- 98% efficiency
- Multiplicity 1.2
- No efficiency loss up to 10⁴ Hz/cm²
- Stable operation in high intensity pion beam – No discharge over 10⁸ 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)*

$P(N_e)$ – the probability that the avalanche has N_e electrons

Get Signal pulse-height distribution with peaked Polya distribution

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

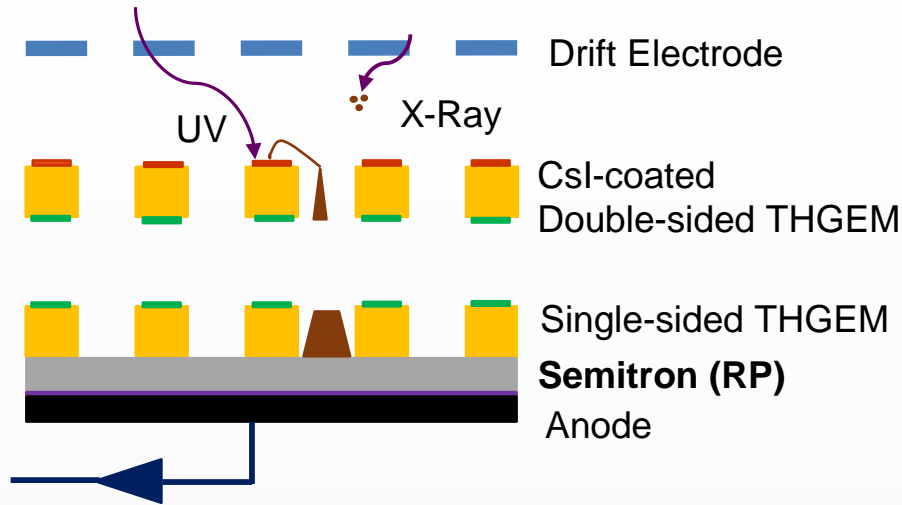
$$P(N_e) = \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{N_e}{\bar{N}_e}\right)^\theta \exp\left[-(1+\theta)\frac{N_e}{\bar{N}_e}\right] \quad (1)$$

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

$$f = \left(\frac{\sigma_{N_e}}{\bar{N}_e}\right)^2 = \frac{1}{1+\theta} \quad (2)$$

Byrne J, NIM A 74 (1969) 291-296

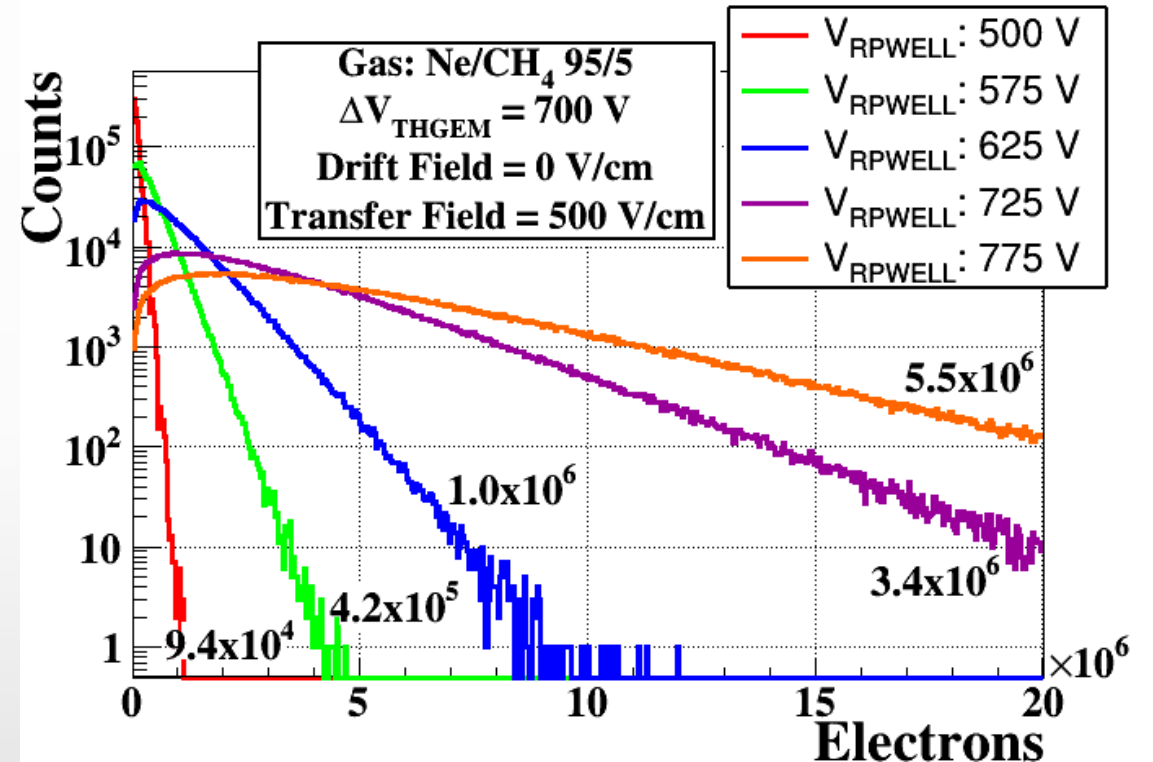
RPWELL-based 2-stage UV-photon detector (RT)



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

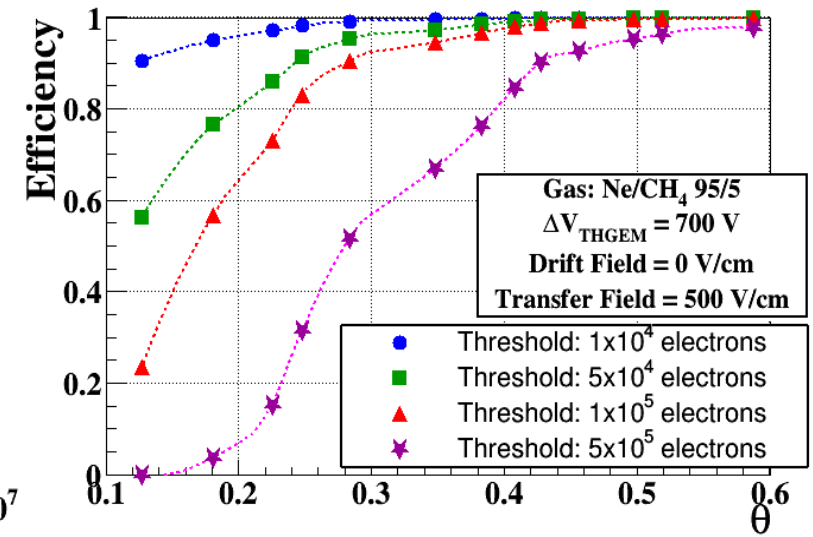
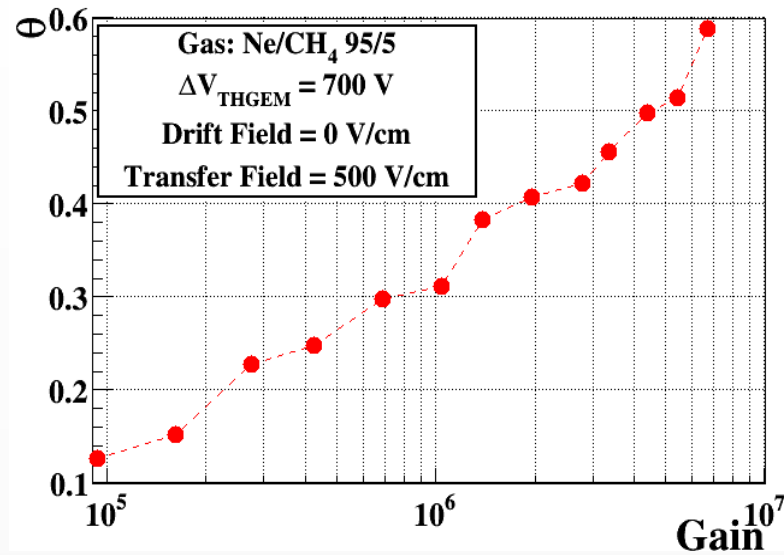
Single Electron Spectrum Evolution, $\Delta V_{RP} = 500 - 775V$



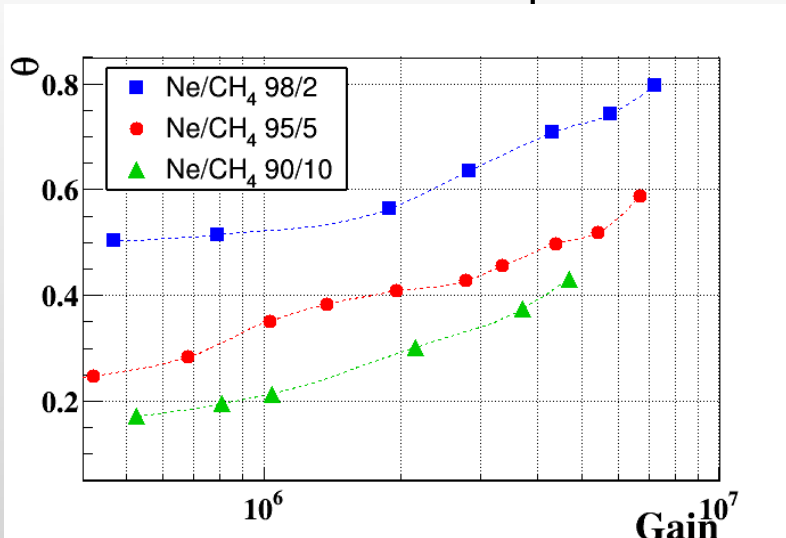
- Double Stage RPWELL – high dynamic range of gain
- Clear Polya distribution, improves with higher gain
- Stable operation up to high gain

RPWELL-based 2-Stage UV-photon Detector (RT) - Effects of Gain and θ

- The spectra were fitted with $P(N_e, \theta)$
- Efficiency estimated numerically - from the fitted spectrum
- Electronics threshold $\sim 10^4$ electrons → **Detecting single electrons ($\theta \sim 0.2$) with $> 90\%$ efficiency**



Observed Gas Mixture dependence



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

Cryogenic-RPWELL

In collaboration with :

Carlos Pecharromán (Instituto de Ciencia de Materiales de Madrid, ICMM)

Miguel Morales (Instituto Galego de Fisica de Altas Enerxias – IGFAE-USC) and

Diego Gonzalez Diaz (Instituto Galego de Fisica de Altas Enerxias – IGFAE-USC)

Thanks!

Challenges for low-T operation: Resistive-plate materials

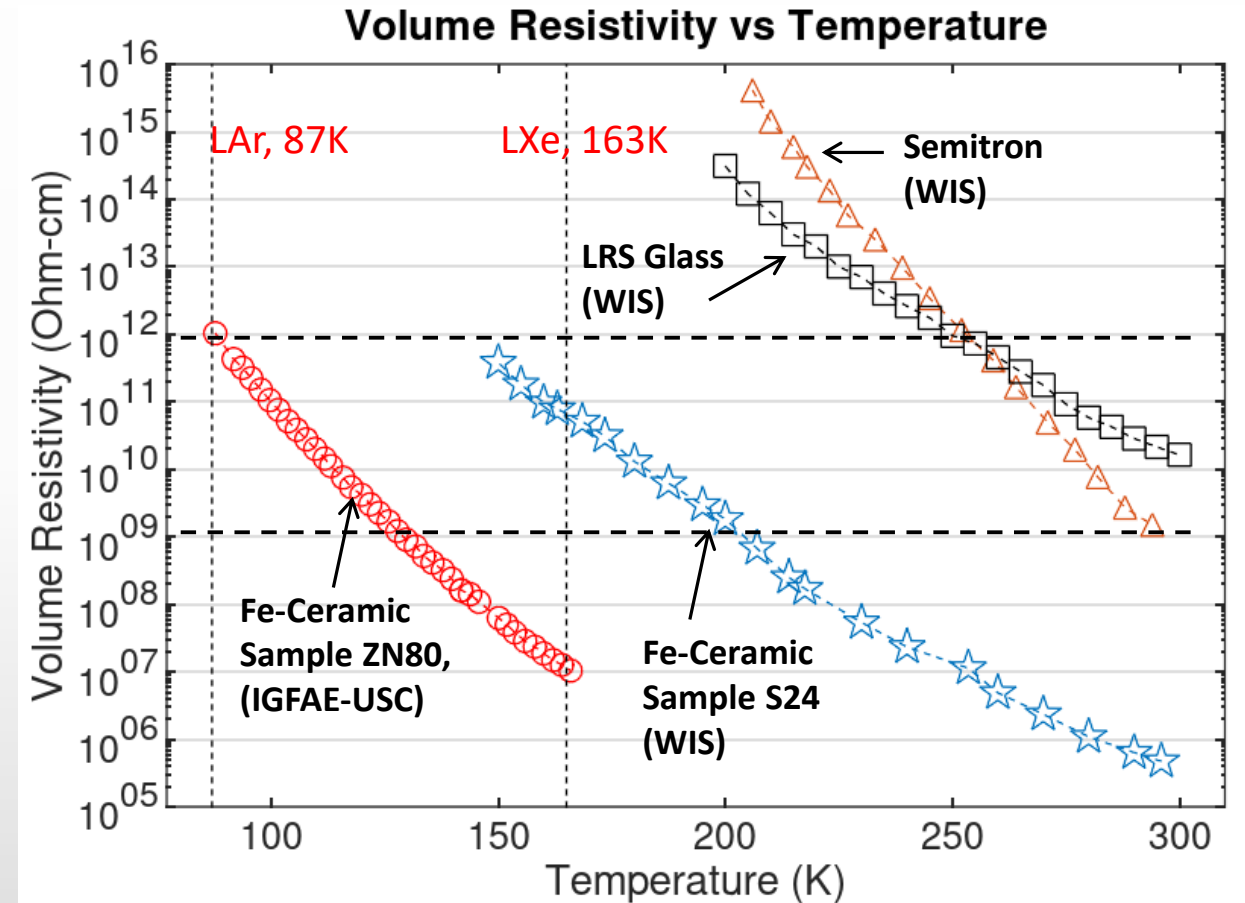
Material	Source	Volume Resistivity (ρ)@ RT	Resistivity as f(T)
Semitron ESD 225 (Acetal based)	Quadrant Plastics USA	$1.5 \times 10^9 \Omega\text{-cm}$	Quenches discharges completely at RT. ρ increases exponentially with decreasing T. Investigated with small RPWELL prototypes
Low Resistivity Silicate (LRS) Glass	Prof. Wang Yi; Tsinghua University, China	$2 \times 10^{10} \Omega\text{-cm}$	Quenches discharges completely at RT. ρ increases exponentially with decreasing T. Investigated @ RT with up to $50 \times 50 \text{ cm}^2$ RPWELL
Ferrite Ceramics	C Pecharromán, M Morales et al, ICM/CSIC, Spain	$\sim 10^5 - 10^7 \Omega\text{-cm}$.	ρ increases exponentially with decreasing T but tunable . Investigated in RPWELL down to 150K

Other Resistive materials tested \rightarrow Fail to quench Discharges @ RT and/or low T):

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

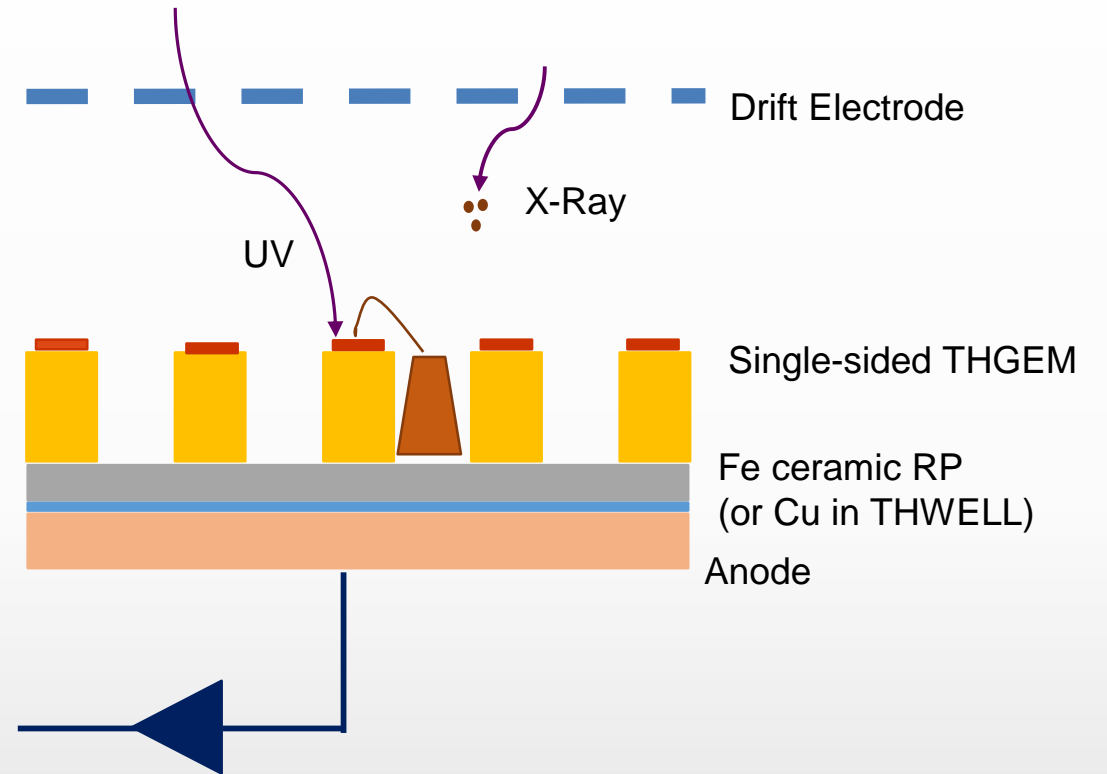
The Resistive Plate - Fe Ceramics

- ❖ Resistive materials range $\rightarrow \rho \sim 10^9 - 10^{12} \Omega\text{-cm}$ (LXe & LAr T's)
- ❖ Semitron & LRS Glass (suitable @ RT)
 $\rho > 10^{14} \Omega\text{-cm}$ around 200K.
- ❖ Fe-Ceramics - robust ceramic composites with tunable electrical properties (C Pecharrromán, M Morales et al; 2013 JINST 8 P01022)
- ❖ Sample S24 : $\rho \sim 10^{11} \Omega\text{-cm}$ @ LXe Temp (measured in controlled conditions).
- ❖ Preliminary ρ measurements down to LAr T. Promising results with ZN80
- ❖ Dedicated experiments ongoing @ IGFAE-USC, Spain and WIS to understand the behavior.



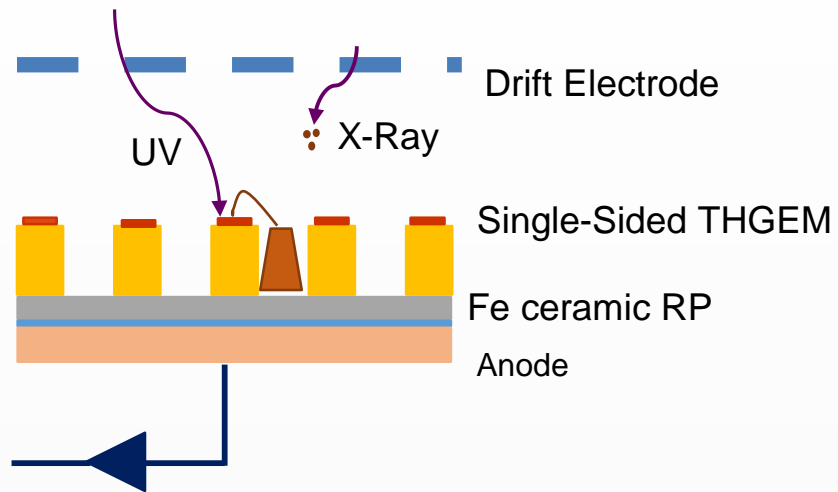
First Fe-Ceramic RPWELL @ LXe T

- ❖ First proof of discharge-free RPWELL detector operation at **163K !!**
- ❖ Fe-Ceramic RPWELL tested in Ne/5%CH₄ at RT & low T in LN₂ + ethanol bath down to 160 K (**$\rho \sim 10^{11} \Omega\text{-cm}$**)
- ❖ Detector investigated with X-rays & single UV-photons (RPWELL without/with CsI photocathode)

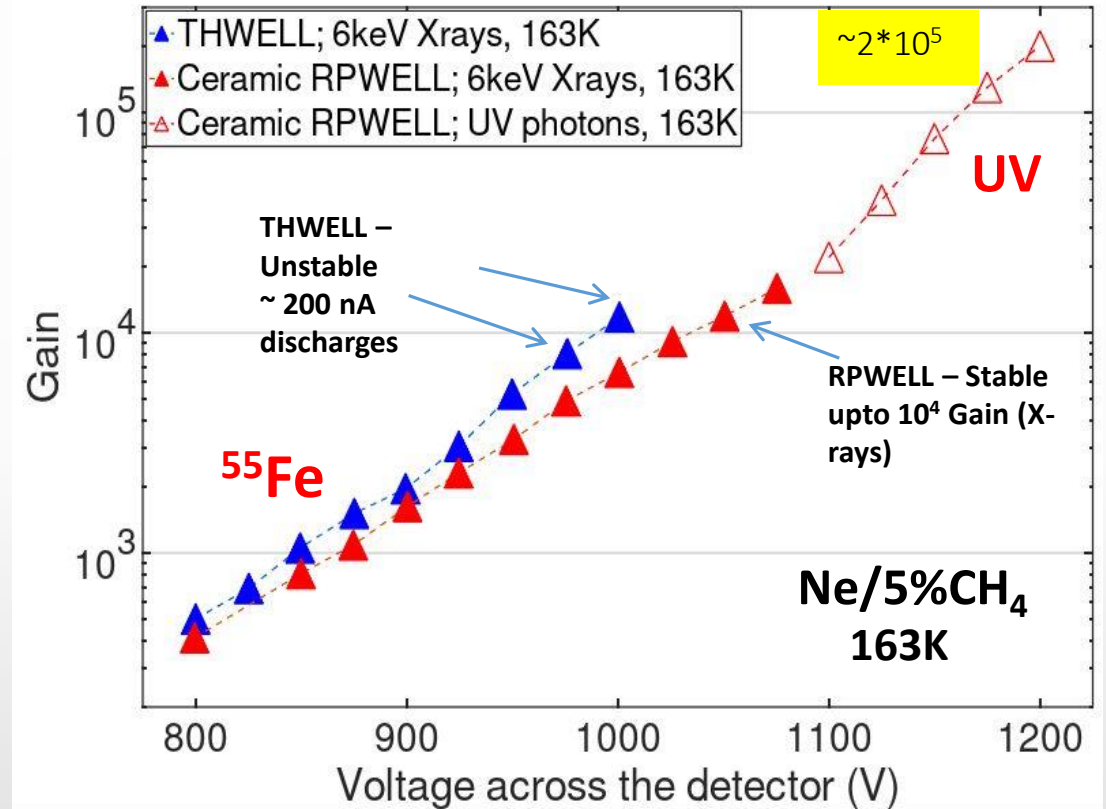
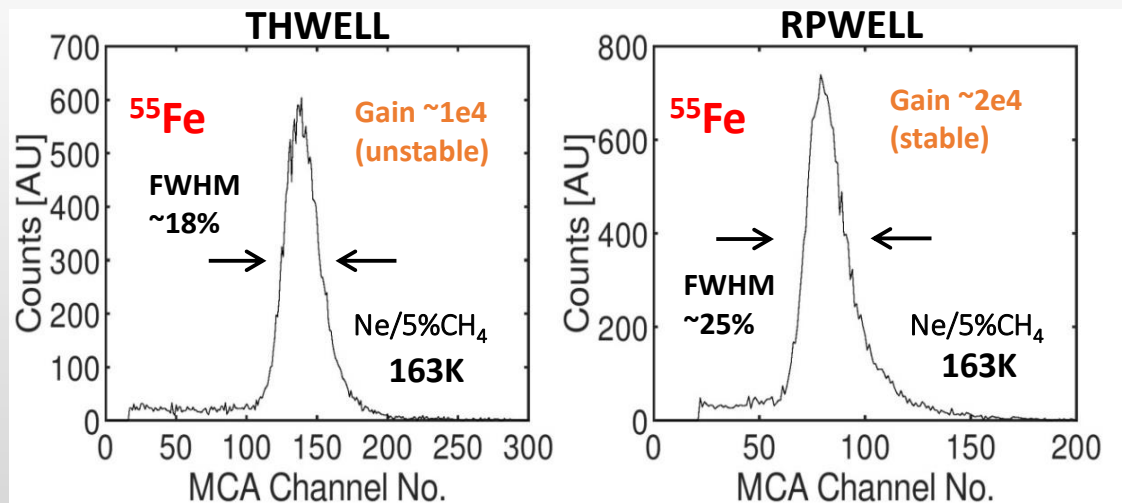


Fe Ceramic **RPWELL** compared to **THWELL**
(same THGEM, but with standard Cu anode)

Single-stage Cryo-RPWELL – first results @ 163K

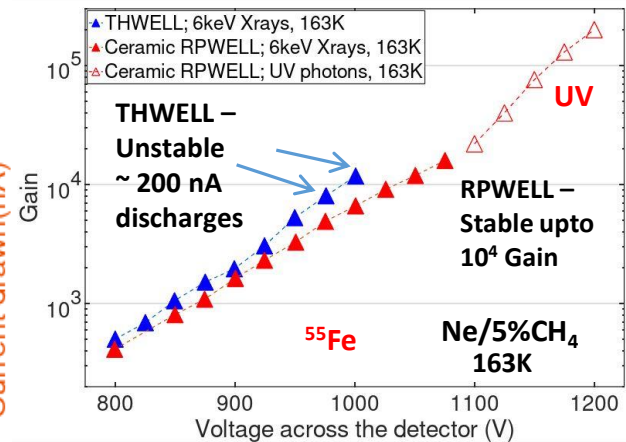
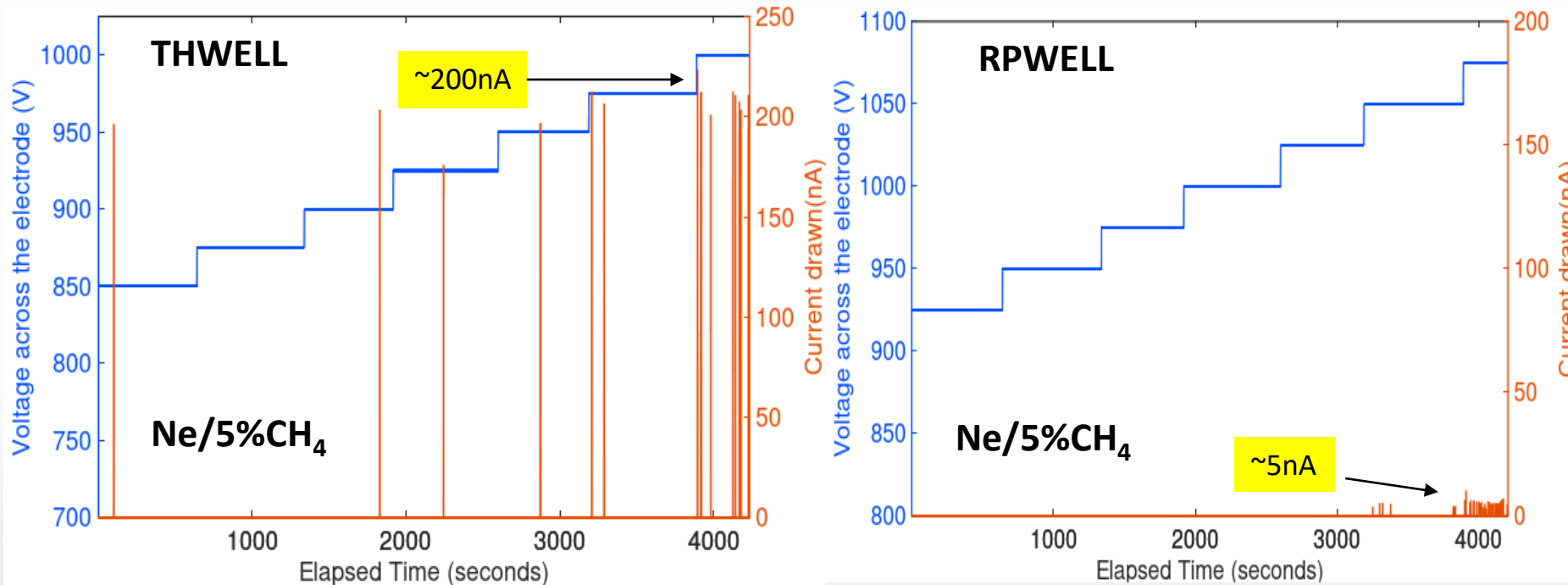


Pulse Height Spectra with X-rays



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

Cryo-RPWELL Results @ 163K – Discharge behavior



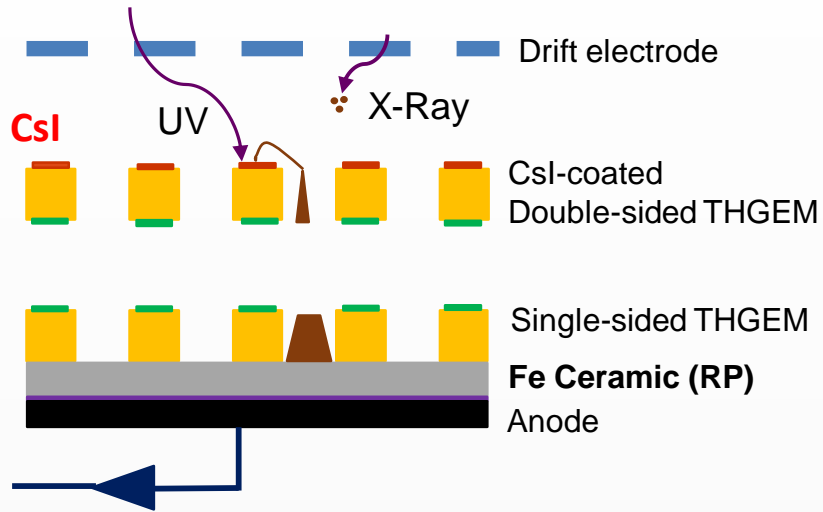
Discharge behavior at 163K :

RPWELL → **Discharge-free operation** upto 10^4 gain. $\sim 5\text{nA}$ discharges @ gain $> 10^4$.

THWELL → $\sim 200\text{nA}$ discharges! Onset of discharges around 10^3 gain (850V) .

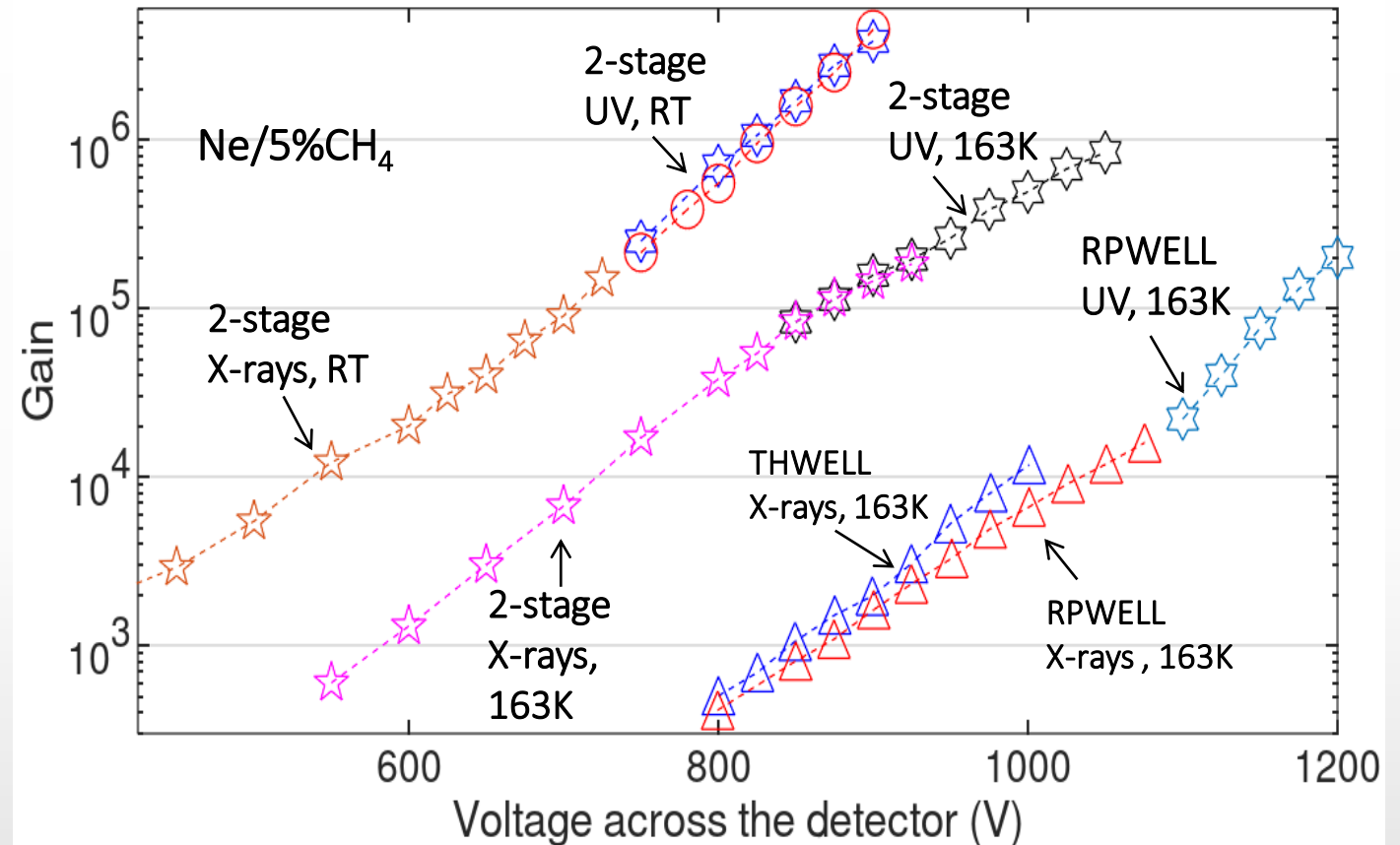
Unstable @ 10^4 gain. Regular discharges

2-stage THGEM+ Cryo-RPWELL – first results @ 163K



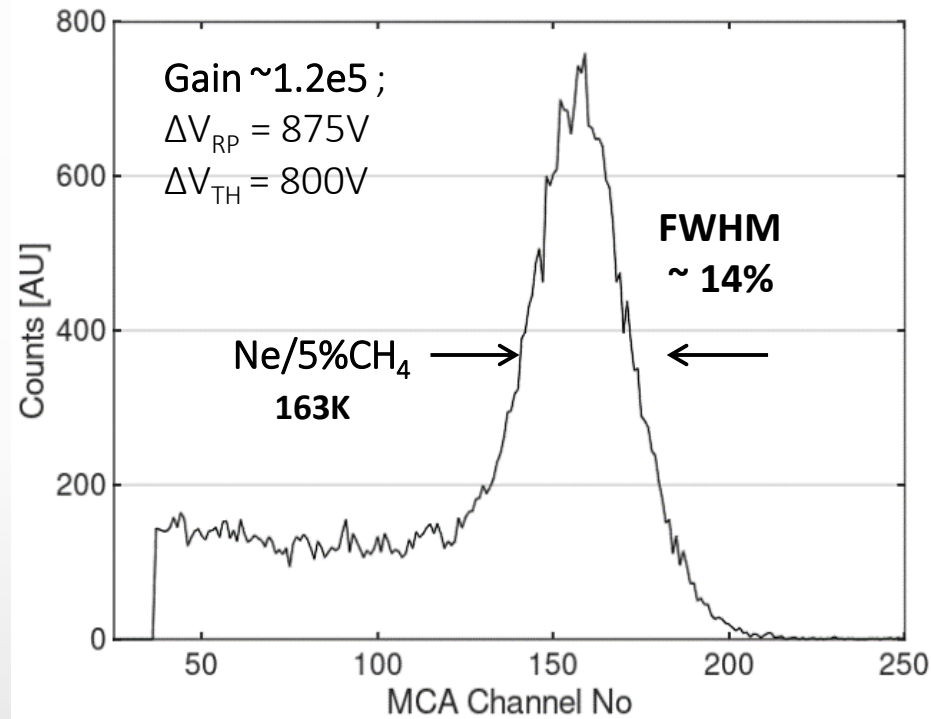
Detector parameters :

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

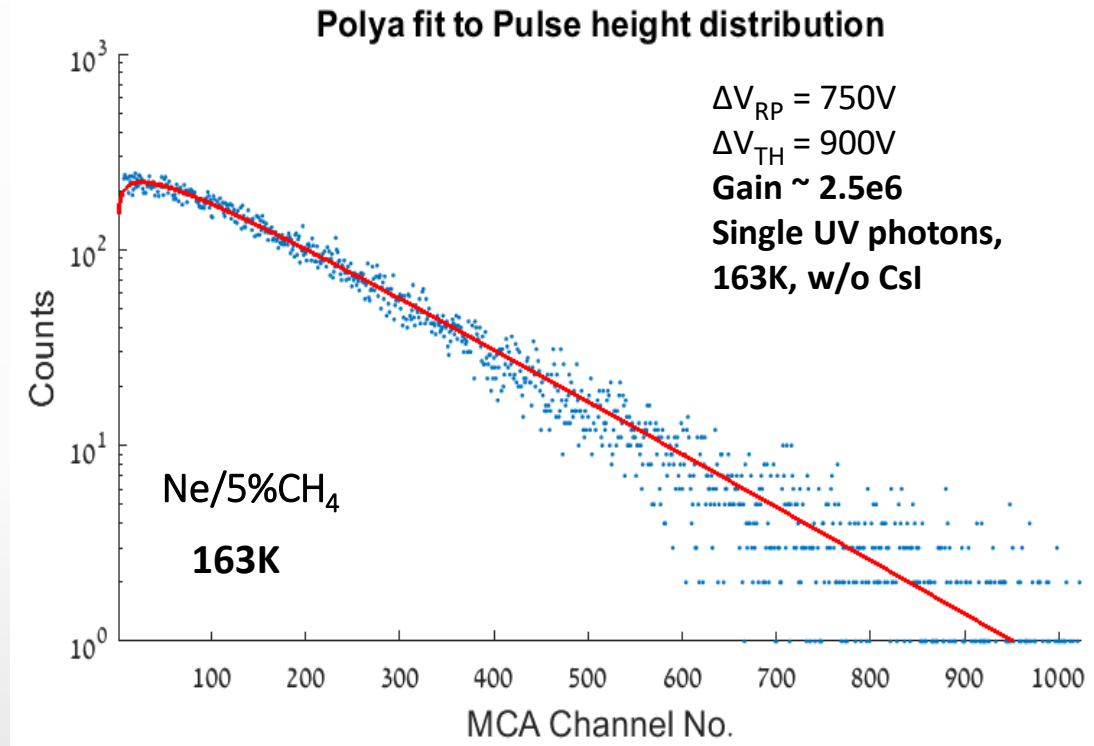


2-stage THGEM + Cryo-RPWELL (Ne/5%CH₄) →
Gain >10⁵ with X-rays @ RT and 163K
Gain >10⁶ with single UV photons @ RT and
Gain ~10⁶ @ 163K

2-stage THGEM+ Cryo-RPWELL – first results @ 163K



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



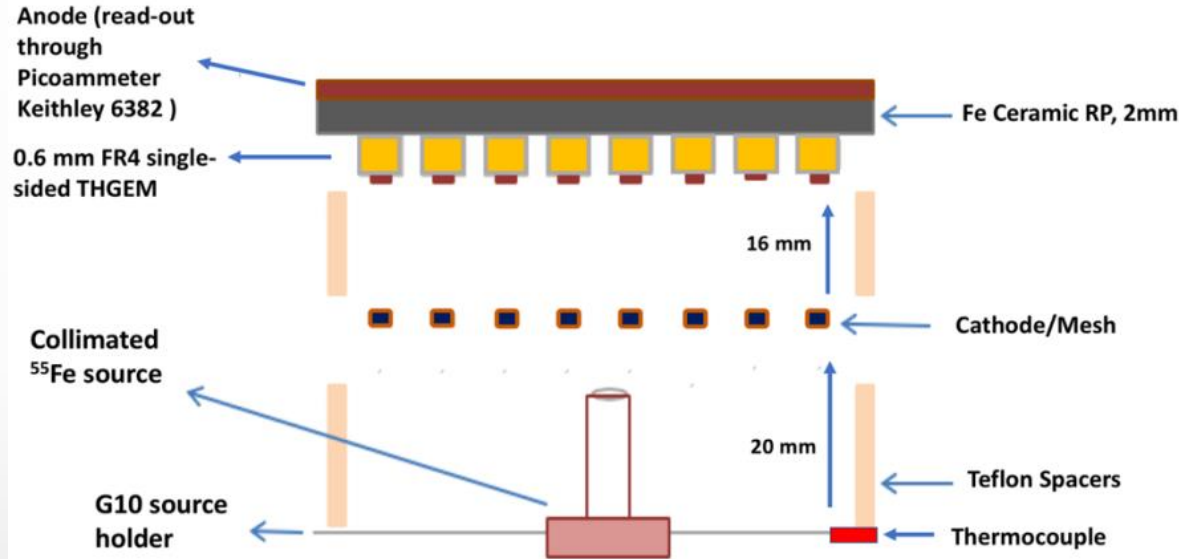
Clear Polya distributions obtained @ T = 163K with the double-stage detector with Single UV-photons

Cryo-RPWELL based noble liquid detectors -- Investigating possible enhancement of maximum achievable stable detector gain in ultrapure Ar vapor

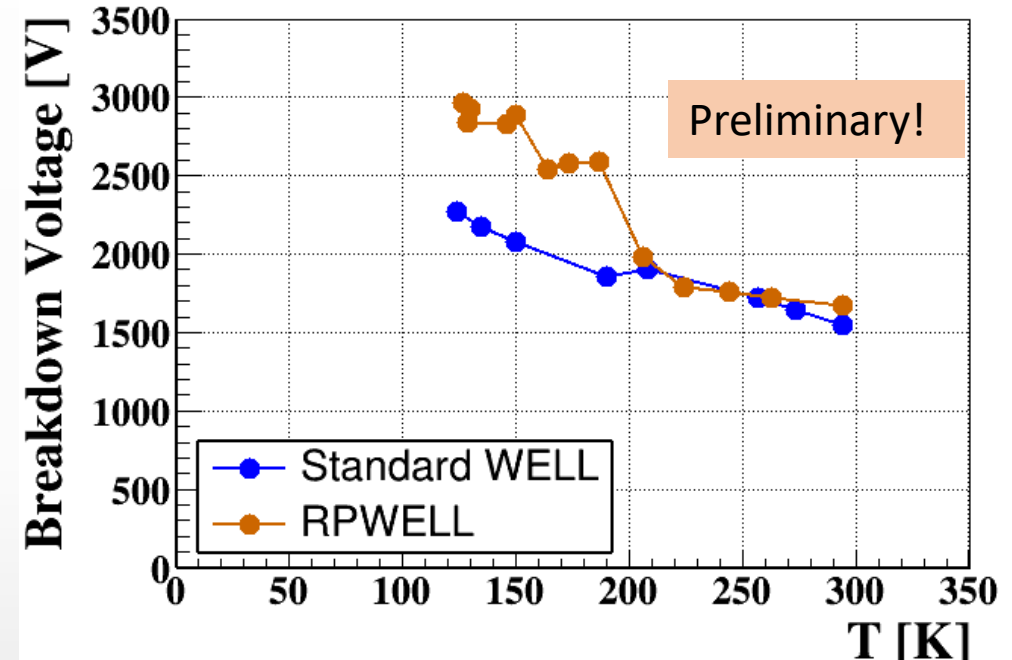
Cryo-RPWELL charge multipliers in dual-phase noble-gas detectors

Dedicated LAr cryostat @ WIS – WISArD

(Weizmann Institute Argon detector)



Preliminary Breakdown Voltage Measurements



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

- 200-300K – No difference in breakdown voltages \rightarrow Fe-Ceramic ρ inadequate to quench discharges!
- $T < 200\text{K}$ $\rightarrow \rho \sim 10^9 \Omega\text{-cm}$ \rightarrow Effect of RP clearly seen. Higher RPWELL Breakdown Voltages.

Summary & Outlook

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