Recent Advances with RPWELL detectors: Physics and potential applications

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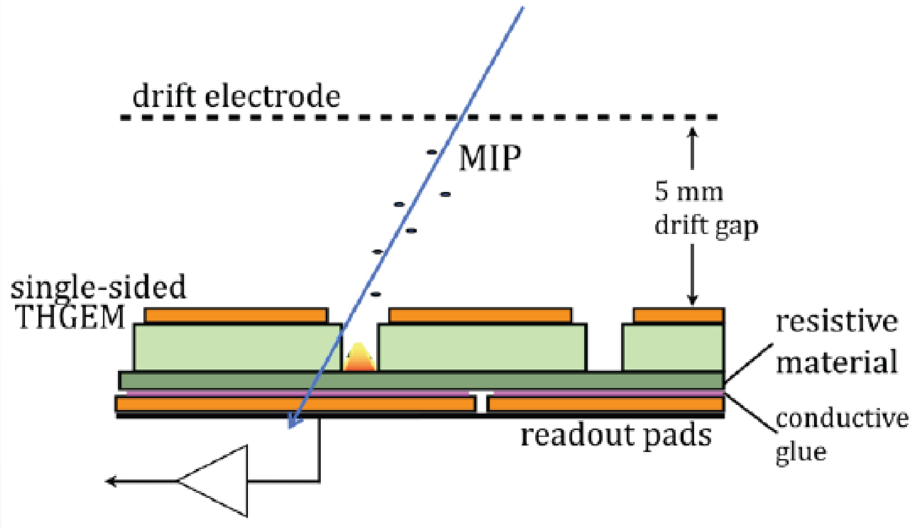
The Resistive-Plate WELL (RPWELL): a robust single-element detector

- Single-sided THGEM
- Coupled to segmented readout through material of high bulk resistivity ($10^9 - 10^{12}\ \Omega\ cm$)
- 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 50x50 cm^2 RPWELL prototypes tested
- Gain stabilization mechanisms studied
- Moderate counting rates (~10^4 Hz/cm^2)
- Sub-mm localization resolution (σ ~ 280 μm)



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**.

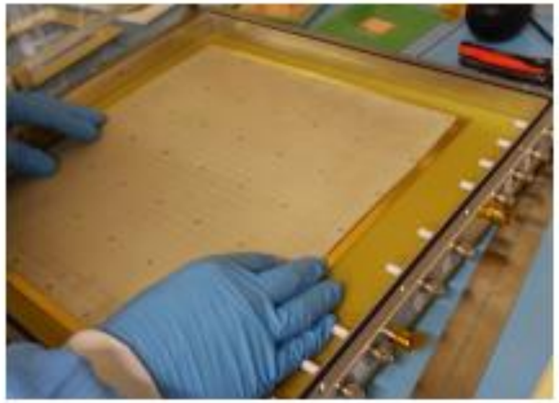
Single-stage **sampling elements** for (Semi) Digital Hadronic Calorimeter – **(S)DHCAL** - Up to 50x50 cm^2 RPWELL prototypes (**Talk by Dan Shaked Renous**). *arXiv:1904.05545v1*

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

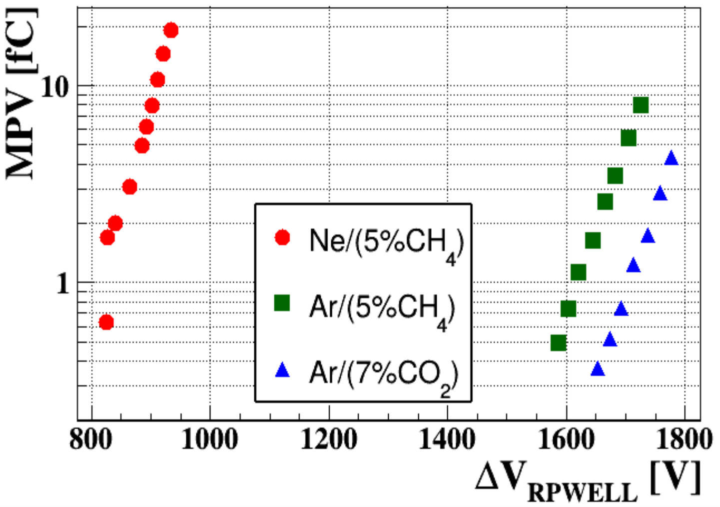
Cryogenic RPWELL-based detectors at LXe & LAr Temperatures (T) →

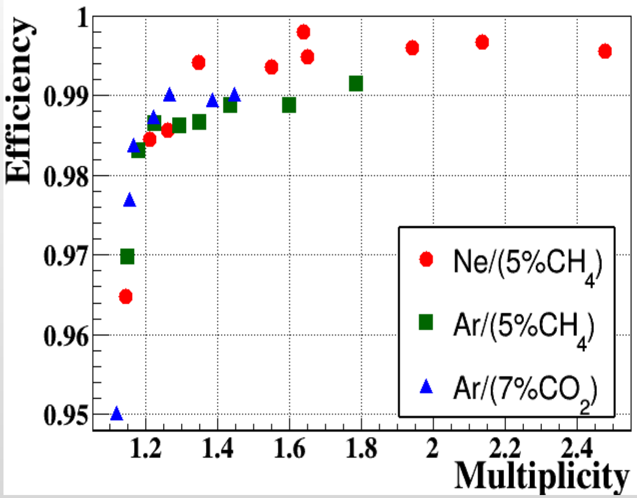
- UV-photon detection in noble-liquid detectors with **Cryogenic Gaseous Photomultipliers (GPM);** neutrino physics, Dark Matter & other rare-event searches, fast-neutron and Gamma-imaging.
- **Charge multipliers in dual-phase noble-gas detectors**: investigating possible operation at higher stable gain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

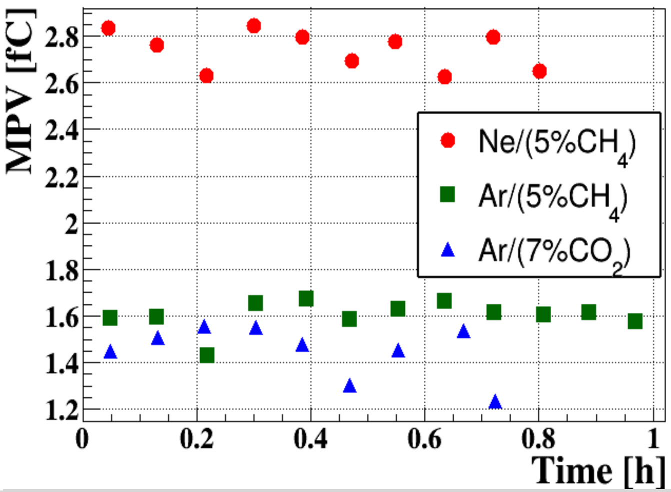
Single-stage sampling elements for (Semi) Digital Hadronic Calorimeter – (S)DHCAL



30x30 cm^2 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 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)

$P(N_e)$ – 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**

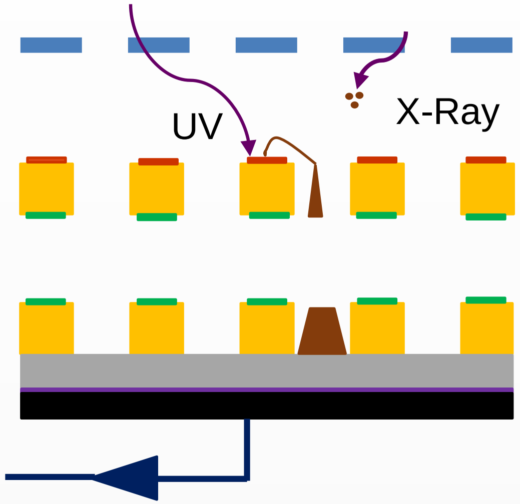
$$P(N_e) = \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{N_e}{\overline{N_e}}\right)^{\theta} \exp\left[-(1+\theta)\frac{N_e}{\overline{N_e}}\right] \quad (1)$$

where $\overline{N_e}$ is the mean gain and θ the Polya parameter which gives the relative gain variance f:

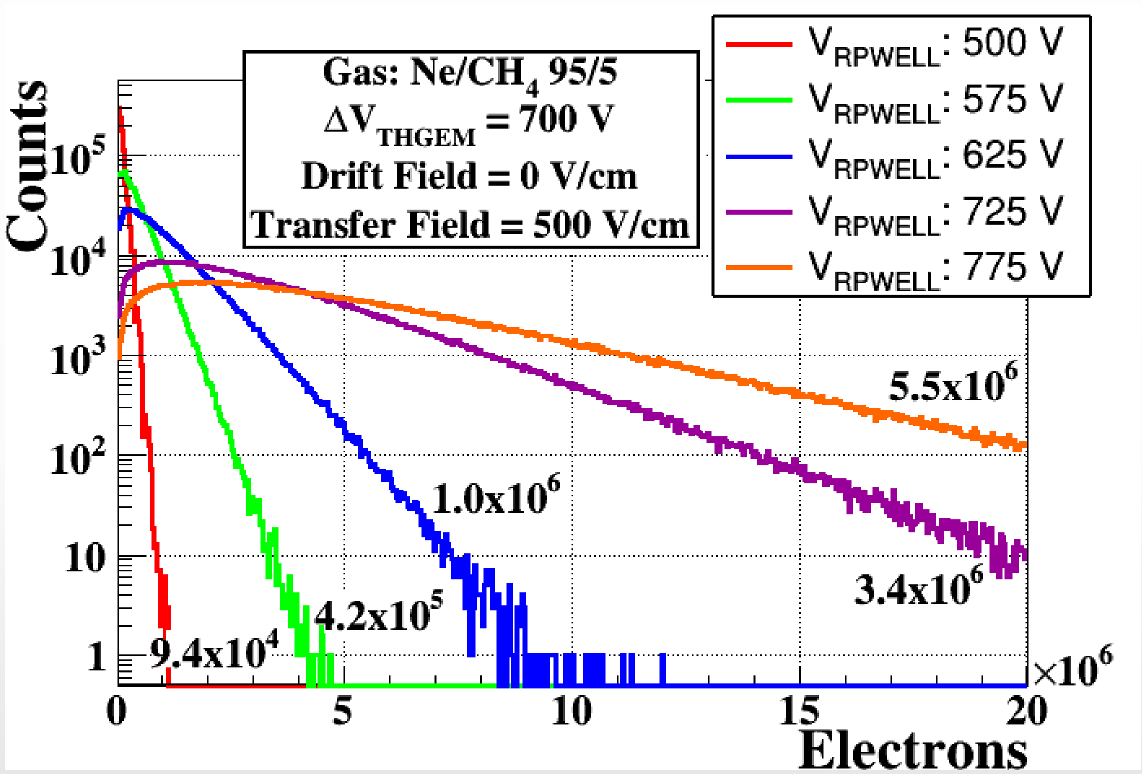
$$f = \left(\frac{\sigma_{N_e}}{\overline{N_e}}\right)^2 = \frac{1}{1+\theta}. \quad (2)$$

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

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



Single Electron Spectrum Evolution, ΔV_{RP} = 500 – 775V



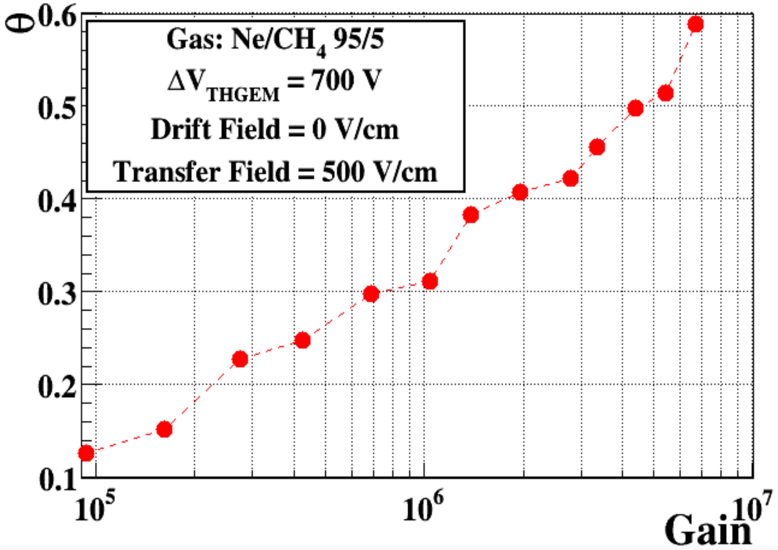
Detector parameters :

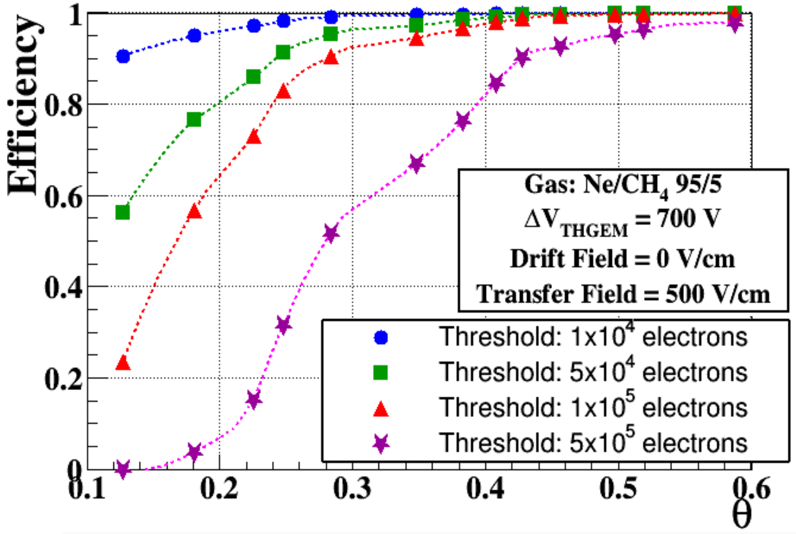
- 5 mm Drift Gap; 2 mm Transfer gap
- 0.6 mm thick CsI-coated Double-sided THGEM
- 0.4 thick Single-sided THGEM
- 0.4 mm thick Semitron as RP
- Source: Hg Lamp
- Gas: Ne/5%CH_4

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

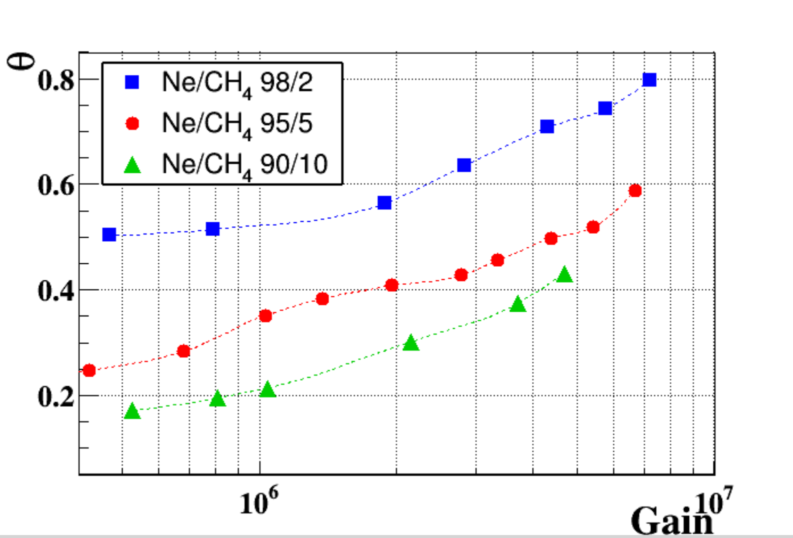
RPWELL–based 2-Stage UV-photon Detector (RT) - Effects of Gain and θ

- The spectra were fitted with P(N_e ,θ)
- Efficiency estimated numerically - from the fitted spectrum
- Electronics threshold ~10^4 electrons → **Detecting single electrons (θ ~ 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 (ε>90%) under 6 keV X-ray background.
- **Ongoing measurements:** lower gains, Ar-mixtures & background rate dependence

Cryogenic-RPWELL

<u>In collaboration with :</u>

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

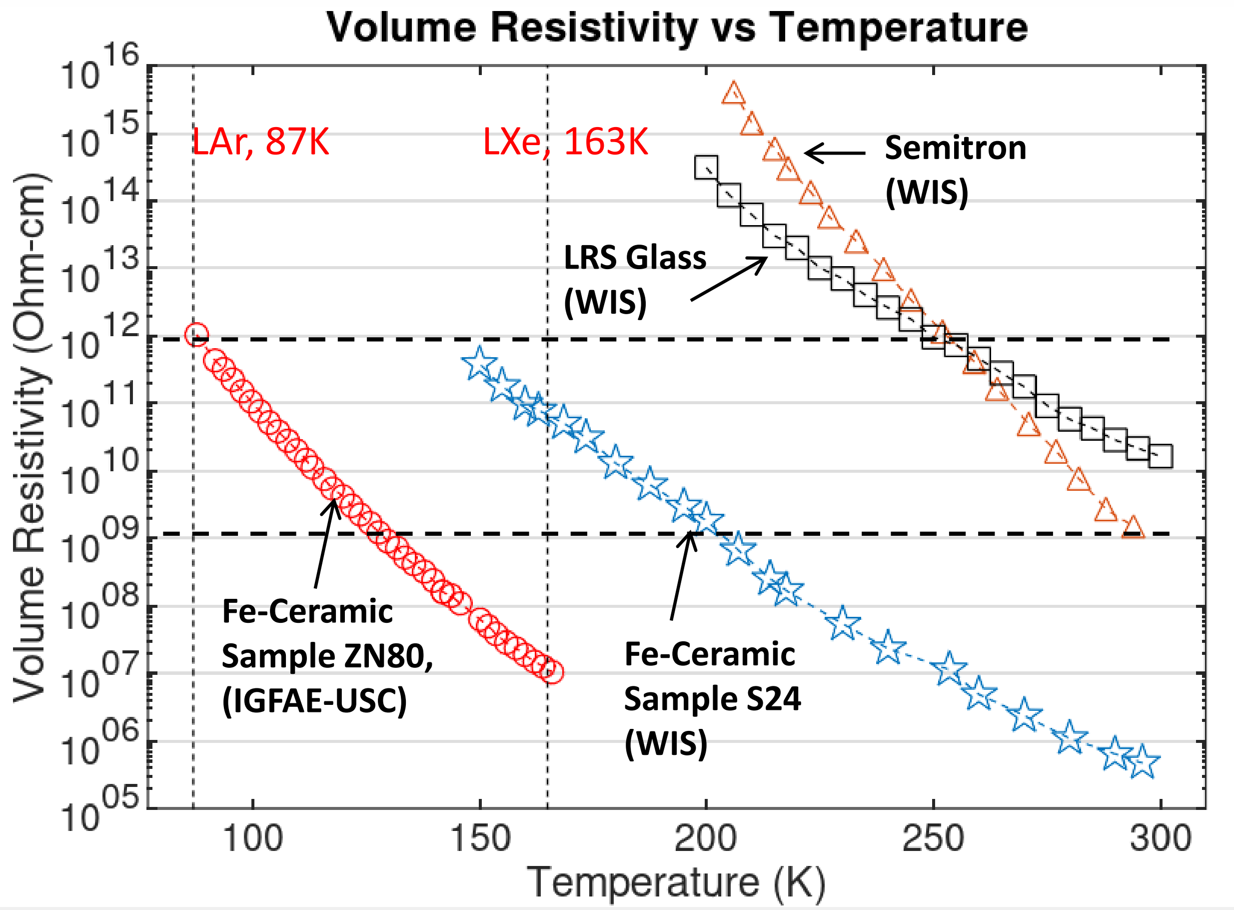
Material	Source	Volume Resistivity (ρ)@ RT	Resistivity as f(T)
Semitron ESD 225 (Acetal based)	Quadrant Plastics USA	1.5×10^{9} Ω-cm	Quenches discharges completely at RT. **ρ** increases exponentially with decreasing T. Investigated with small RPWELL prototypes
Low Resistivity Silicate (LRS) Glass	Prof. Wang Yi; Tsinghua University, China	2×10^{10} Ω-cm	Quenches discharges completely at RT. **ρ** increases exponentially with decreasing T. Investigated @ RT with up to 50x50 cm^2 RPWELL
Ferrite Ceramics	C Pecharromán, M Morales et al, ICMM/CSIC, Spain	~10^{5} - 10^{7} Ω-cm.	**ρ** increases exponentially with decreasing T but **tunable**. Investigated in RPWELL down to 150K

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, ρ ~ 10^{6} – 10^{7} Ω-cm, constant as f(T); ρ too low - fails to quench discharges.
2. *(PTFE + 1.5% Carbon)* -> 3M, USA, ρ ~ 10^{7} - 10^{8} Ω-cm (function of Carbon content); constant as f(T); ρ too low - fails to quench discharges.
3. *Araldite + Graphite* (Graphite % from 15-30 %) -> Fabricated @WIS, ρ ~10^{8} - 10^{14} Ω-cm. Fails to quench discharges.
4. *Si-based Ceramics* -> Prof. Lothar Naumann, HZDR, Germany, ρ ~10^{8} Ω-cm. ρ too low @ RT increases exponentially with decreasing T, unsuitable @low T

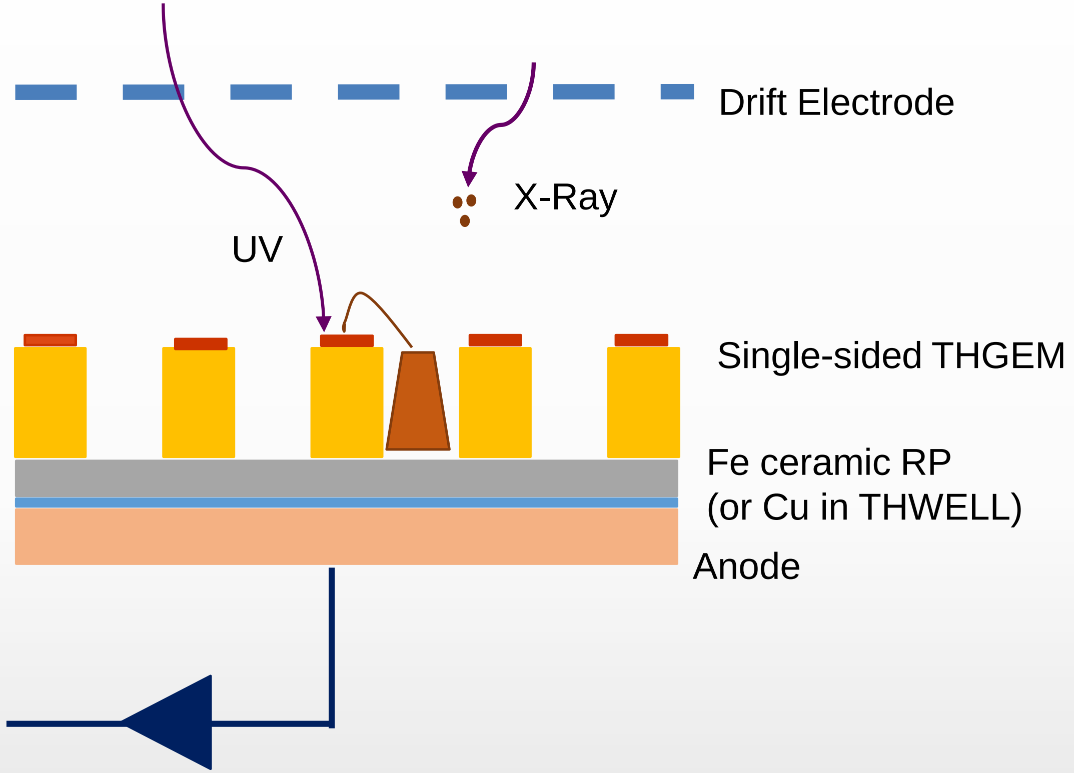
The Resistive Plate - Fe Ceramics

- Resistive materials range → $\rho \sim 10^9 - 10^{12}\ \Omega$-cm (LXe & LAr T's)
- **Semitron & LRS Glass (suitable @ RT)** **$\rho > 10^{14}\ \Omega$ -cm** around 200K.
- **Fe-Ceramics** - robust ceramic composites with **tunable electrical properties** (C Pecharromán, M Morales et al; 2013 JINST 8 P01022)
- Sample S24 : **$\rho \sim 10^{11}\ \Omega$-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.



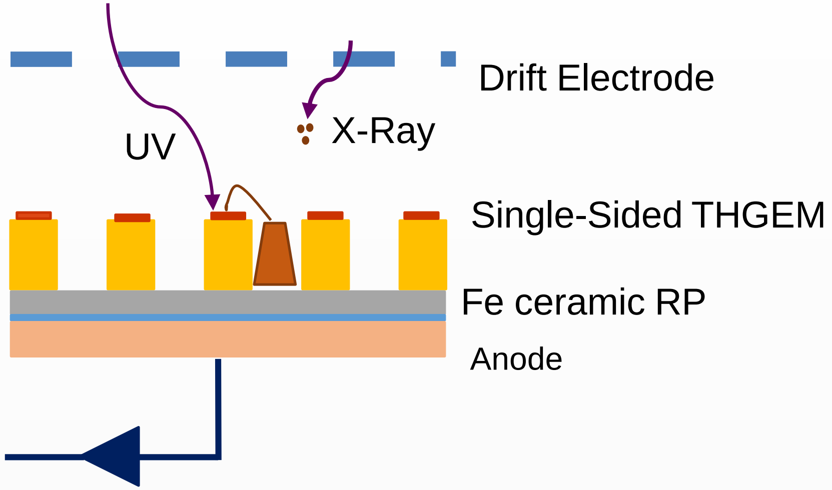
First Fe-Ceramic RPWELL @ LXe T

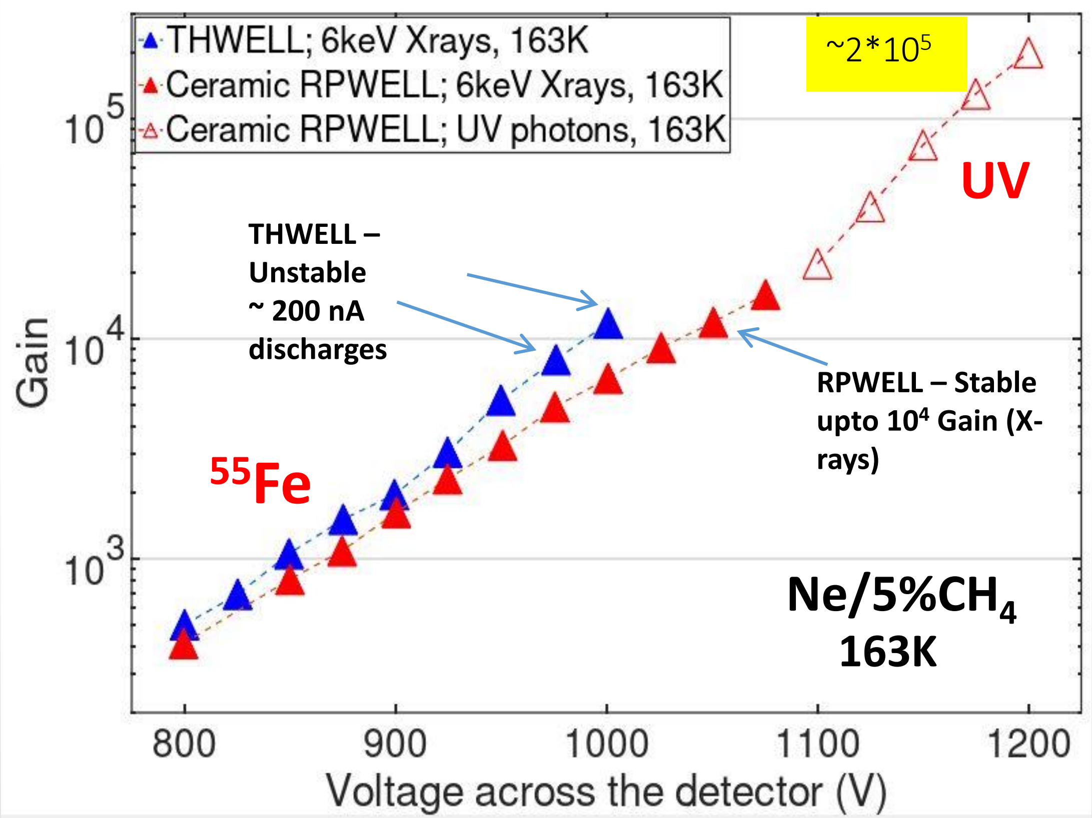
- First proof of discharge-free RPWELL detector operation at 163K !!
- Fe-Ceramic RPWELL tested in Ne/5%CH_4 at RT & low T in LN_2 + ethanol bath down to 160 K ($\rho \sim 10^{11}$ Ω-cm)
- Detector investigated with **X-rays** & **single UV-photons** (RPWELL **without/with CsI** photocathode)



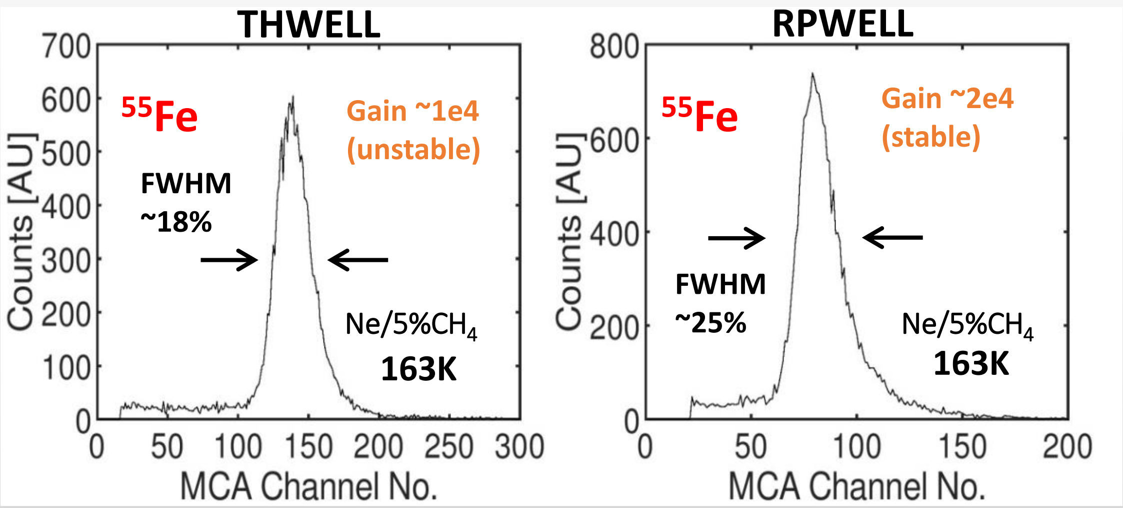
Fe Ceramic **RPWELL** compared to **THWELL** (same THGEM, but with standard Cu anode)

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



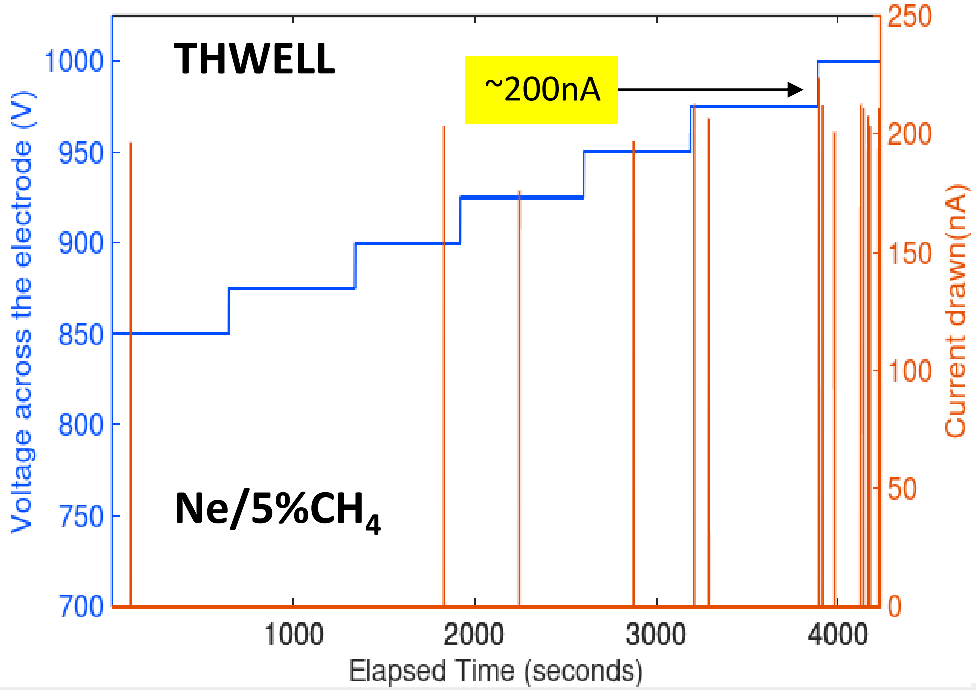


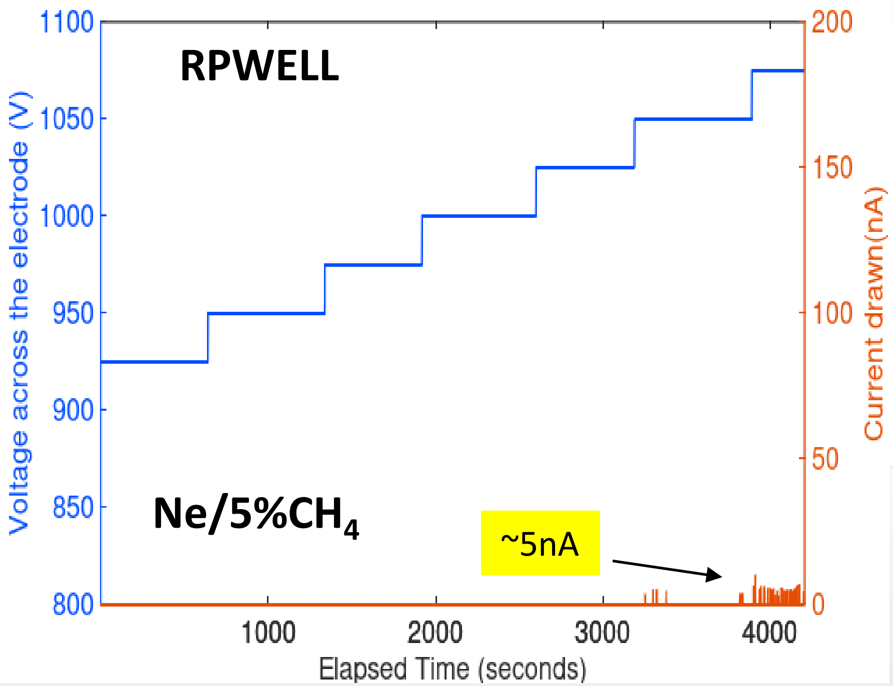
Pulse Height Spectra with X-rays

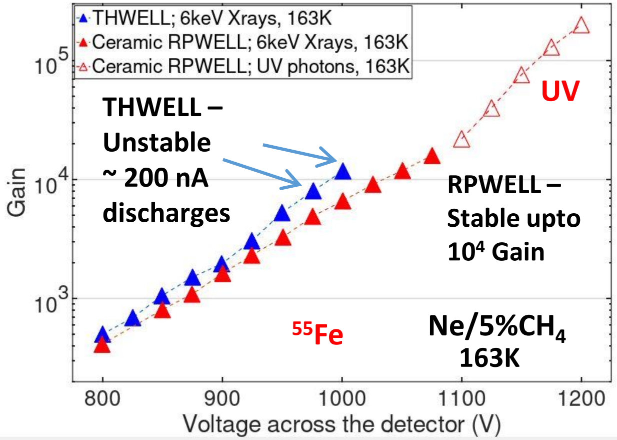


Discharge-free RPWELL operation up to **~10^4 gain with X-rays**, and **~10^5 with single UV-photons** (without CsI) **@ 163K**

Cryo-RPWELL Results @ 163K – Discharge behavior



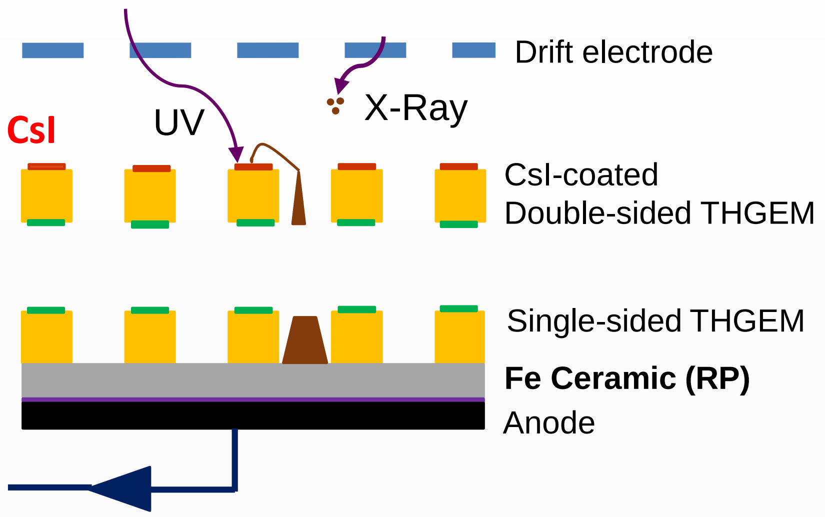


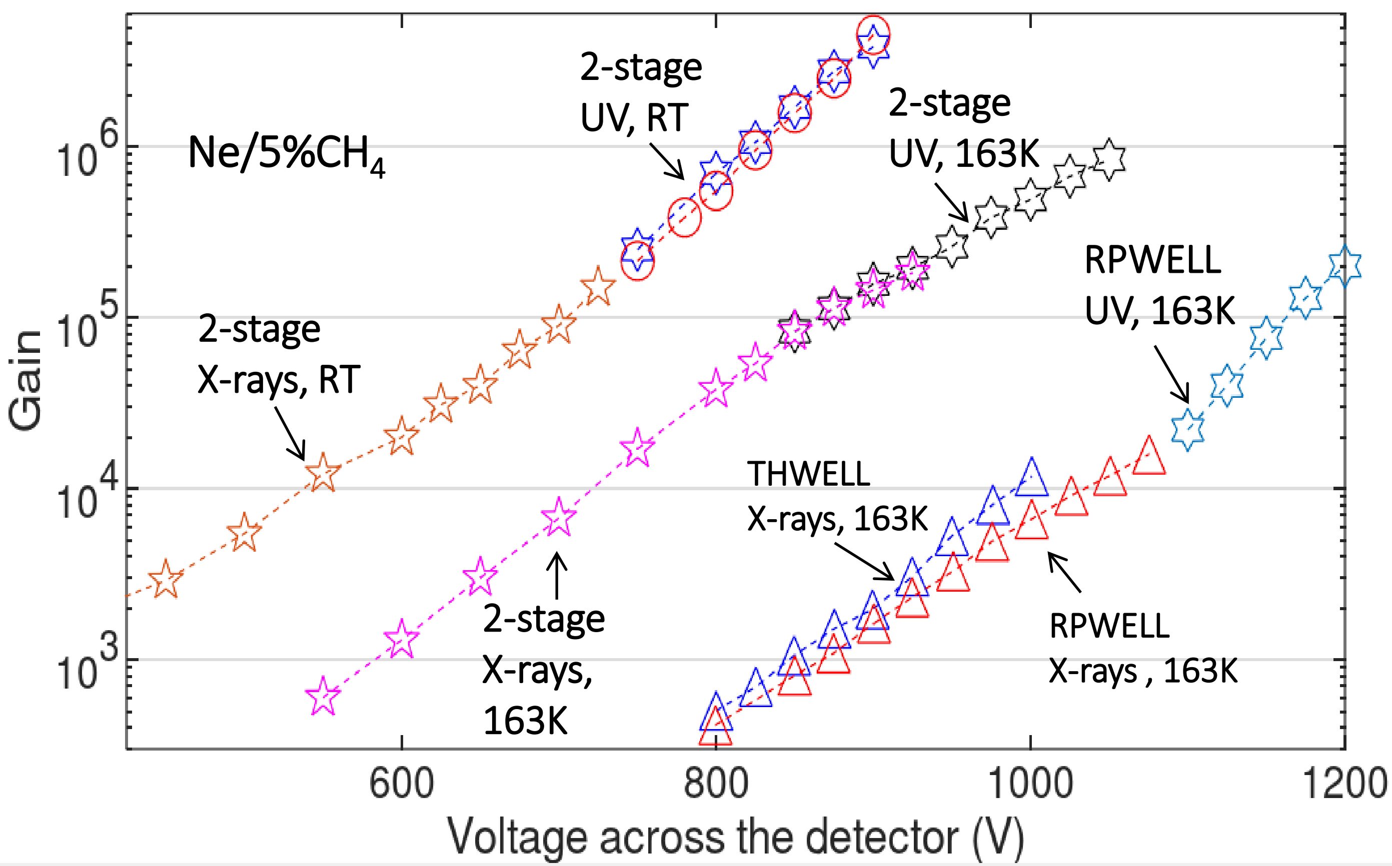


Discharge behavior at 163K :

RPWELL → **Discharge-free operation** upto **10^4 gain.** ~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 thick Single-sided THGEM
- 2.1 mm thick **Fe ceramic as RP**
- **Source :** H_2 discharge lamp

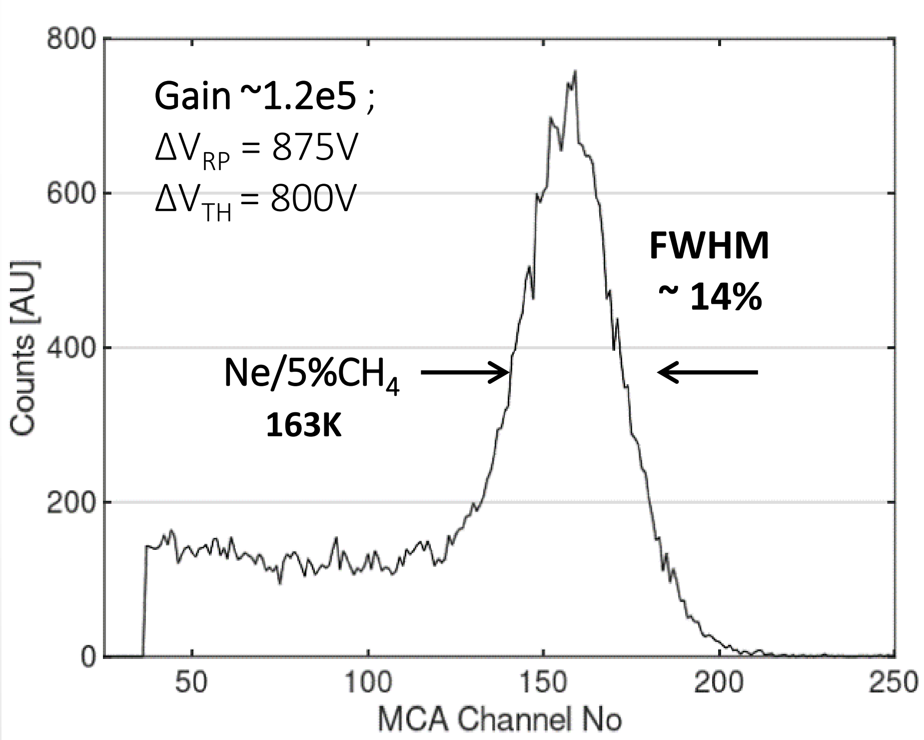
2-stage THGEM + Cryo-RPWELL (Ne/5%CH_4) →

Gain >10^5 with X-rays @ RT and 163K

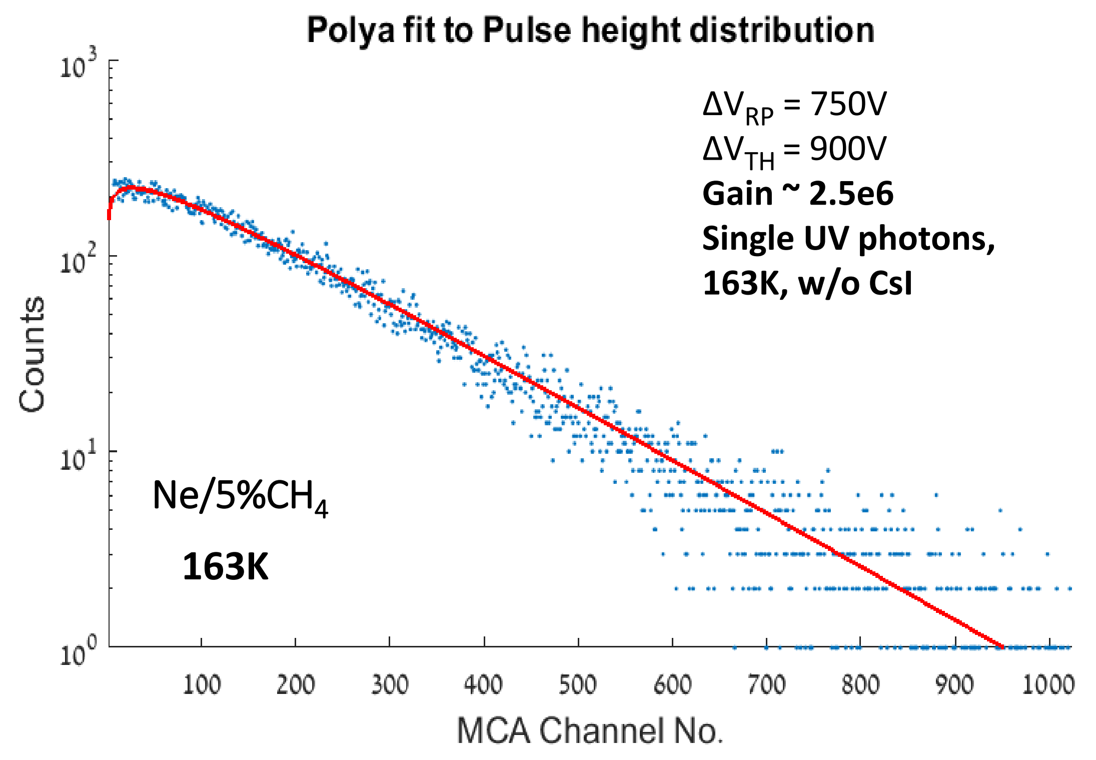
Gain >10^6 with single UV photons @ RT and

Gain ~10^6 @ 163K

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



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

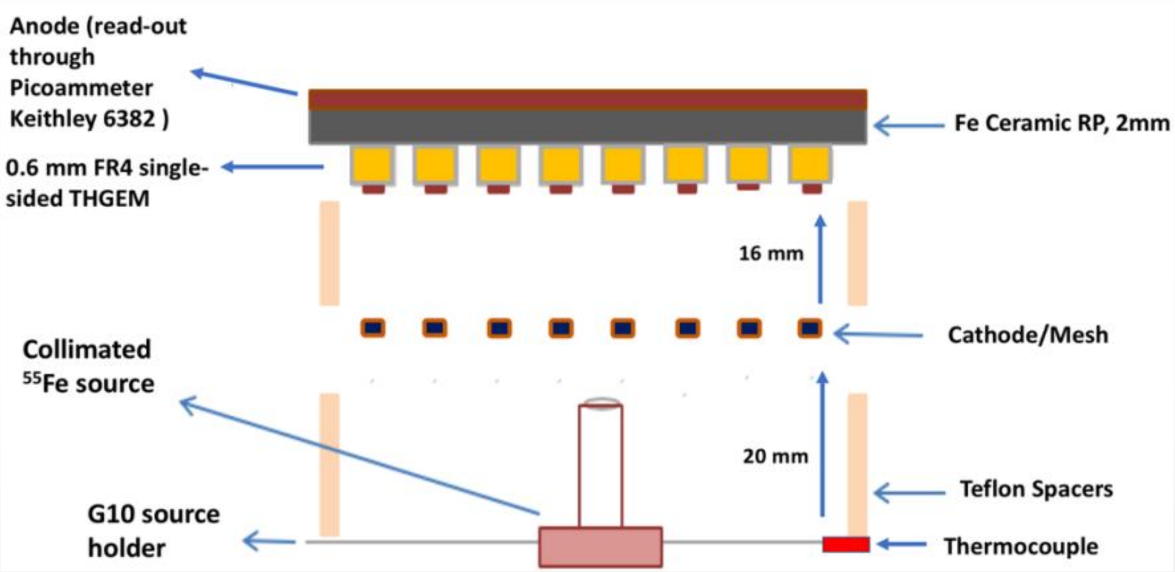


Clear Polya distributions obtained @ T = 163K with the double-stage detector with Single UV-photons

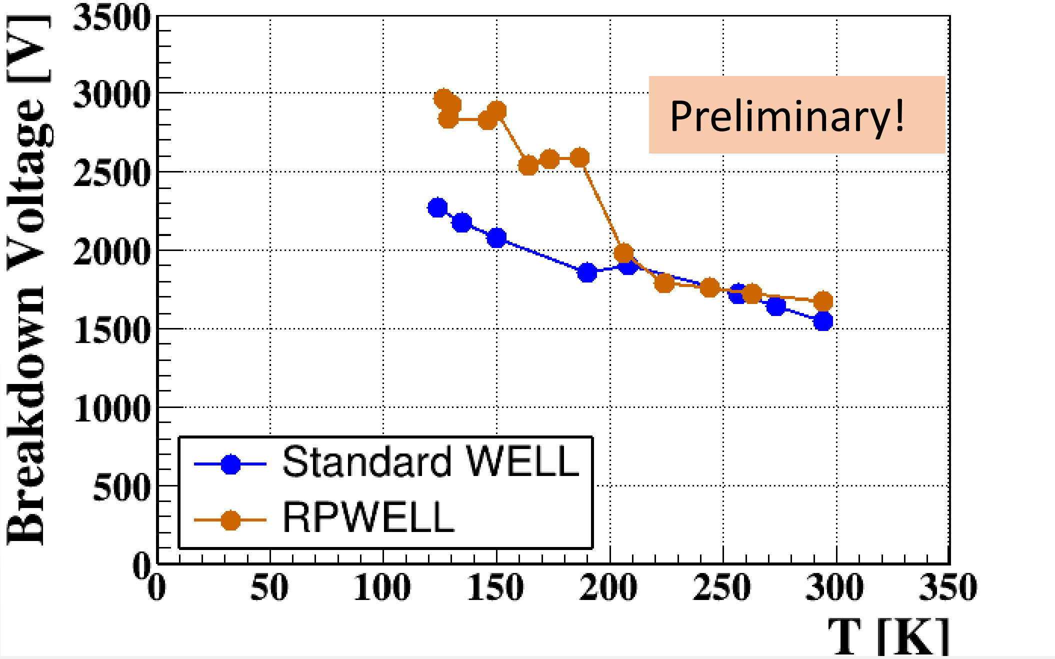
Cryo-RPWELL based noble liquid detectors -- Investigating possible enhancement of maximum achievable stable detector gain in ultrapure Ar vapor

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 -> ρ ~ 10^6-10^7 Ω-cm @ RT**):

- **200-300K** – No difference in breakdown voltages -> Fe-Ceramic **ρ inadequate** to quench discharges!
- **T< 200K** --> ρ ~ 10^9 Ω-cm ➔ 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%CH_4.
  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%CH_4)
  Gain ~10^4 with X-rays, and ~10^5 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%CH_4)
  Gain >10^5 with x-rays and ~10^6 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!!