The RPWELL - its physics and potential applications

S. Bressler, L. Arazi, P. Bhattacharya, A. Breskin, A. Coimbra, E. Erdal, L. Moleri, A. Roy, D. Shaked-Renous, A. Tesi
Weizmann Institute of Science

Three fronts

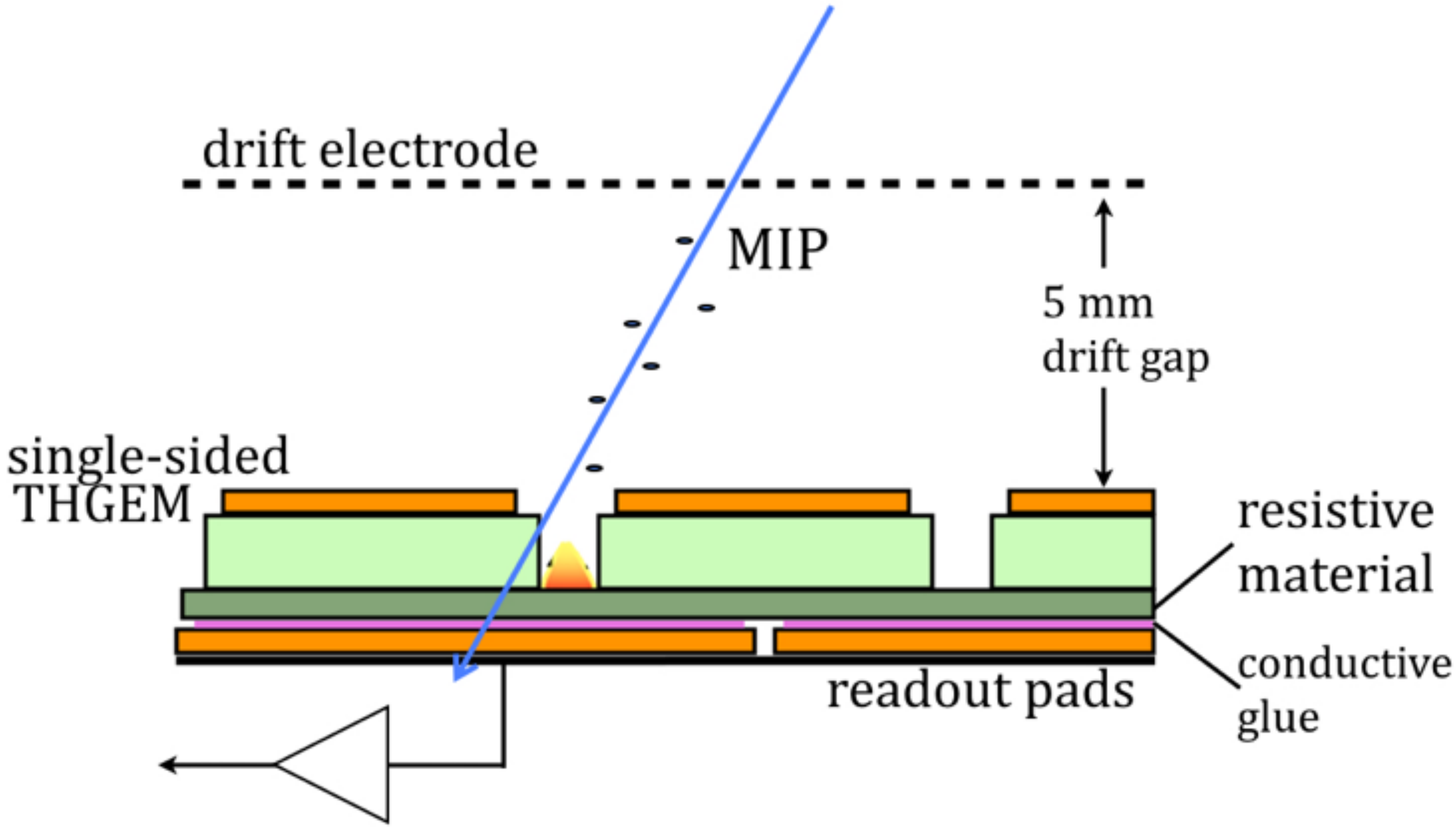
- Upscaling
- Characterization
- Cooling down (not discussed today)

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

RPWELL Resistive Plate WELL

JINST 8 (2013) P11004

- Single sided THick Gaseous Electron Multiplier (THGEM)
- Coupled to the readout anode through material of high bulk resistivity



RPWELL Resistive Plate WELL

JINST 8 (2013) P11004

- Single sided THick Gaseous Electron Multiplier (THGEM)
- Coupled to the readout anode through material of high bulk resistivity

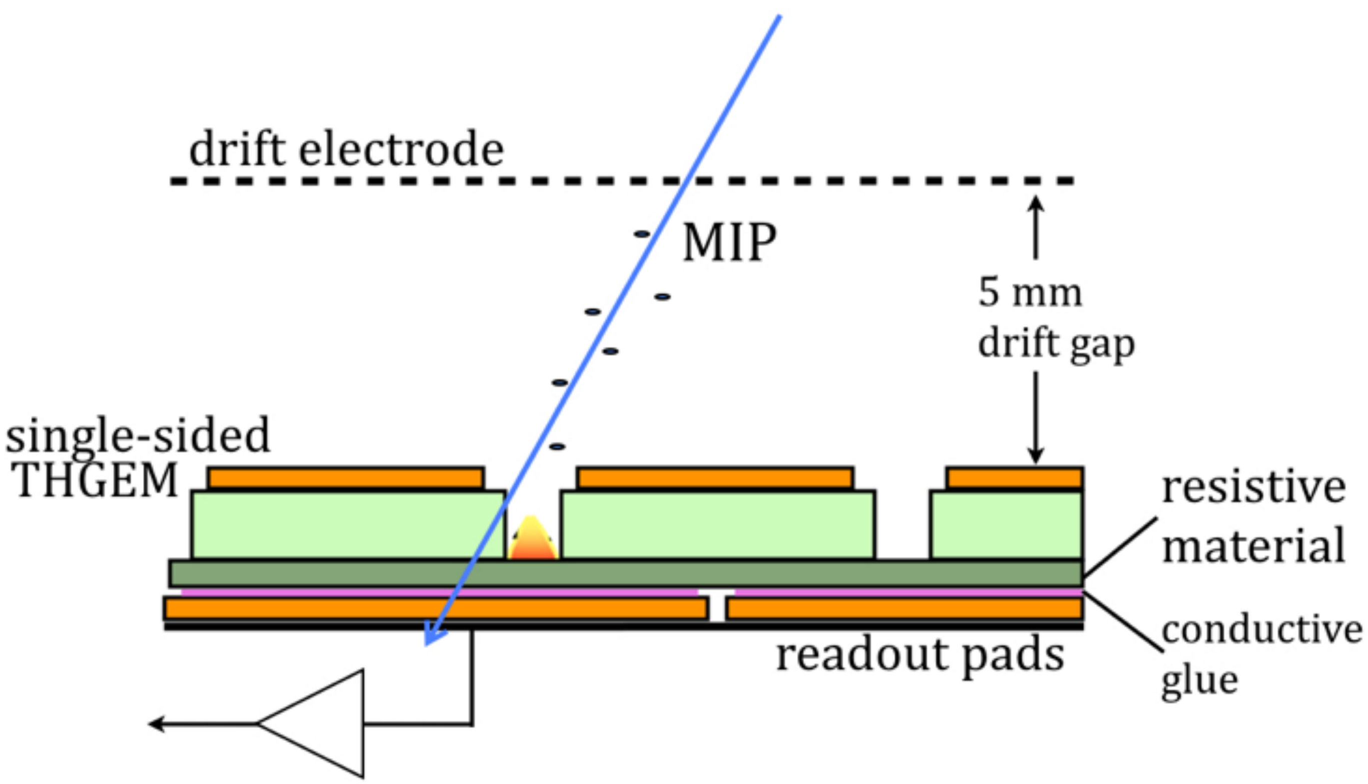
Main characteristics

JINST 11 (2016) no. 01 P01005

NIM A845 (2017) 2620265

JINST 11 (2016) no. 09 P09013

- High gain (>10^5) with single element
- High detection efficiency (~99%)
- Moderate gain loss under high rate of incoming particle fluxes
- Discharge free operation
  - With Ne- and Ar-based gas mixtures
  - At muon and high rate pion beams
  - Under broad dynamic range of primary ionization

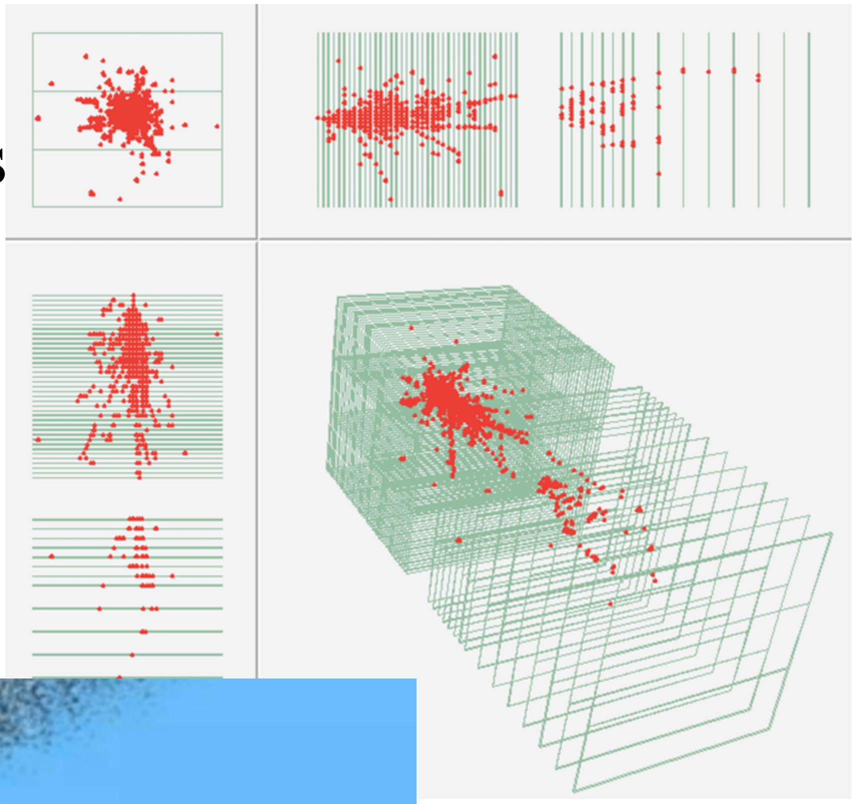


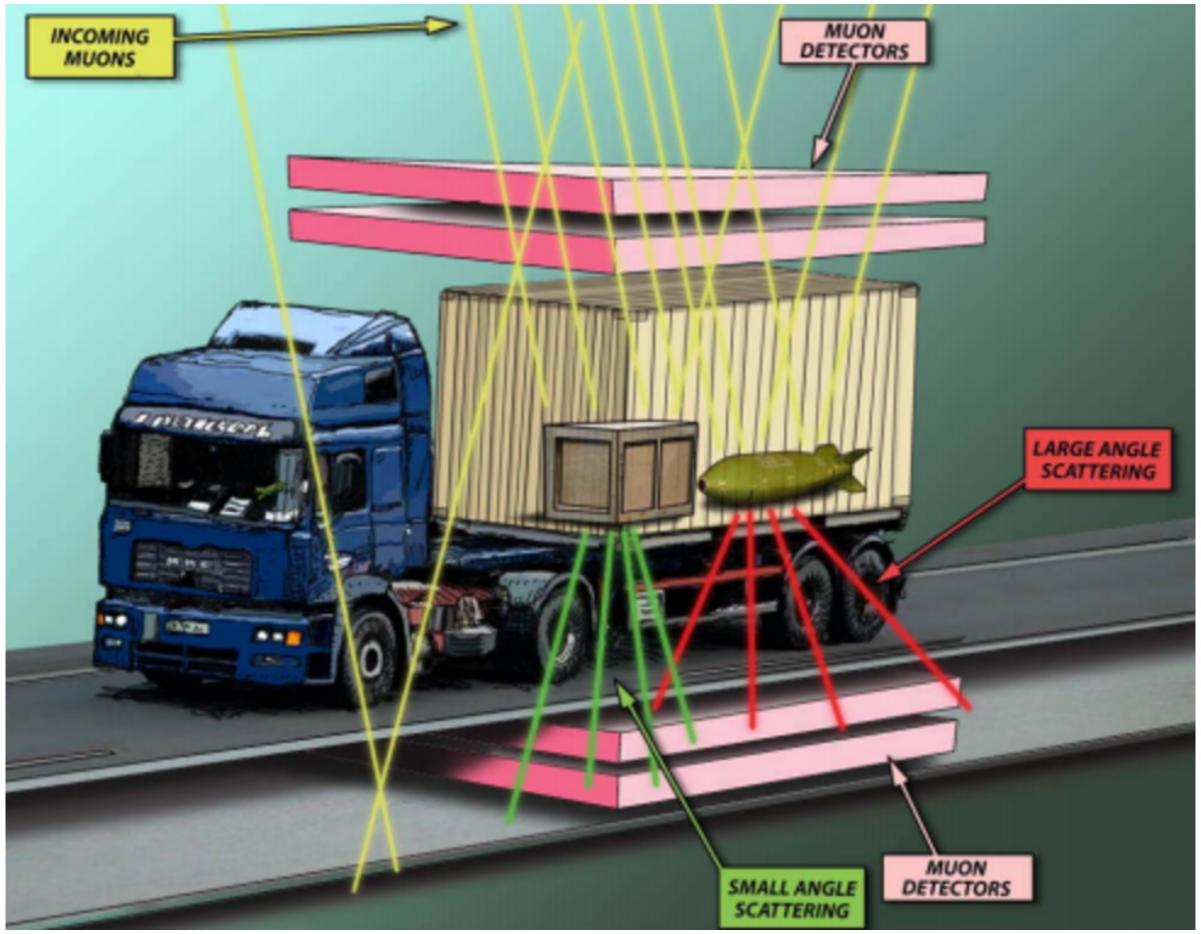
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

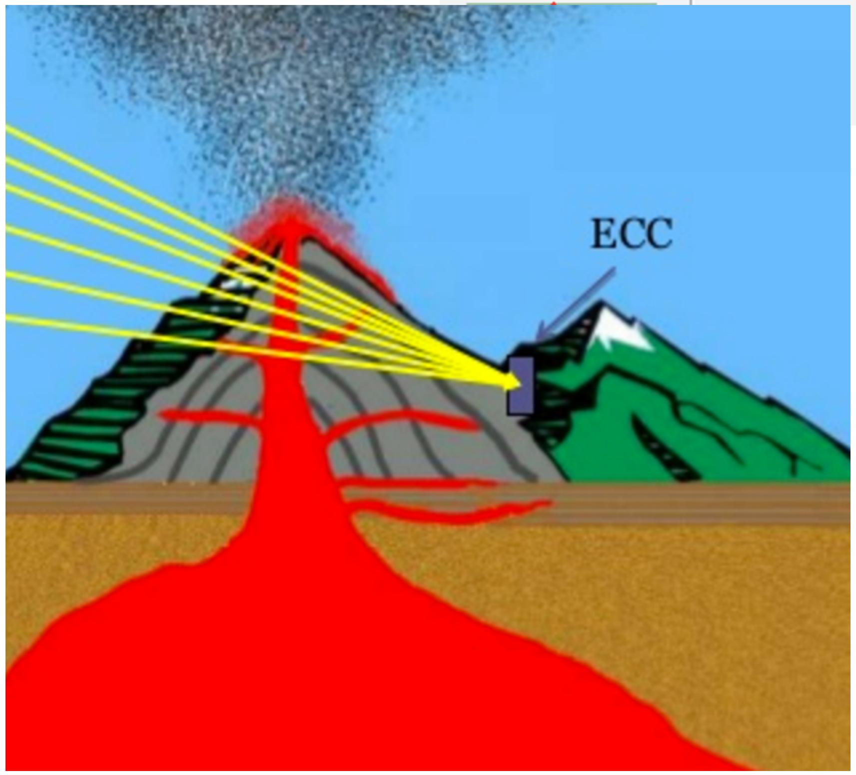
Upscaling From 3×3 cm² to 50×50 cm²

Motivation

- Applications requiring cost-effective large area detectors with moderate spatial resolution
  - (Semi) Digital Hadronic Calorimeter - (S)DHCAL
  - Muon tomography for homeland security
  - Volcanology and many more







מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

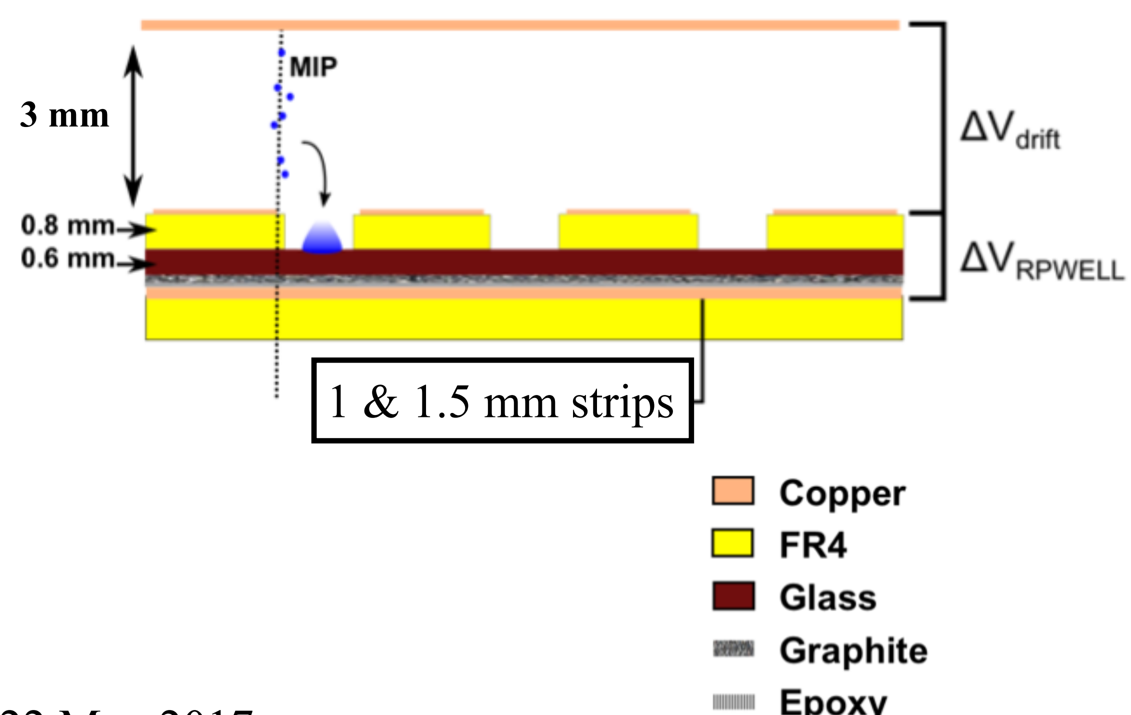
Upscaling — From 3×3 cm^2 to 50×50 cm^2

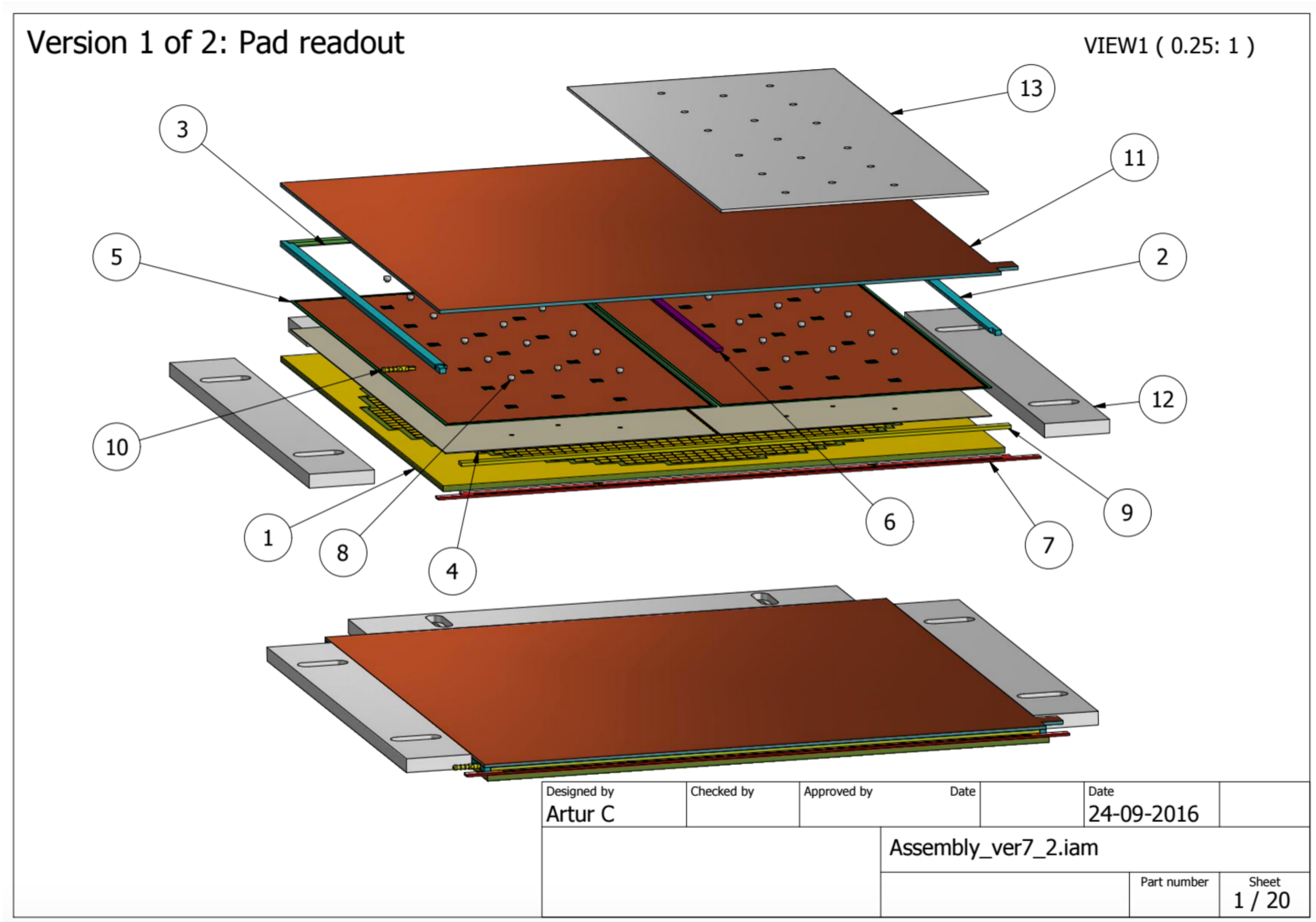
3×3 cm^2 ⇒ 10×10 cm^2 ⇒ 30×30 cm^2 ⇒ 50×50 cm^2

Motivation

- Applications requiring cost-effective large area detectors with moderate spatial resolution
  - (Semi) Digital Hadronic Calorimeter - (S)DHCAL
  - Muon tomography for homeland security
  - Volcanology and many more

Design



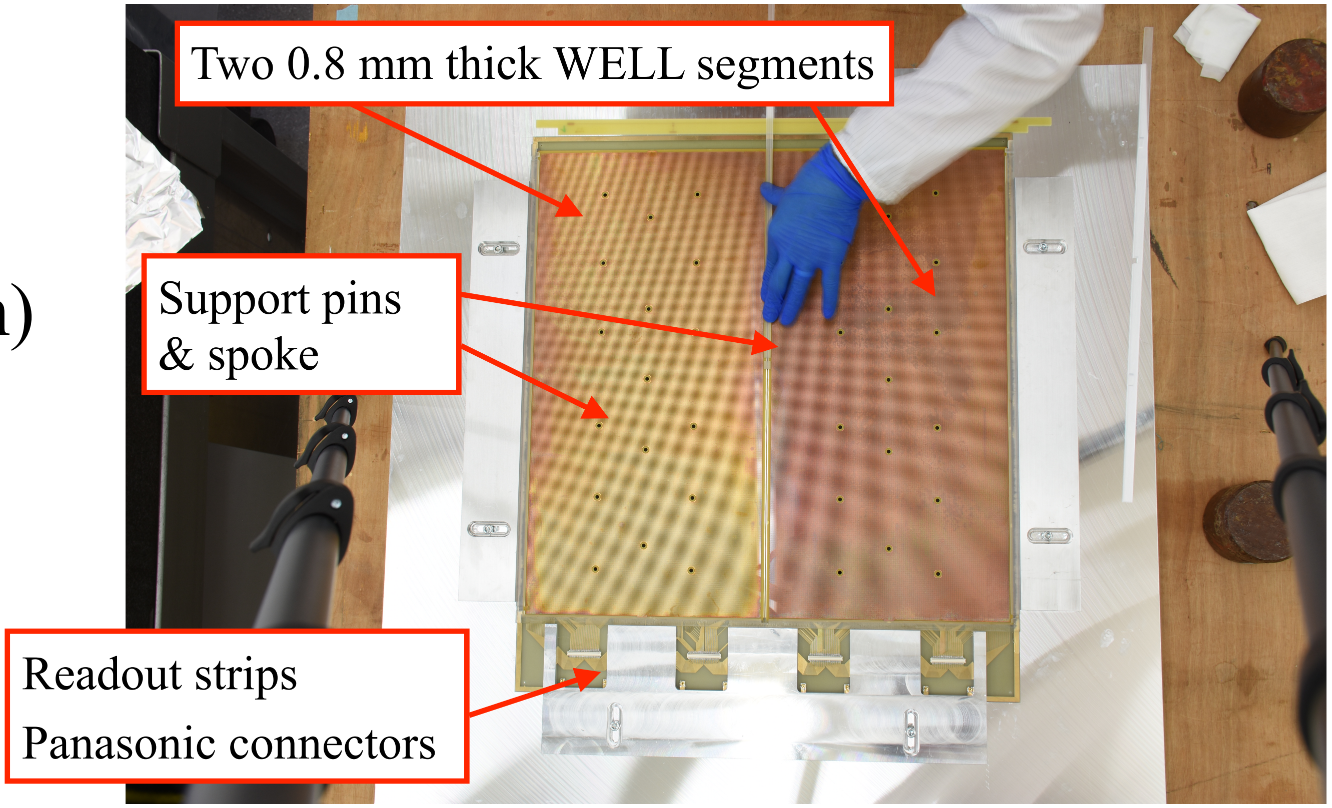


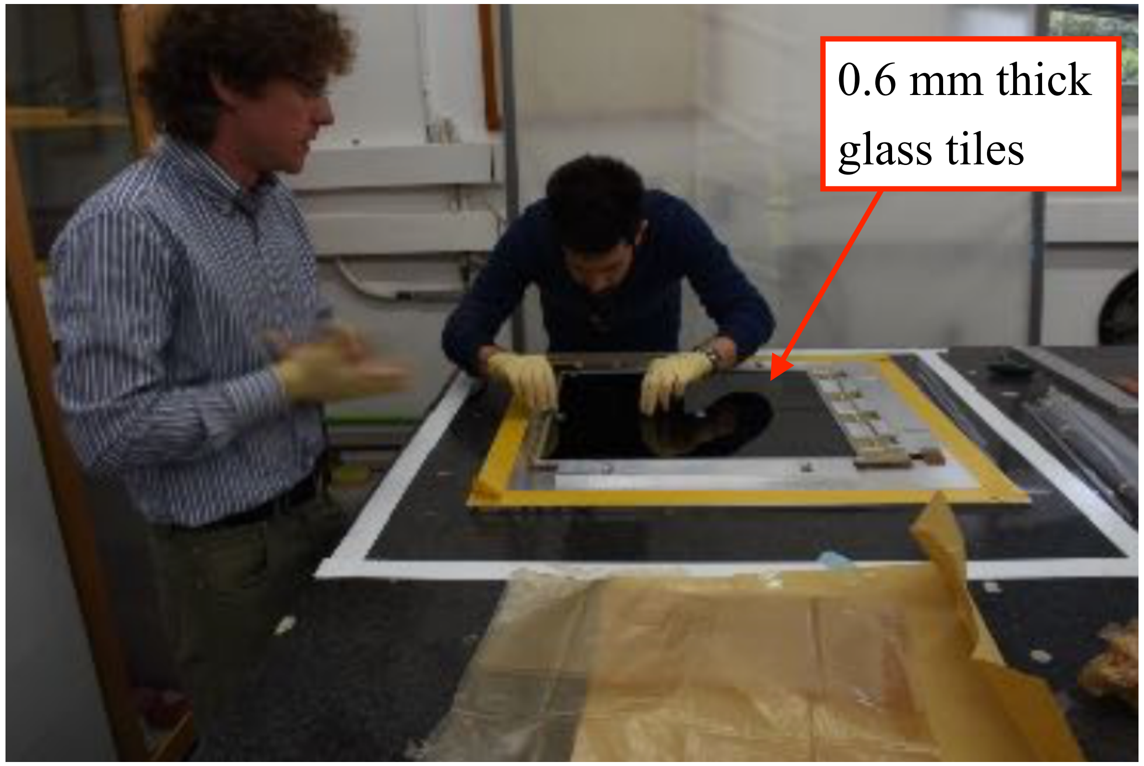
Upscaling From 3×3 cm^2 to 50×50 cm^2

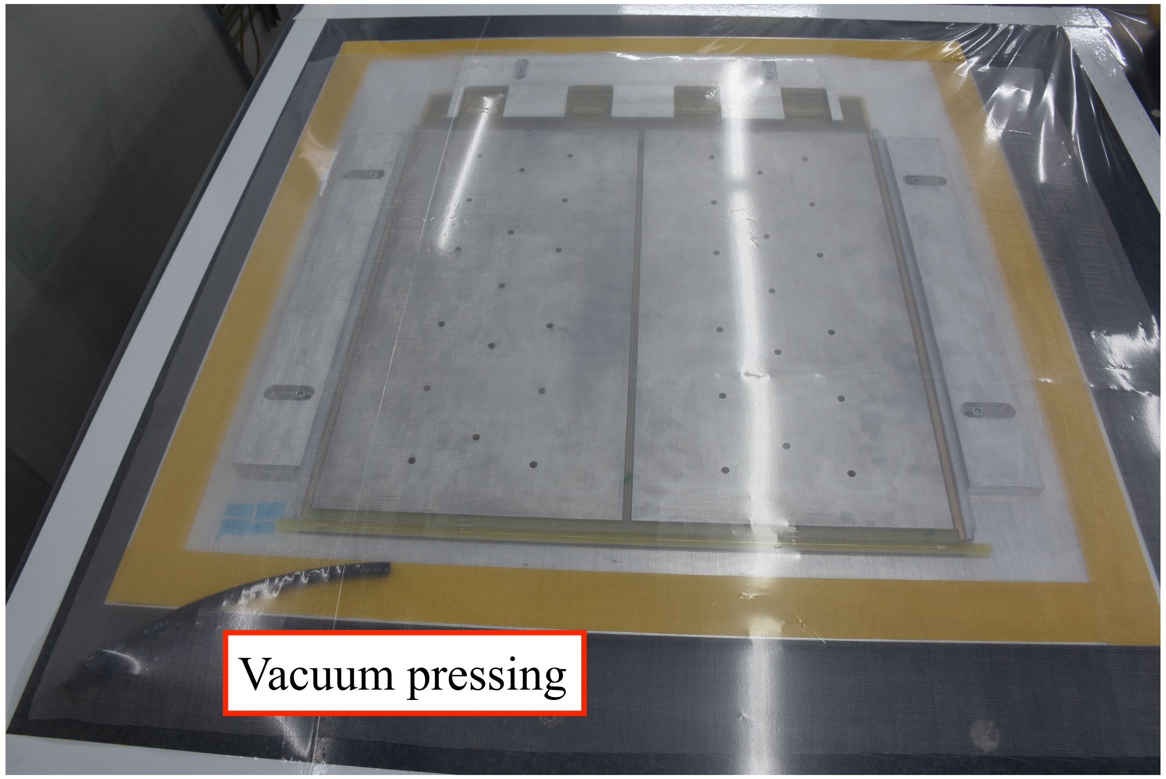
Assembly

- Strip readout (1 & 1.5 mm pitch)
- Silicate glass Resistive Plate (10^9 Ωcm)

  [J.-b. Wang et al., NIM A621 151]
- Anode to glass coupling through graphite-epoxy layer (~MΩ)
- Gluing under vacuum





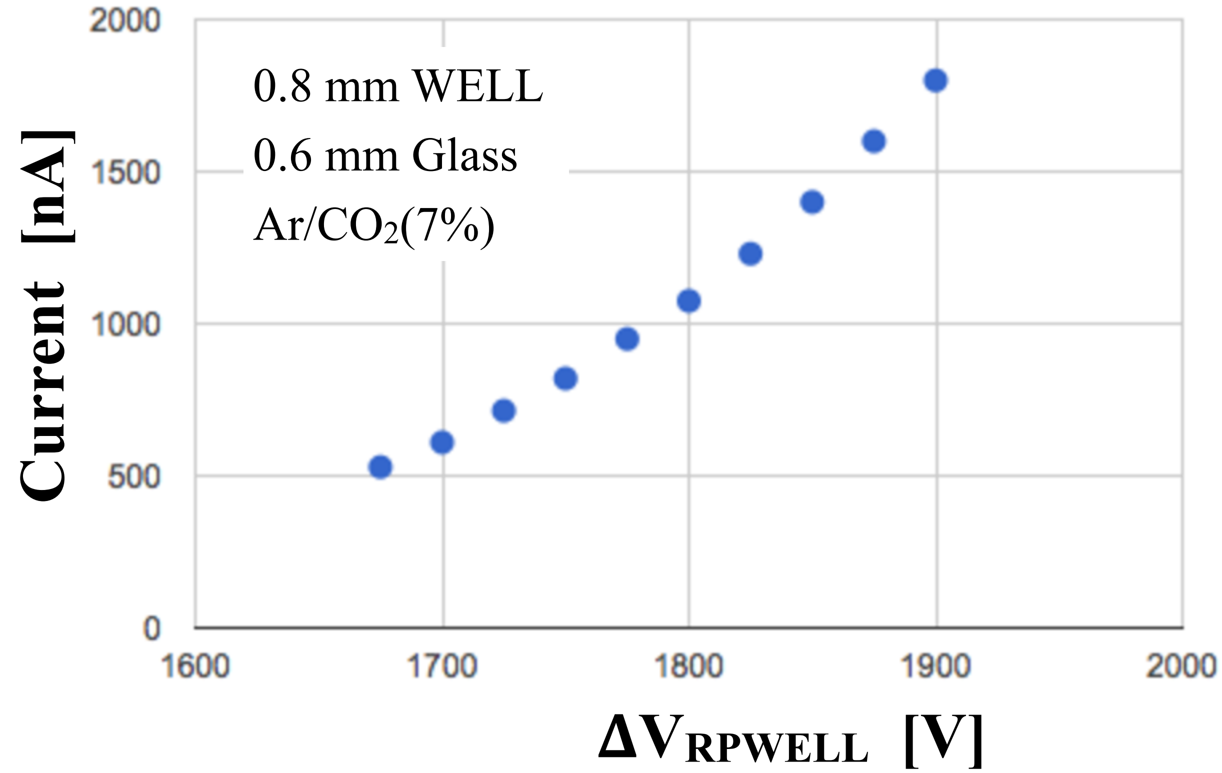


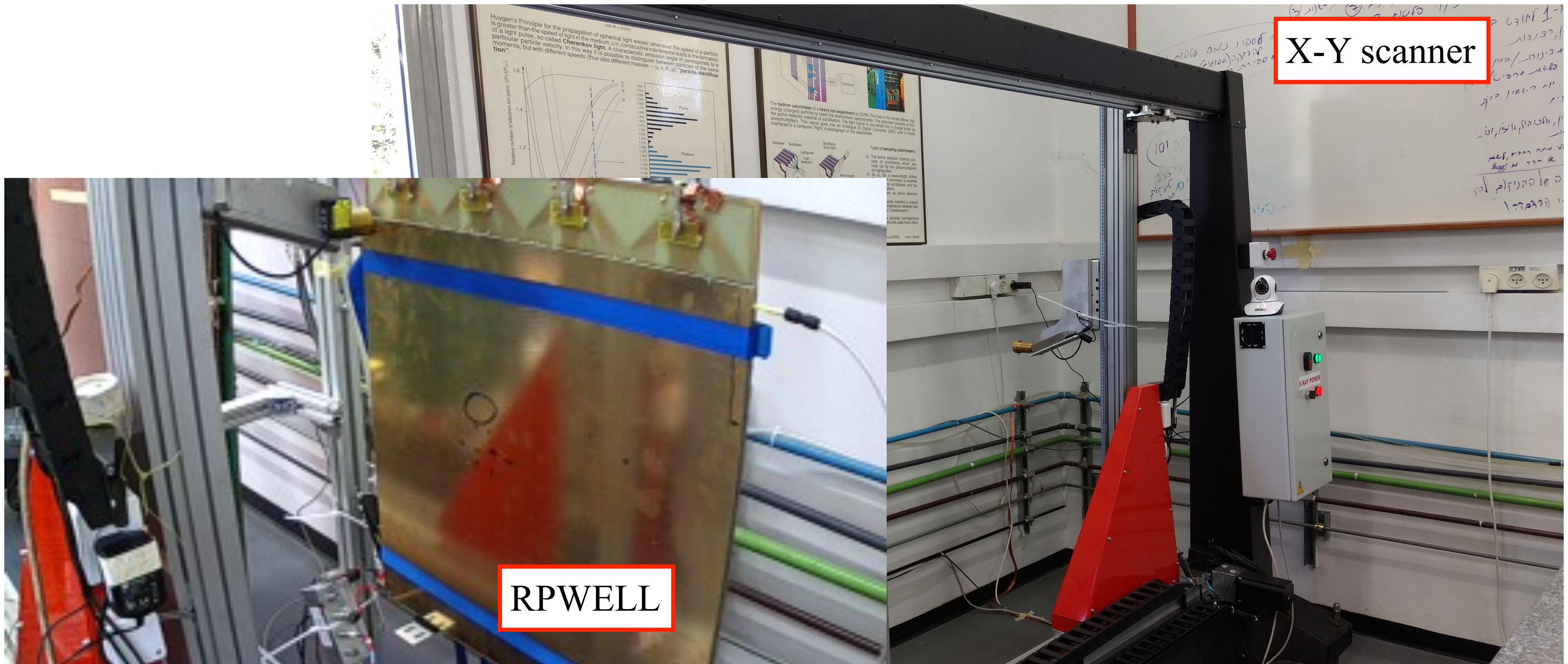
Upscaling From 3×3 cm^2 to 50×50 cm^2

Performance

- Studies conducted with X-Y scanner
  - Developed for the ATLAS sTGC
- Ag-target x-ray tube ⇒ 22 KeV photons
  - Penetrating the 3 mm FR4 cover (cathode)
- High intensity (~400 KH$_z$/mm^2)
- HV current monitoring synchronized with the source position

3×3 cm^2 ⇒ 10×10 cm^2 ⇒ 30×30 cm^2 ⇒ 50×50 cm^2

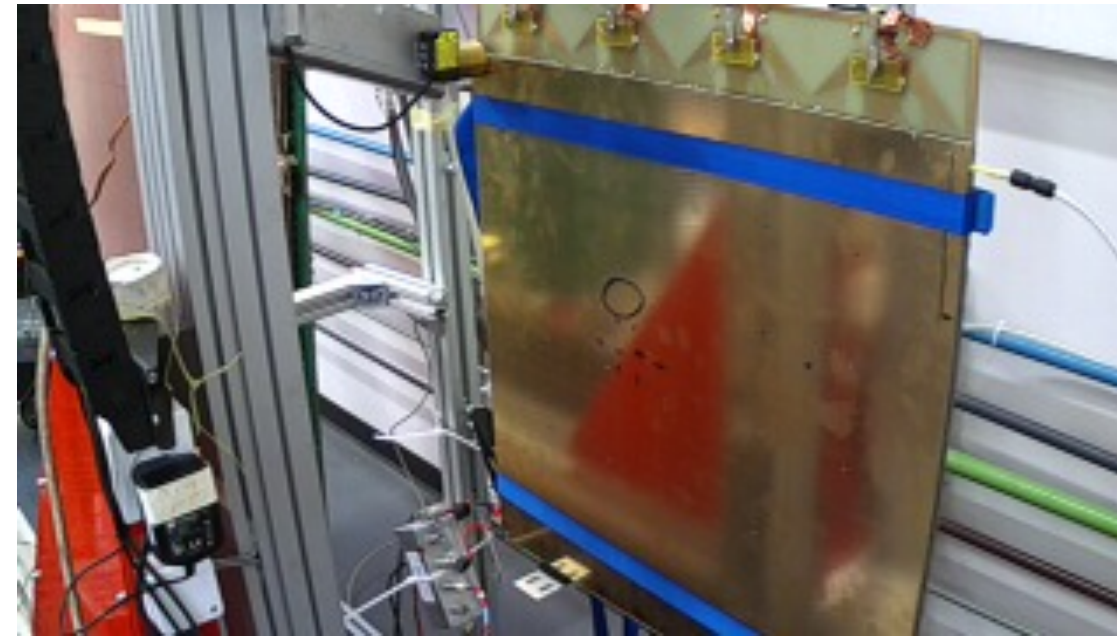




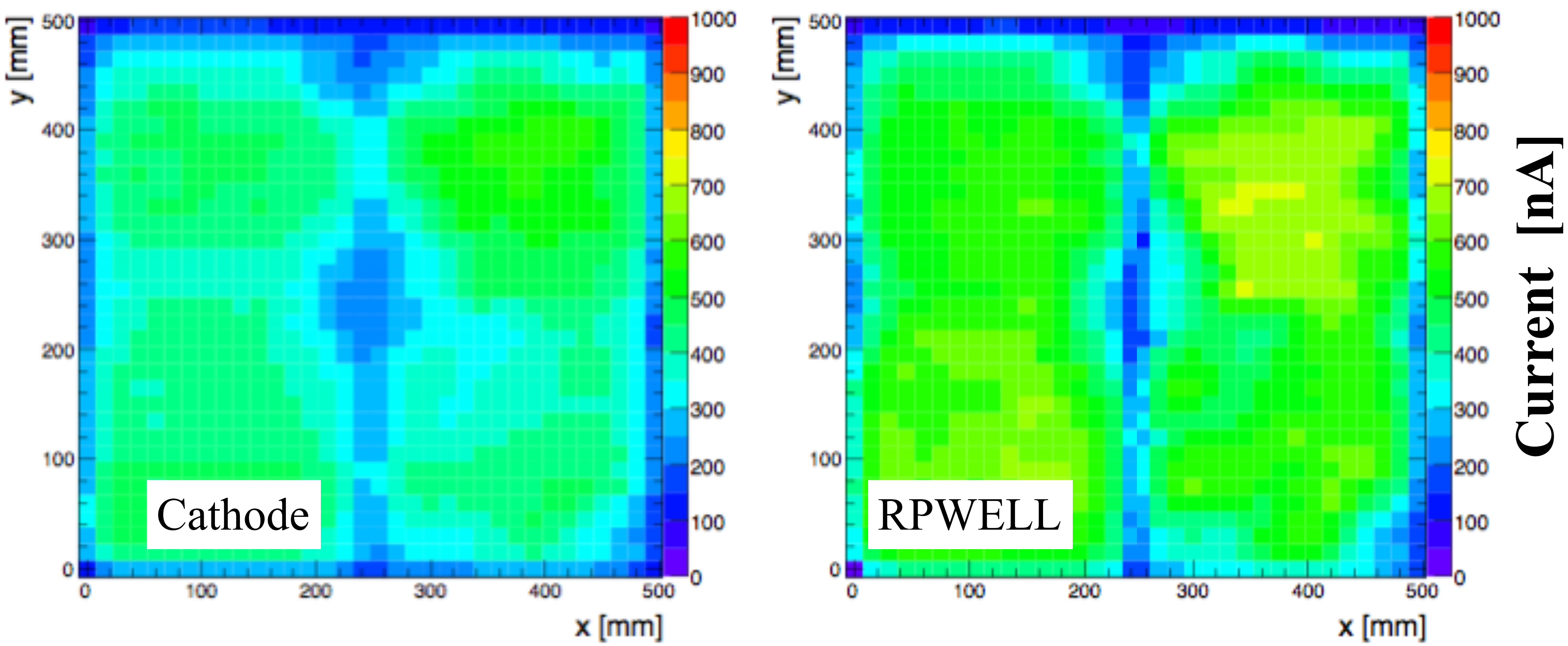
Upscaling — From 3×3 cm^2 to 50×50 cm^2

Performance

- Studies conducted with X-Y scanner
  - Developed for the ATLAS sTGC
- Ag-target x-ray tube ⇒ 22 KeV photons
  - Penetrating the 3 mm FR4 cover (cathode)
- High intensity (~400 KH_z/mm^2)
- HV current monitoring synchronized with the source position



$Ar/CO_2(7\%)$
$\Delta V_{RPWELL} = 1800$ V
Flux ~ 400 kH_z/mm^2
30 sec/point



- **Stable operation**
- **Some non-uniformities**
  - under study

Upscaling — From 3×3 cm^2 to 50×50 cm^2

Next steps

- In the lab
  - Investigate & solve the non-uniformities (correlated with the glass tiles)
- In-beam evaluation (soon)
  - Detection efficiency
  - Uniformity
  - Discharge probability
  - Position resolution
  - Energy resolution
  - …

(S)DHCAL

- Project shared with LAPP and Demokritos
- Build prototype
  - With Pad readout
  - With the MICROROC chip
  - Design and assembly procedure identical to the one used
- Test in the lab and in the beam
- .
- .
- Incorporate within a stack of ~20 sampling elements; MICROMEGAS and RPWELL

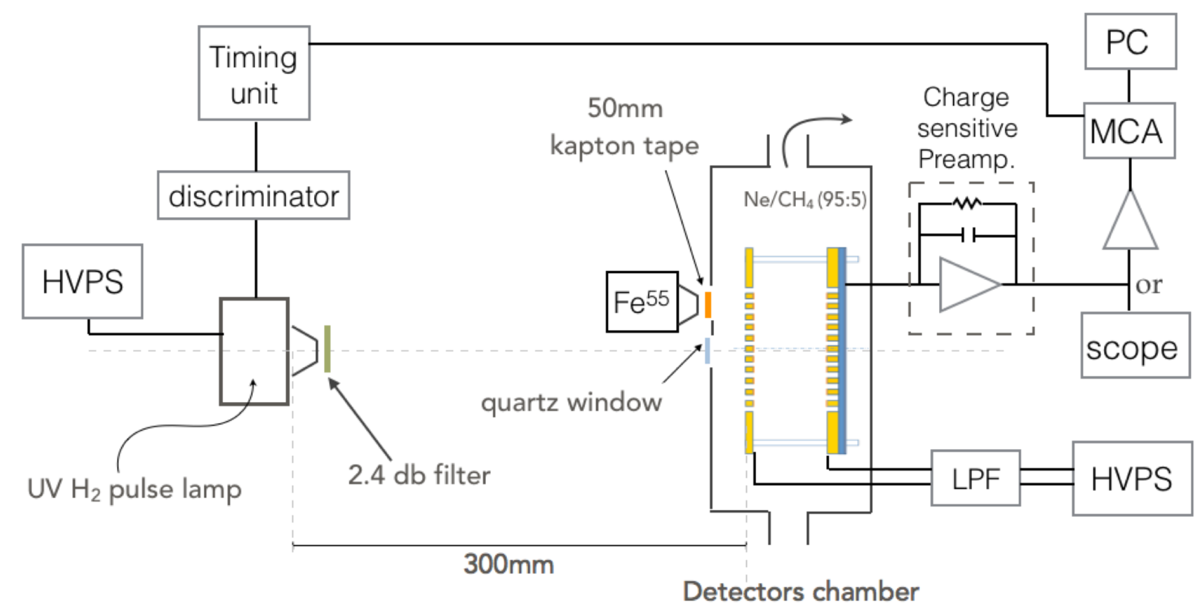
Objectives

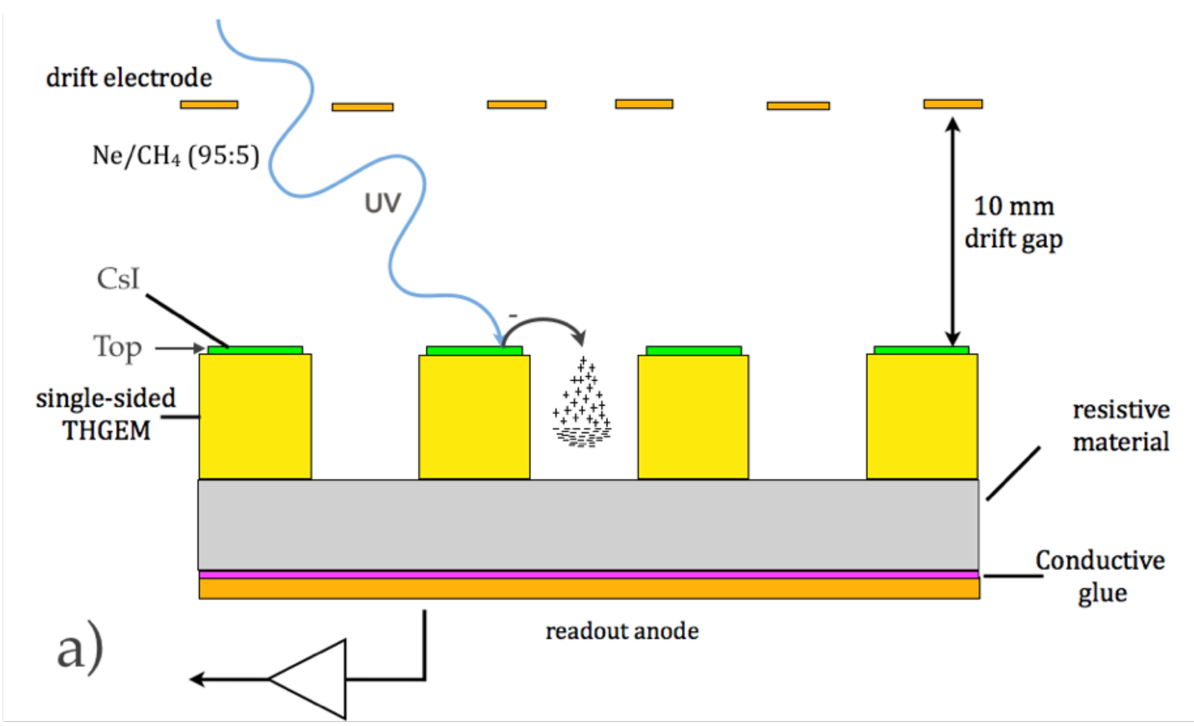
- Determine the performance of an RPWELL detector
- Understand the physics processes governing the RPWELL performance
- Optimize the detector
  - Geometry
  - Materials
  - Design

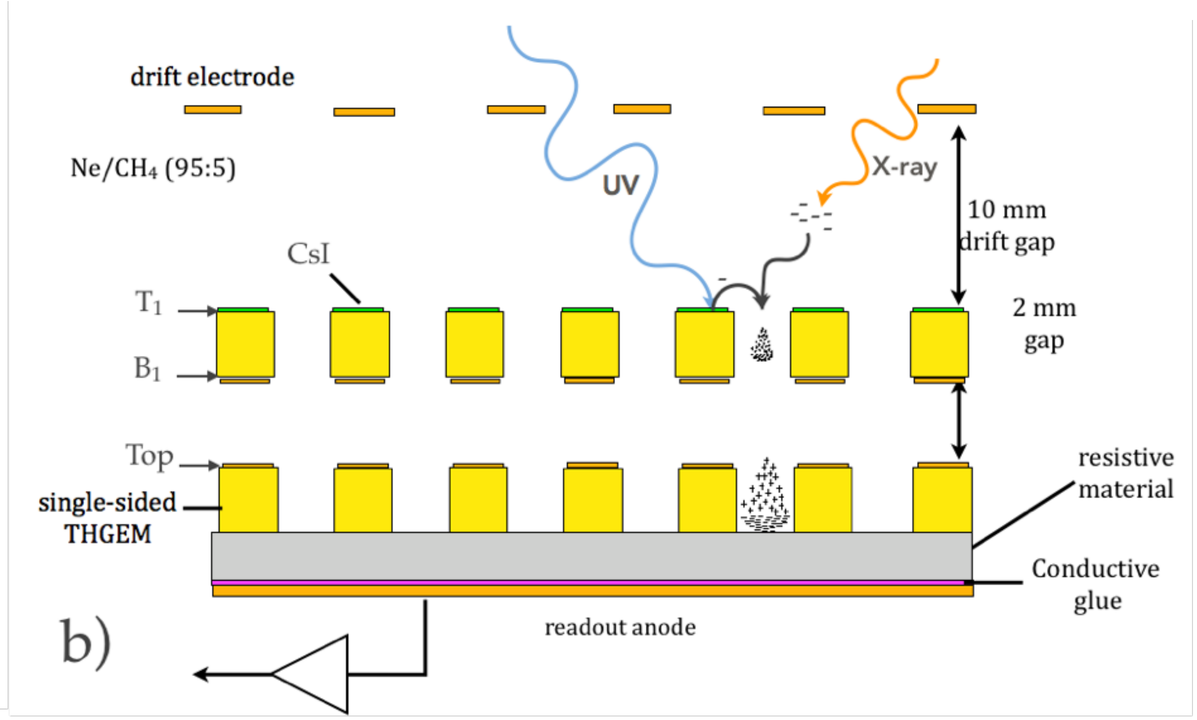
UV detection

Objective

- Characterize single-stage and double-stage RPWELL-based configurations as UV detectors
- Achieve high gain and high detection efficiency under stable operation
  - Expose to events with higher primary charge (dynamic range)



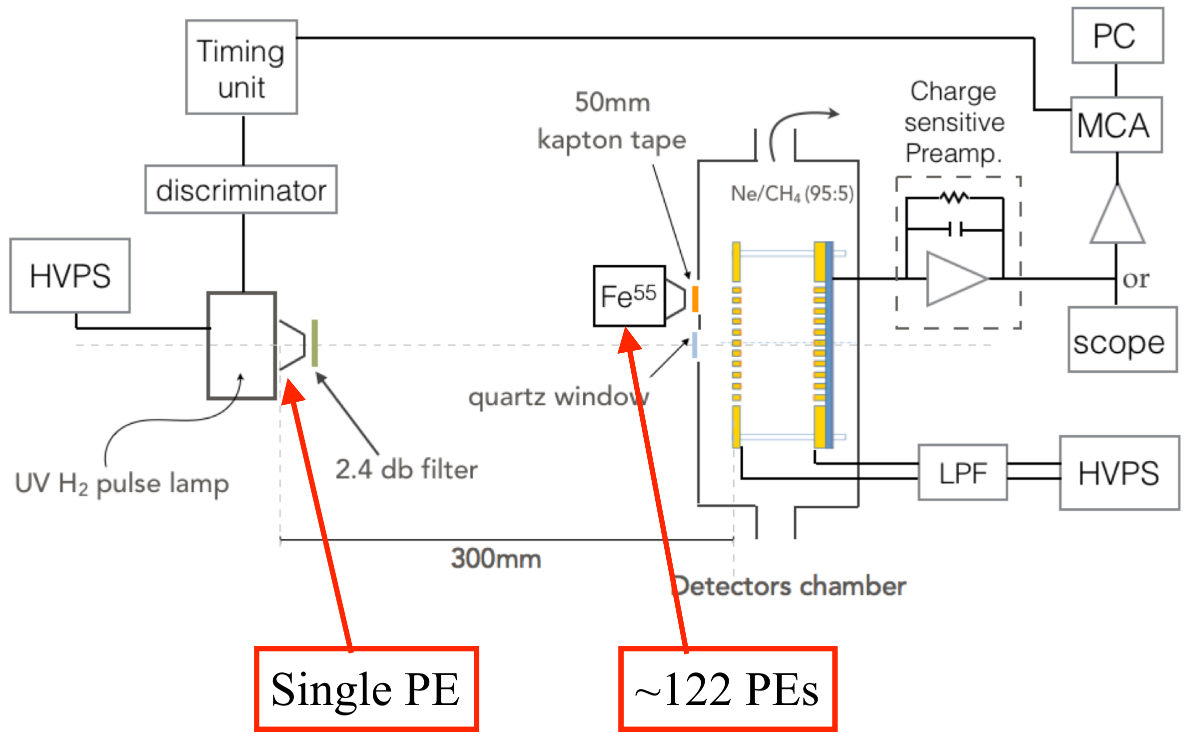


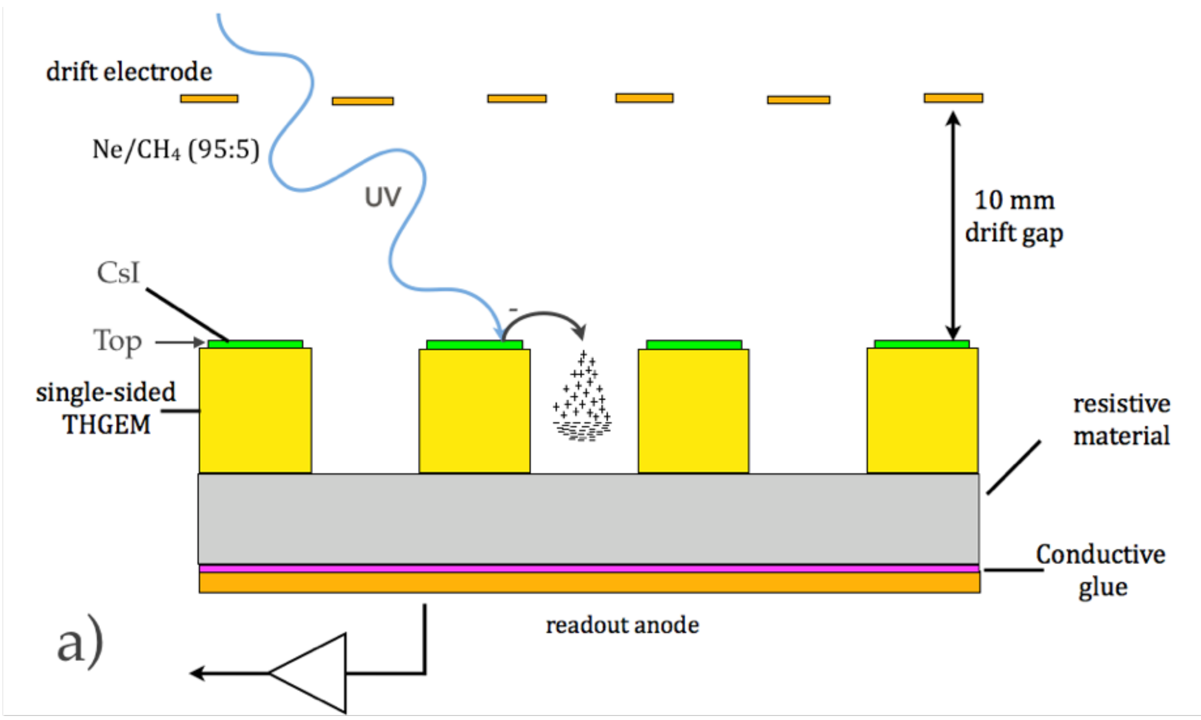


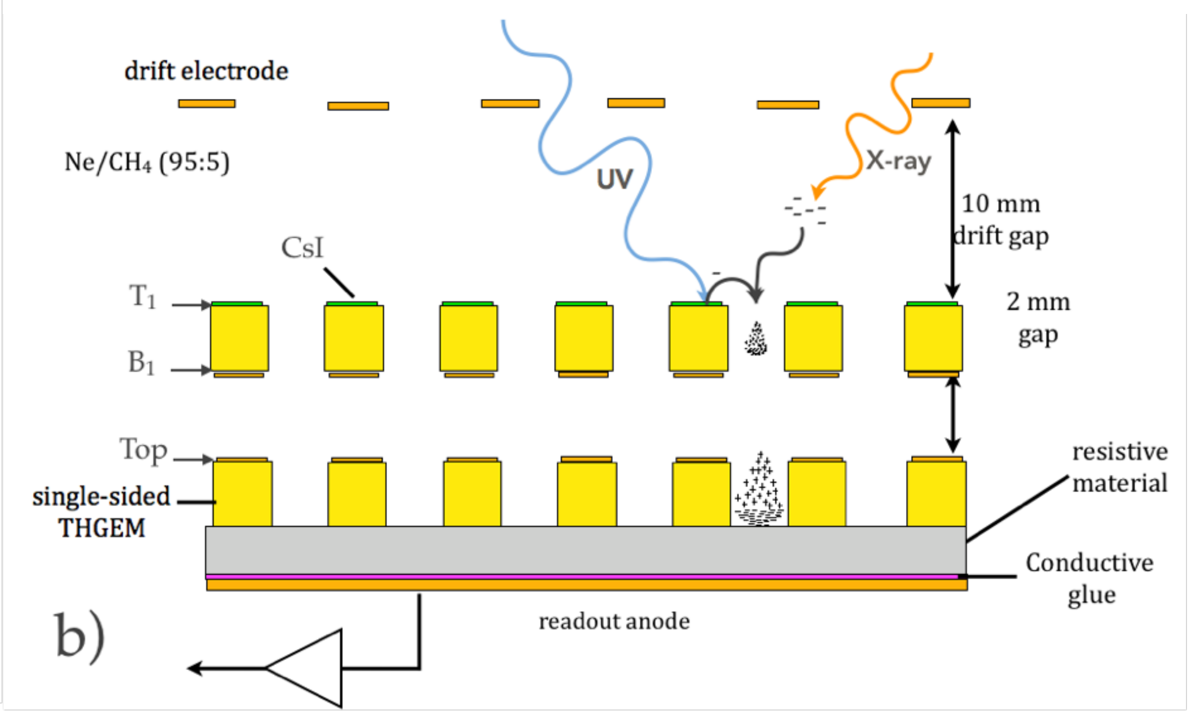
UV detection

Objective

- Characterize single-stage and double-stage RPWELL-based configurations as UV detectors
- Achieve high gain and high detection efficiency under stable operation
  - Expose to events with higher primary charge (dynamic range)

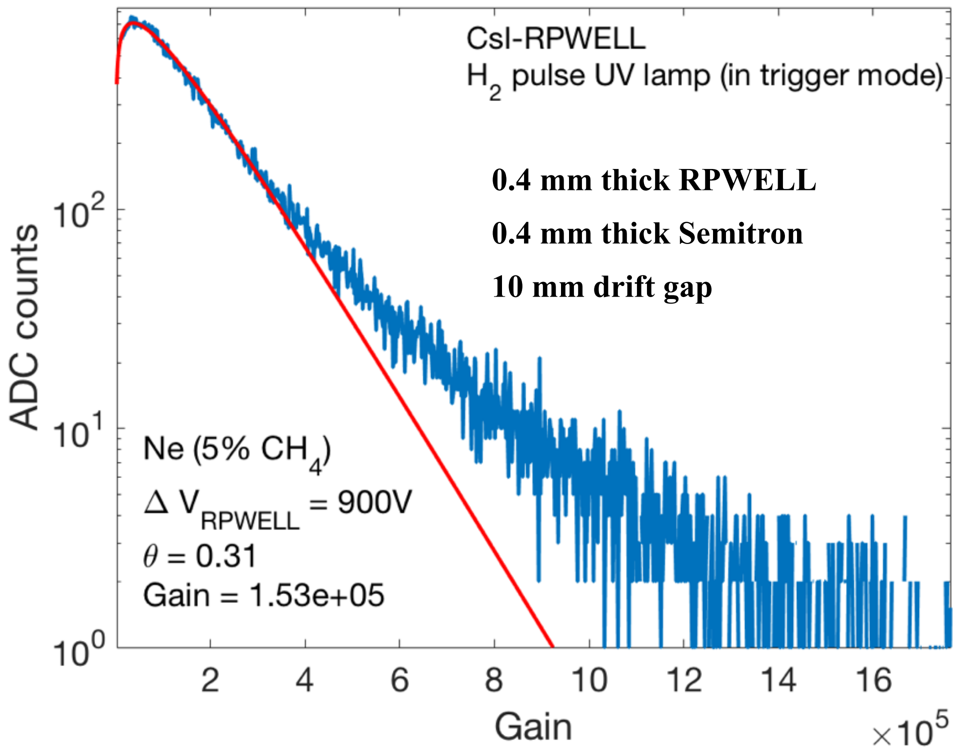


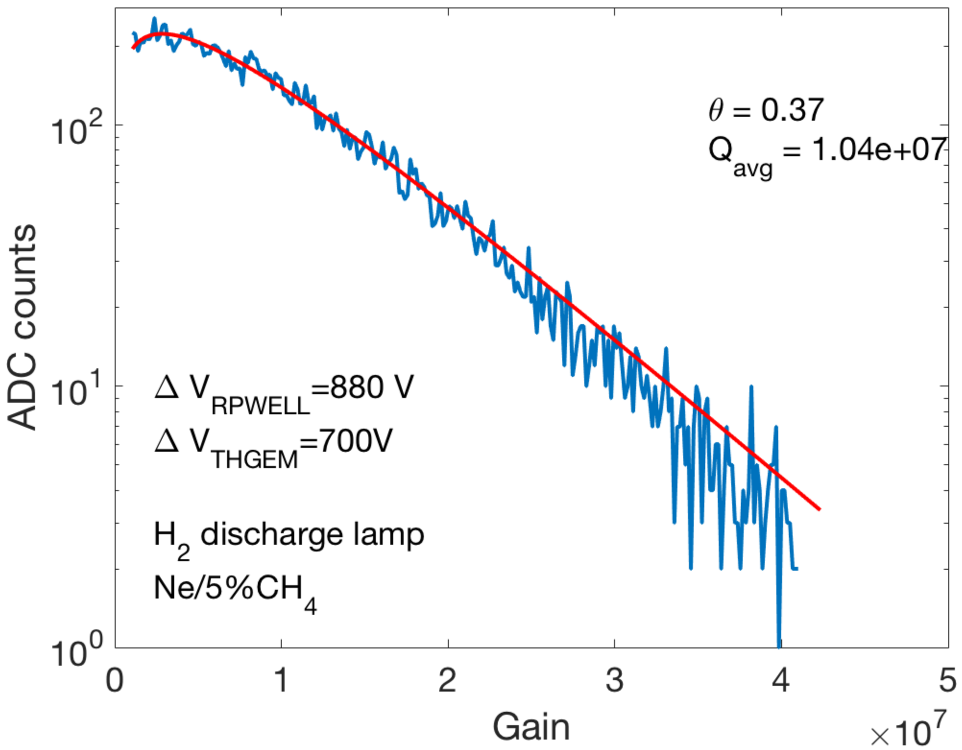




Results

- Clear Polya distribution observed with both configurations





0.4 mm thick RPWELL
0.4 mm thick THGEM
0.4 mm thick Semitron
10 mm drift gap (no field)
2 mm transfer gap

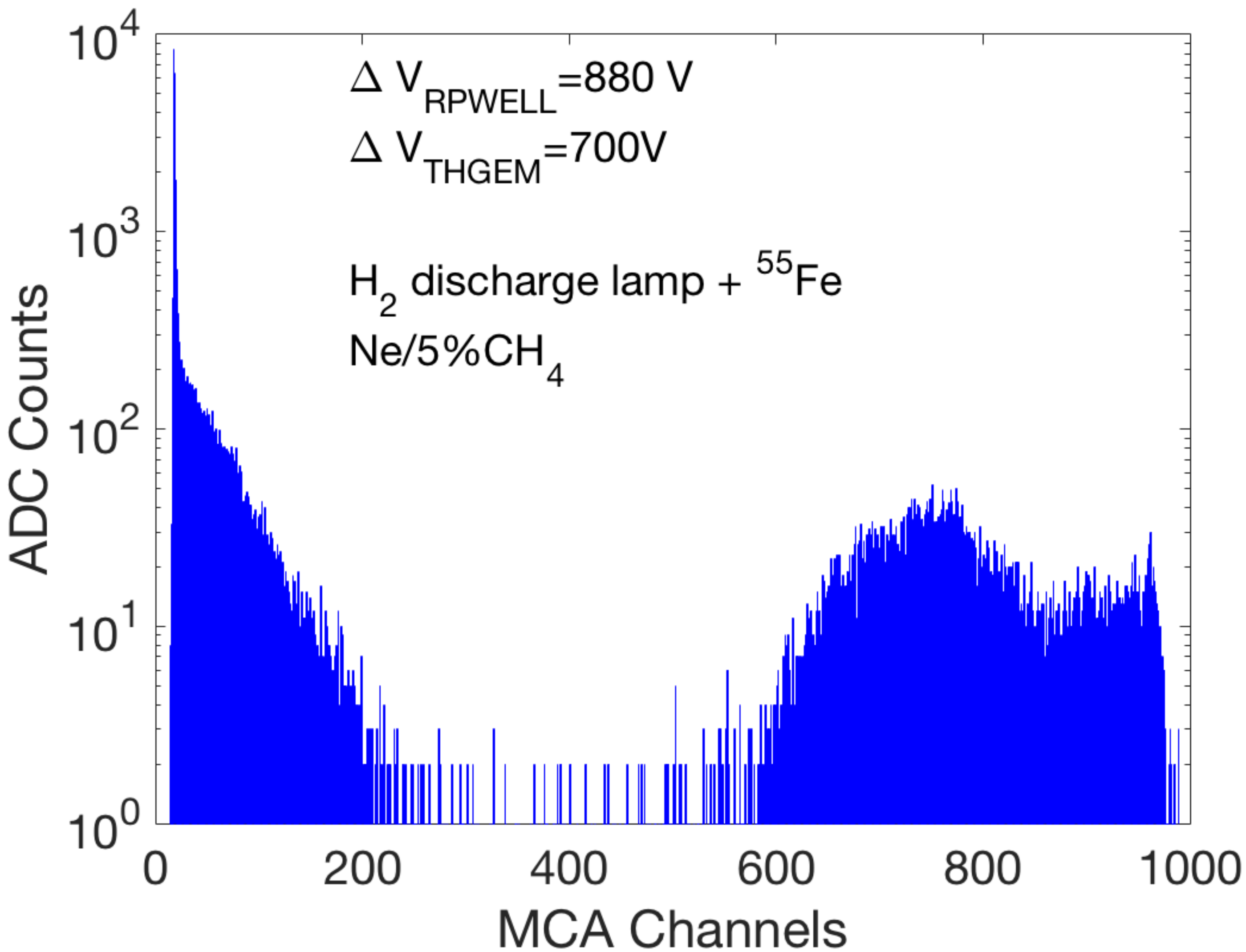
UV detection

Results

- Clear Polya observed with both configurations
- Dual stage detector - stable UV detection while exposed to 6 KeV x-rays background under a gain of ~10^7

Conclusions

- Dual-stage RPWELL based detector is an excellent candidate UV detector
- Rate dependence: under study



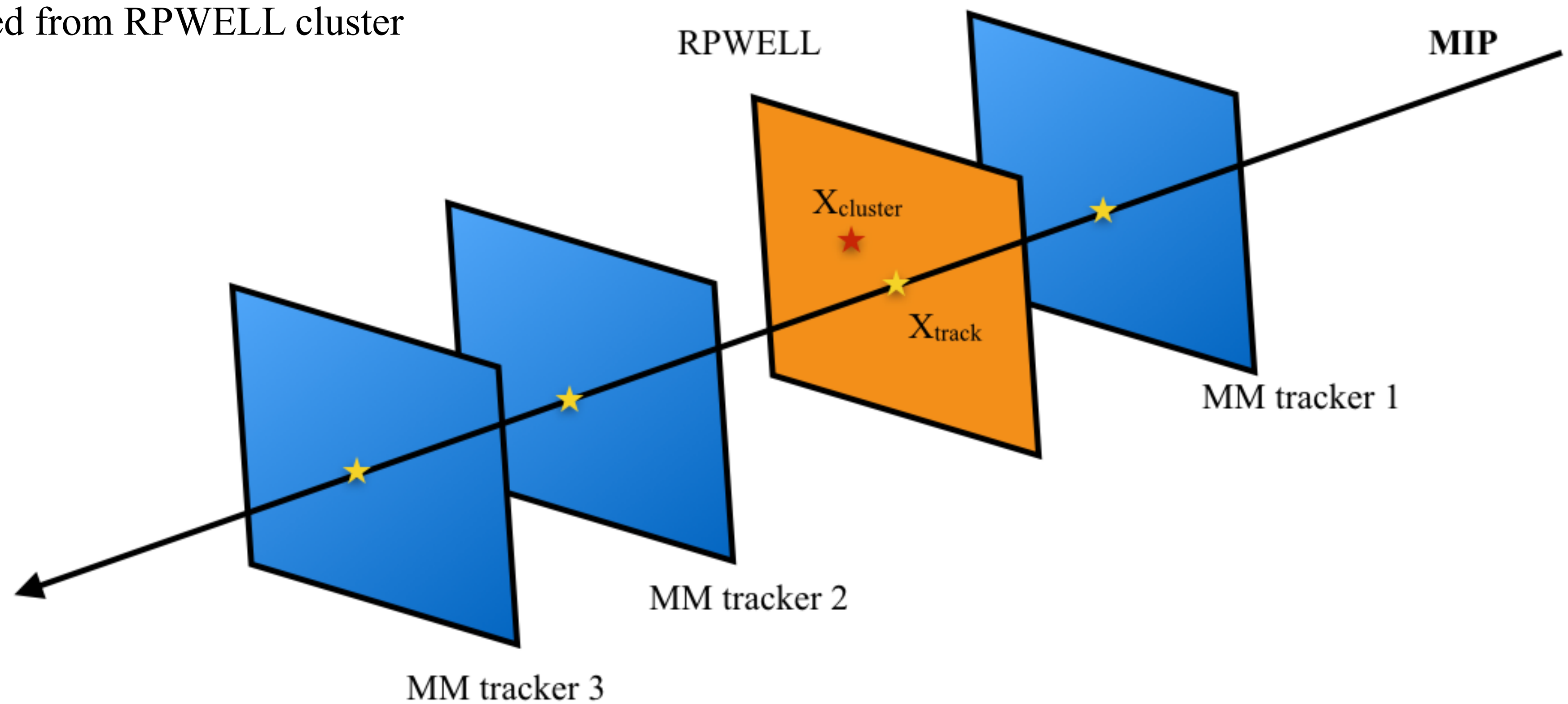
מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE

Position resolution

Background

- Imaging properties studied in THGEM-based structures
  - Resolution of a few 100 μm (FWHM)
  - No access to local effect
- In beam measurements compares the reconstructed position to the real track position
  $\Delta X = X_{track} - X_{cluster}$
  - X_{track}- position reconstructed from track extrapolation
  - $X_{cluster}$ - Position reconstructed from RPWELL cluster

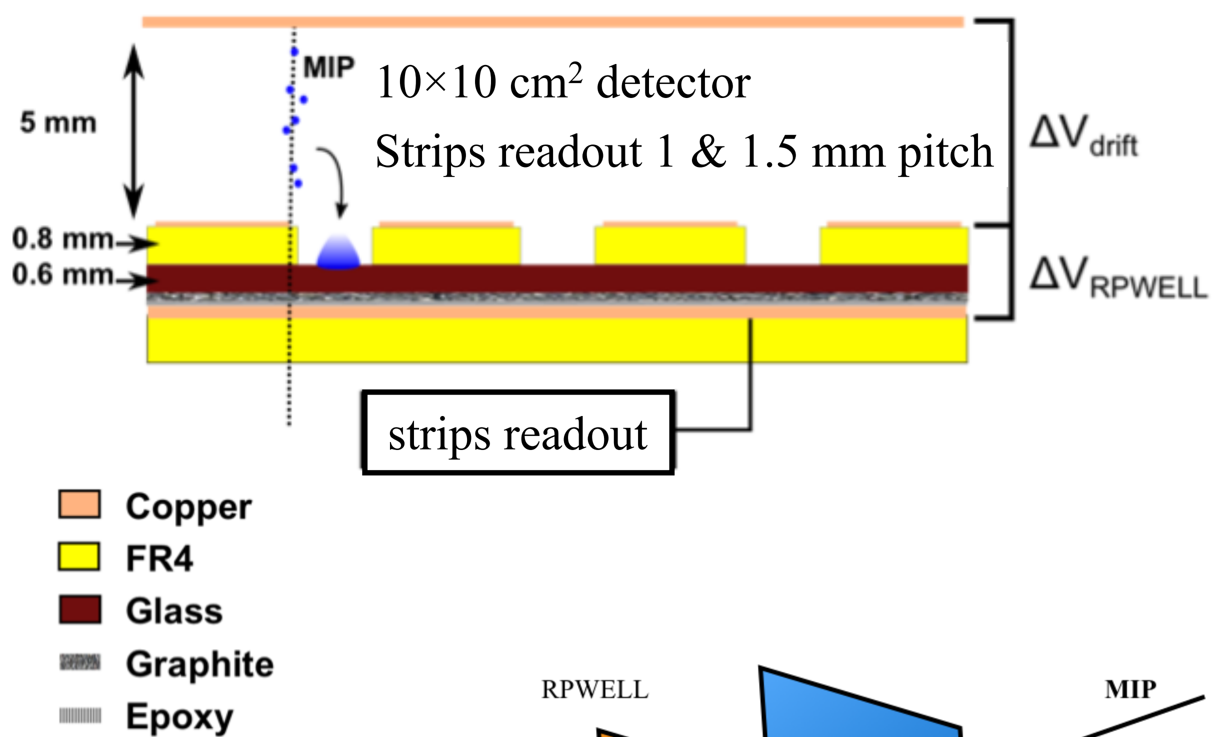
[Cortesi et. al. JINST 2 09 2007 P09002]
[Cortesi et. al. JINST 4 08 2009 P08001]
[Silva et. al. JINST 8 05 2013 P05016]
[Lopez et. al. JINST 8 09 2013 P09002]

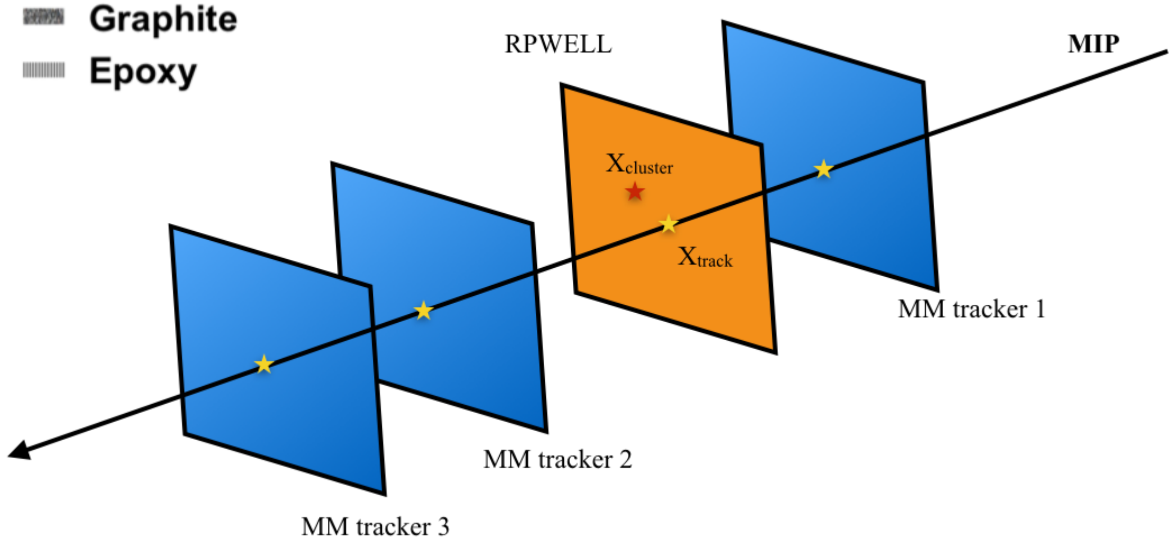


Position resolution

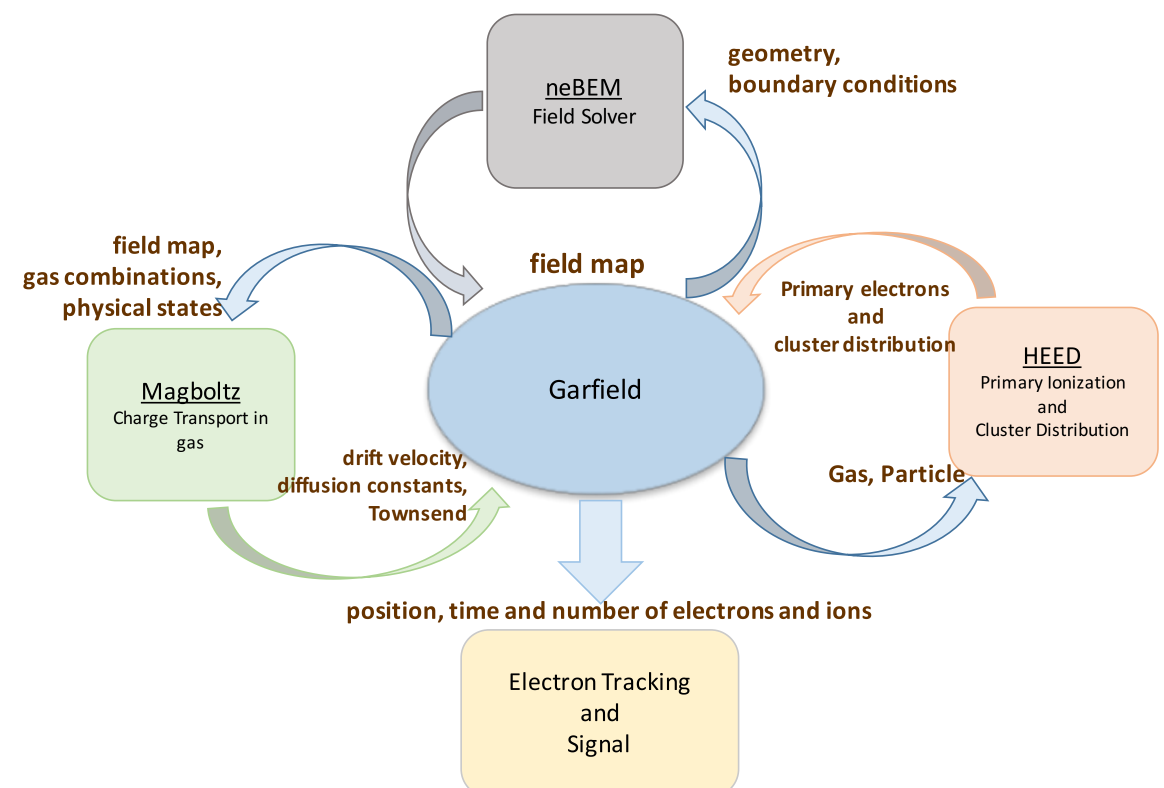
This study

- In beam measurement -
  $\Delta X = X_{track} - X_{cluster}$





- Comparison to a detailed simulation
  - Primary charge deposited by 150 GeV muons
  - Drift into the THGEM holes
  - Charge multiplication
  - Signal induction (electron and ion drift)
  - Emulate electronics response
  - Cluster position reconstructed as the weighted average

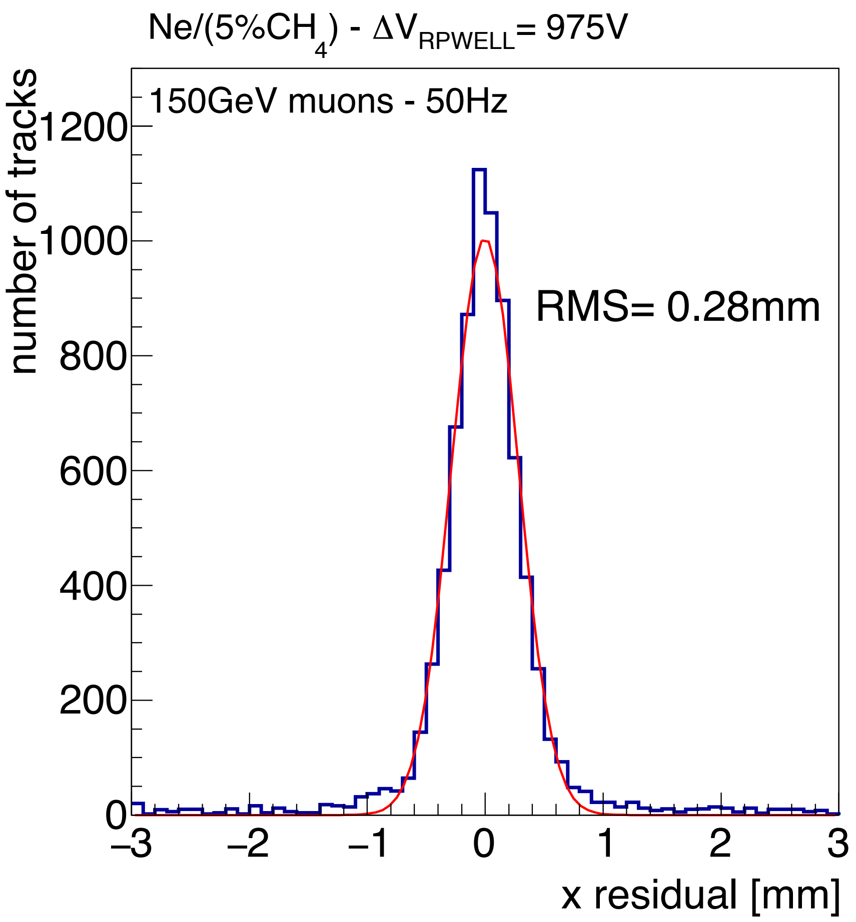


Position resolution

In preparation

Results

- Global resolution 280 μm

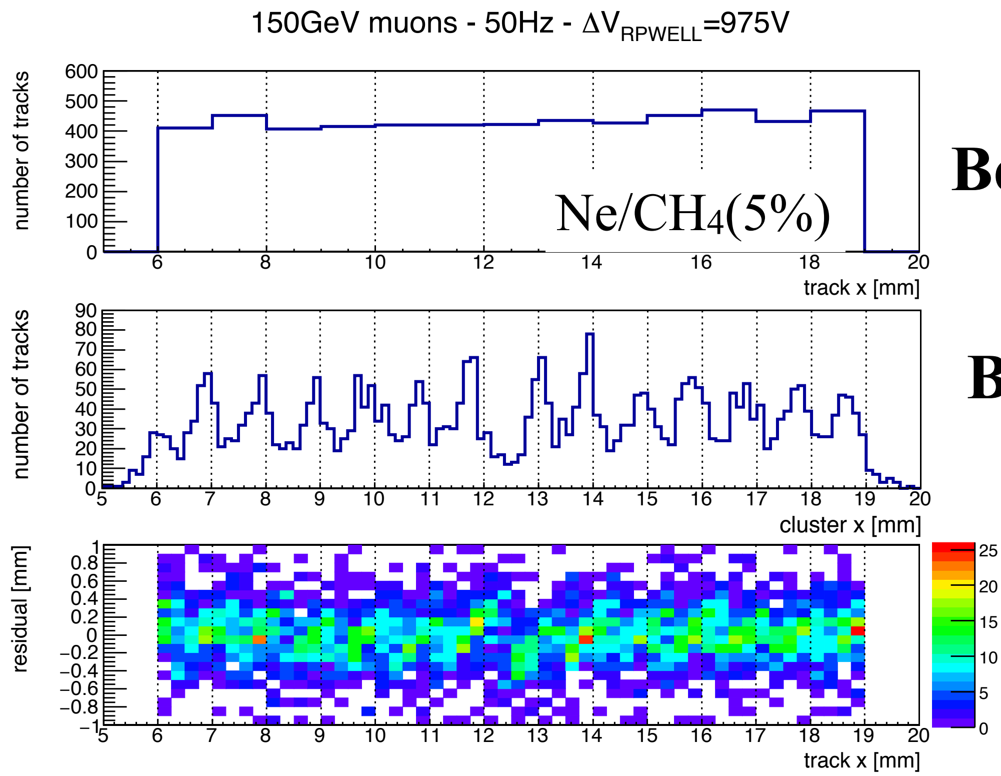


Position resolution

In preparation

Results

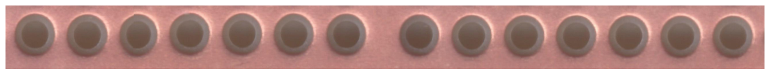
- Global resolution 280 μm RMS
- Local resolution
  - Dictated by the hole pattern - here hole pitch 0.96 mm
  - The probability for charge sharing between neighboring holes



Beam profile measured by the tracker

Beam profile measured by the RPWELL

Local residuals $\Delta X = X_{track} - X_{cluster}$



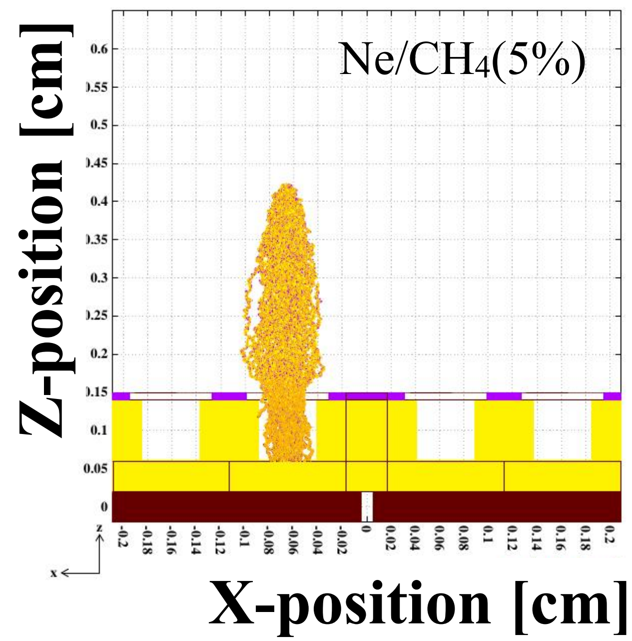
Hole pattern

Position resolution

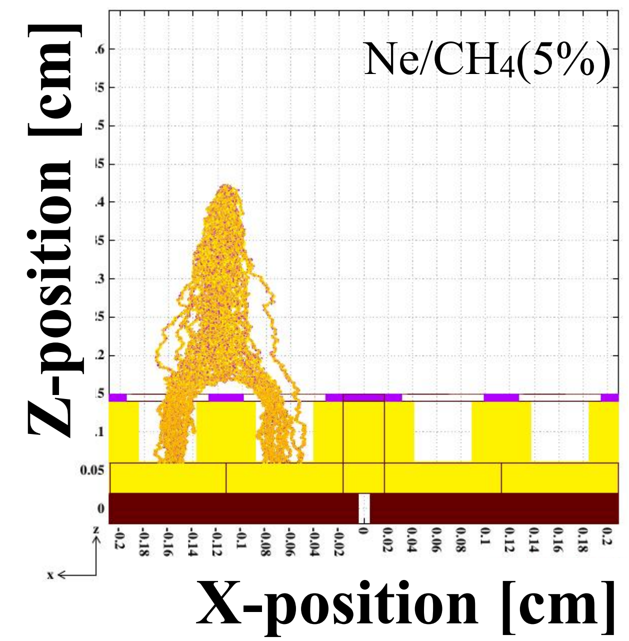
Results

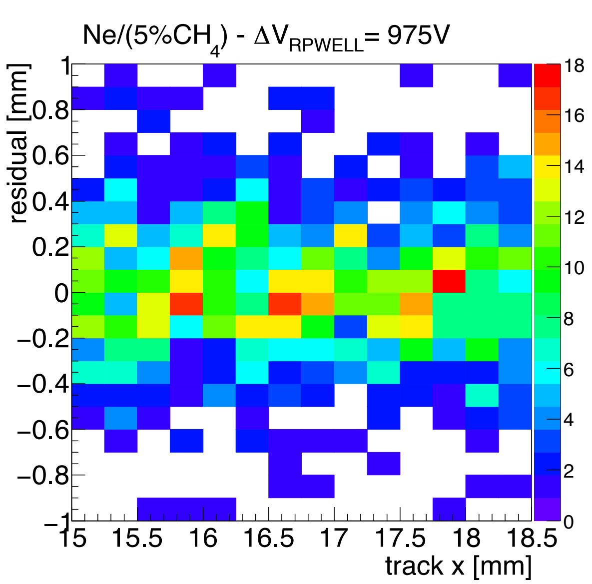
- Global resolution 280 μm RMS
- Local resolution
  - Dictated by the hole pattern - here hole pitch 0.96 mm
  - The probability for charge sharing between neighboring holes
- Results well reproduced in the simulations

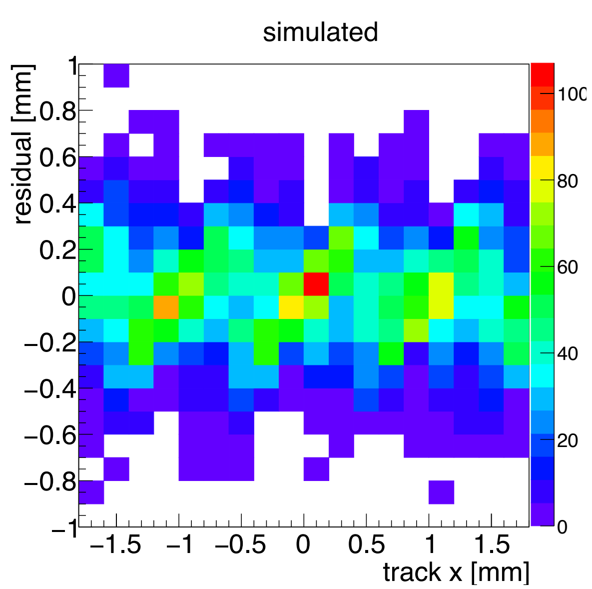
Hole center



Between holes







Conclusions

- RPWELL (THGEM) resolution dictated by the hole pitch

In preparation

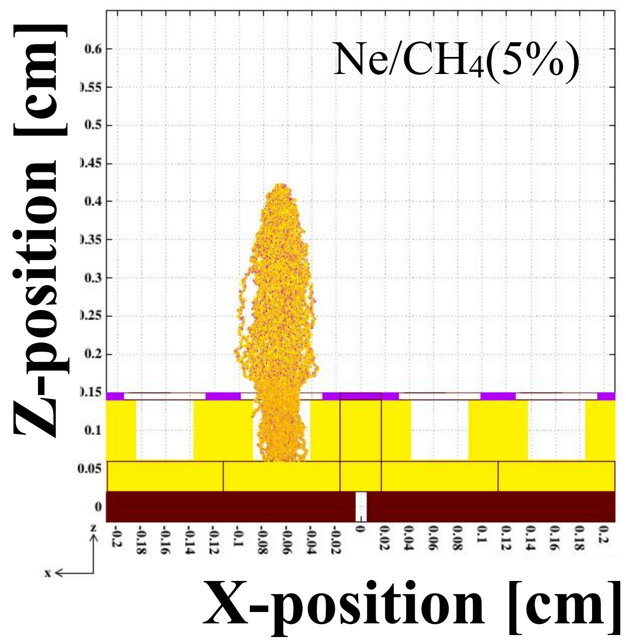
Characterization

Position resolution

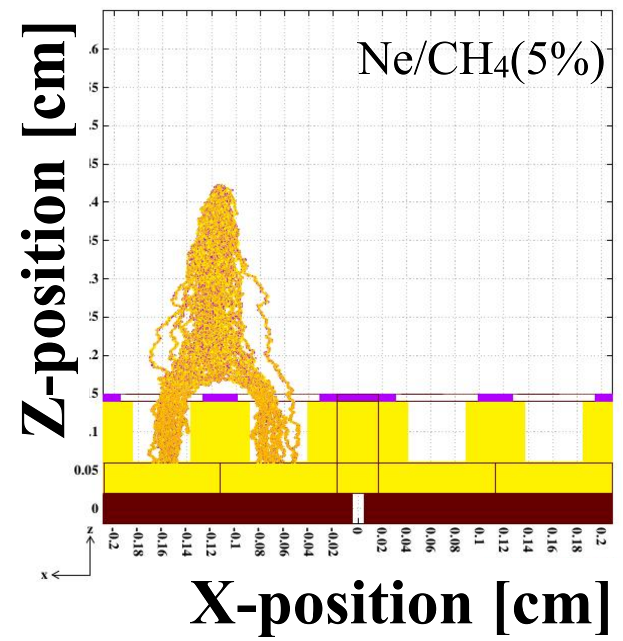
Possible optimization

- Similar response in Ne- and Ar-based gas mixtures (simulation only)
- Advantages to smaller pitch

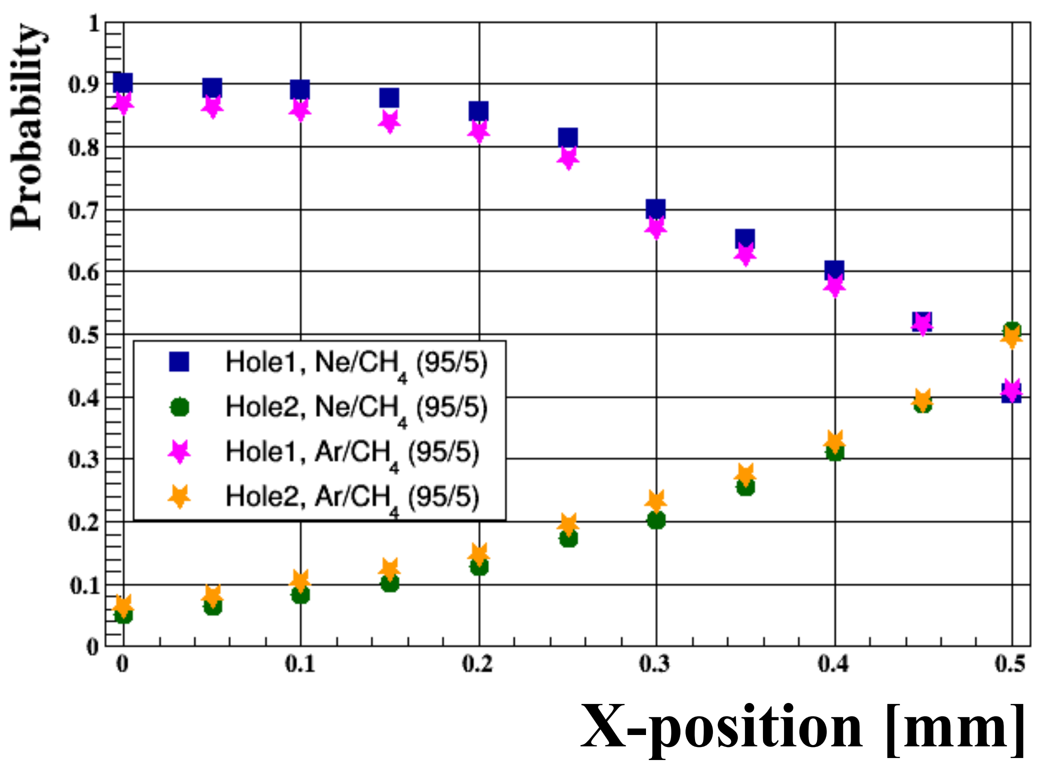
Hole center



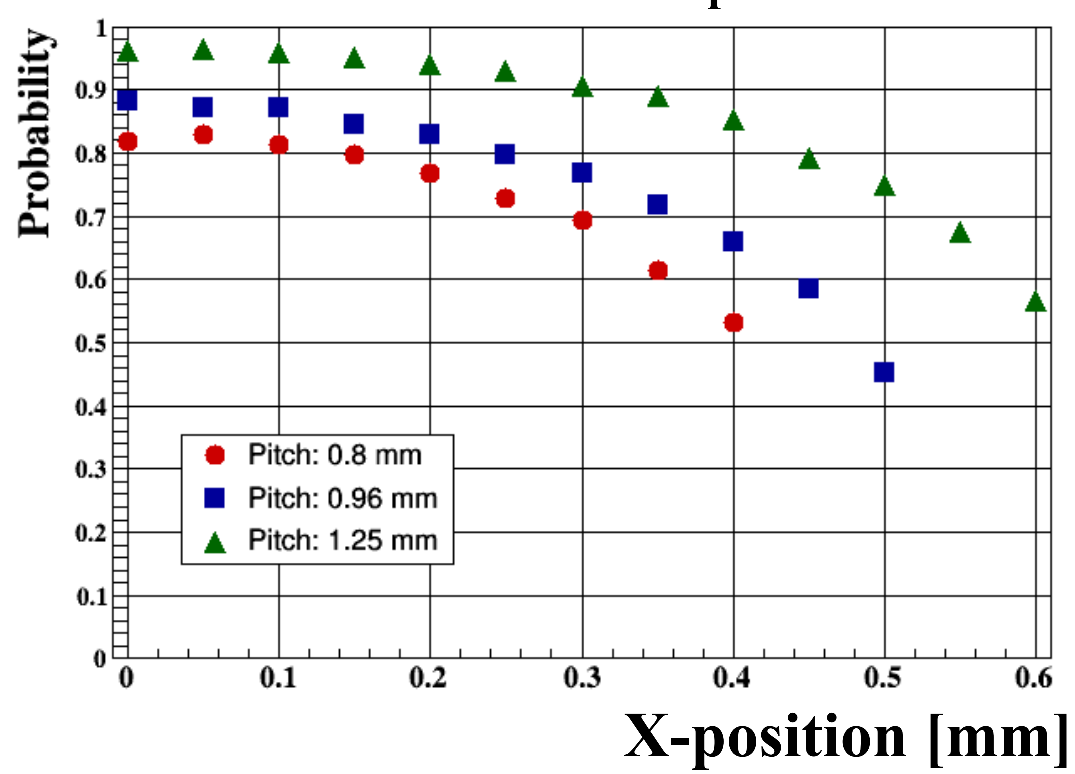
Between holes



The probability of an electron to focus into the central hole (hole 1) or the neighboring hole (hole 2) as a function of distance from the center of hole 1



The probability of an electron to focus into the central hole (hole 1) as a function of distance from the center of hole 1 for different pitch sizes



Signal formation

Signal formation

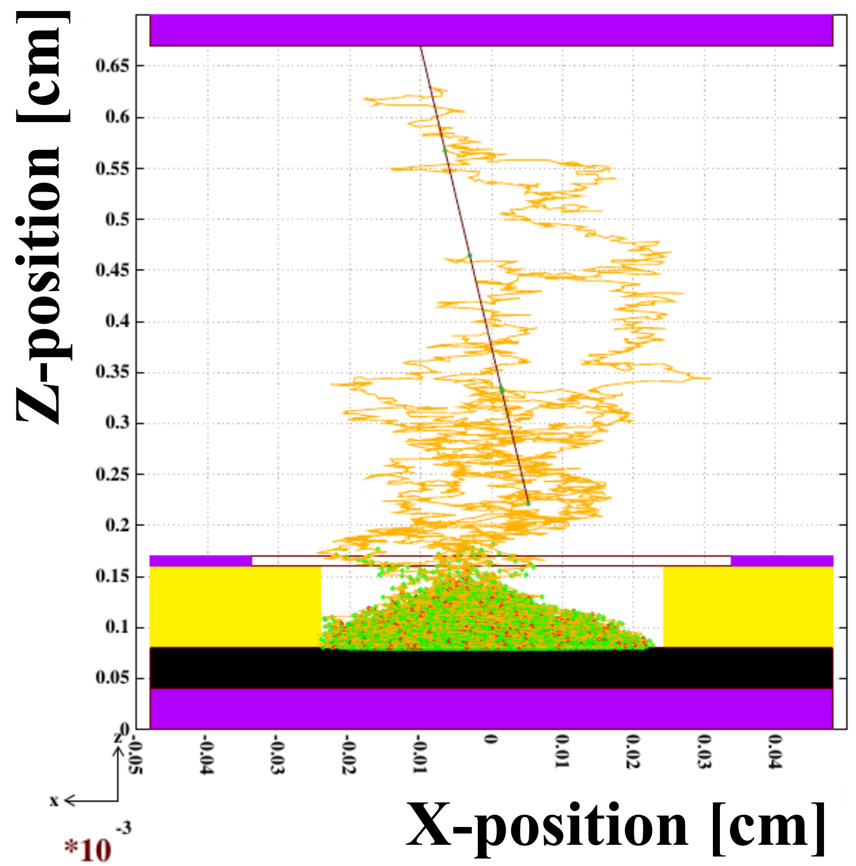
Objectives

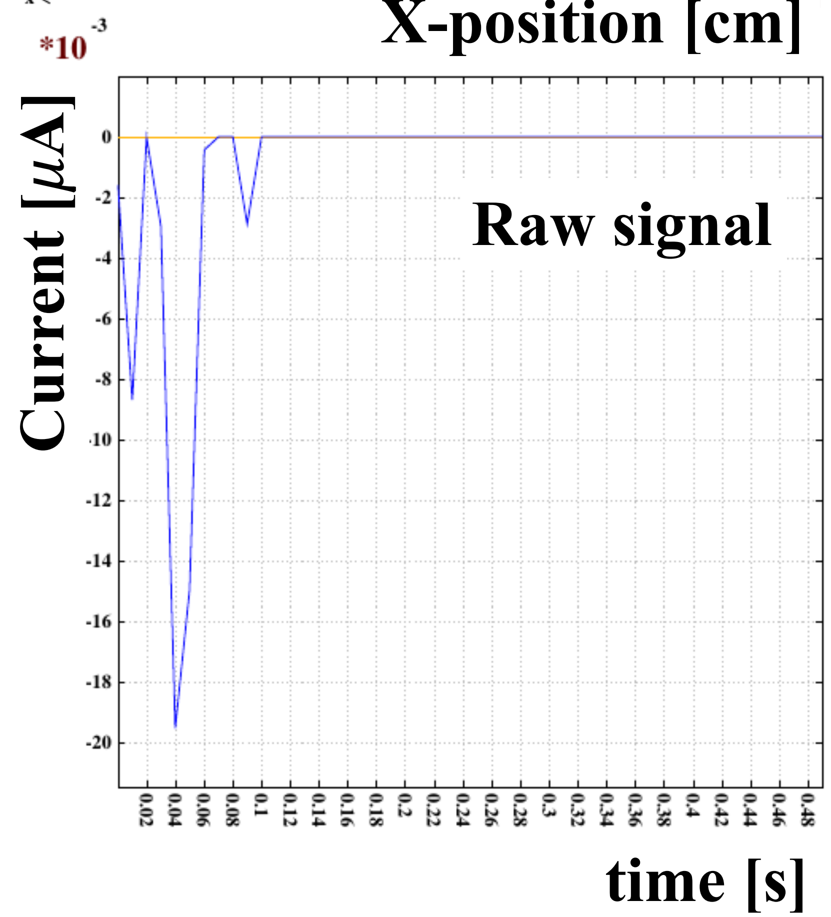
- Understand the effects determining the ***measured*** signal shape
- Including the effect of the readout electronics

Simulation framework

- Heed - cluster properties - size, count, energy, position
- Magboltz - gas property - drift velocity, diffusion coefficient, Townsend coefficient, attachment coefficient
- Drift of primary electrons and production of secondary electrons in the amplification zone
- Shockley-Ramo theorem - raw signal

$$I = -q\,\frac{\vec{v} \times \vec{E}_w}{V}$$

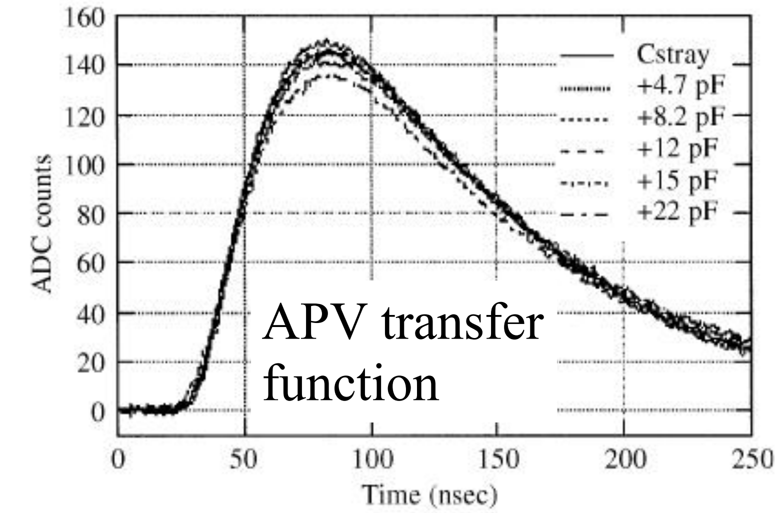




Characterization — Signal formation

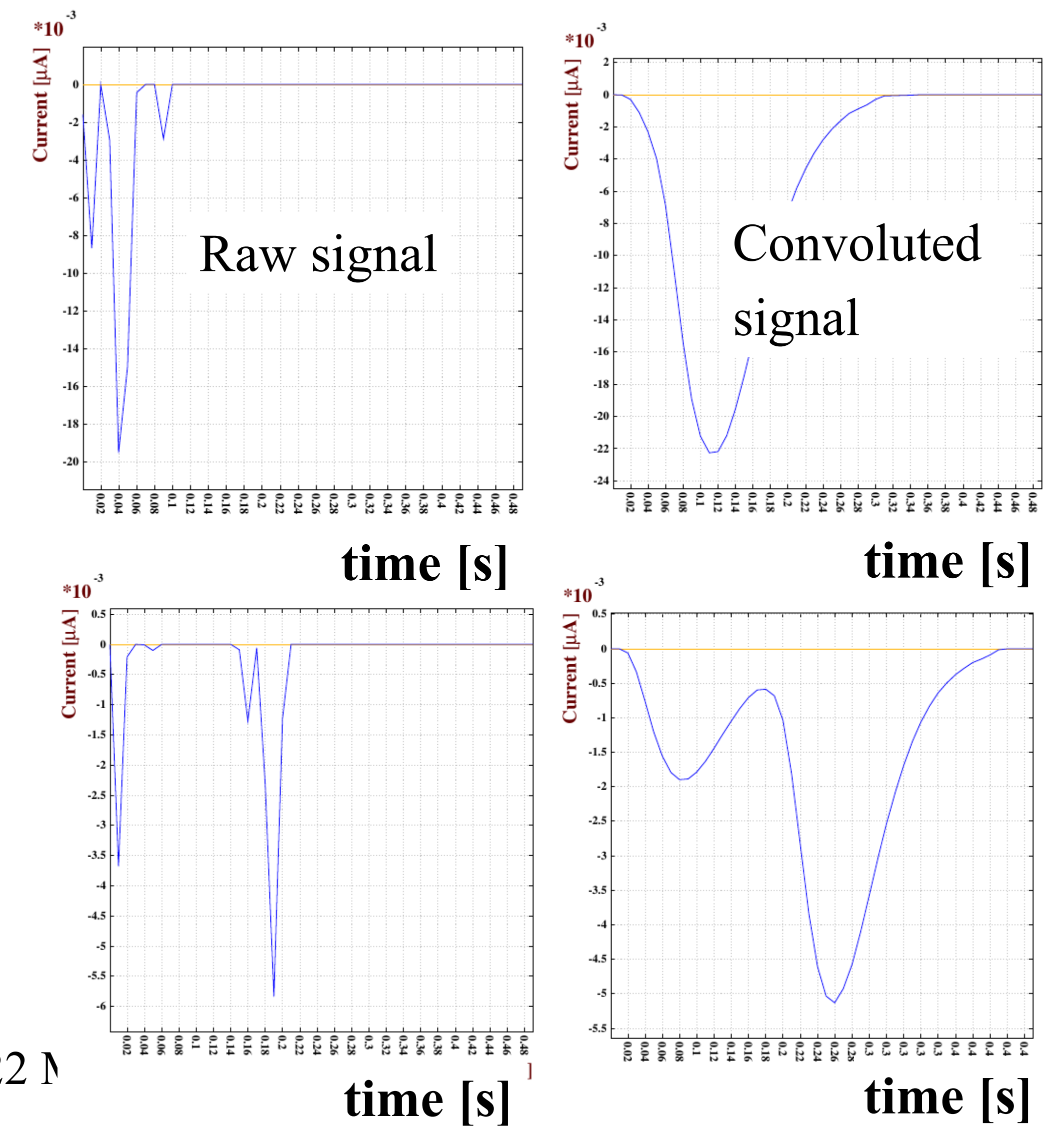
Electronics response

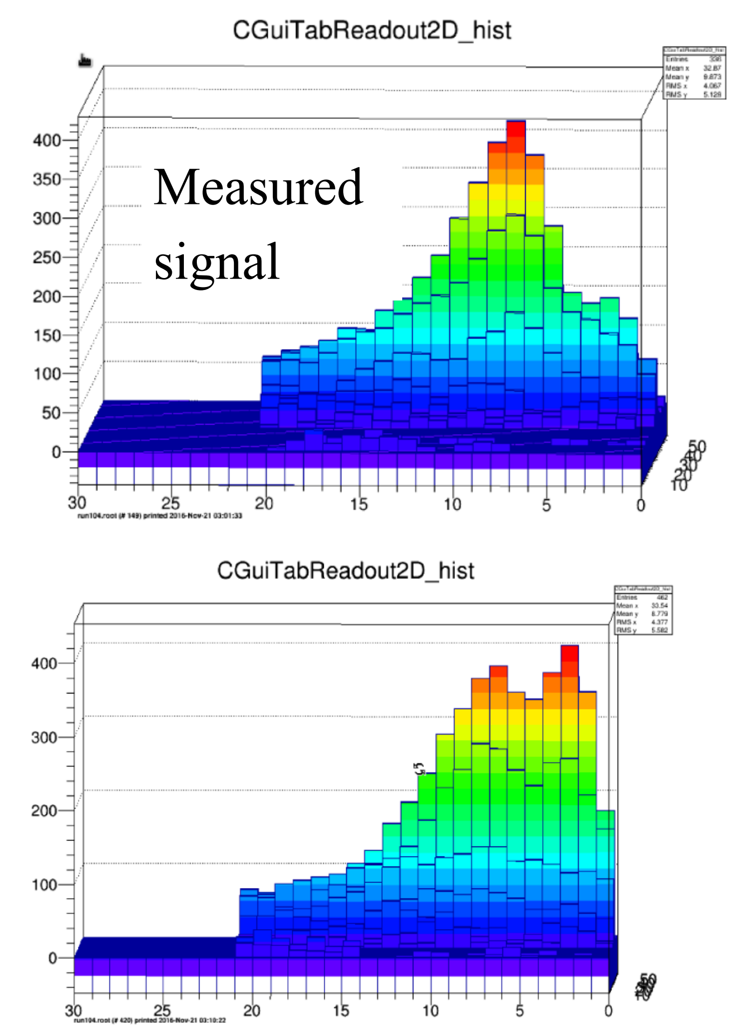
- Convolution with the electronics transfer function
  - APV25 - 25 ns shaping time



Preliminary results

- Qualitative comparison with APV25 data recorded in muon beam





Next steps

- Other sources
  - x-ray, UV
- Other readout elx
  - Charge, Current
- Other gas mixtures

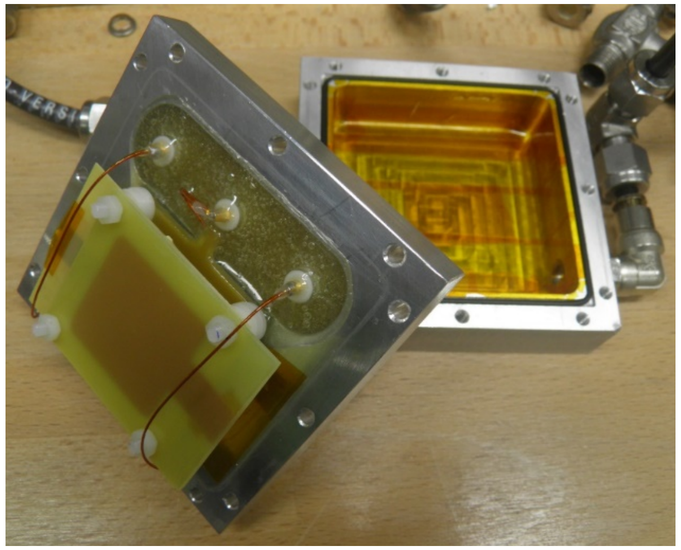
S. Bressler
WEIZMANN INSTITUTE OF SCIENCE

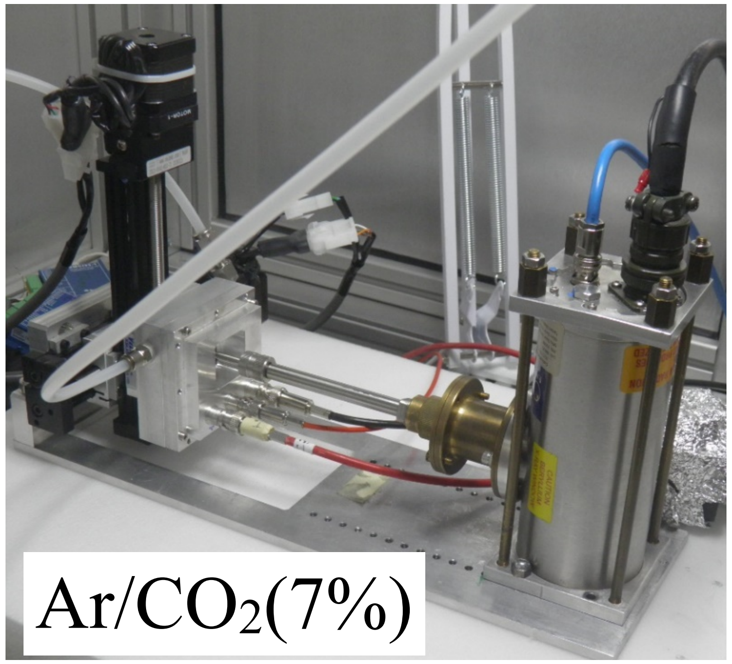
Edge effects

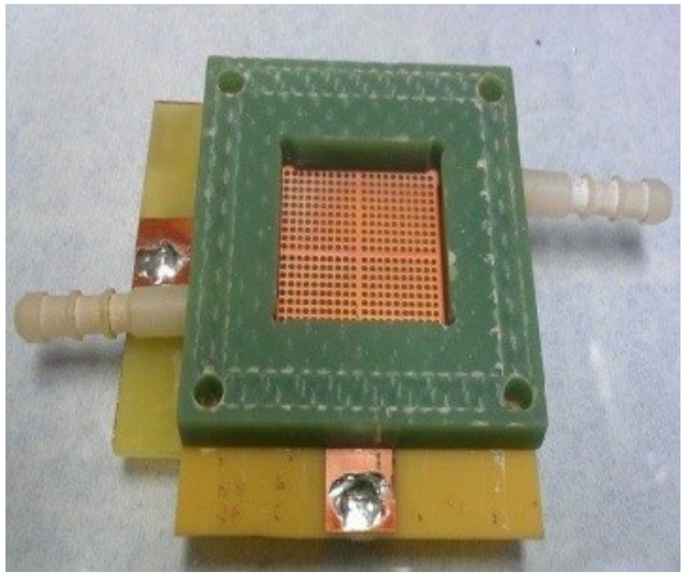
Characterization — Edge effects

Objectives

- Understand the effect of the edge on the performance
- Control the active area







Setup

- Studies conducted with X-Y scanner (1 mm steps)
- Cu-target x-ray tube $\Rightarrow$ 8 KeV photons
- High intensity
- Scans performed at different frame-edge distances from the holes, and without a frame

Characterization

Edge effects

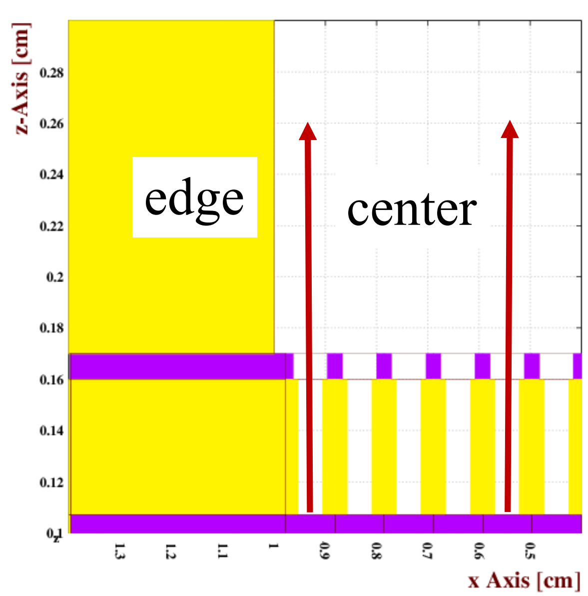
Analysis

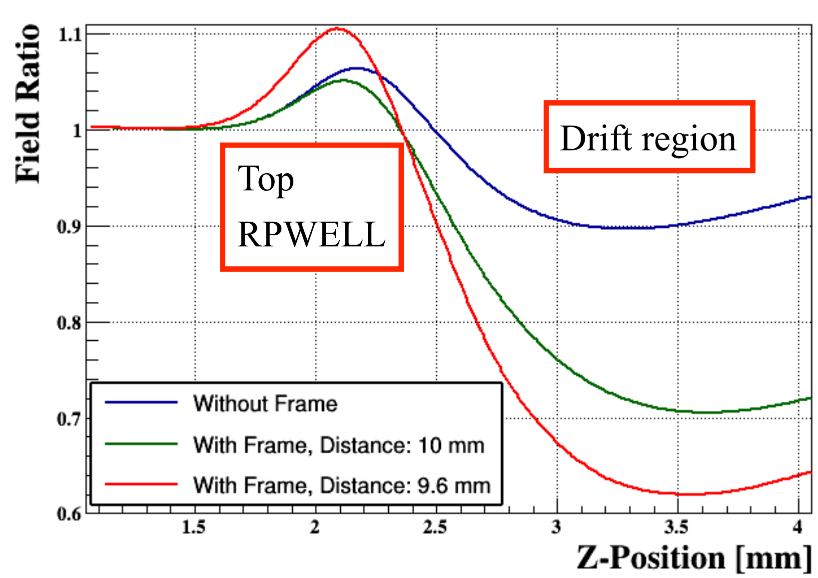
- For each point look at $R = \frac{G_{Frame}(i,j)}{G_{No-Frame}(i,j)}$
- Cancels out systematic effects
  - Electrode thickness non-uniformity
  - Fringe field

[Alexeev et. al. JINST 9 2014 C03046]

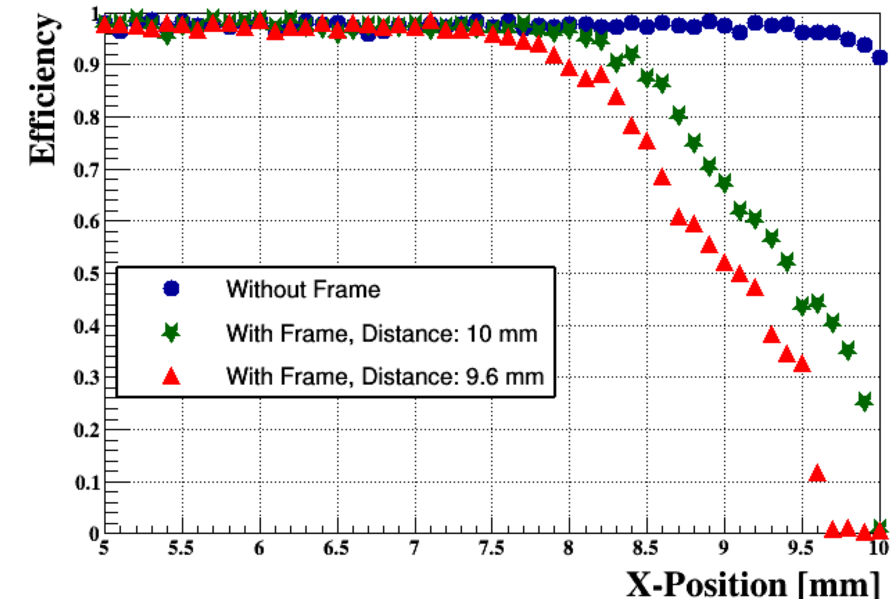
Simulation

- Different field map along the Z-axis in the edge-hole compared to other holes
- Lower charge collection efficiency into the edge hole (~1.5 mm effect penetration)

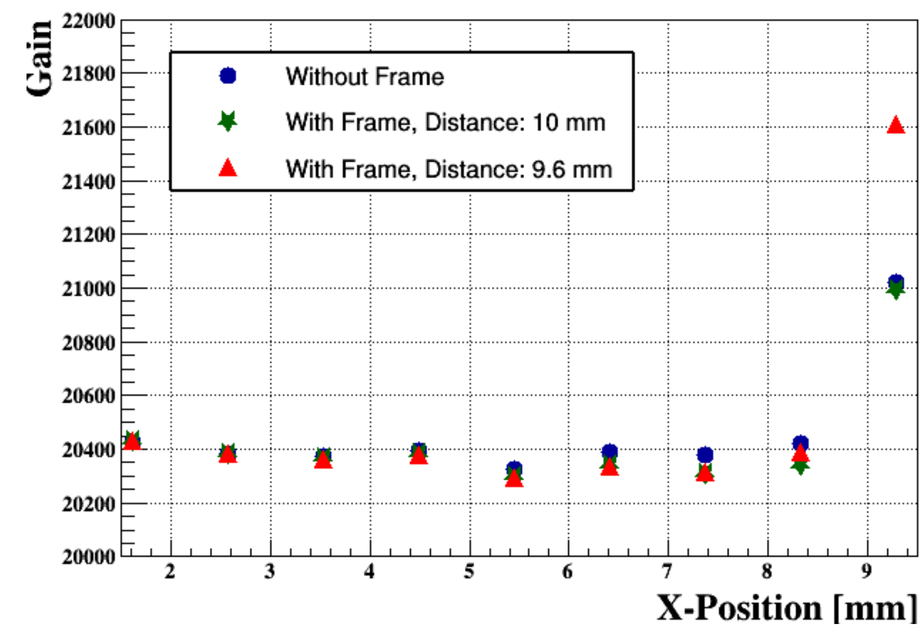




Electron collection efficiency as a function of the distance from the edge



The gain as a function of the distance from the edge

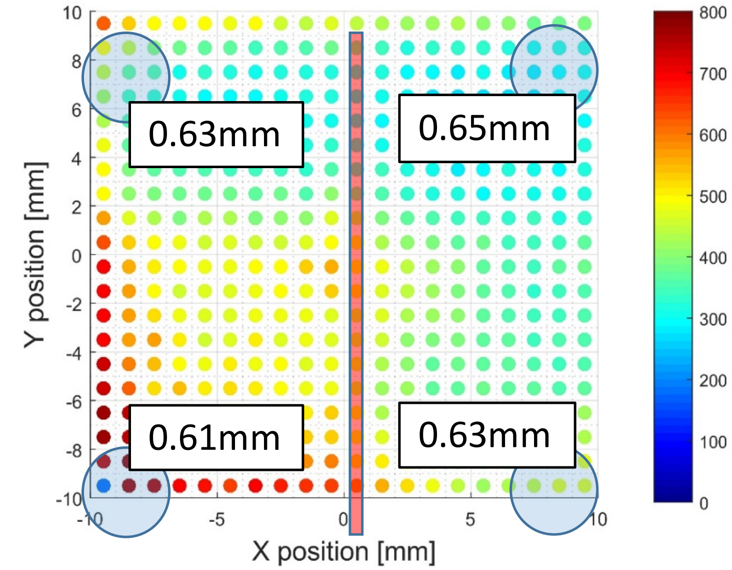


Edge effects

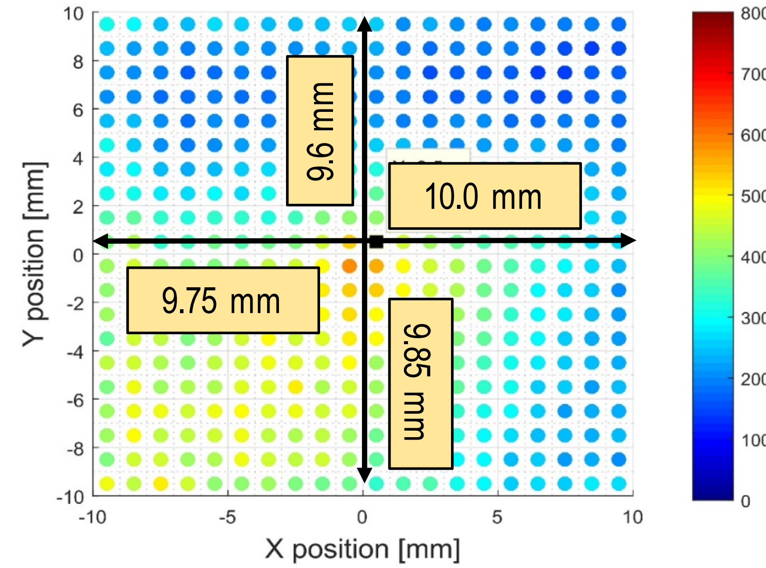
Results

- Observed correlation between the penetration of the edge effect and the distance to the frame
- The effect is larger than anticipated by the simulation ⇒ we have more to understand

Gain map without frame

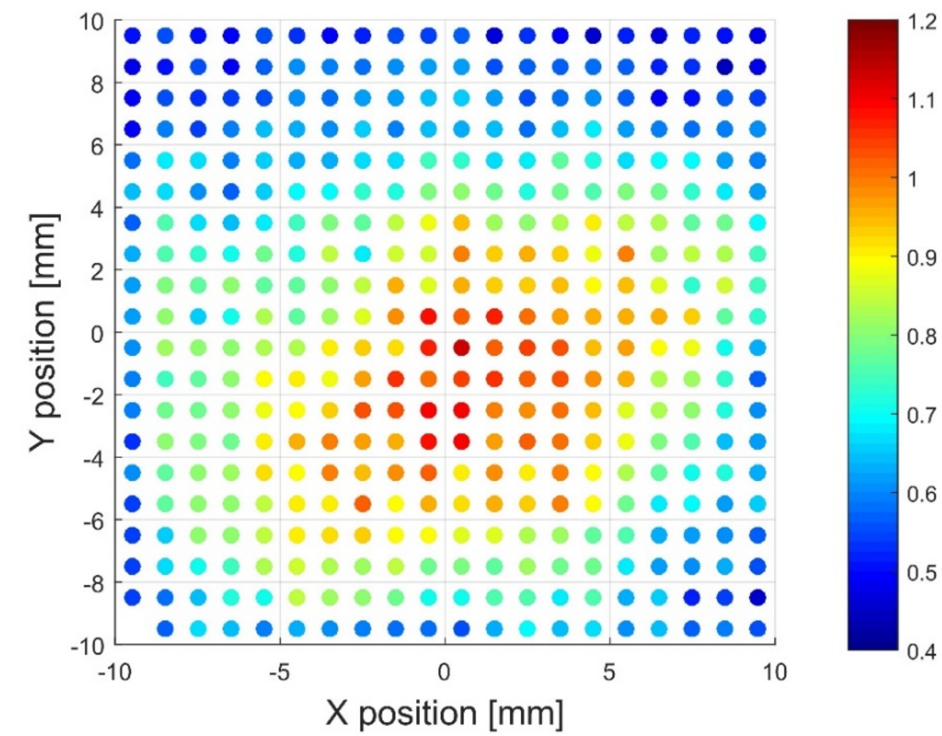


Gain map with frame



Gain ratio

$$R = \frac{G_{Frame}(i,j)}{G_{No-Frame}(i,j)}$$



Transients

Transients

Objectives

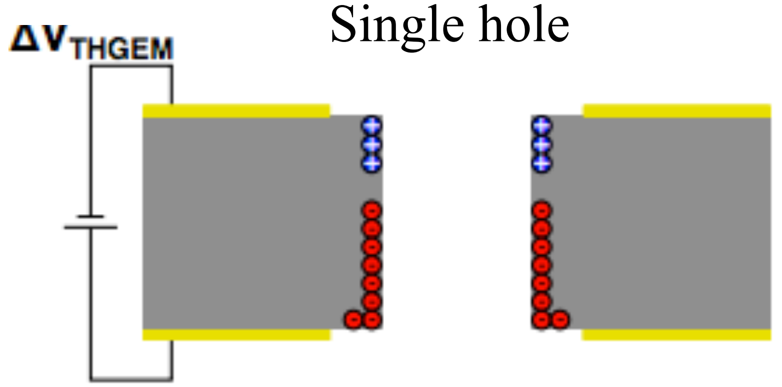
[Alexeev et. al. 2015]

[Cortesi et. al. 2015]

- Study gain instabilities in RPWELL
  - Reported in many studies of THGEM detectors
- Understand the physics processes governing them
- Understand related time scales

The charge accumulation / evacuation paradigm

Single hole



- Charges accumulate on the insulators [Correia et. al.]
- Charges evacuate through various mechanisms
- Gain stabilization occurs when the two processes reach equilibrium
- The **"stable gain"** is determined by the charge distribution at steady state

Transients

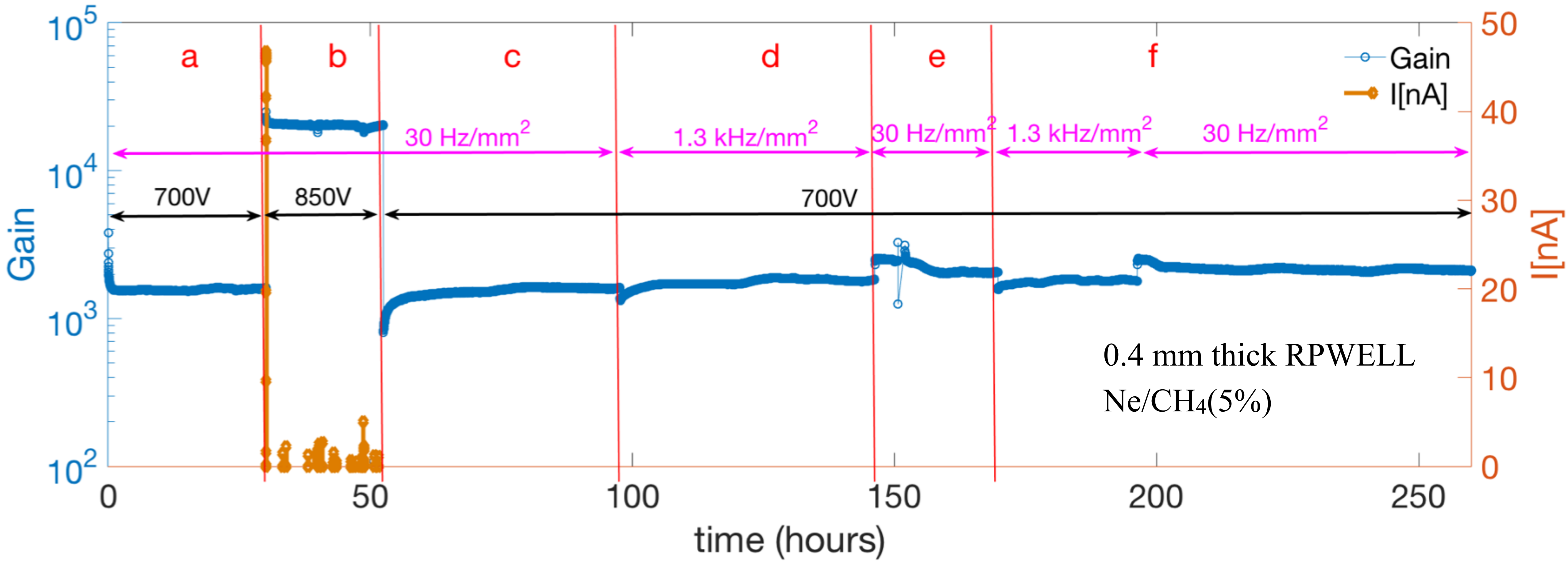
Methodology

- Expose the detector to extreme change in operation conditions
  - Operation voltage
  - Irradiation rate

⇒ Impose different initial conditions on the detector

- Wait sufficient time for gain stabilizations

low-high-low voltages/gain transition **low-high-low-high-low rate transition**



WEIZMANN INSTITUTE OF SCIENCE

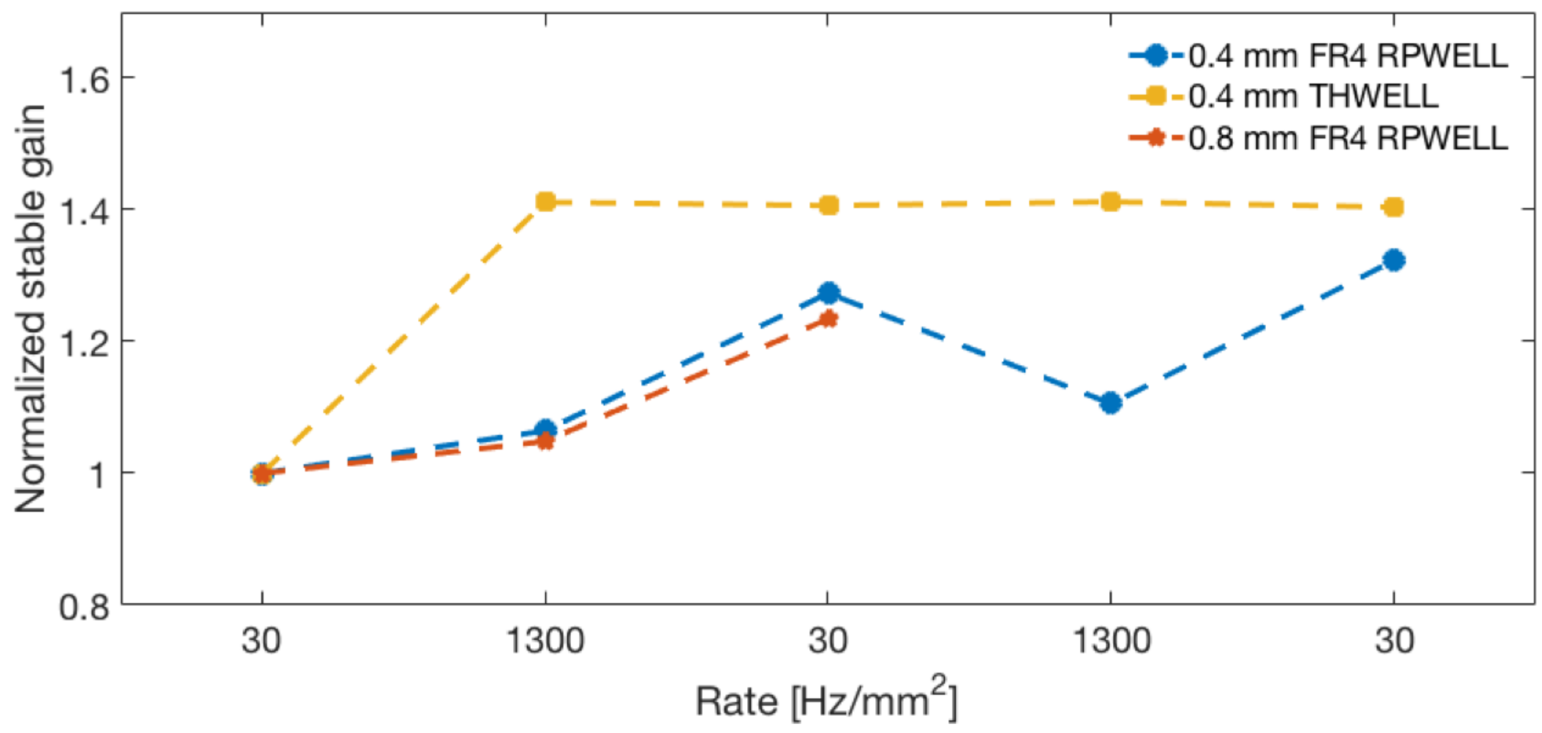
Transients

In preparation

Highlights

- FR4 made (RP)WELL hole-electrode changes the steady state after the first transition from low to high rate
- Bare-THWELL (Thick-WELL with no RP) detectors are not affected by these rate changes
- RPWELL detectors are affected

Stable gain along the low-high-low-high-low rate transition



מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

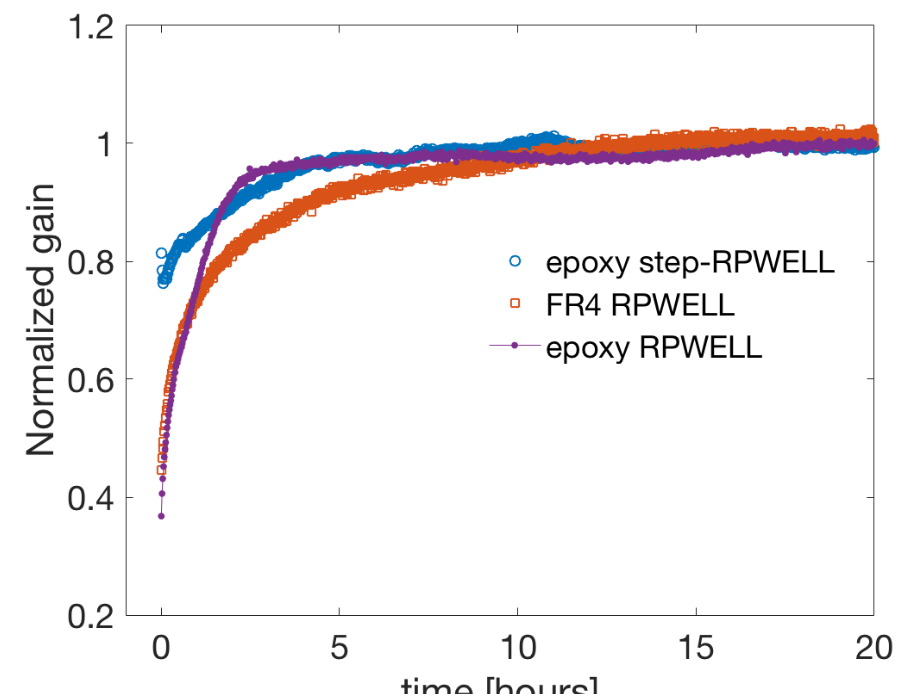
Transients

In preparation

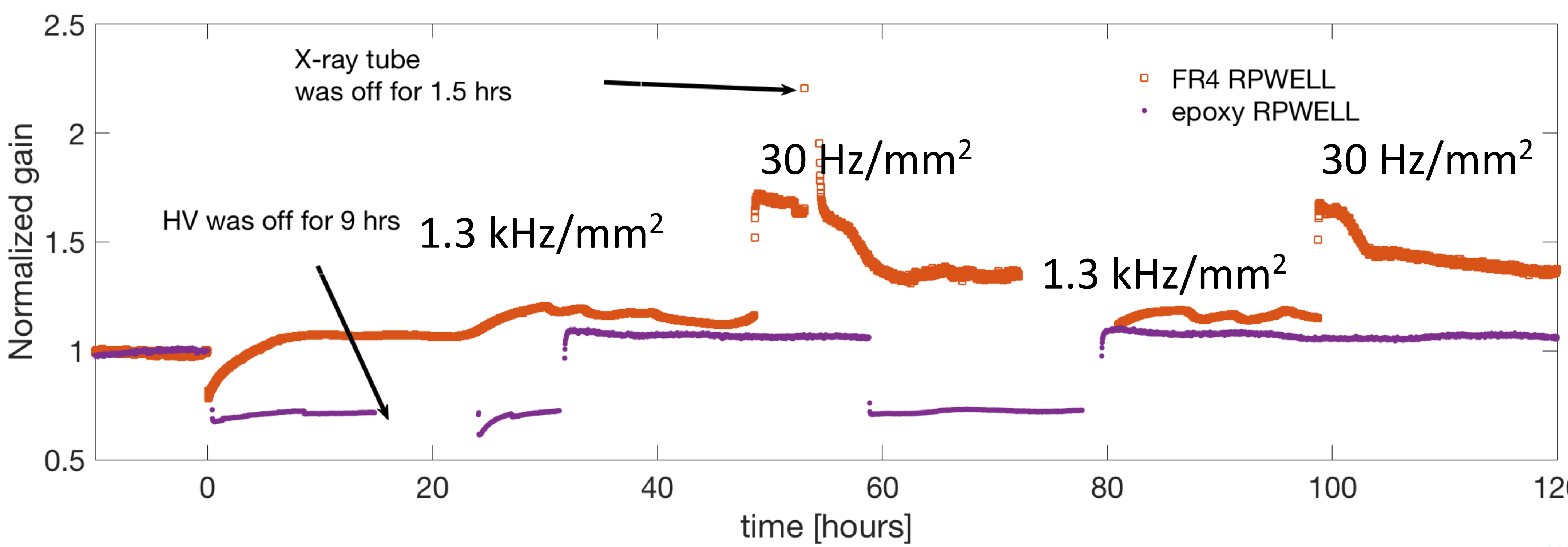
Highlights

- FR4 made (RP)WELL hole-electrode changes the steady state after the first transition from low to high rate
- Bare-THWELL (Thick-WELL with no RP) detectors are not affected by these rate changes
- RPWELL detectors are affected
- Epoxy made RPWELL is less affected by both kind of abrupt transitions and stabilizes faster

Transition from high to low voltage



Rates transition



Summary

- Rich activity in three fronts

- Upscaling - in the context of (S)DHCAL but not only
  50×50 cm^2 detector has been assembled and tested in the lab
  - Tests in the beam are foreseen in July
  - Tests as a sampling element in (S)DHCAL prototype are foreseen towards the end of the year

- Characterization
  - Stable operation as UV detector also when exposed to 6 KeV x-rays
  - Position resolution is measured and understood
  - Edge effects are addressed
  - Better handle on transients
  - Epoxy made THGEM responds faster than an FR4 THGEM

- Cooling down - feasibility study for cryogenic applications
  - Look for resistive material with the right resistivity at cryogenic temperatures