מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Novel concepts for Charge & Light readout

Shikma Bressler, Weizmann Institute of Science

Introducing two concepts

Cryo-RPWELL

Cryogenic Resistive Plate WELL

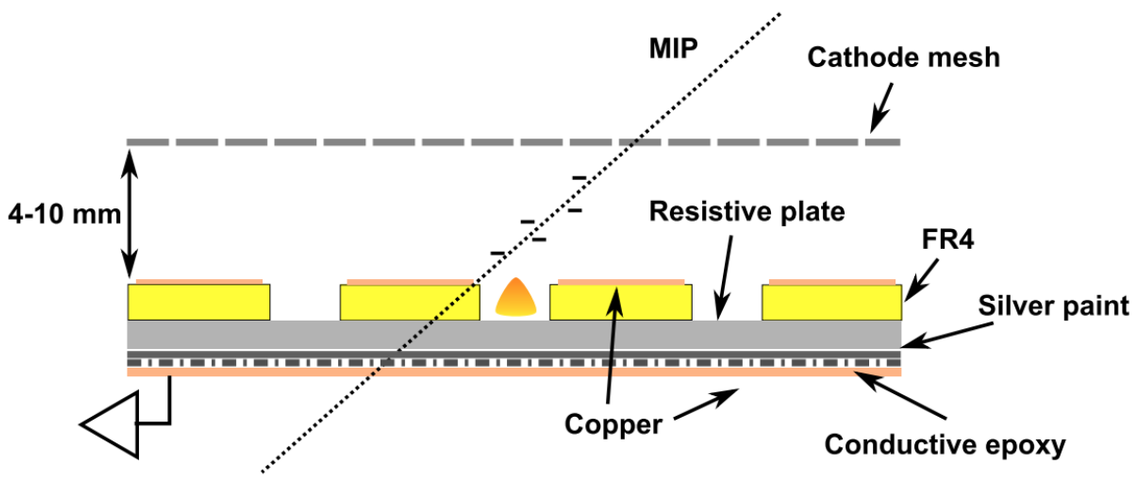
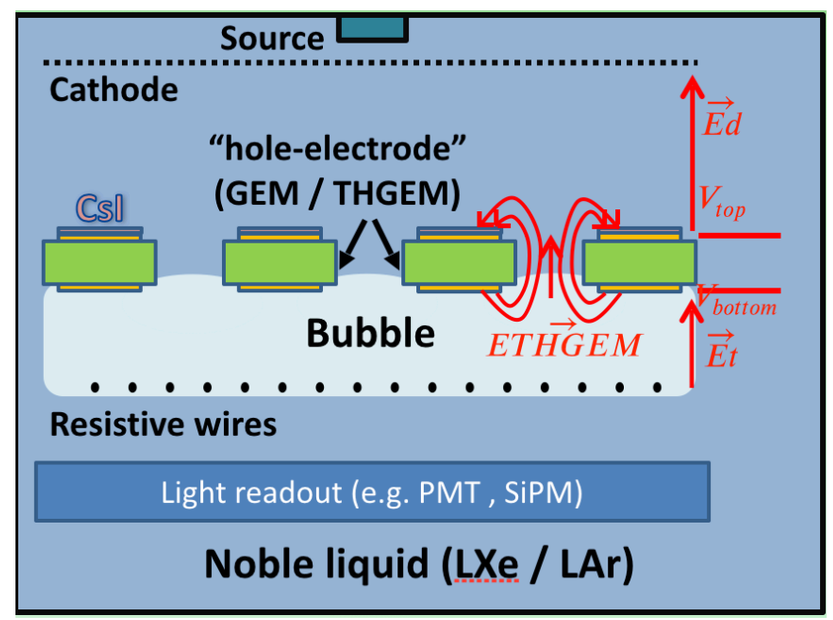


Figure 1. The Resistive-Plate WELL (RPWELL) configuration with a resistive anode and a readout electrode. The WELL, a single-faced THGEM, is coupled to a copper anode via a resistive plate. Charges are collected from the copper anode. In some experiments the WELL was directly coupled to the metal anode.

A. Rubin, L. Arazi, SB, L. Moleri, M. Pitt, A. Breskin [arXiv:1308.6152]

Bubble assisted-LHM

Bubble assisted Liquid Hole Multiplier



First Demo in LXe:
L. Arazi et al. 2015 *JINST* 10 P08015 [arXiv:1505.02316]
E. Erdal et al. 2015 *JINST* **10** P11002 [arXiv:1509.02354]

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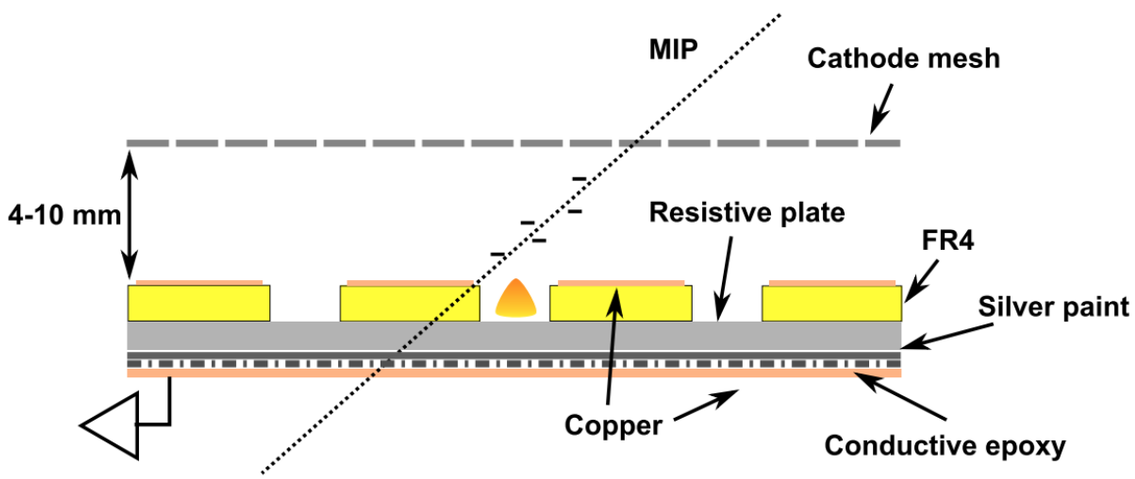

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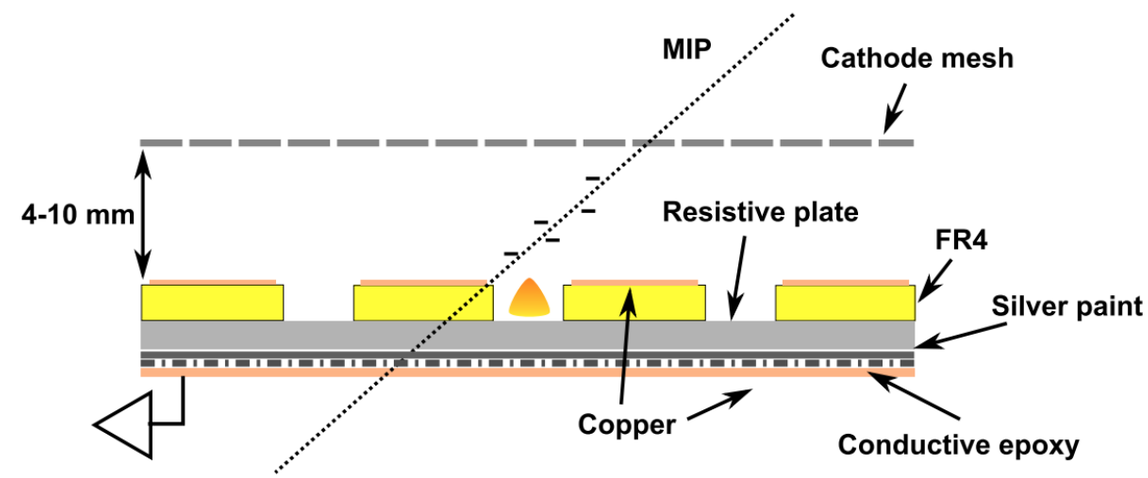
The Resistive Plate WELL (RPWELL)

- Single sided THick Gaseous Electron Multiplier (THGEM (== LEM))
- Coupled to segmented readout through material of high bulk resistivity $(10^8 - 10^{10}\ \Omega cm)$
  - Combining MPGD and RPC concepts
- *Discharge free operation at high gain depending on the primary ionization* $(10^4 - 10^7)$
- Moderate rate capabilities



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Studied and tested extensively by our group
- main fronts

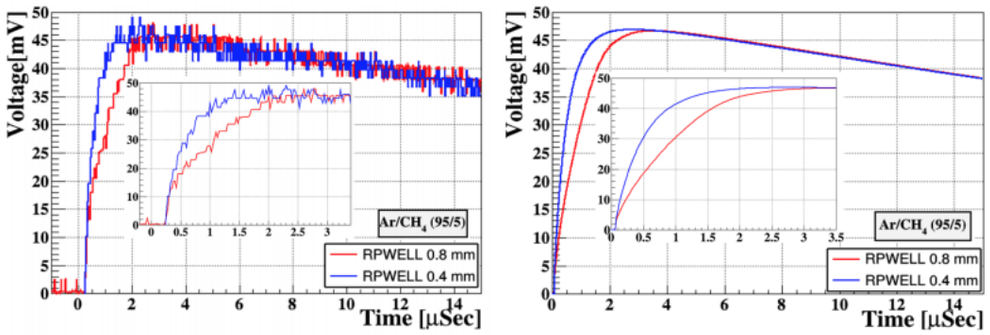
- Characterization
- Attempt to understand the physics processes governing its response
- Scaling up - transition from small- to large-area detectors
- Readout element in potential applications @ RT (DHCAL)

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

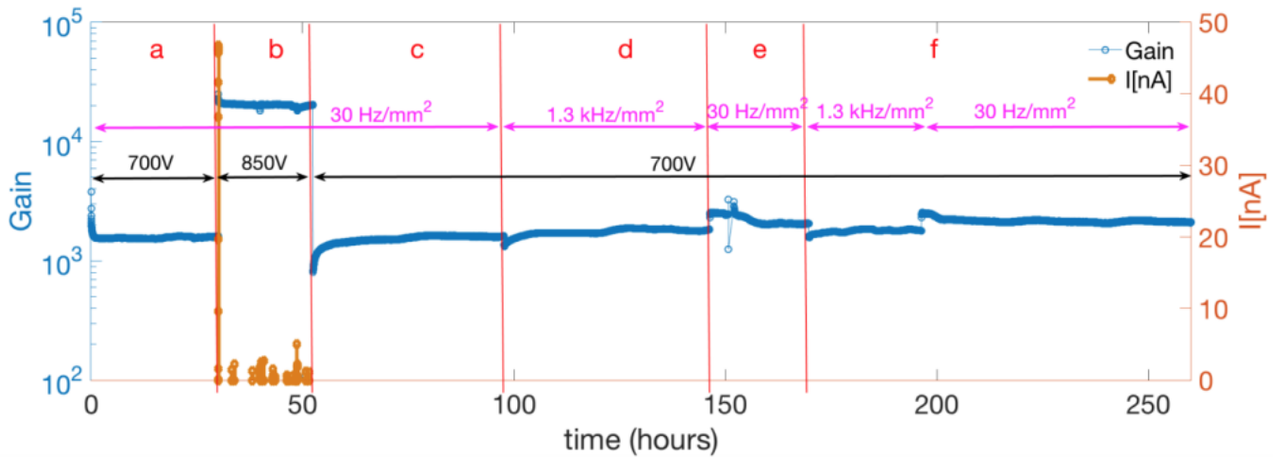
The RPWELL - Characterization & Physics

Looked at many properties in the context of different questions

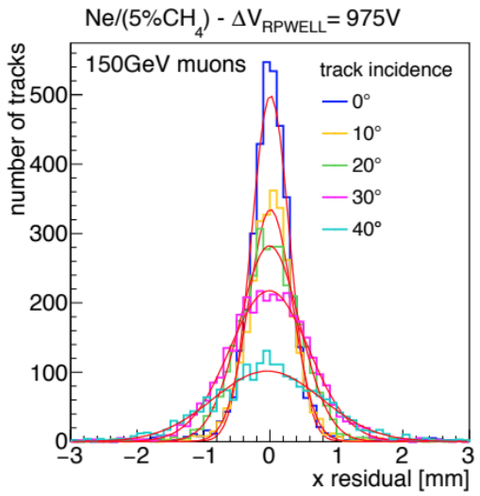
Signal formation 1810.12597
L. Moleri, P. Bhattacharya, SB

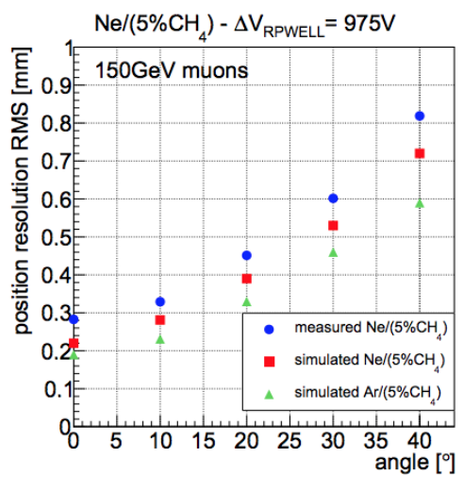


Stabilization 1707.04356
D. Shaked-Renous, A. Roy, A. Breskin, SB

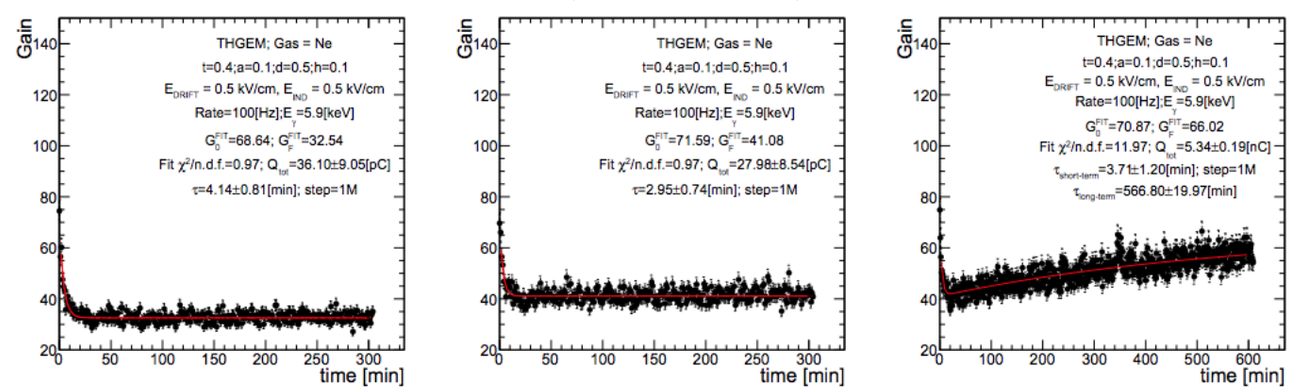


Spatial resolution 1707.00125
L. Moleri, P. Bhattacharya, A.E.C. Coimbra, A. Breskin, SB





Stabilization 1801.00533
M. Pitt, P. M. M. Correia, SB, A. E. C. Coimbra, D. Shaked Renous
C. D. R. Azevedo, J. F. C. A. Veloso, A. Breskina

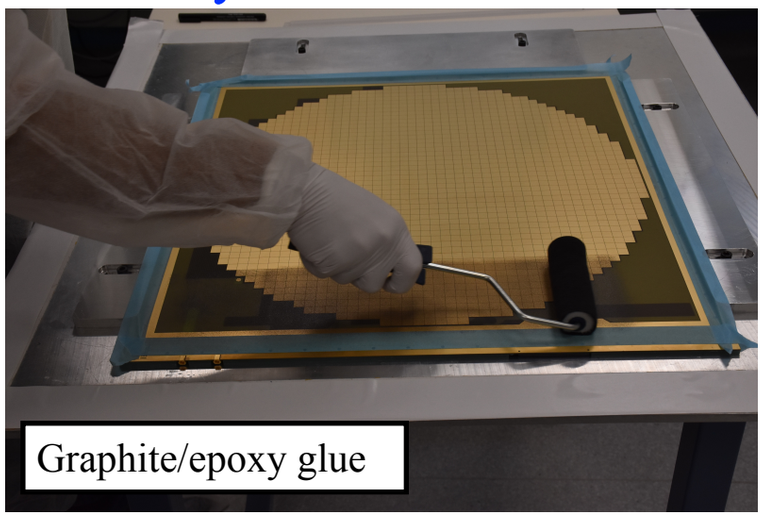


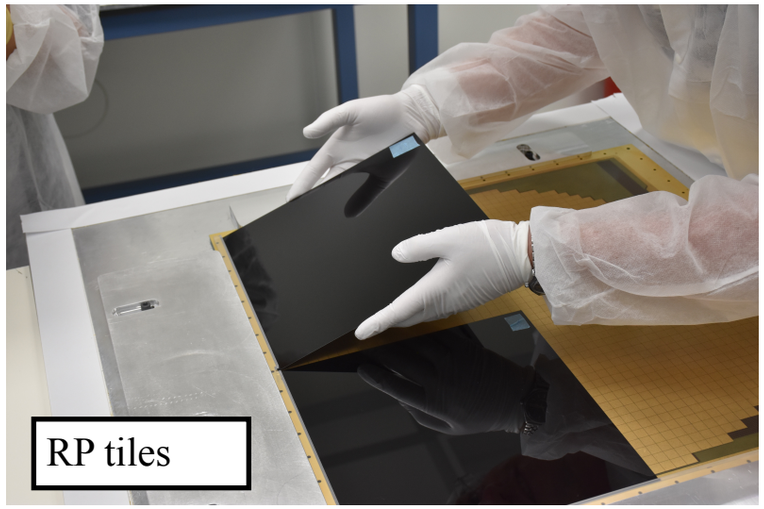
Still not all is clear

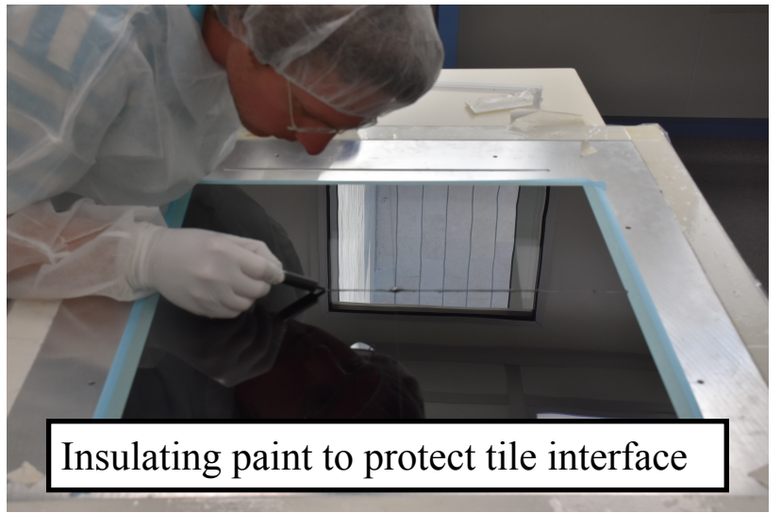
- Most important - modeling of the role of the resistive layer

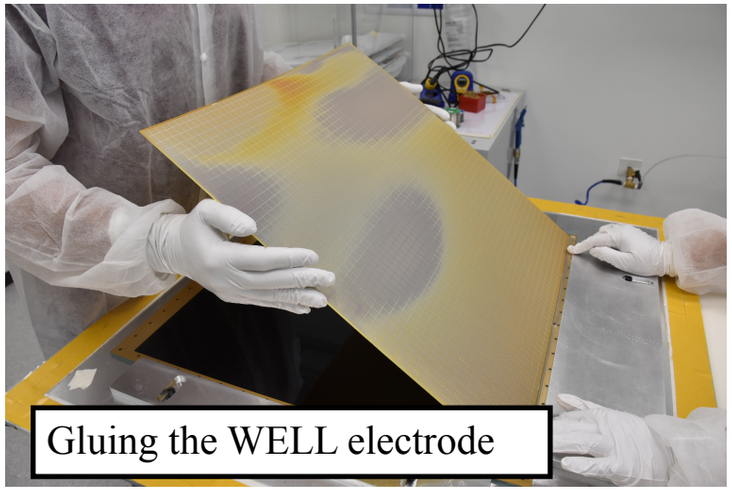
The RPWELL - Scaling up

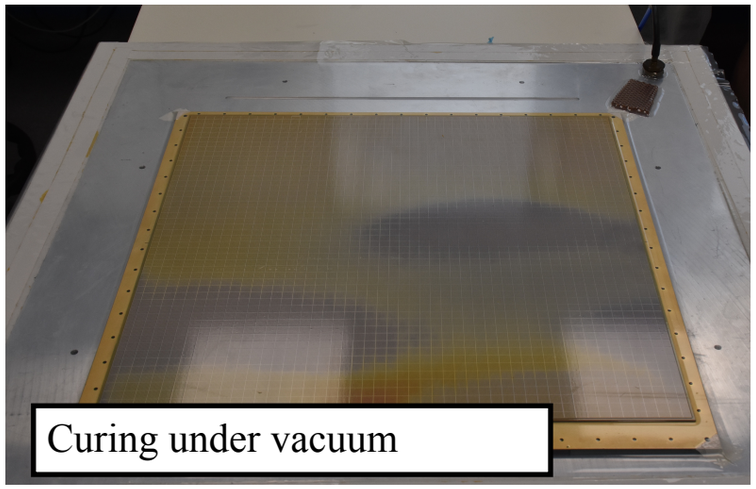
Assembly


Graphite/epoxy glue


RP tiles

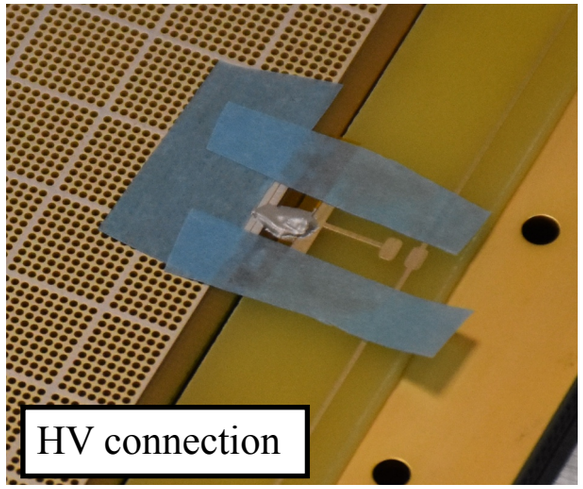

Insulating paint to protect tile interface


Gluing the WELL electrode

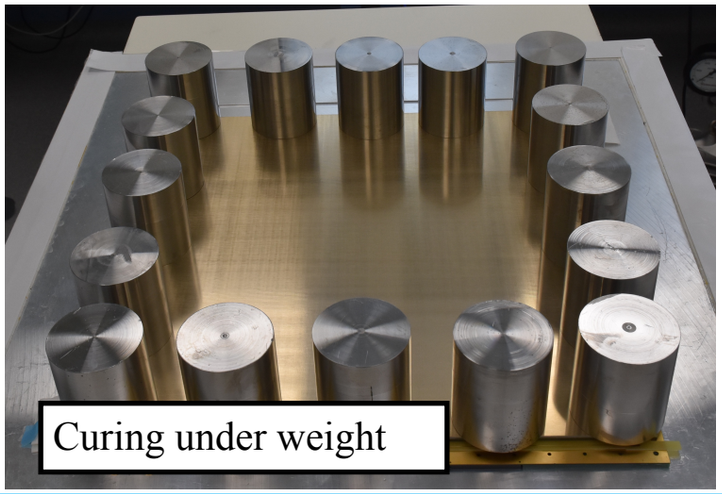

Curing under vacuum

Publication in preparation

A. Coimbra, L. Moleri, P. Bhattacharya,
D. Shaked-Renous, SB


HV connection

Cathode gluing

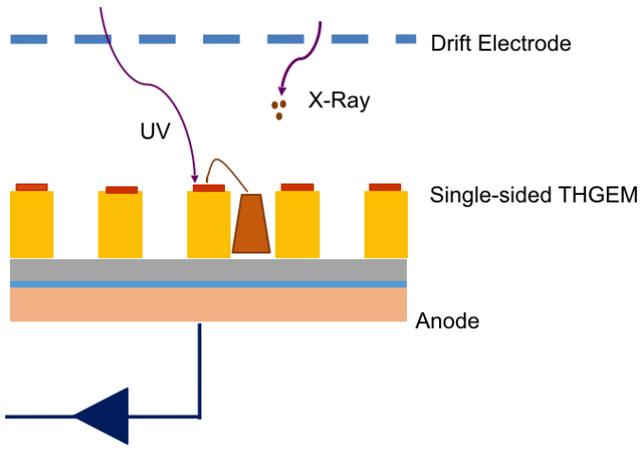

Curing under weight

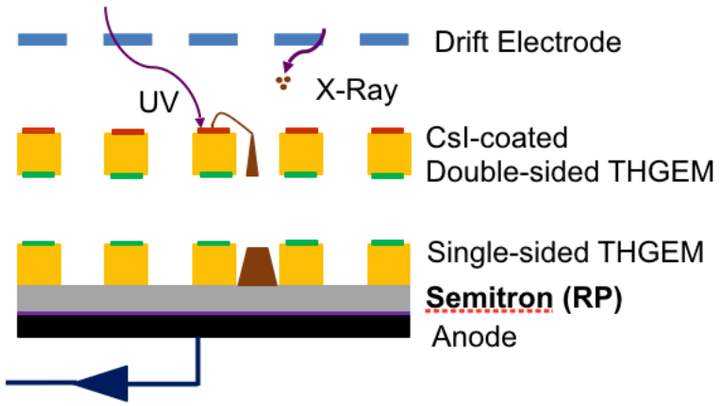
RPWELL - a single UV photon detector @ RT

Single- and double-stage configurations

- Source: Hg Lamp
- Ne & Ar-based gas mixtures

- Measured Polya distribution
  - paves the way toward high PDE
- Stable operation at high gains

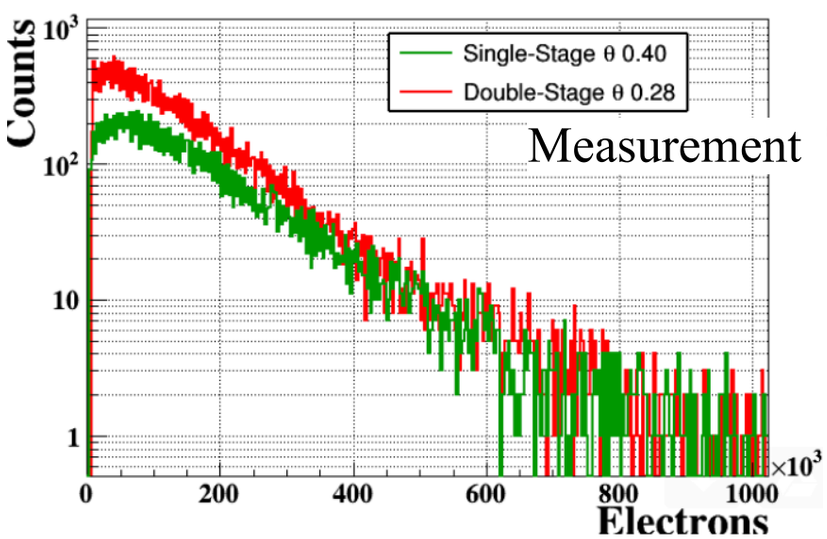


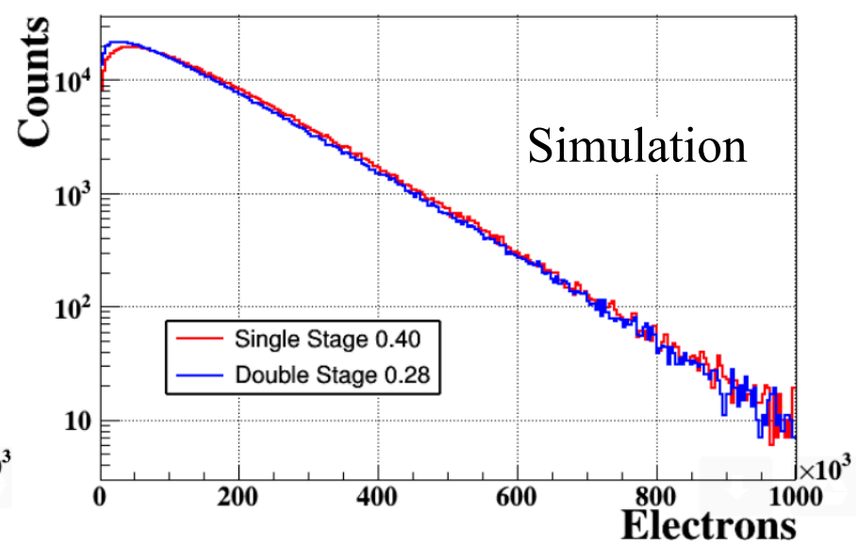


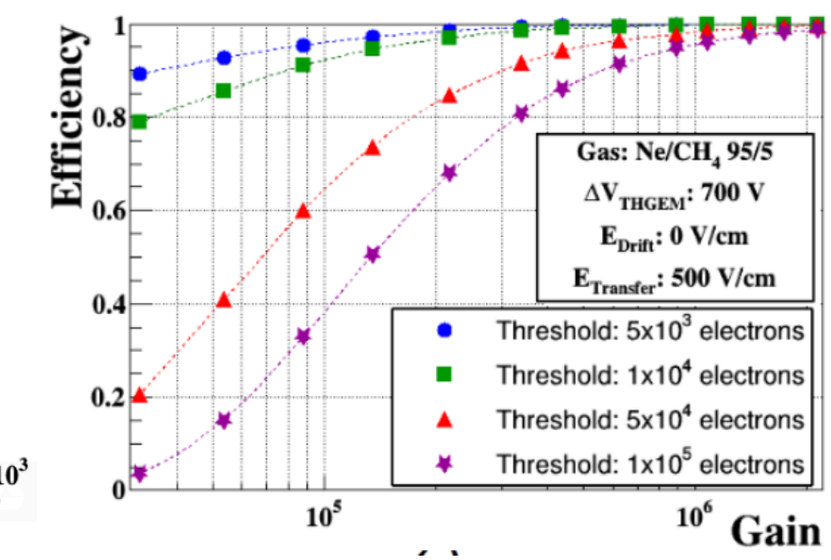
- 5 mm Drift Gap; 2 mm Transfer gap
- 0.6 mm thick CsI-coated Double-sided THGEM
- 0.4 thick Single-sided THGEM
- 0.4 mm thick Semitron as RP

Publication in preparation

Spectra @ gain ~1.5×10^5







Cryogenic-RPWELL

Can the RPWELL outperform LEMs?

- LEM == THGEM
- RPWELL reached ~100 times higher gain at stable operation conditions relative to THGEM
- If RPWELL is as effective in noble-liquids as it is in room temperature… maybe

Target performance

- 10 better Signal/Noise relative to the LEMs
- Similar or better spatial resolution
- Similar or better energy resolutions

… But we are not there yet…

Challenge I

- Find materials with the right bulk resistivity at LAr temperature (~87 K)

Table 1. List of materials failing to quench discharges at cryogenic temperatures

Material	Source	Resistivity @ RT	Resistivity as function of T	Discharge Quenching at Cryo T
Tivar EC & Tivar ESD (UHMW-PE)	J. Vavra SLAC, USA	$\rho \sim 10^6$ - 10^7 Ω·cm	Constant	Fails; low ρ value
PTFE + 1.5% Carbon	3M, USA	$\rho \sim 10^7$ - 10^8 Ω·cm	Constant	Fails; low ρ value
Araldite + Graphite (Graphite - 15-30 %)	Fabricated @WIS	$\rho \sim 10^8$ - 10^{14} Ω·cm	Constant	Fails; non-uniform resistivity
Si-based Ceramics	L. Naumann, HZDR, Germany	$\rho \sim 10^8$ Ω·cm	Increases exponentially with decreasing T	Fails; ρ too high @ LXe T

Cryogenic-RPWELL

- Recent publications
  A. Roy, et. al, ”First results of Resistive-Plate Well (RPWELL) detector operation at 163 K”, JINST 14 (2019) no.10, P10014

A. Roy

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Recent Advances with RPWELL detectors: Physics and potential applications

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

[1] Ben Gurion University
[2] Weizmann Institute of Science
[3] Negev Nuclear Research Centre
[4]Technion - Israel Institute of Technology

Research performed at the Detectors Group at WIS Physics Faculty, under partial support of the Israel Science Foundation, I-CORE Program of the Planning and Budgeting Committee, common fund of the RD51 collaboration at CERN (the Sampling Calorimetry with Resistive Anode MPGDs (SCREAM)project)

A. Roy – Advances with RPWELL | MPGD 2019, La Rochelle May 5-10, 2019 | 1

Cryogenic-RPWELL

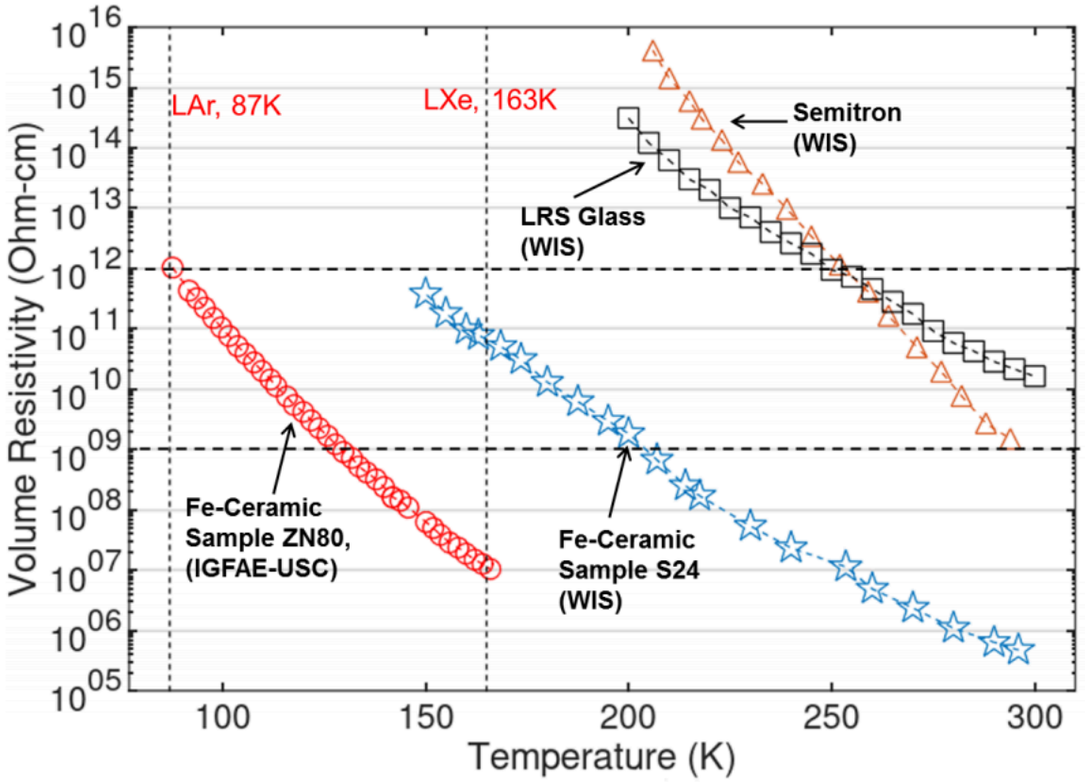
Resistive material

- Target resistivity: $\rho \sim 10^9 - 10^{12}$ Ω-cm @ LXe & LAr T's
- Semitron & LRS Glass (suitable @ RT) $\rho > 10^{14}$ Ω -cm around 200K.

Fe-Ceramics

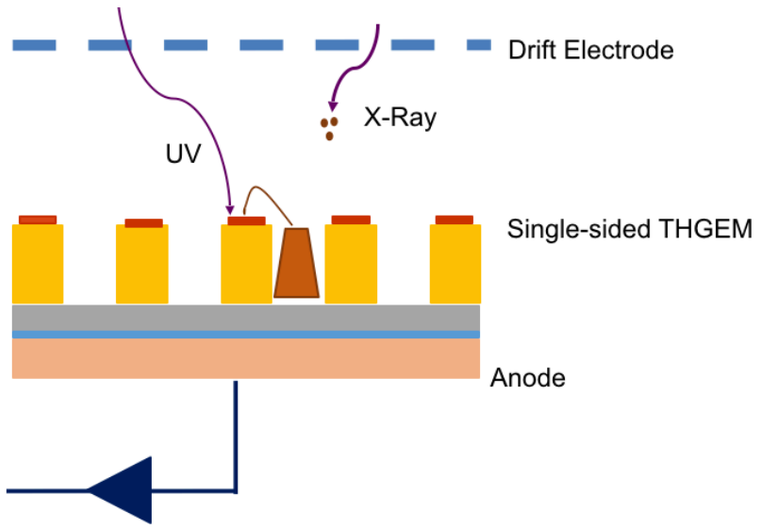
- Robust ceramic composites with tunable electrical properties
  C Pecharromán, M Morales et al; 2013 JINST 8 P01022
- Provided several samples for us
  - Sample S24 : $\rho \sim 10^{11}$ Ω-cm @ LXe Temp (measured in controlled conditions).
  - Preliminary ρ measurements down to LAr T. Promising results with ZN80

- Dedicated experiments ongoing @ IGFAE-USC, Spain and WIS to understand the behavior.



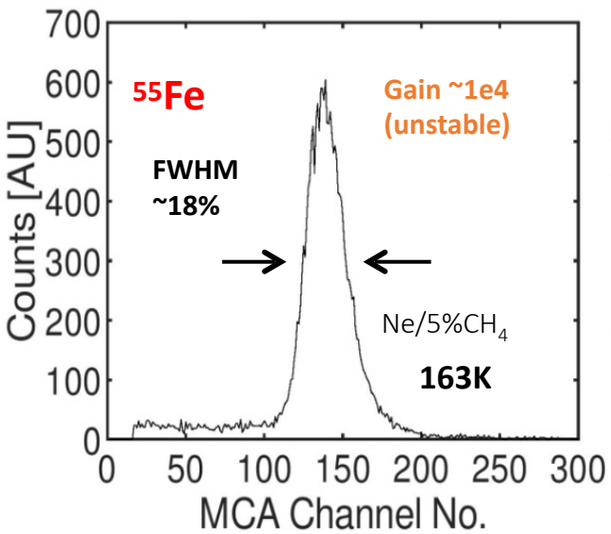
Fe-Ceramic-RPWELL

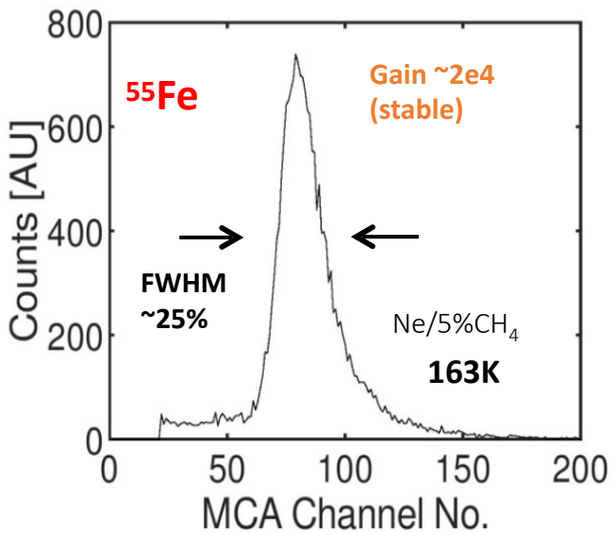
- First proof of discharge-free RPWELL detector operation at 163K
- **Tested in Ne/5%CH_4 at RT & low T in LN_2 + ethanol bath down to 160 K (ρ~ 10^{11} Ω-cm)**
  - **Not in dual-phase Xe**
- Detector investigated with X-rays & single UV-photons (RPWELL without/with CsI photocathode)

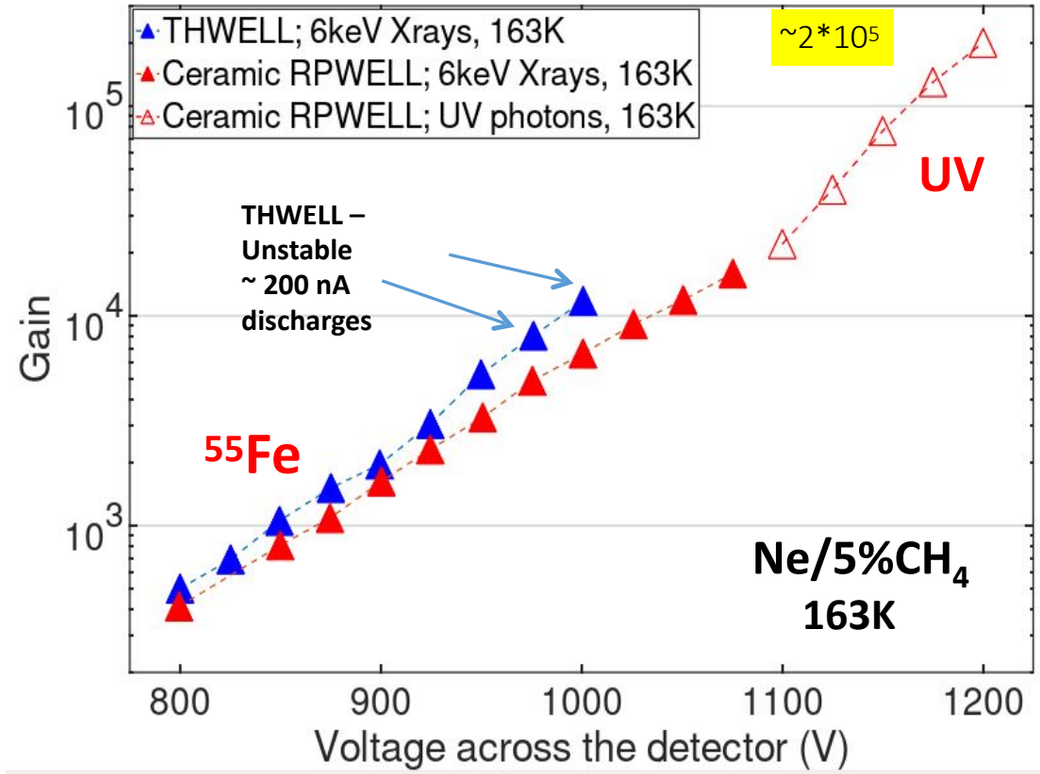


- Performance compared to regular THWELL with no resistive plate
- THGEM/LEM geometry not optimized

Pulse Height Spectra with X-rays





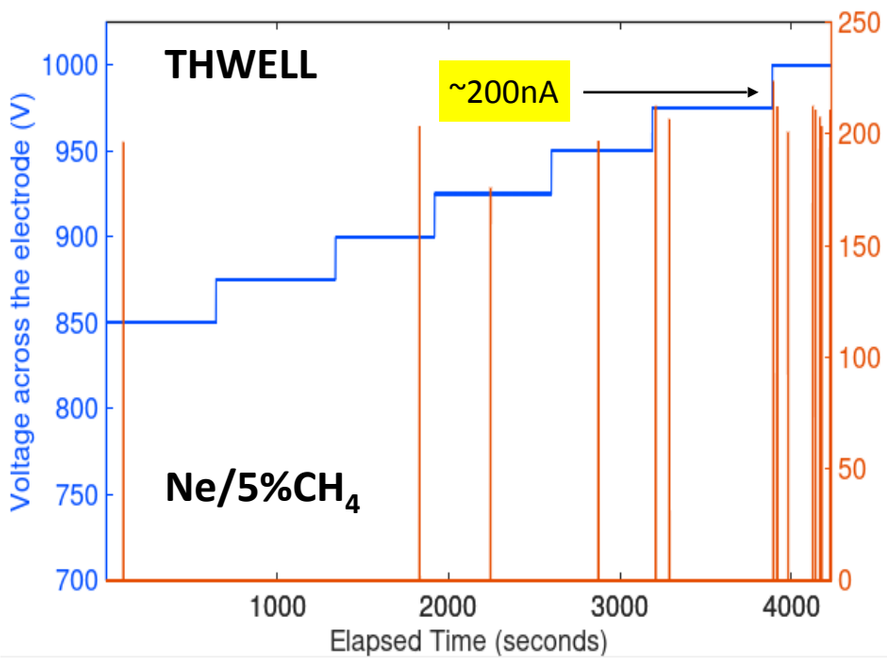


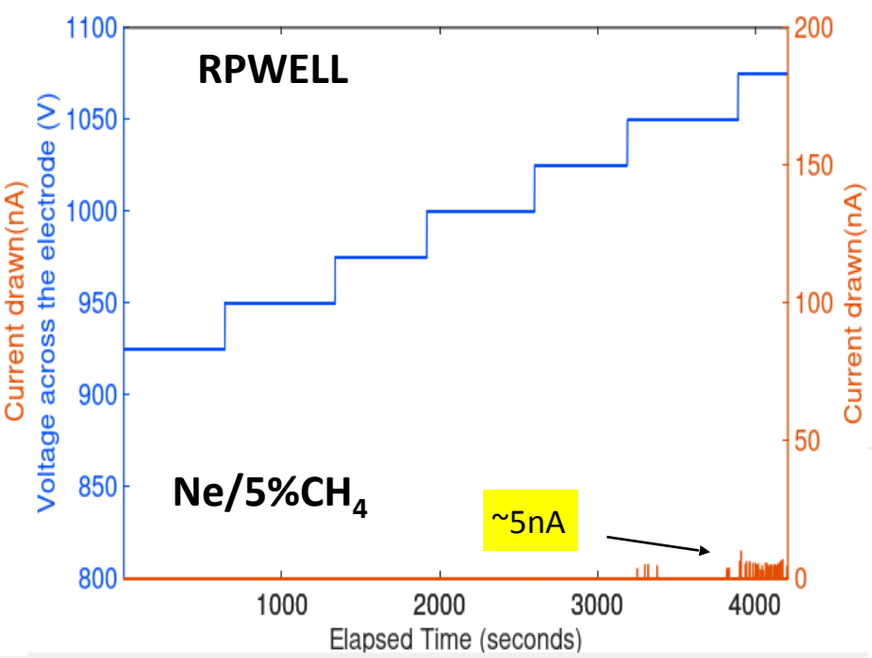
Discharge-free RPWELL operation up to **~10^4 gain with X-rays**, and **~10^5 with single UV-photons** (without CsI) **@ 163K**

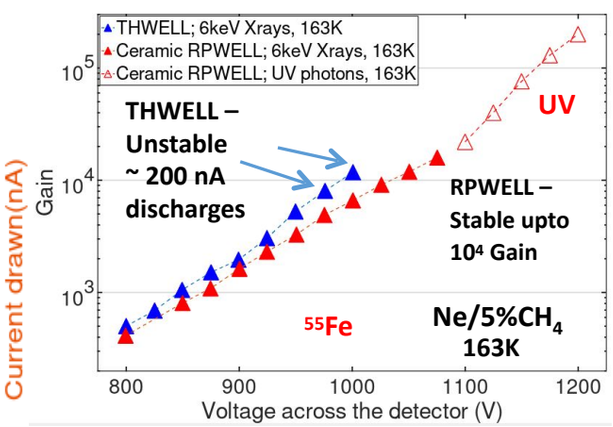
Fe-Ceramic-RPWELL

Discharge behavior

- Cryo-RPWELL: discharge free operation up to a gain of 10^4
  ~5 nA discharges @ gain > 10^4
- THWELL: ~200 nA discharges
  Onset of discharges around a gain of 10^3 (850 V)
  Unstable @ gain of 10^4 with regular discharges



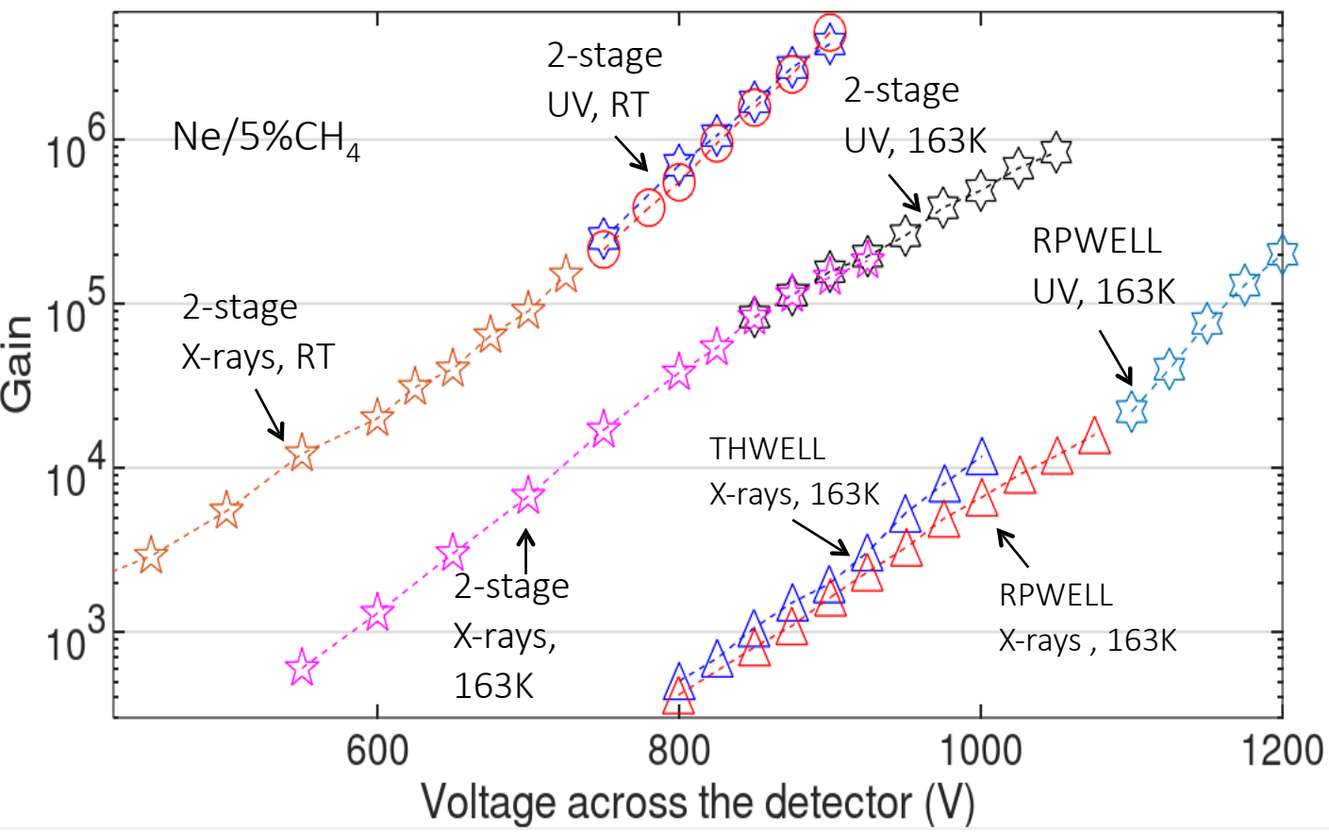


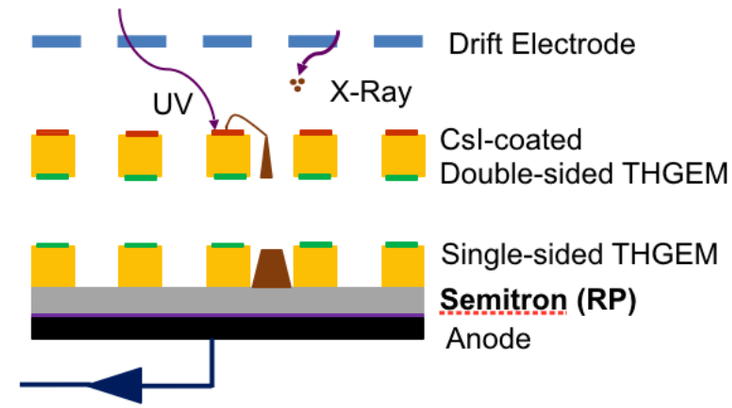


Double stage Cryo-RPWELL

Discharge behavior

- 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





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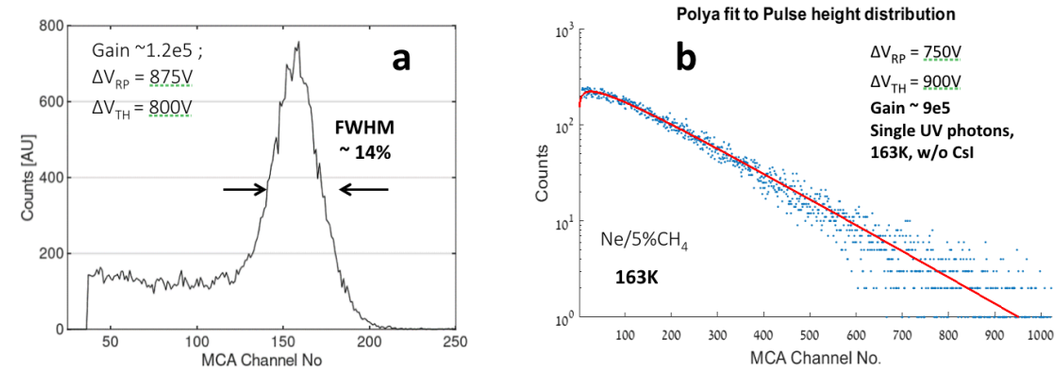


Charge spectra @ 163 K

- ^{55}Fe X-ray: peak with 14% FWHM
- Single photon/electron: Clear Polya

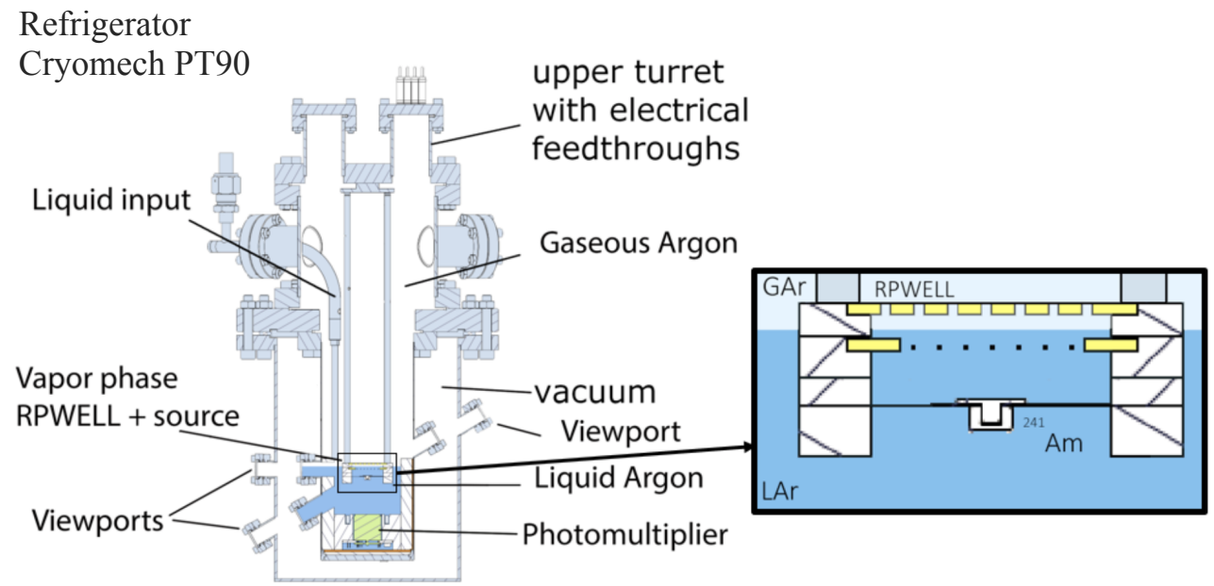
Cryo-RPWELL in Dual phase LAr

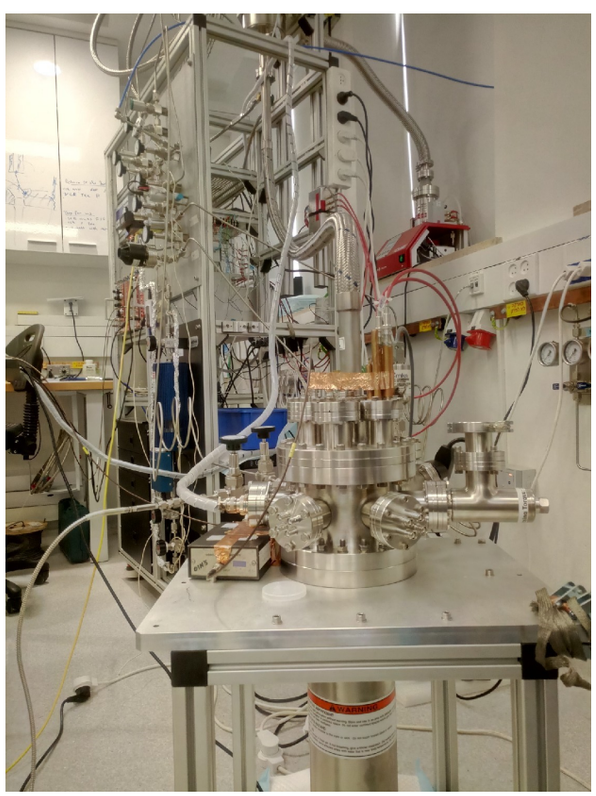
WISArD

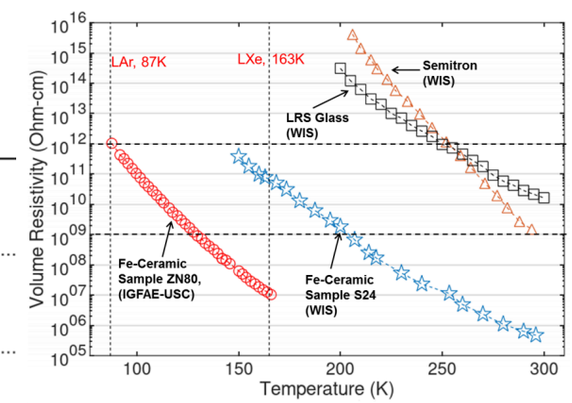
- 200-300K – No difference in breakdown voltages ⇒ Fe-Ceramic

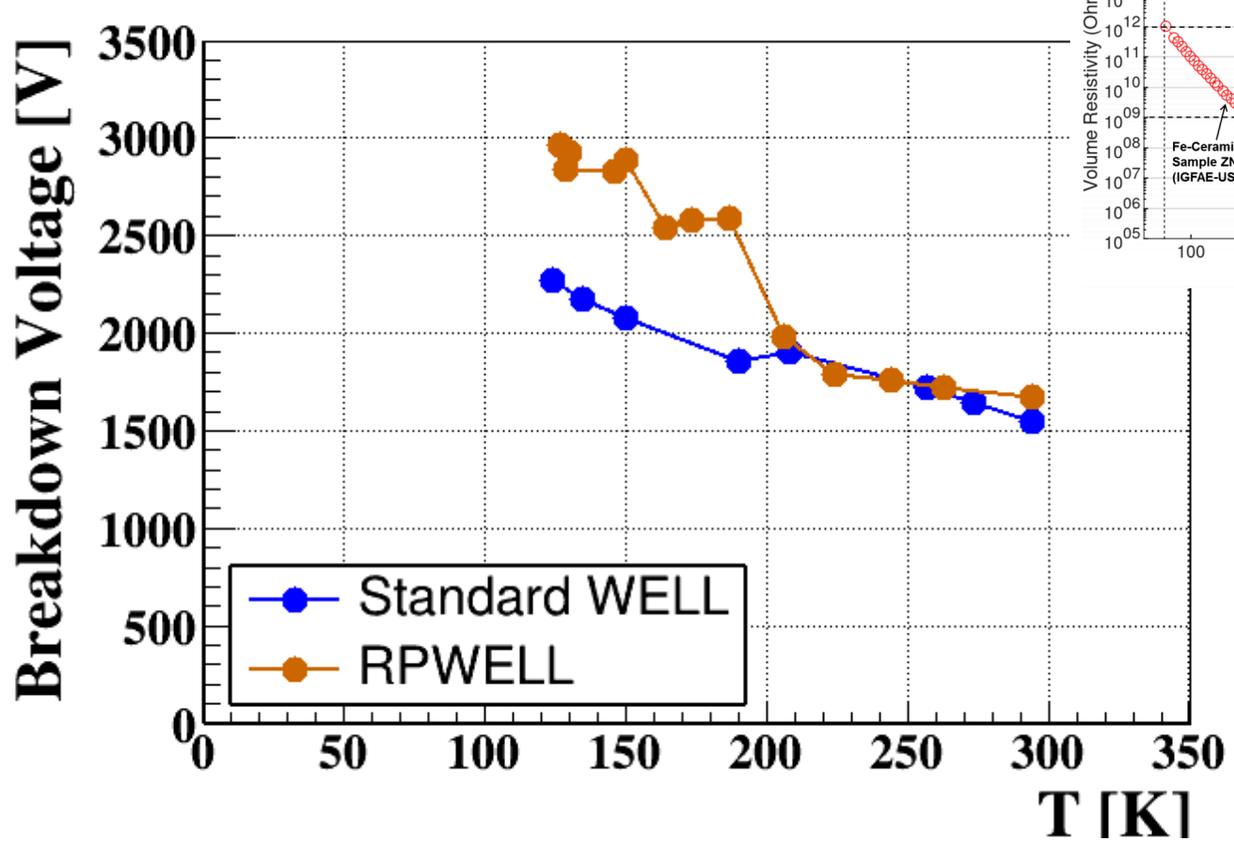
  ρ inadequate to quench discharges
- T< 200K ⇒ ρ ~ 10^9 Ω-cm ⇒

  Effect of RP clearly seen. Higher RPWELL Breakdown Voltages.









Cryo-RPWELL - Quick summary

- The immediate challenge - Material with the right bulk resistivity at CT
- Fe-Ceramics - promising candidate
  - Tunable resistivity values with post treatment curing
- Successful demonstration at LXe temperature
  - Operated with cooled Ne/5%CH4 gas mixture
  - Discharge free operation at high gains
    - > an order of magnitude relative to regular THWELL
    - Both ^{55}Fe x-ray and single UV photons (THWELL coated with CsI photocathode)
  - So far only with small area detectors

Cryo-RPWELL - Next steps

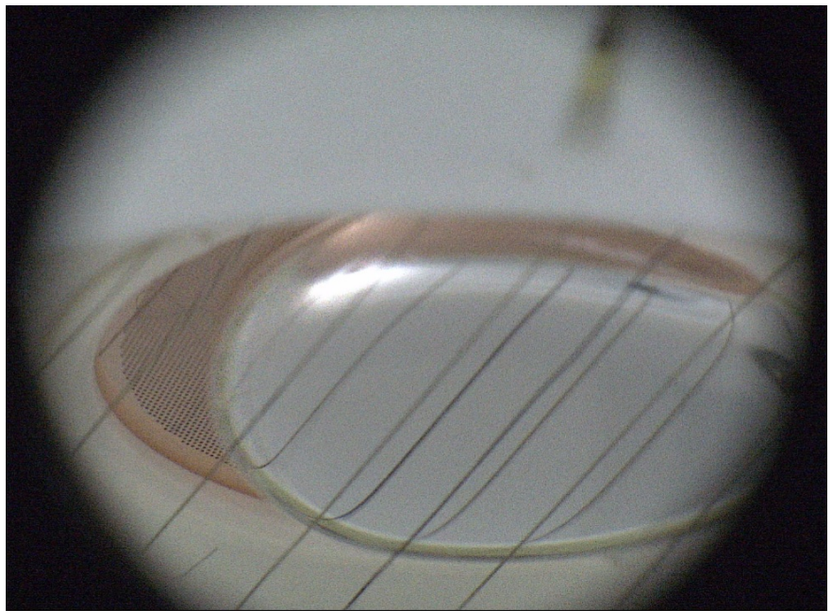
- Demonstration in LAr
  - Get viable sample for LAr
  - Proof of concept in dual phase LAr
  - Optimized geometry for LAr

- And more
  - Other resistive materials
  - Larger areas
  - …..

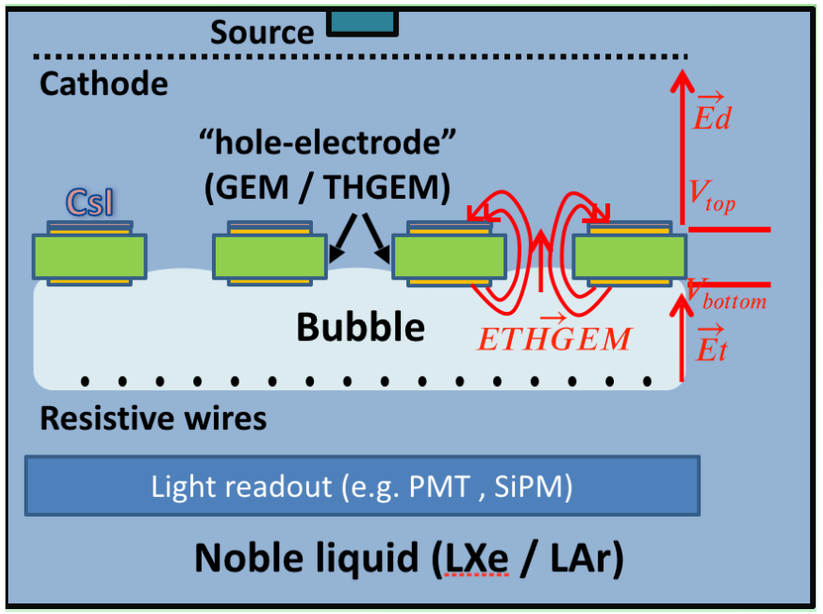
Introducing two concepts

Bubble assisted-LHM

Bubble assisted Liquid Hole Multiplier



A bubble in LXe



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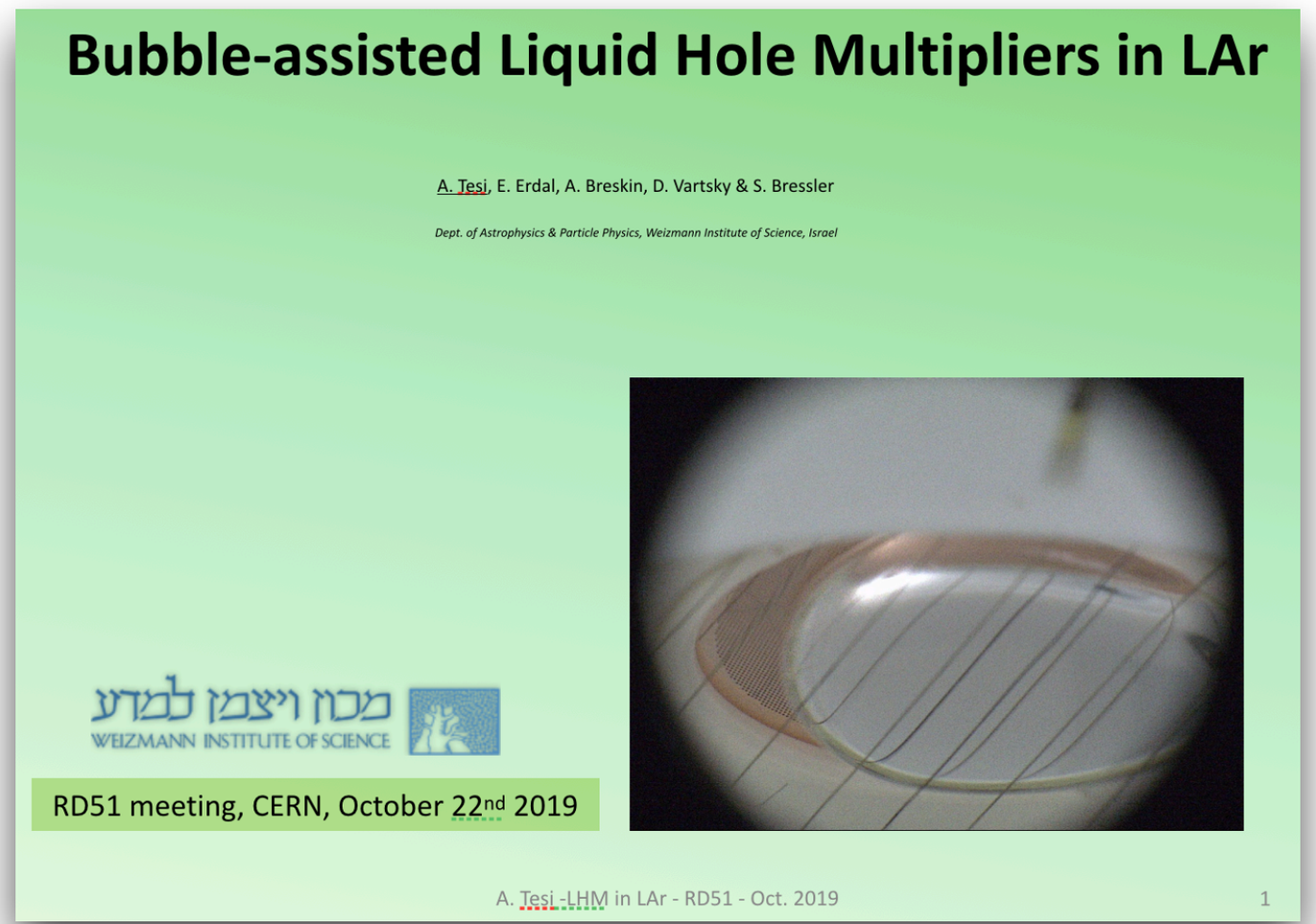
L. Arazi et al. 2015 *JINST* 10 P08015 [arXiv:1505.02316]
E. Erdal et al. 2015 *JINST* **10** P11002 [arXiv:1509.02354]

Bubble assisted LAr-LHM

- Recent publications
  E. Erdal, A. Tesi, A. Breskin, D. Vartsky and S. Bressler, "First demonstration of a bubble-assisted Liquid Hole Multiplier operation in liquid argon", Accepted for publication in JINST [arXiv:1908.04974]

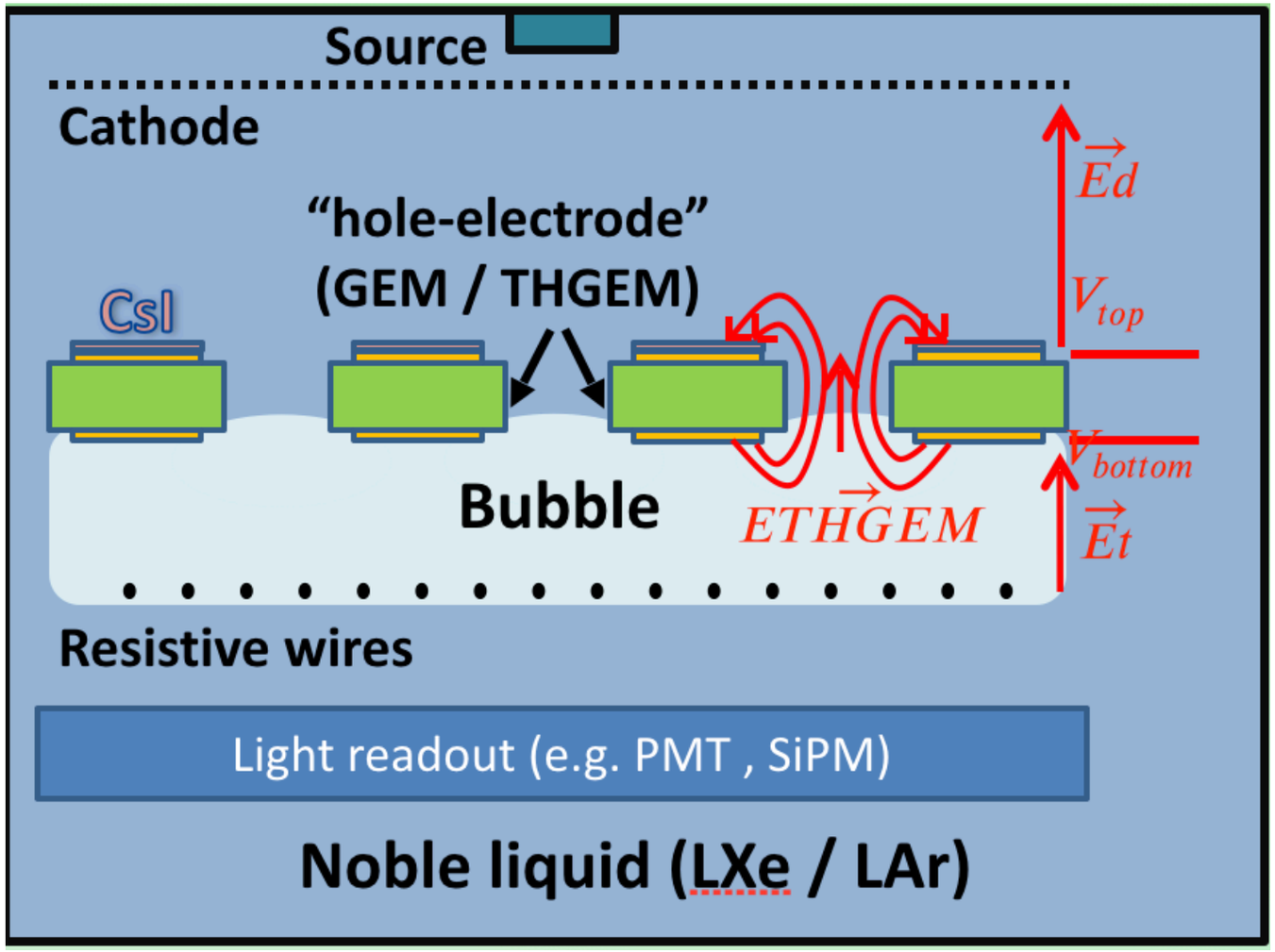
A. Tesi



Bubble assisted LAr-LHM

The concept - detector geometry

- A CsI-coated perforated electrode (GEM, THGEM) immersed in the noble liquid
- A bubble is inflated using resistive wires and trapped underneath the electrode
- A dedicated light readout (PMT, SiPM) placed below the wires
- Defining 3 electric fields:
  - E_d – Cathode-Top
  - E_{THGEM} – Top-Bottom
  - E_t – Bottom-Wires

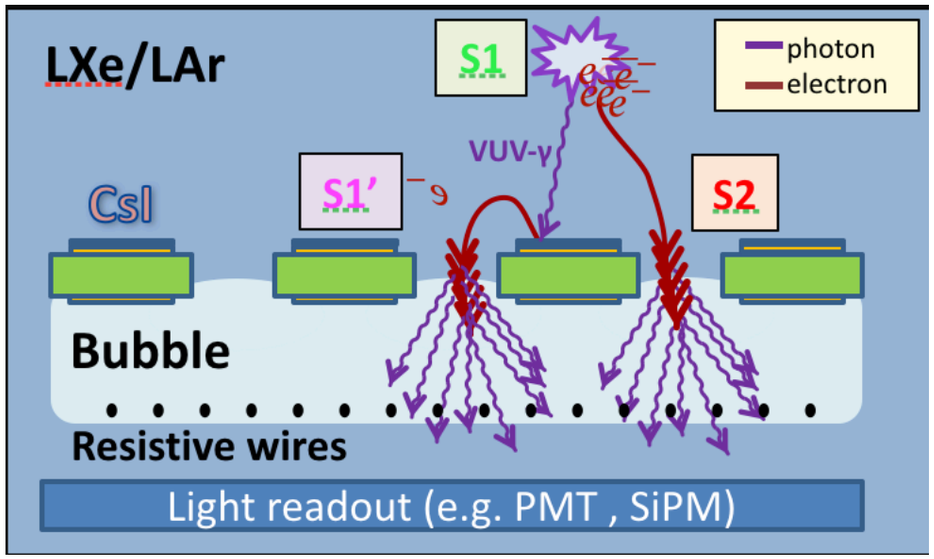


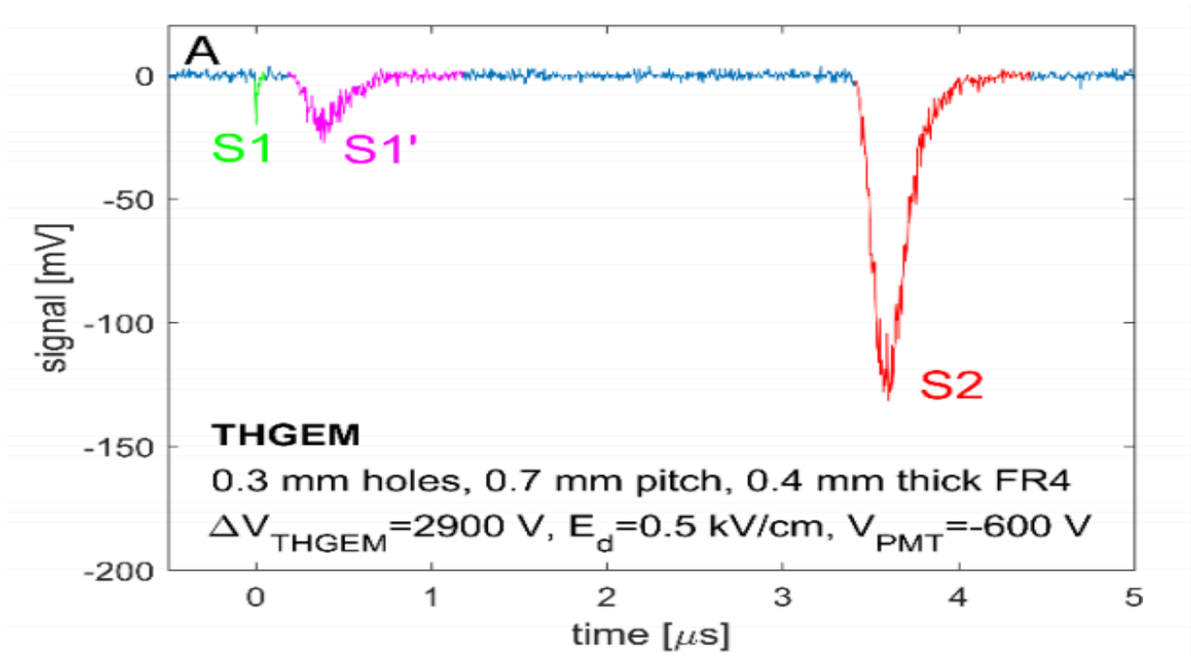
Bubble assisted LAr-LHM

The concept - physics

Radiation-induced electroluminescence from a bubble trapped in noble liquid

- Typical pulse shape contains 3 components
  - S1 – Primary scintillation light due to de-excitation
  - S1' – Electroluminescence induced by a single photoelectron extracted from the photocathode
  - S2 – Electroluminescence induced by ionization electrons extracted from the liquid and transferred into the gaseous phase towards the THGEM bottom
- Without E_t electrons drifts towards the bottom part of the GEm/THGEM
- With E_t electrons travel through the bubble reaching the wires





L. Arazi et al. 2015 *JINST* 10 P08015
E. Erdal et al. 2015 *JINST* **10** P11002

Main results in LXe

E. Erdal et al. 2015 JINST **10** P11002
E. Erdal et al. 2018 *JINST* **13** P12008
E. Erdal et al. 2019 *JINST* **14** P01028

- Successful operation as a charge and light readout
  Light yield: **up to 400 photons/e/4π**
- Systematic comparison of different geometries (THGEM/GEM/SC-GEM)
  SC-GEM: highest gain
- Modest charge multiplication in the bubble in addition to EL
  ~8 for E_t~2-15 kV/cm
- Very good $\mathbf{E_{RES}}$ **~ 6% RMS with α**

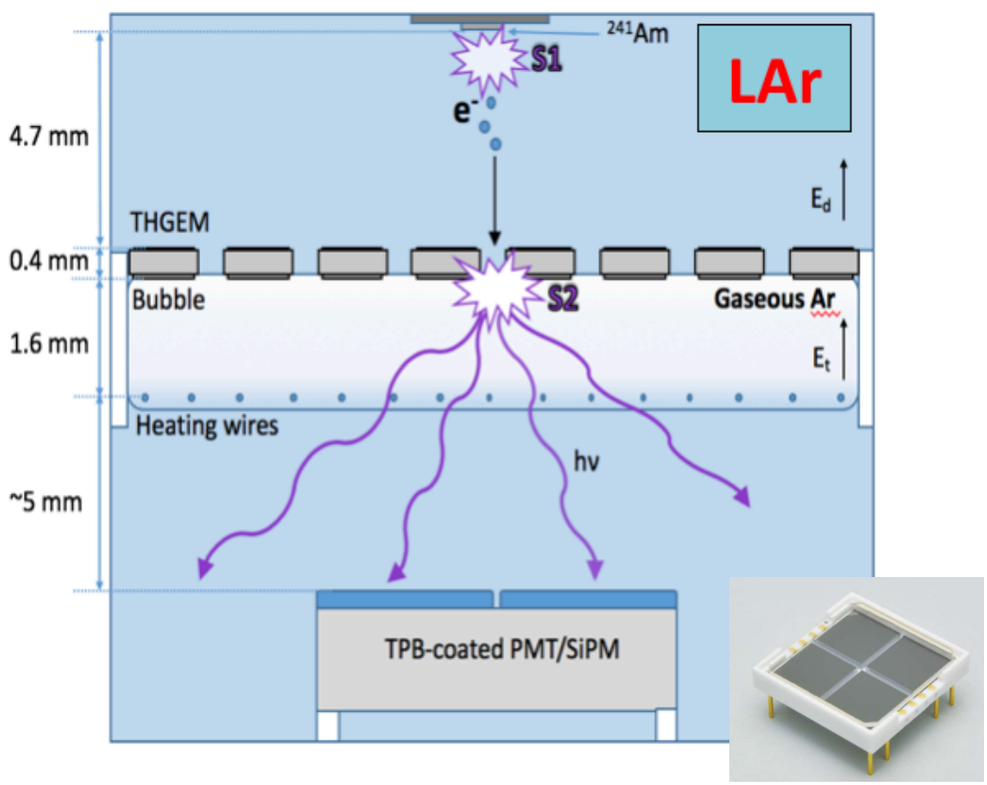
  (~7000 primary e^- - no recombination, ~2000 VUV-induced pe^-)
- Imaging of an ^{241}Am source with pixelated (Quad-SiPM) readout
  R_{xy} ~ 200μm RMS

Does the bubble concept work also in LAr?

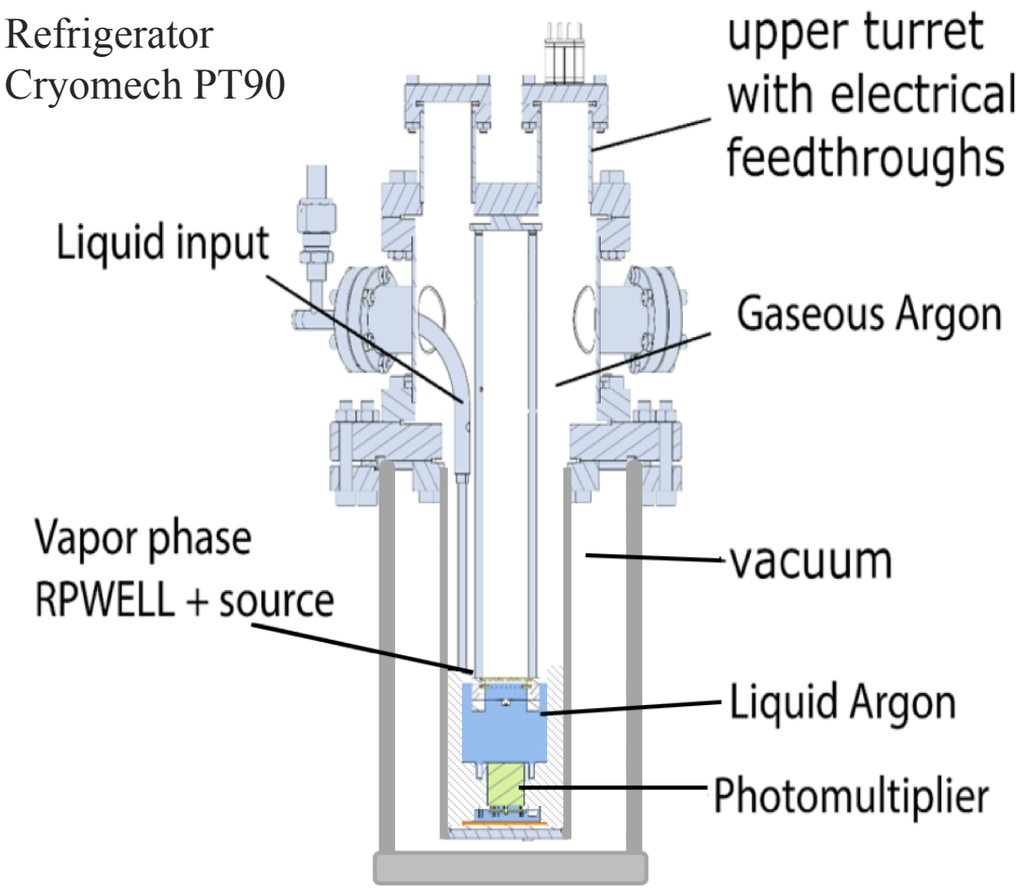
Bubble assisted LAr-LHM

WISArD

- The cryostat
- Current tested LHM configuration
  - 0.4 mm thick THGEM
  - No CsI coating - no S1' signal
  - Readout:
    - Four-elements windowless SiPM (Hamamatsu VUV4 MPPC S13371- 6050CQ-02, total area 12x12 mm^2)
    - Similar response to PMT/TPB



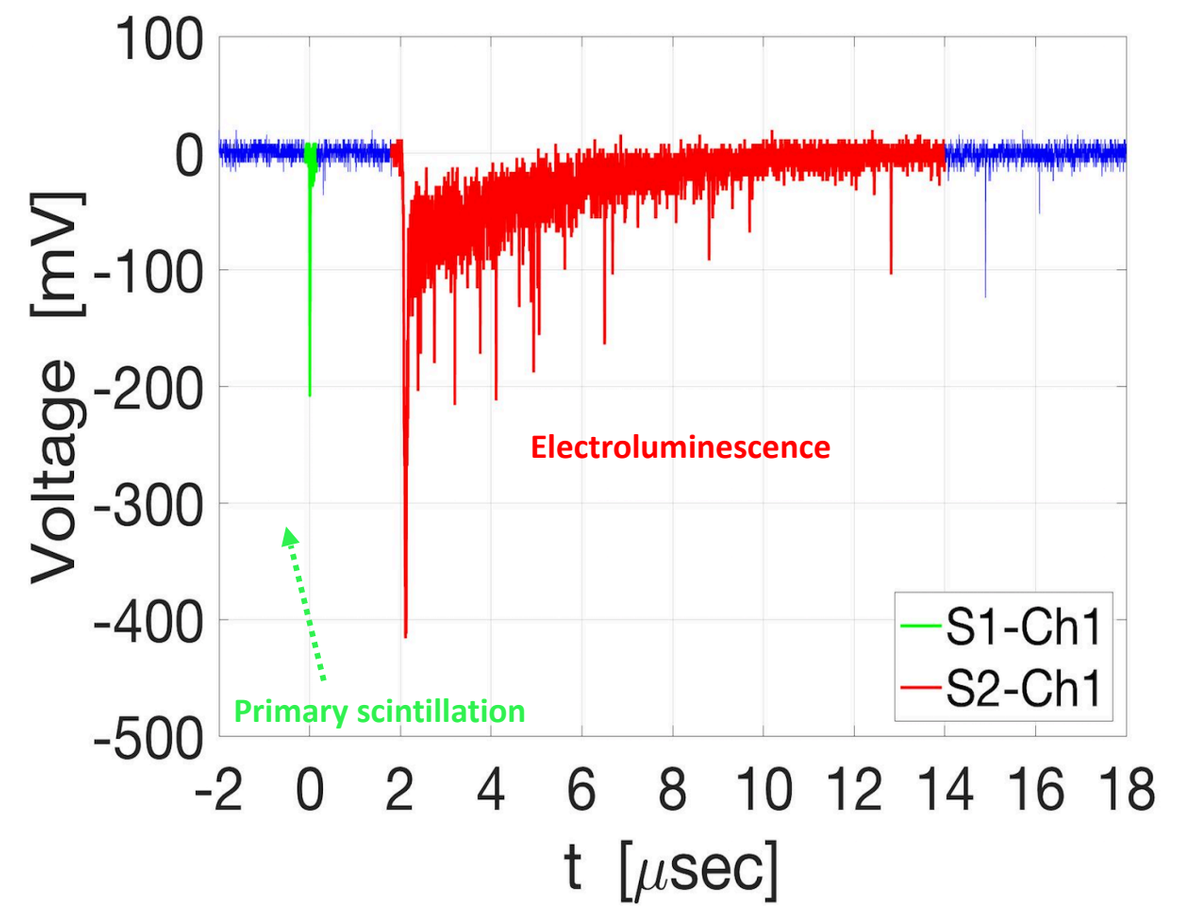
Refrigerator
Cryomech PT90

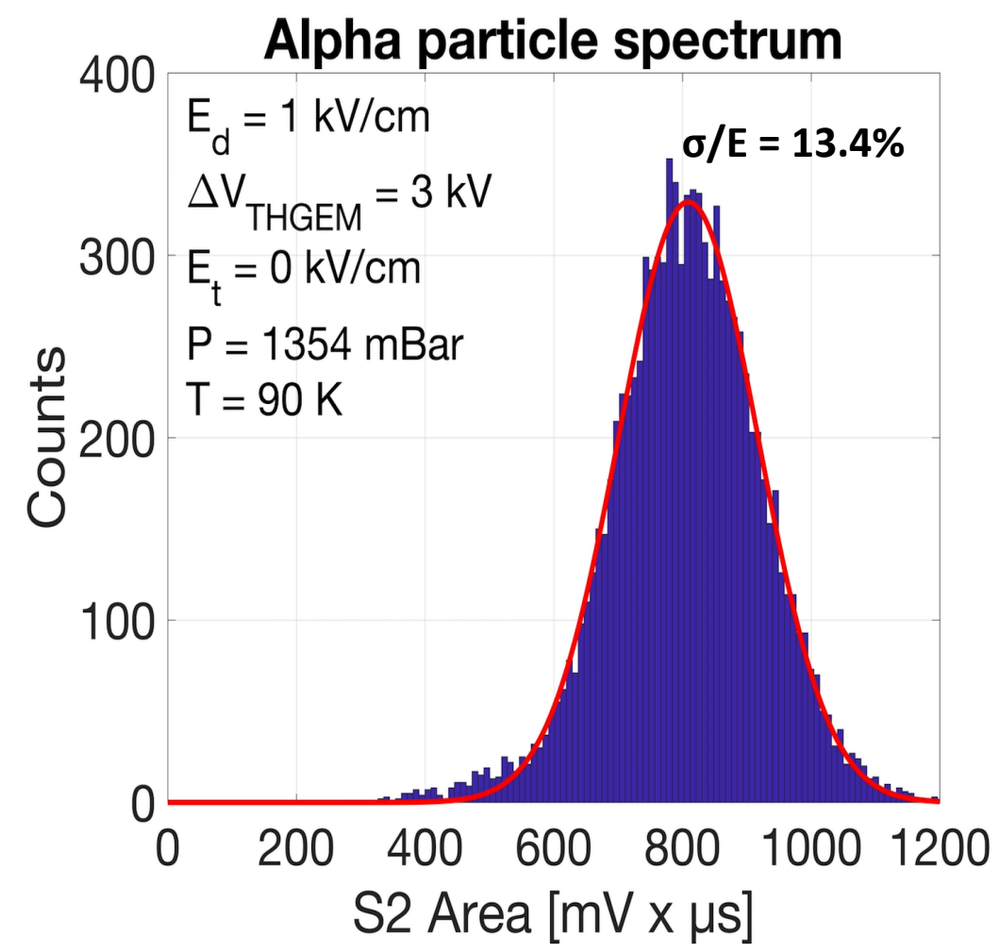


LAr-LHM is working

Proof of concept in LAr

- Wave form
  - Alpha-particle induced single-event waveform, recorded by a TPB-coated PMT
  - no CsI - no S1'
- Energy resolution - ~14%

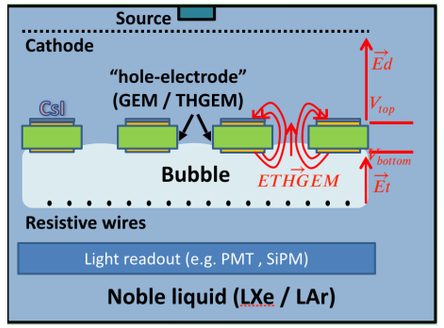


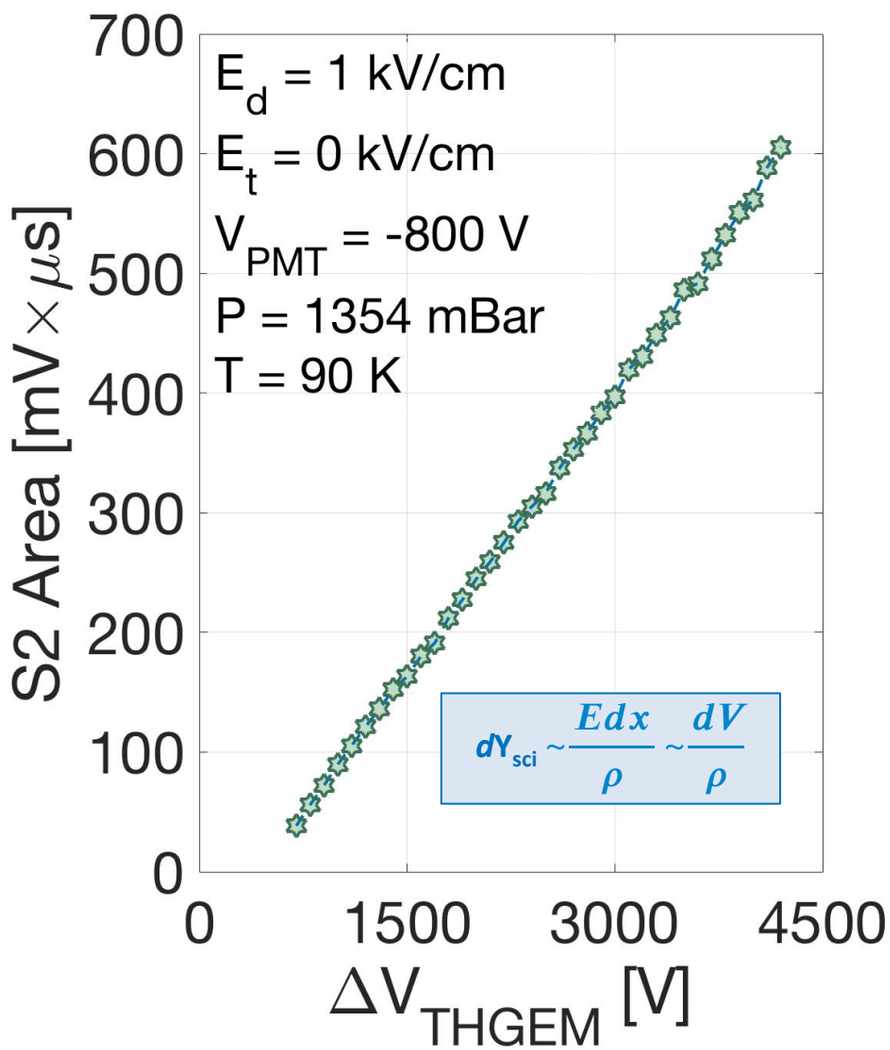


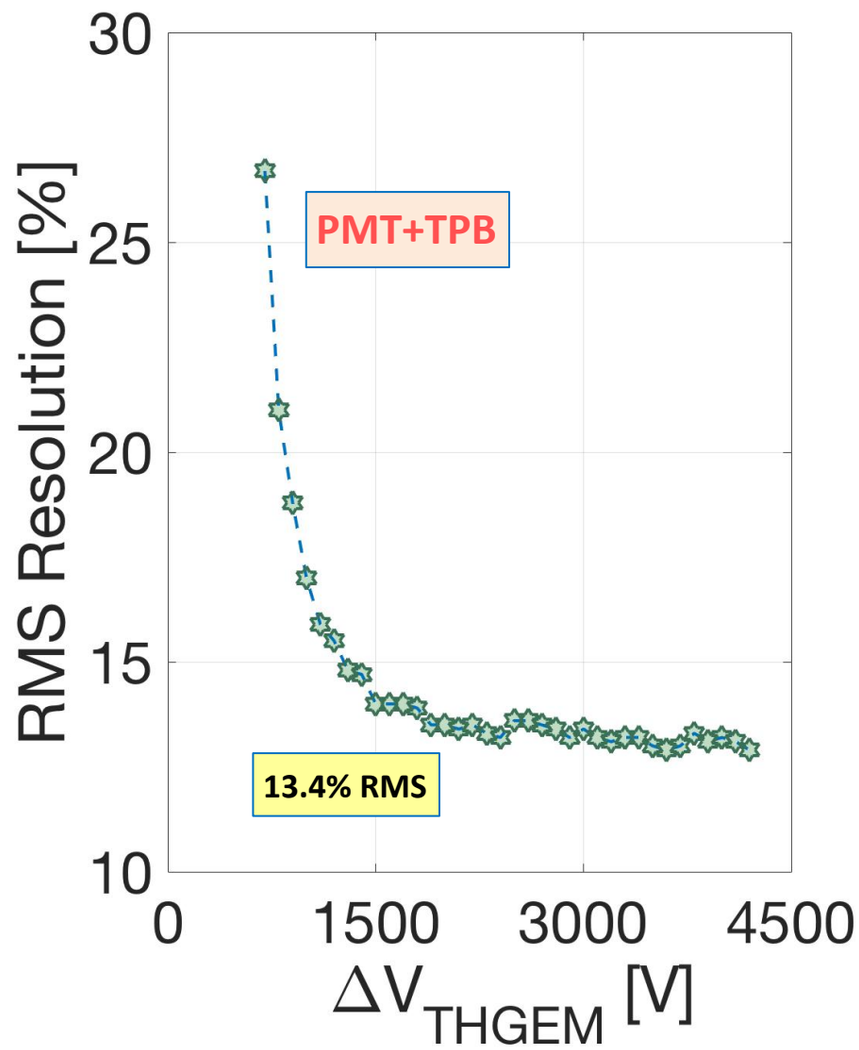
Response of LAr-LHM

Voltage configuration without transfer field

- Electrons drift towards the bottom of the THGEM electrode
- Average pulse area linear with THGEM field
  Indication for electroluminescence without charge gain
- Energy resolution improves with THGEM field
  Reaching a plateau



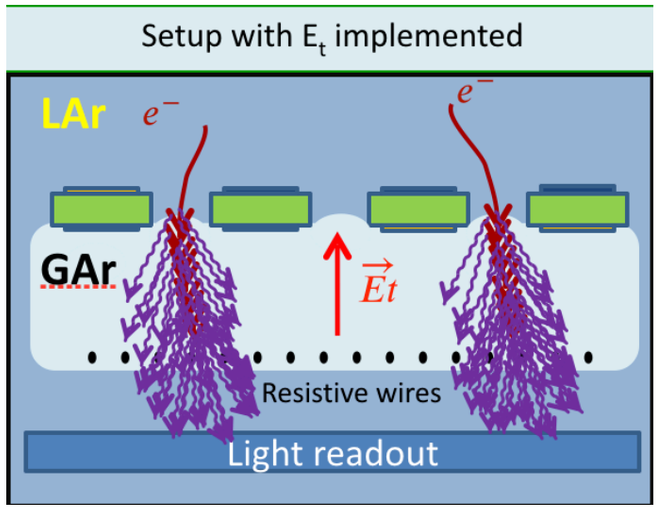


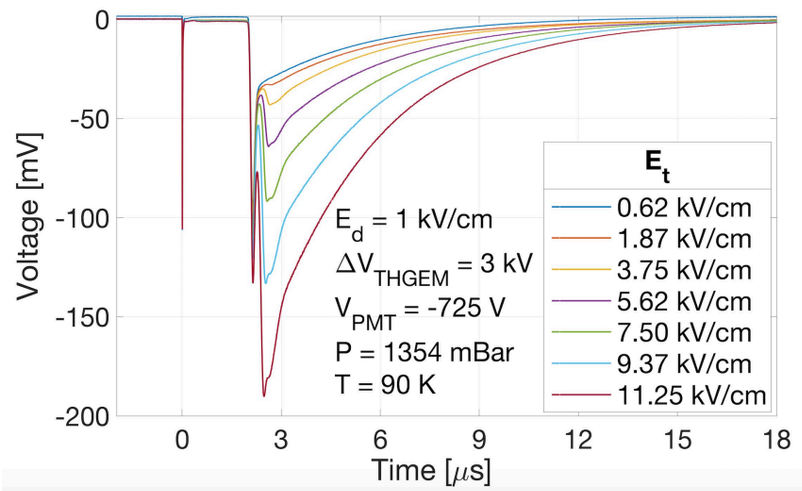


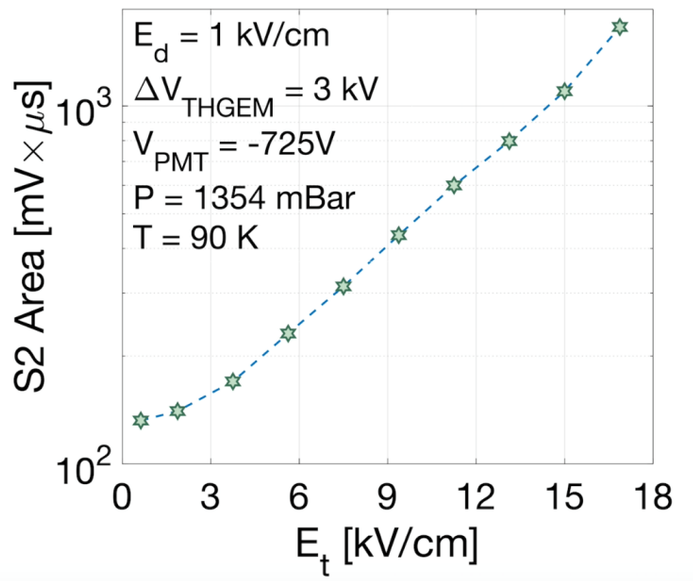
Response of LAr-LHM

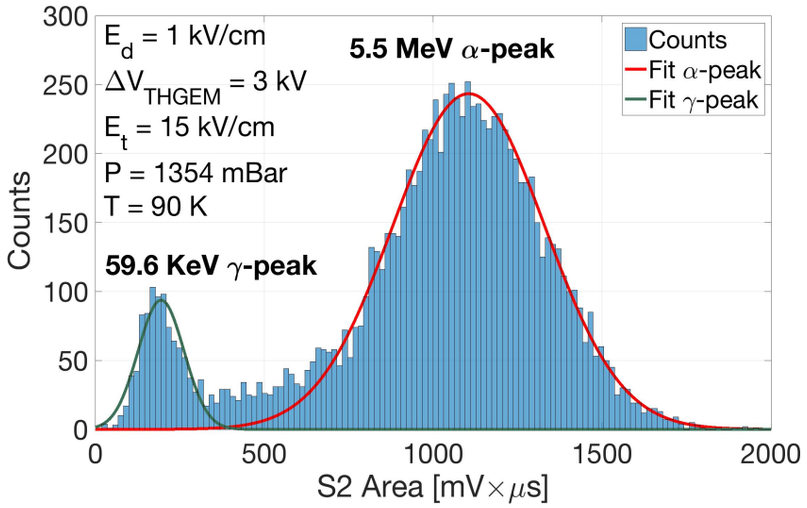
Voltage configuration with transfer field

- Electrons drift along the bubbles towards the wires
  - High electrical field close to the wires
- Charge multiplications at high enough field indicated by
  - Average pulse shape - 2 peaks in S2
  - Average pulse area exponential with high THGEM field
- Gain sufficiently high to see also the gamma component of the ^{241}Am
  - Large recombination of the alpha induced electrons
    S2 area ratio different from energy ratio







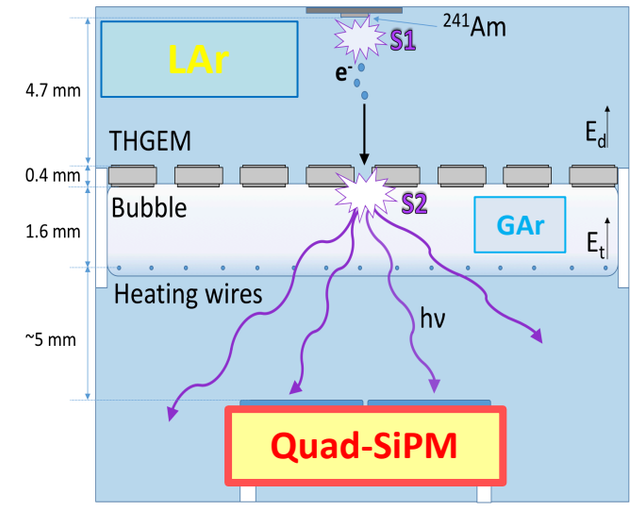


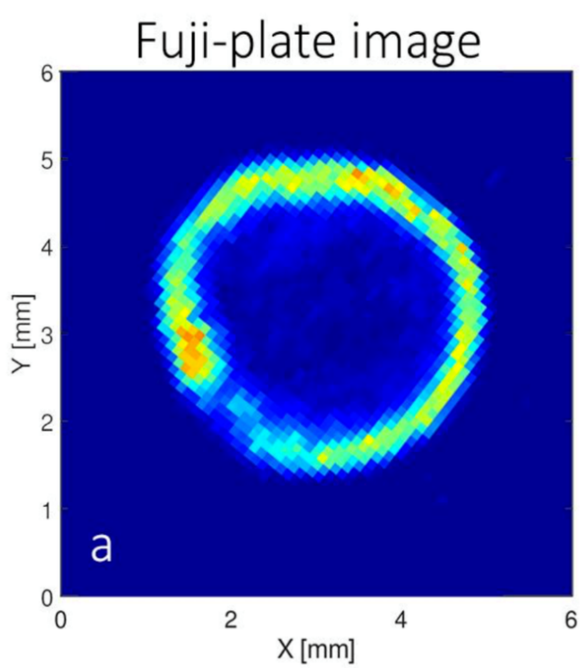
LAr-LHM - spatial resolution

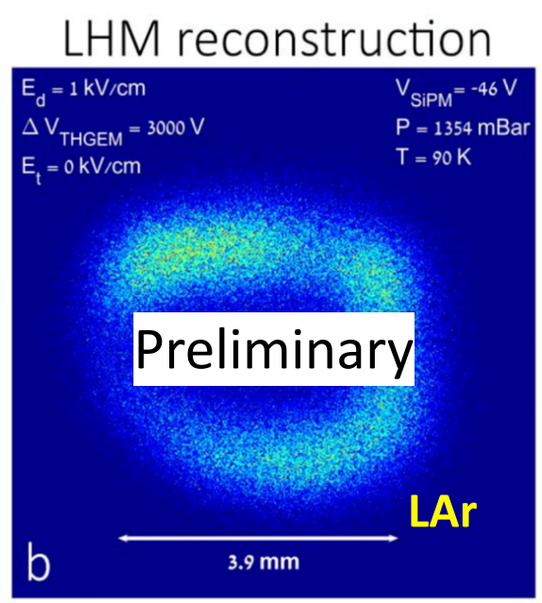
Proof of concept

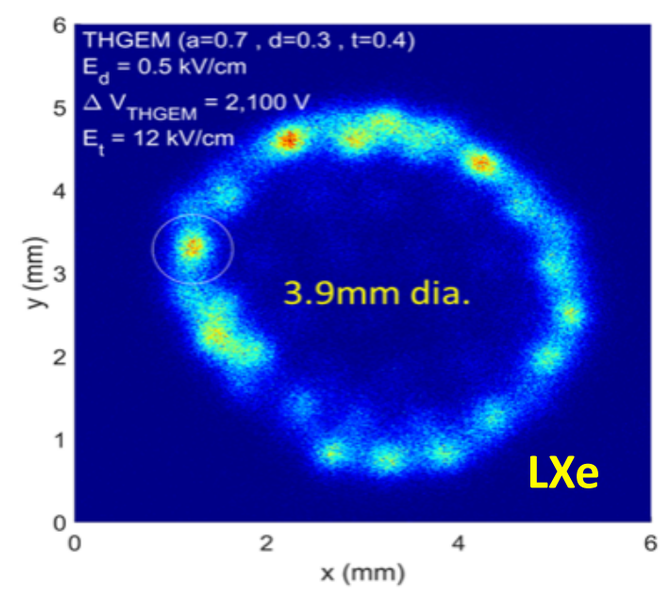
- Imaging of ^{241}Am source
- Sub-mm reconstruction resolution
  simple center-of-gravity algorithm (very preliminary)
- Poorer resolution relative to LXe
  - 600 μm relative to 200 μm

$$\vec{R} = \frac{A \cdot \sum L_i \cdot \vec{r}_i}{\sum L_i}$$









LAr-LHM - Quick summary

- Successful demonstration of a bubble-assisted LAr-LHM
- Preliminary measurements of several properties – S2 Area vs ΔV_{THGEM}, vs E_t, E_{RES} and R_{XY}
  - Performance far from optimal

LAr-LHM - Next steps

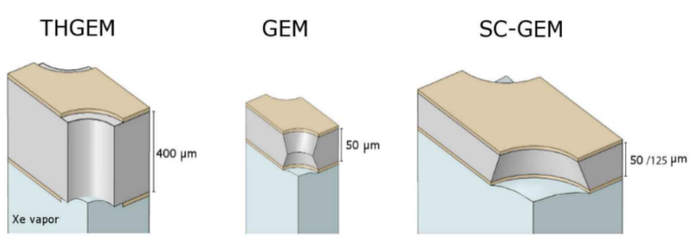
- Two fronts
  - Investigation and modeling of the underlying physics governing the LHM performance
  - Systematic characterization

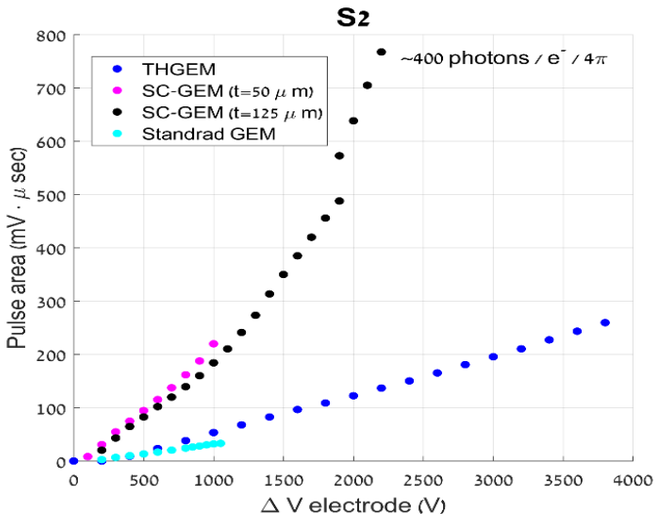
The physics of LAr-LHM

- Pulse shape - understand the different componenets especially of S1
- Bubble dynamics –
  Formation, stability, shape of the liquid-to-gas interface, bubble penetration into the holes
- E_{RES} – We observed a discrepancy (2-fold lower than in Xe). Why?
- PDE – In LXe we measured a 5-fold lower PDE of a CsI-coated electrode than the predicted one. Electron loss. Is this going to happen also in LAr-LHM?
- Electron transfer efficiency – How is it correlated to the liquid-to-gas interface? Does it affect E_{RES}?
- Potential barrier from liquid-to-gas – Does it play a role? (0.69eV in LXe vs 0.2eV in LAr)
- R_{xy} – We observed a difference (3-fold lower than in Xe). Why?

Systematics characterization

- Different electrode geometries
  LXe-LHM - SC-GEM was best
- Measurement of additional properties: mostly PDE
- Operation in depth
- Large area





Introducing two concepts

Cryo-RPWELL

Cryogenic Resistive Plate WELL

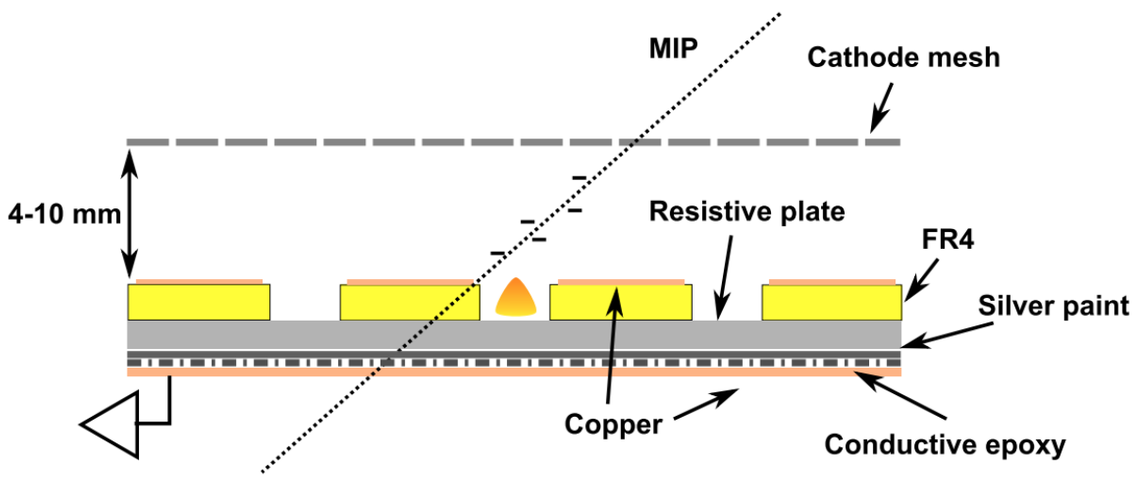
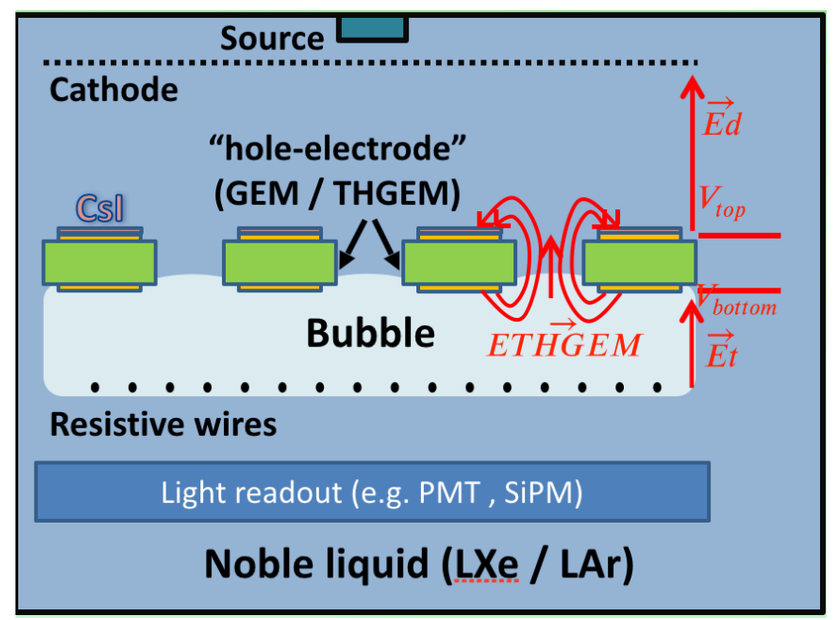


Figure 1. The Resistive-Plate WELL (RPWELL) configuration with a resistive anode and a readout electrode. The WELL, a single-faced THGEM, is coupled to a copper anode via a resistive plate. Charges are collected from the copper anode. In some experiments the WELL was directly coupled to the metal anode.

A. Rubin, L. Arazi, SB, L. Moleri, M. Pitt, A. Breskin [arXiv:1308.6152]

Bubble assisted-LHM

Bubble assisted Liquid Hole Multiplier



First Demo in LXe:
L. Arazi et al. 2015 *JINST* 10 P08015 [arXiv:1505.02316]
E. Erdal et al. 2015 *JINST* **10** P11002 [arXiv:1509.02354]

Outlook

- So far we conducted curiosity driven R&D

- **Could such concepts be useful for DUNE…**
- We will be happy to collaborate with whoever is interested
  - In an attempt to answer the above question
  - In an attempt to better understand the concepts

- Interesting research ahead
- Excellent facilities to perform most of it
- Funding is available

- Curious PhD and postdoc candidates are welcome to join (shikma.bressler@weizmann.ac.il)