Comparative study of resistive MPGDs with VMM3a/SRS readout

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on behalf of Weizmann group

(side-part of the RD51 Common project, MPGD-CALO)

2nd DRD1 Collaboration Meeting
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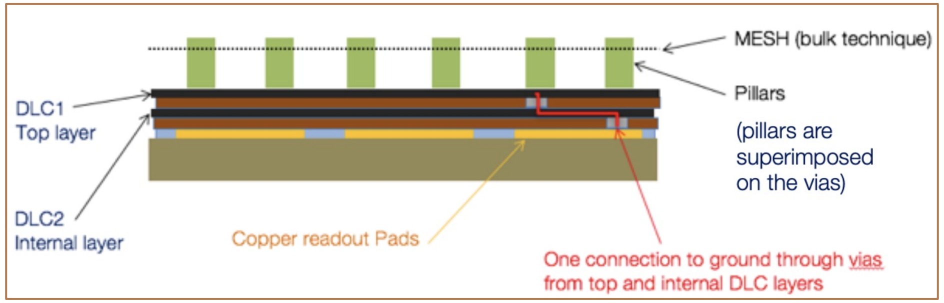
Introduction

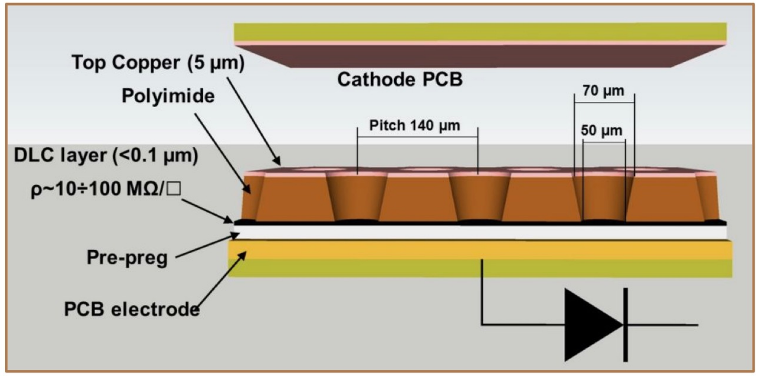
- Goal: compare three resistive MPGD technologies
  - MM (~ 50 MΩ/☐ DLC)
  - uRWELL (~ 100 MΩ/☐ DLC)
  - RPWELL (2 GΩ bulk Glass)
  - RD51 Common project
- VMM3a/SRS readout of 384 × 1 cm^2 pads
- Gas mixture
  - MM, RPWELL: $Ar_{(93)}CO2_{(5)}iC4H10_{(2)}$
  - uRWELL: $Ar_{(93)}CO2_{(5)}iC4H10_{(2)}$

    $Ar_{(70)}CO2_{(30)}$, $Ar_{(45)}CO2_{(15)}CF4_{(40)}$
- Drift gap = 6 mm – amplification gap – RL/RP
- Performance in terms of:
  - Detection efficiency
  - Charge and time response
  - Stability

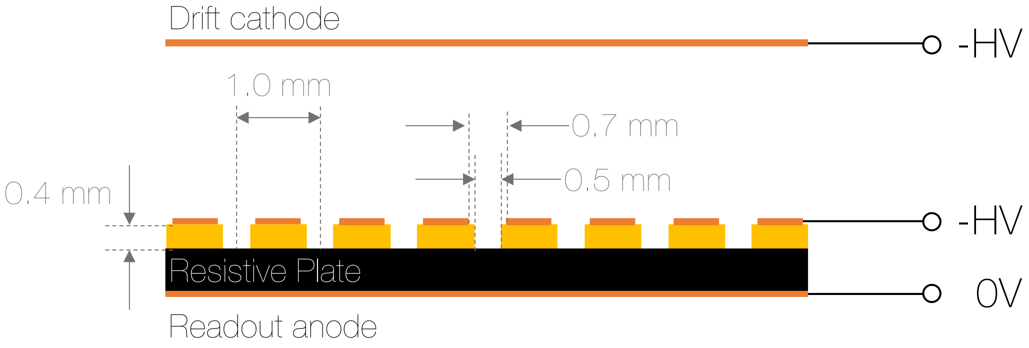
Micromegas, MM



uRWELL

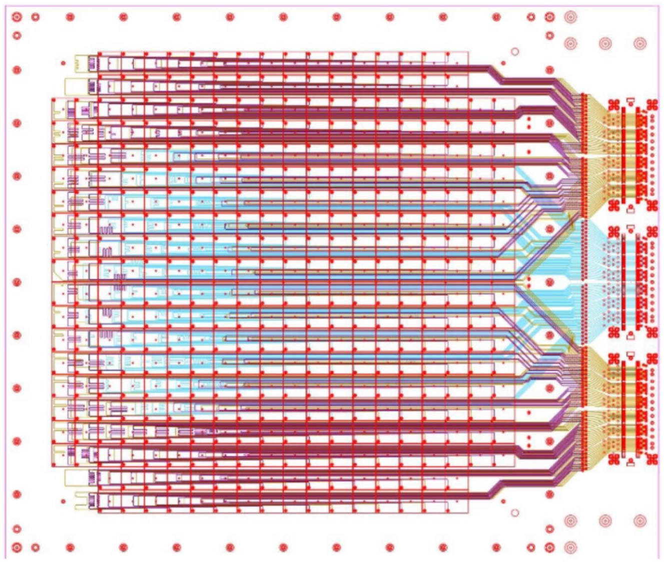


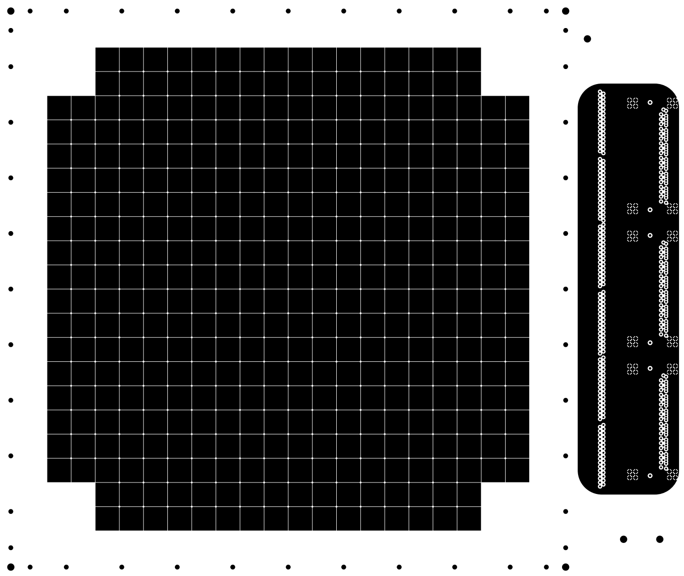
RPWELL



Readout anode

- Pad readout
  - 1×1 cm^2 pad area
  - 384 pads routed in 3 PCB layers to three Hirose connectors
- Resistive layer/plate
  - Micromegas
    - Double DLC layer
    - ~ 50 MΩ/□
  - uRWELL
    - Single DLC layer
    - ~ 100 MΩ/□
  - RPWELL
    - Fe-doped glass
    - 2 GΩ bulk
    - Coupled to anode with epoxy-graphite mixture

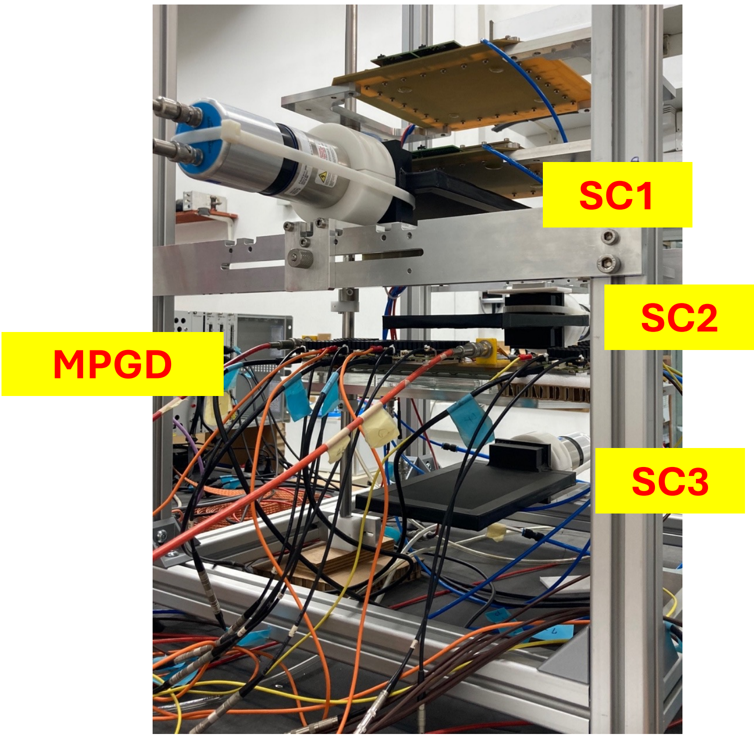


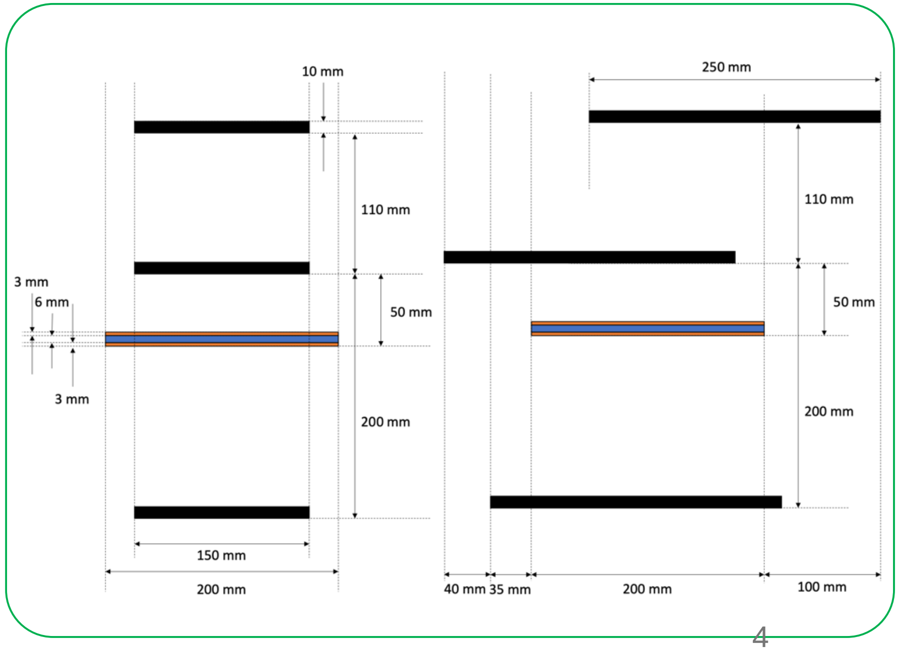


Cosmic test bench

- Three 150×250 mm^2 scintillators (SC)
- Acceptance ~ 150×175 mm^2
- Max angle ~ 44º
- Coincidence logic:

  PMTs → Discr → logic AND unit → NIM –injector → VMM
- Trigger rate ~ 0.8 Hz





Data acquisition

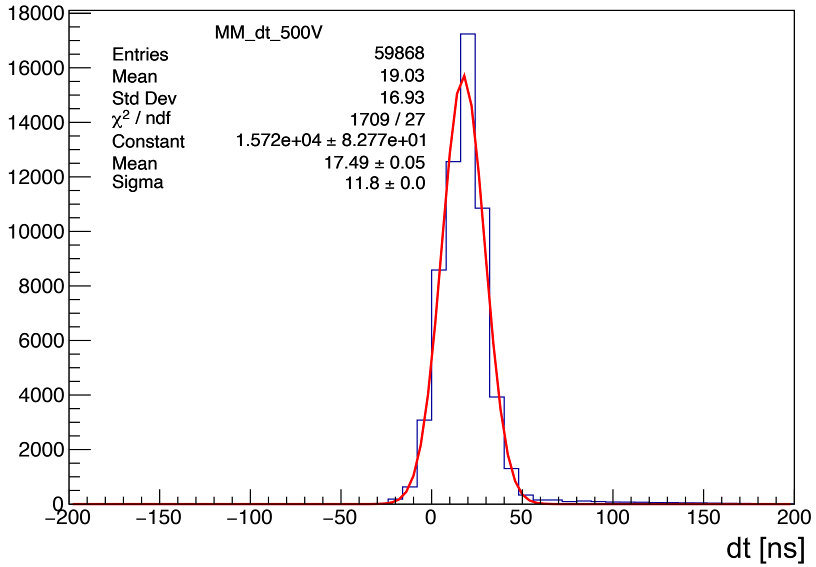
- Continuous with VMM3a/SRS[1]
- 380 active channels (3 deead, 1 masked) + 1 for the trigger
  - 4 VMM hybrids
  - Powered with DVMM
  - 1 FEC
- 3 mV/fC VMM3a gain
- 200 ns shaping time
- Analog signal monitor
  - 1 channel per chip
- Noise: 5 – 10 mV (10^4 – $2{\cdot}10^4$ electrons)
- Threshold: average per channel ~ 30 mV, equivalent to $6{\cdot}10^4$ el

[1] 40 MHz clock

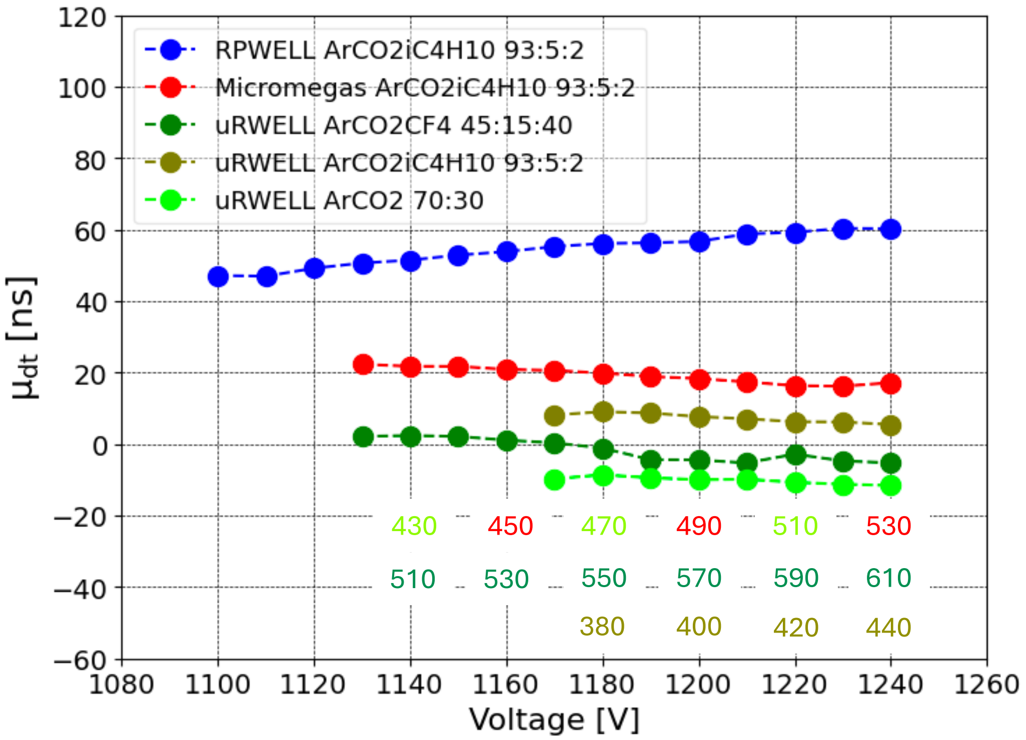
Methodology – data analysis

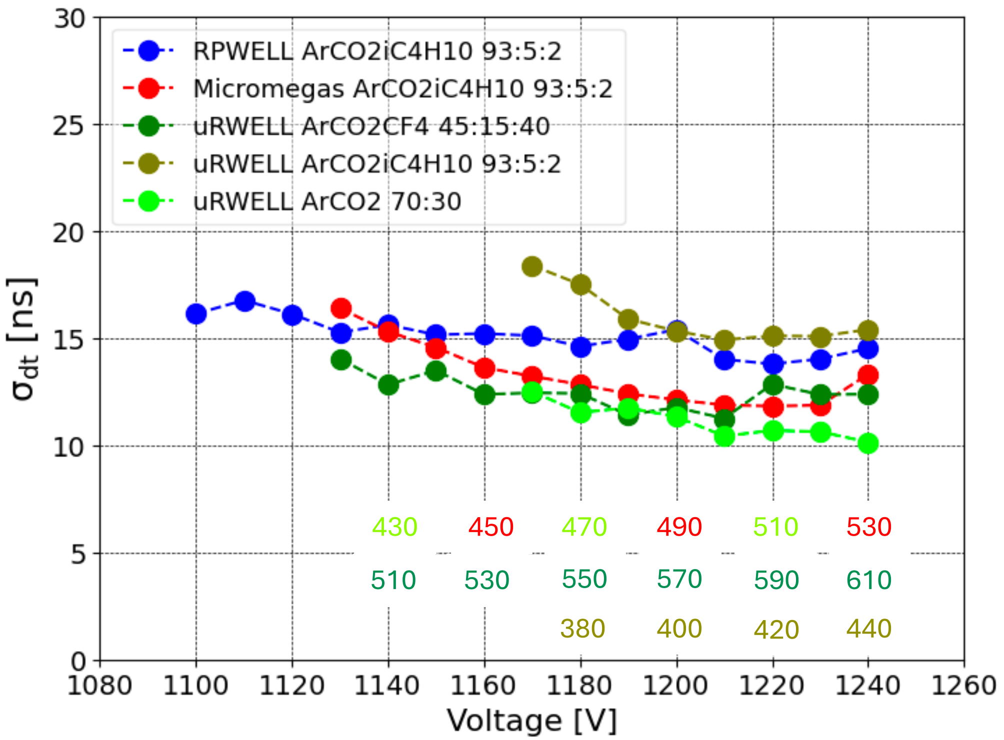
- Cluster reconstruction with vmm-sdat
  - first neighbors with max one missing pad
  - center-of-mass algorithm
- Time correlation between the trigger and the detector
  - dt = t_trigger – t_cluster
- Efficiency calculation
  - Fit dt to Normal distribution
  - Find mean (μ) and sigma (σ) of the fit
  - Count clusters under the "bell" as efficient (μ ± 3σ)
  - In case > 1 cluster found within the selection, choose the one closer in time

MM 500V



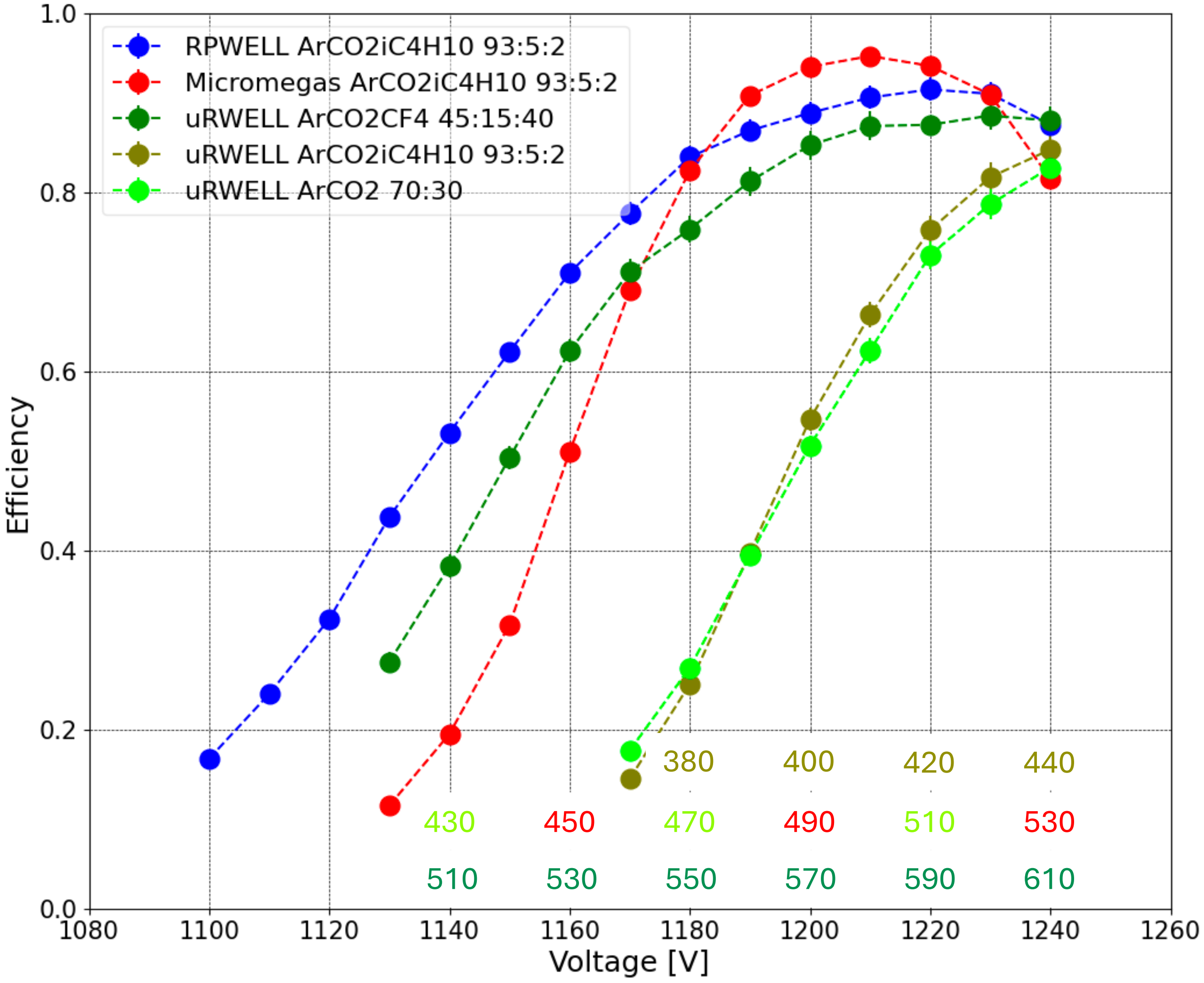
Time results





- Timing depends on the technology and gas mixture
- RPWELL delay is larger due to the slower signal
- RPWELL time resolution is slightly worse (not decoupled from the system time resolution)

Efficiency results



$$E = \frac{clusters\ within\ \mu \pm 3\sigma\ of\ dt}{no\ of\ triggers}$$

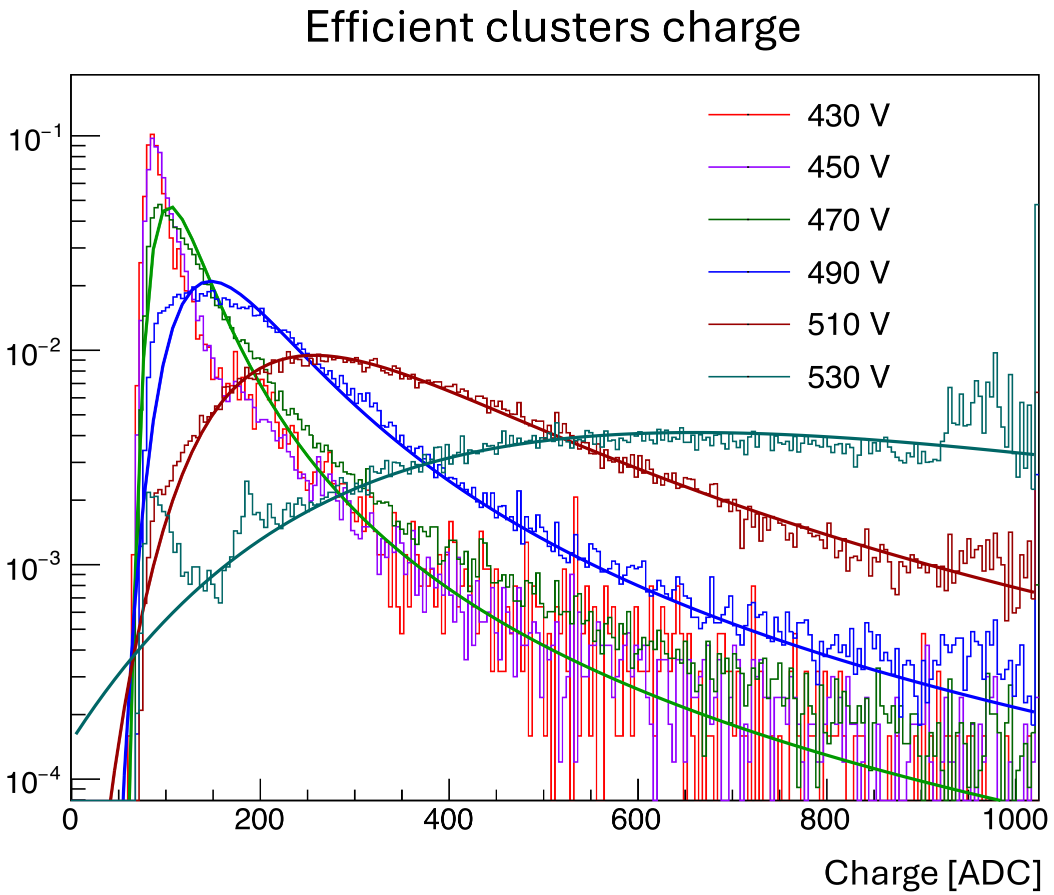
Drift fields

- MM: 1 kV/cm
- RPWELL: 2.5 kV/cm
- uRWELL (ArCF4CO2): 4 kV/cm
- uRWELL (ArCO2iC4H10): 2.0 kV/cm
- uRWELL (ArCO2): 3.5 kV/cm

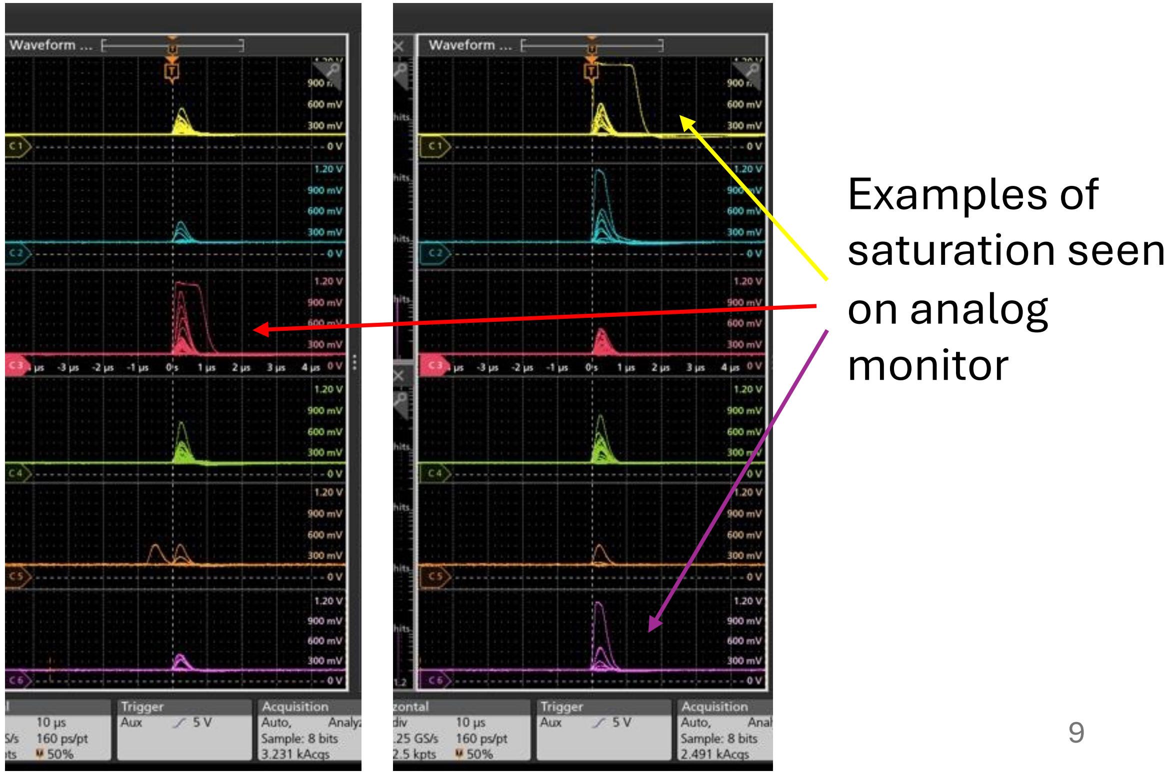
In ArCO2 70:30 and ArCO2iC4H10 93:5:2, uRWELL is approaching discharge regime, will drop these results from now on

Observing drop of efficiency for MM and RPWELL at high gain

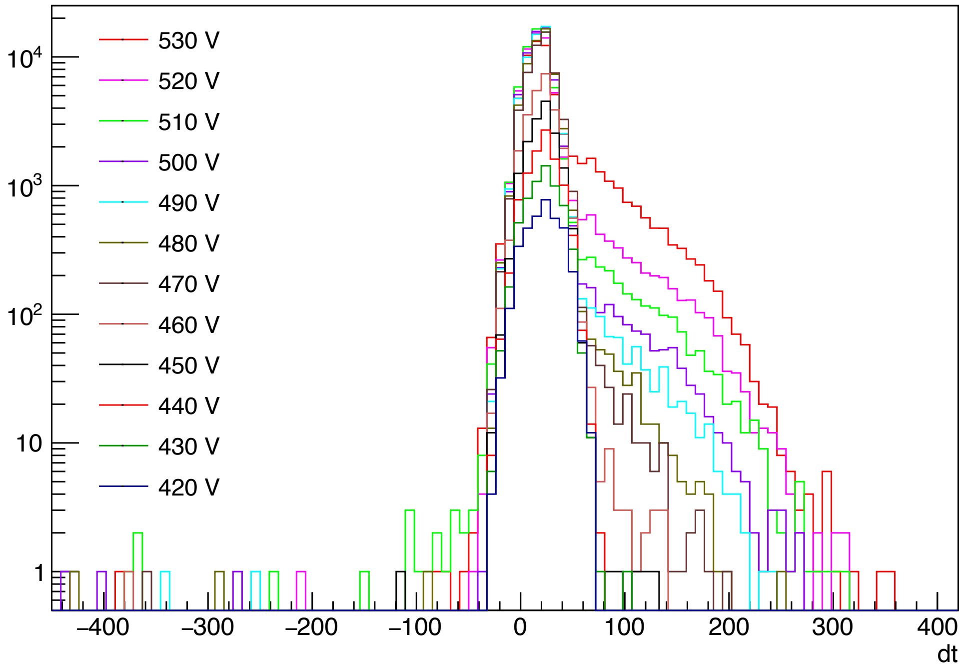
MM measurements

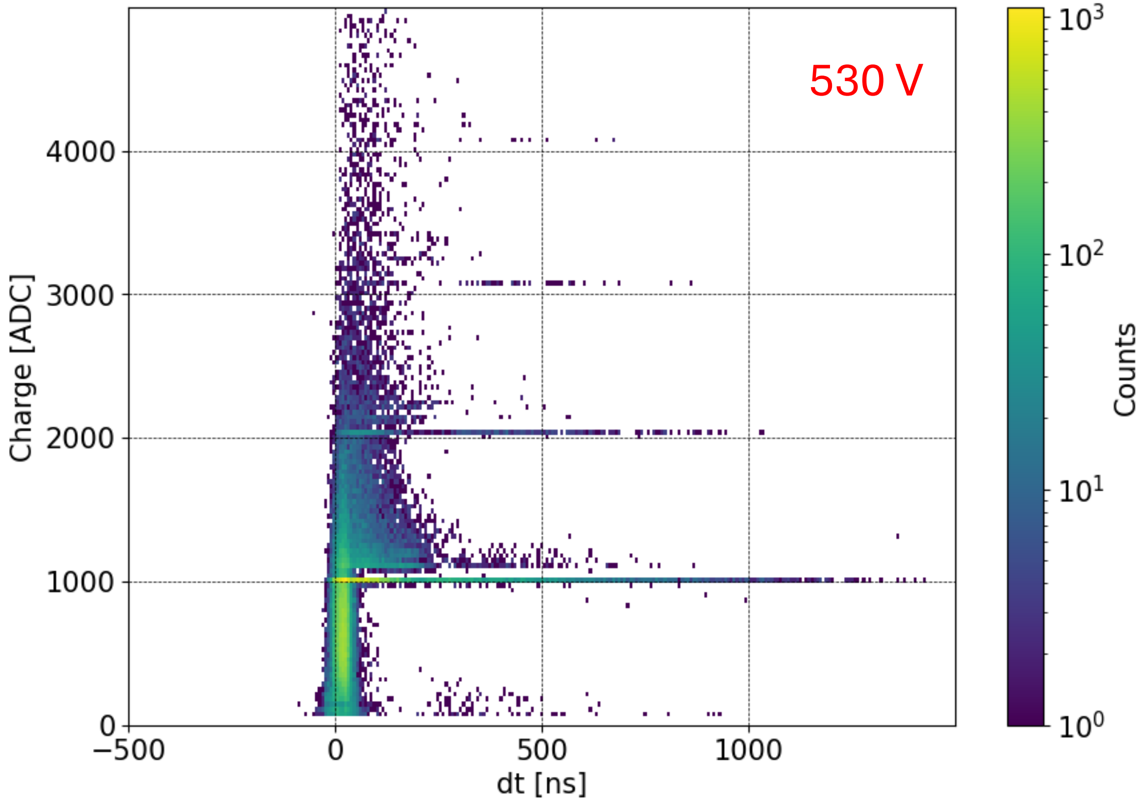


- At high gain, charge saturation is observed
- At max point saturating events predominate



MM measurements



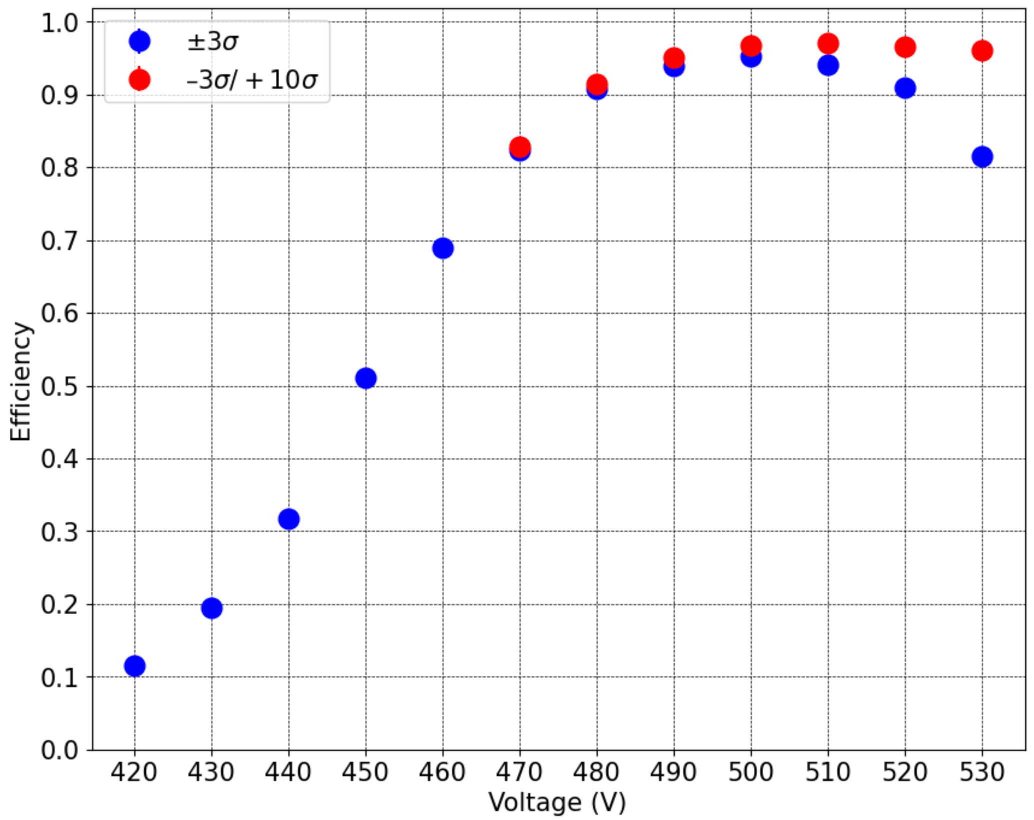


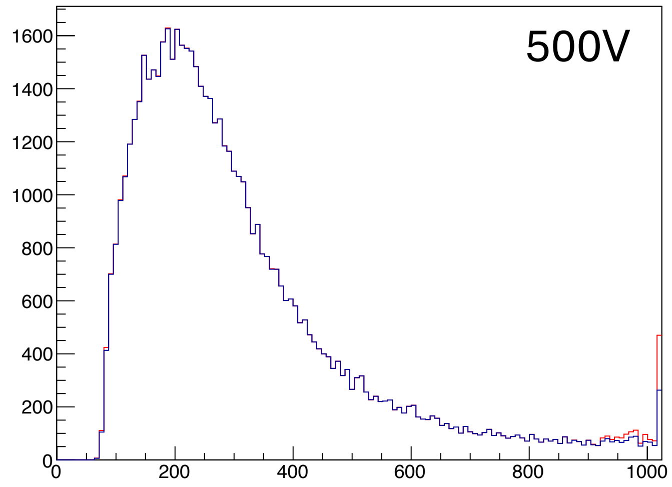
- dt tail observed at high gains
- Saturated clusters delayed by dt > 3σ

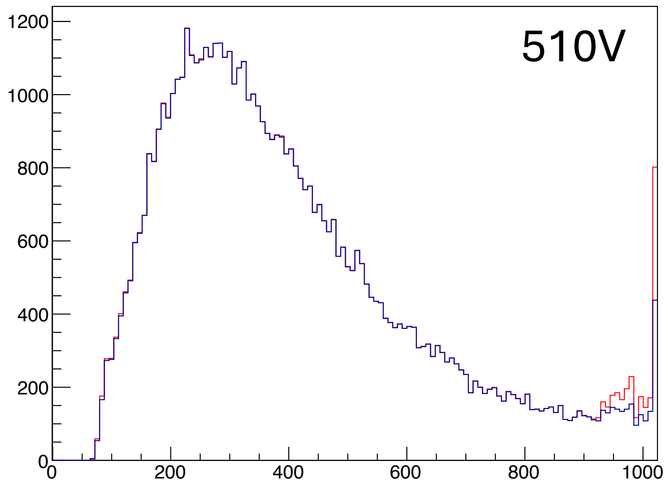
→ Reconsidering dt selection

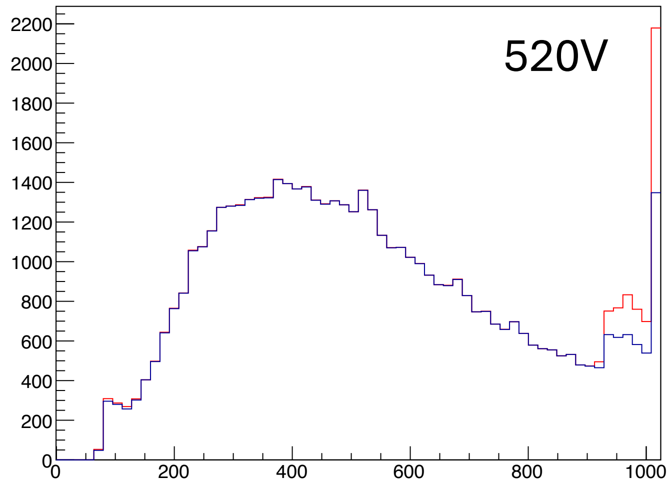
MM measurements

- Increasing dt selection
  - (μ ± 3σ) → (μ - 3σ) & (μ + 10σ)
- Plateau value at 96.6 ± 0.3 %
- Restored clusters are indeed in saturation

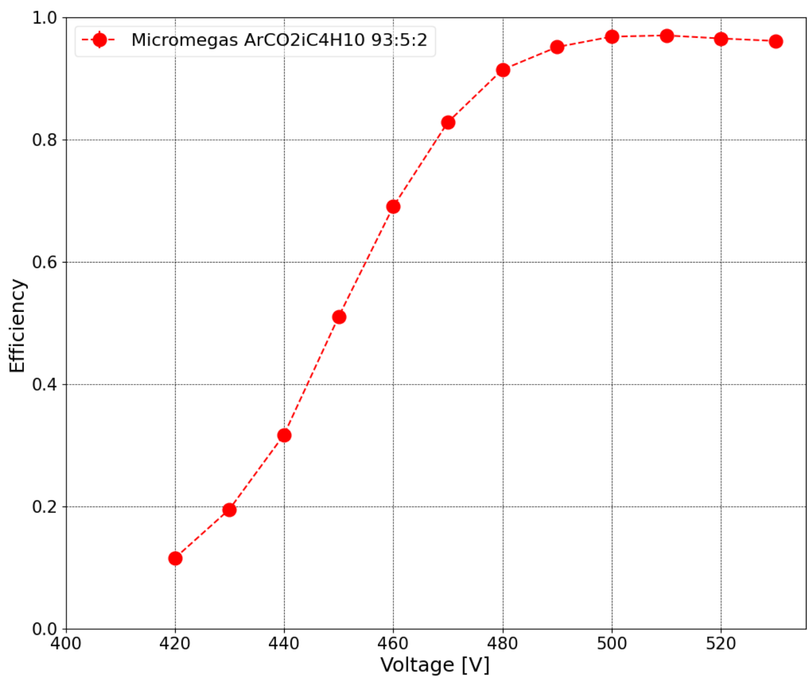




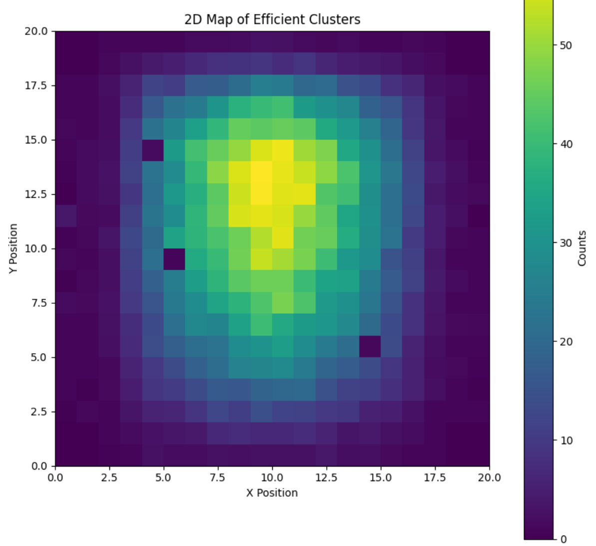




MM measurements



Map of MM trigger acceptance



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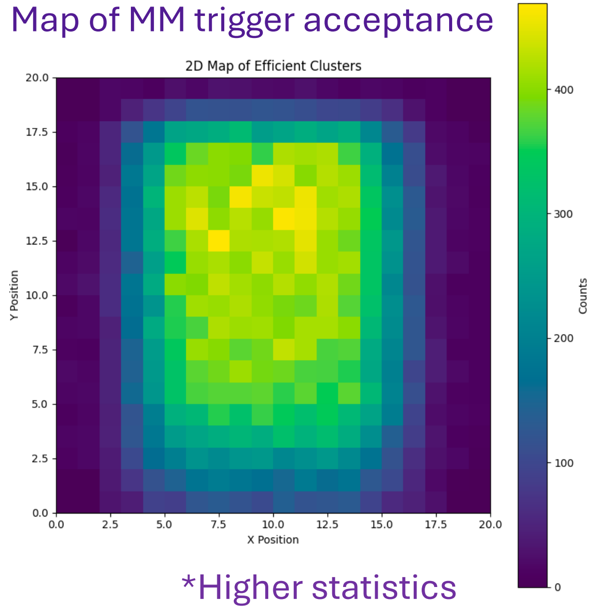


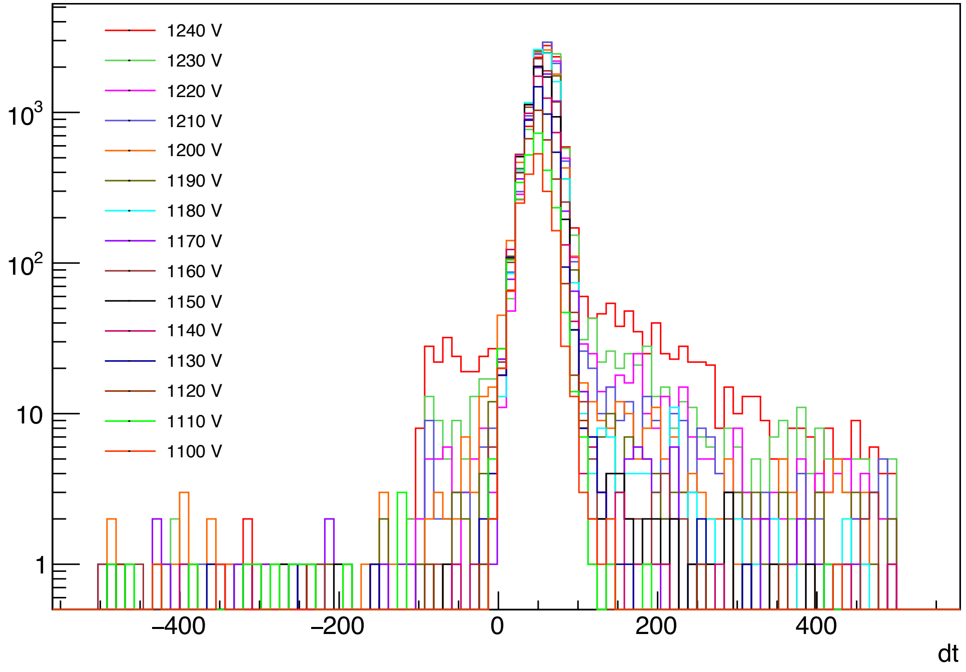
*Higher statistics
*Dead channels restored

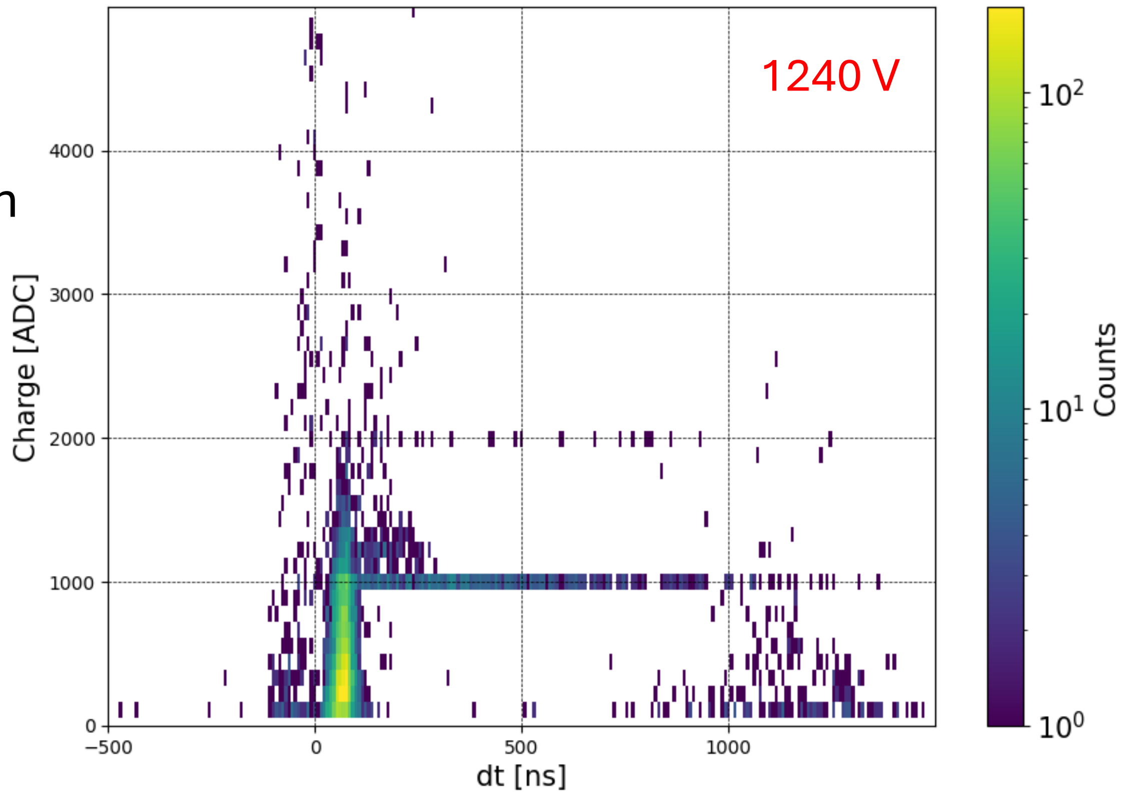
- MM eff.plateau at 96.6 ± 0.3 %
- Acquisition with 3 dead channels
  → correction of 1 %
- Trigger acceptance
  → correction of 1-2 %

→ MM efficiency > 98%

RPWELL measurements

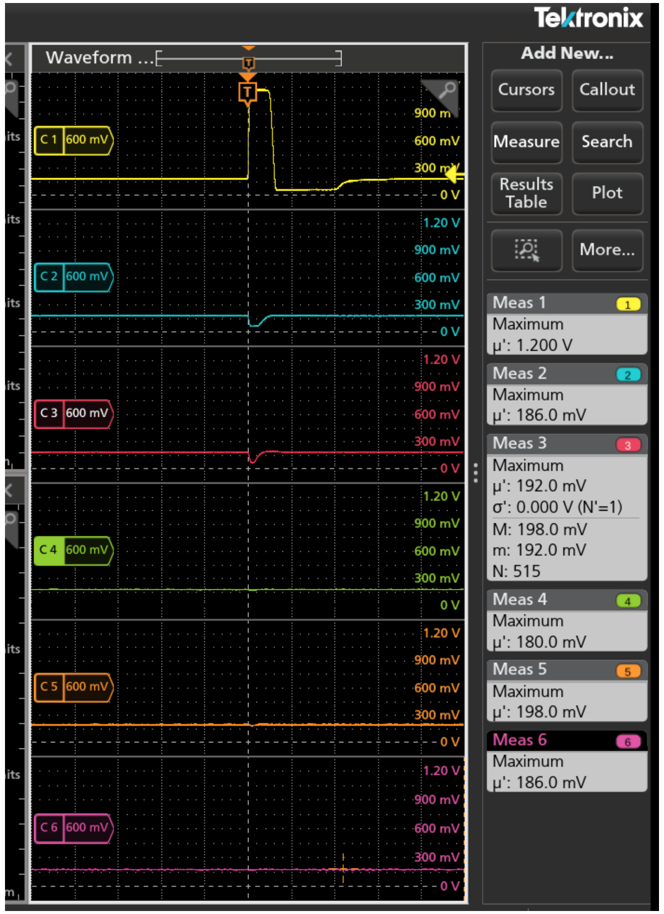
- Saturation similar to MM
- Increasing the selection (±3σ → ± 10σ) results in 94 % efficiency
- Different effect:
  - non-correlated clusters, including saturation



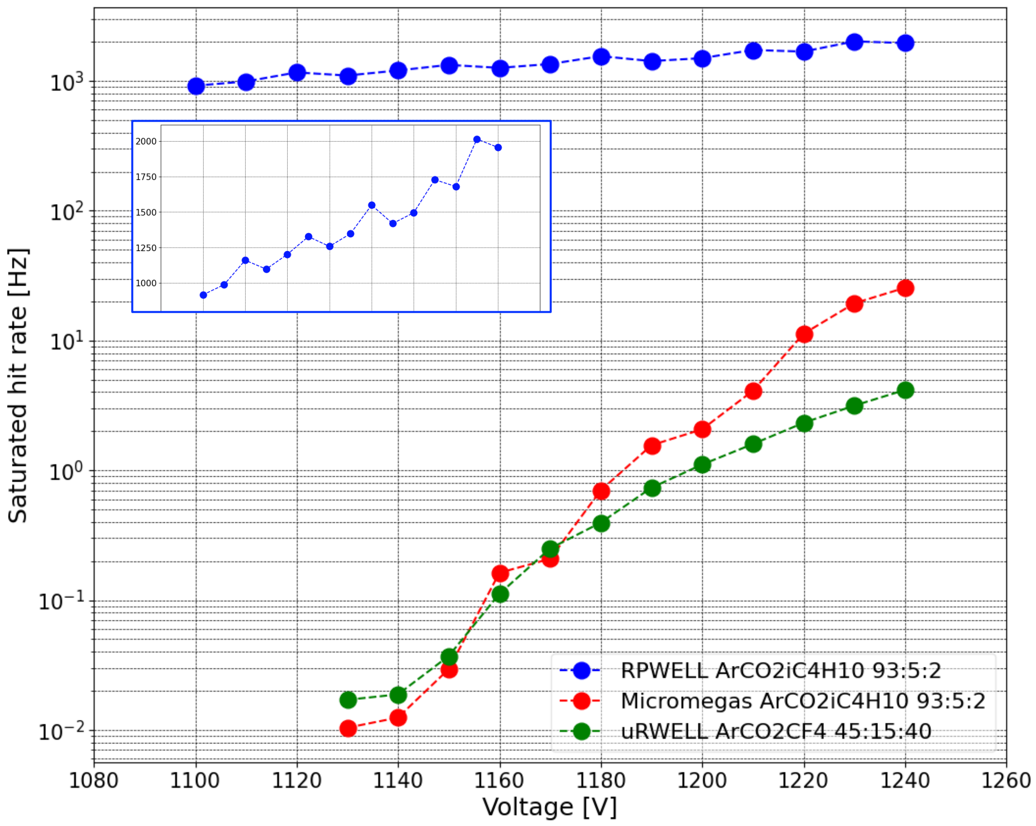


RPWELL instability

Analog signals from the RPWELL



* self trigger on ch1
* one channel per VMM
* 2 us/div



- Saturated signals not correlated with the trigger
- Function of HV
- Dead-time at higher source rate (beam)

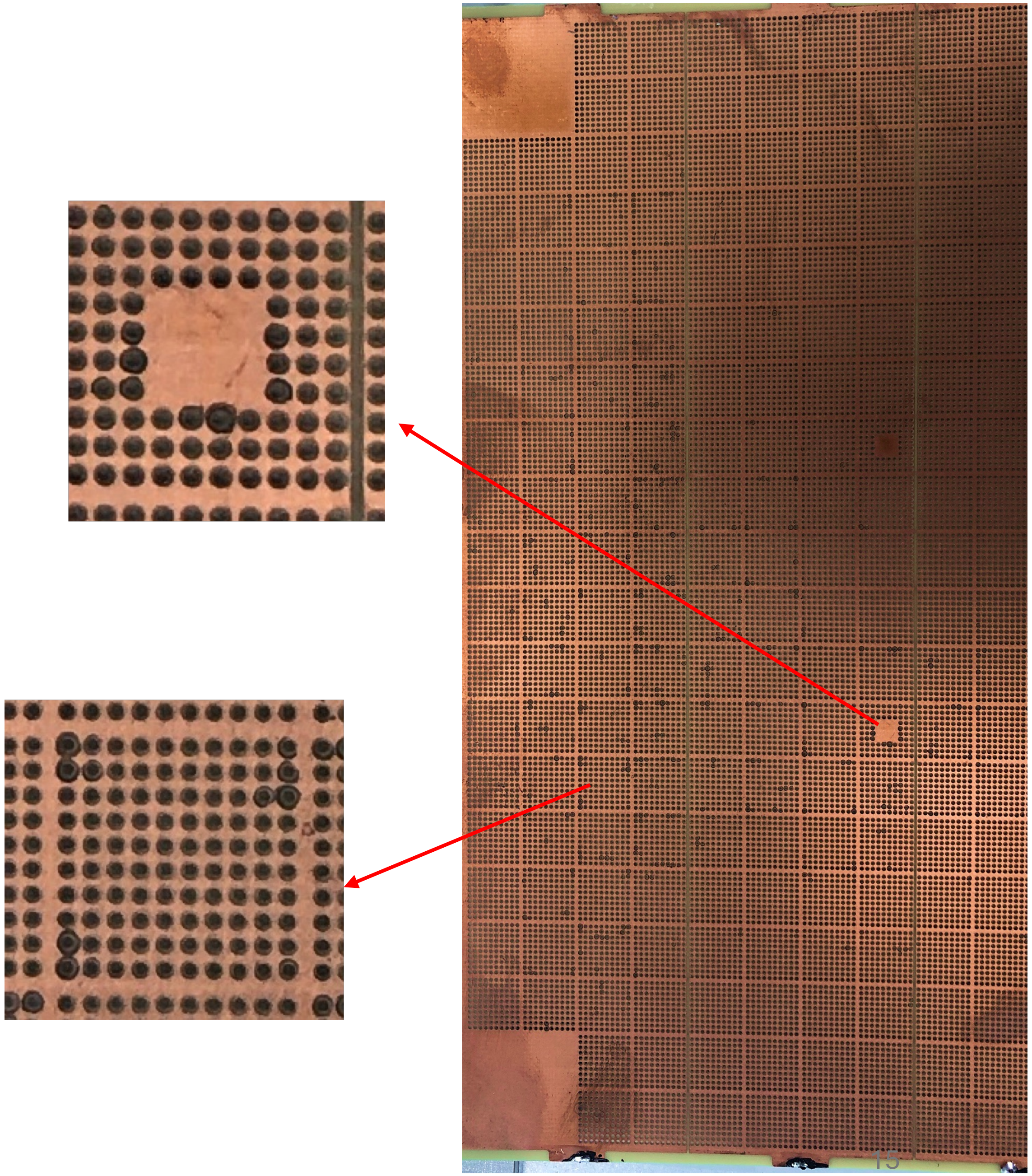
- We believe it is a major design-related problem
  WELL design

RPWELL design

- Electrical instabilities observed at the edges (RPWELL irradiated with 22 keV X-Rays)
  - At gluing points
  - At cross pattern corners

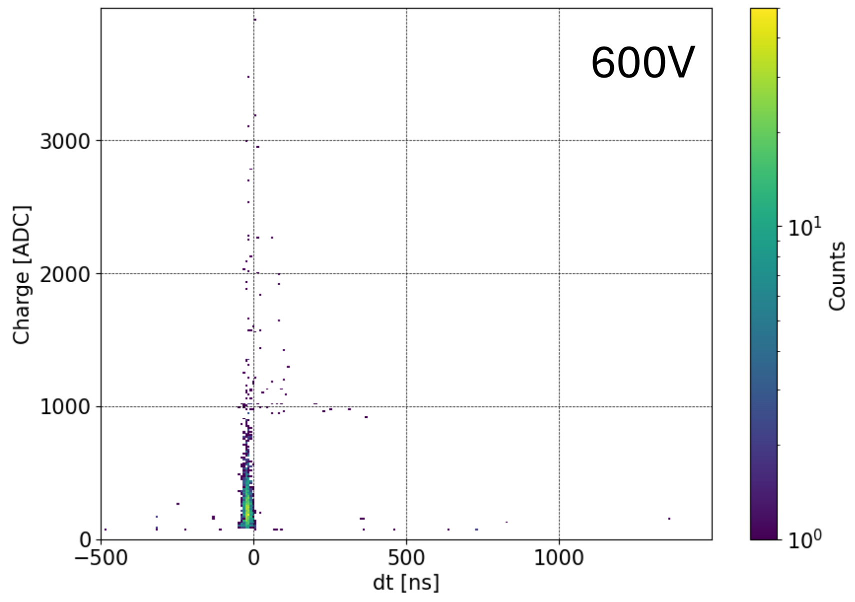
  - Attributed to field non-uniformity

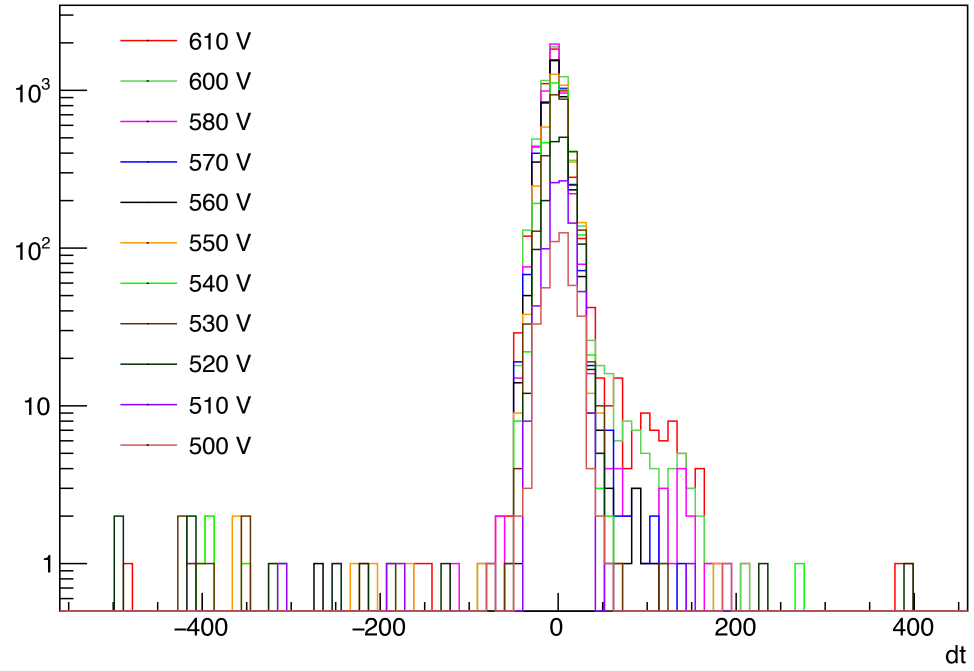
→ Optimizing the design in the next iteration
  - No pad pattern
  - Hexagonal holes pattern
  - Larger holes diameter at the edges

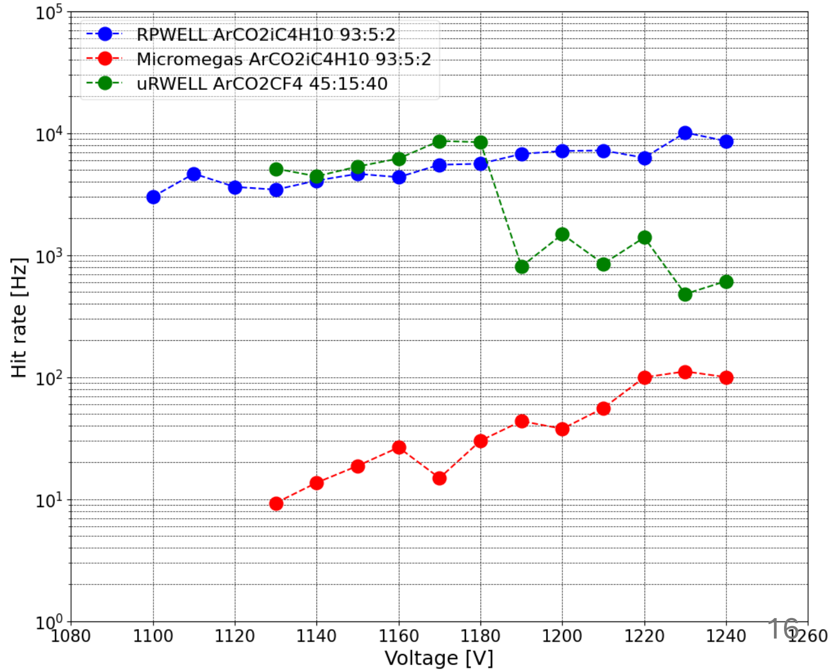


uRWELL measurements

- Different from RPWELL and MM (no saturation)
- Random low amplitude hits
- Hit rate similar to RPWELL
- Under further investigation







Conclusion and outlook

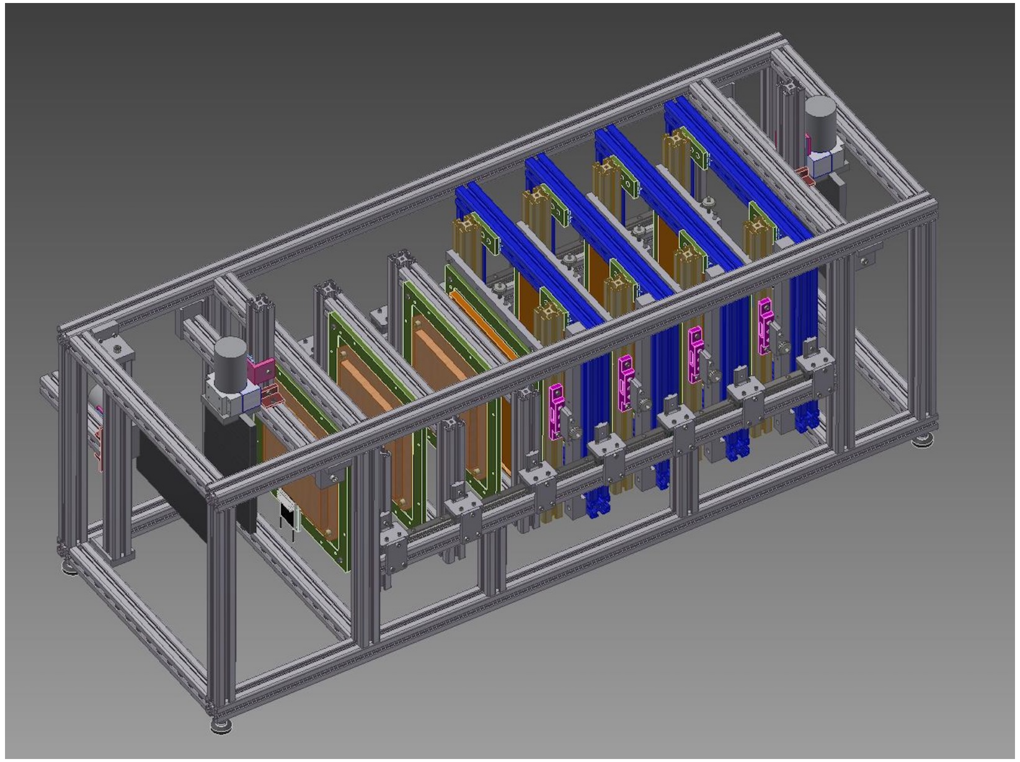
- Efficiency > 90 % reached for three detectors
- Charge saturation affects the dt with the trigger – delay

- Performance of RPWELL and uRWELL affected by random hit rate and has to be further understood

- Currently, building a common setup to test three detectors simultaneously with triple GEM based tracker
  - Planning to join SPS TB in September 2024

SPS NA H4 Test Beam plans

- Aiming to join the last 2024 TB (September)
- Building the setup with 3 SCs, 3 tracking GEMs, and 4 pad detectors (MM, RPWELL, uRWELL + RWELL with lower resistivity and/or different WELL pattern)
- 25 VMM hybrids (12 tracking + 12 pad + 1 trigger)



- Goal
  - Comparative study
    - Efficiency
    - Gain
    - Uniformity
    - Pad multiplicity
    - Rate capability
    - Address dead time

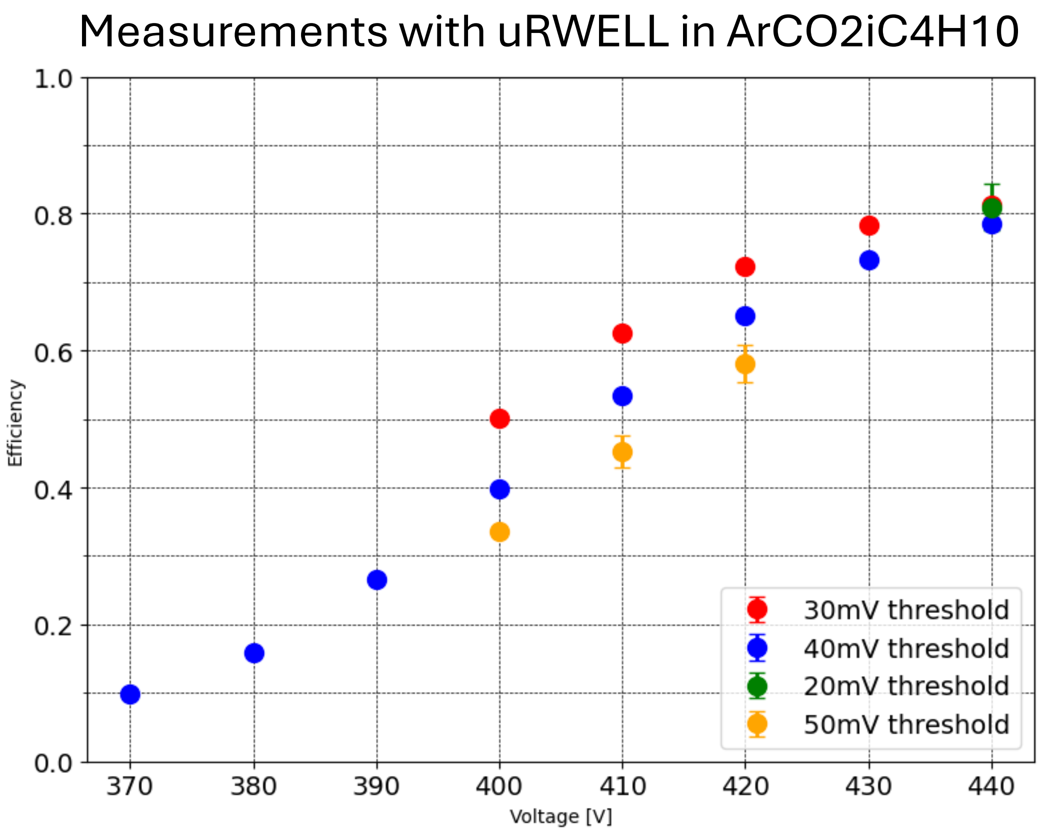
Thank you!

Backup

Threshold effect

- Threshold level set per channel with the calibration procedure provided in Slow Control
- Affects the measurements at low gain

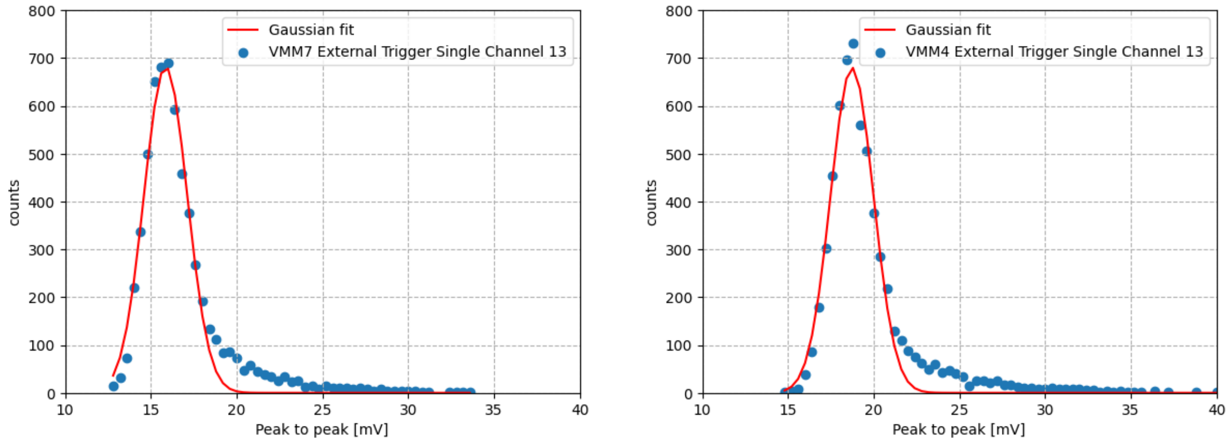
- Threshold was first set for uRWELL (the highest noise level)
- Kept at the same level for MM & RPWELL for consistency



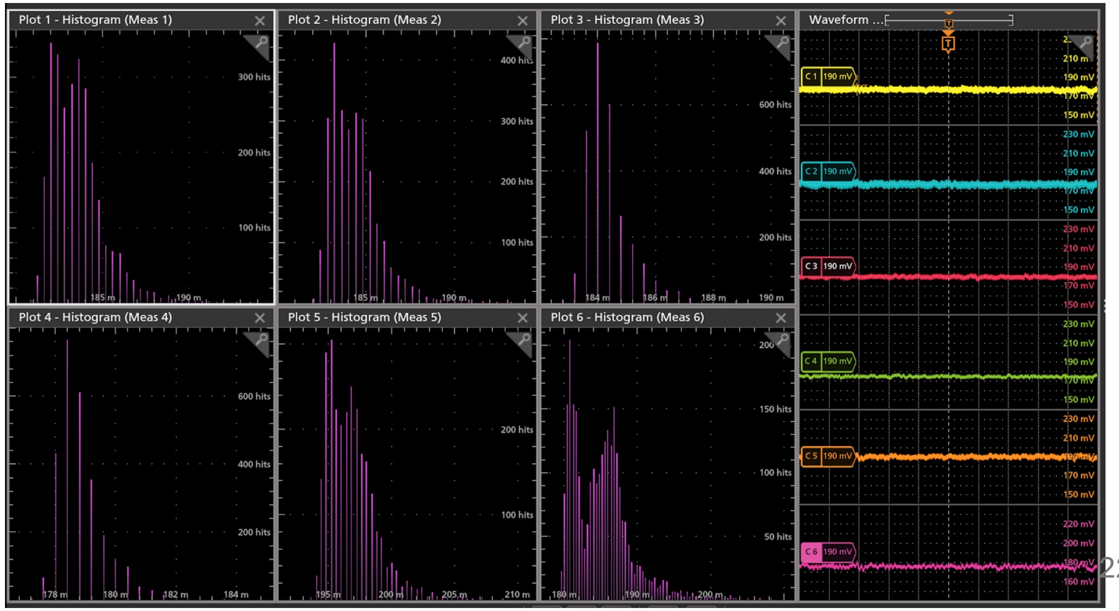
Noise

- Noise level estimated from analog output
- Acquisition with random external trigger
- uRWELL
  - ~ 10 mV
  - $2 \cdot 10^4$ el equivalent
- MM & RPWELL
  - ~ 5 mV
  - 10^4 el equivalent

uRWELL



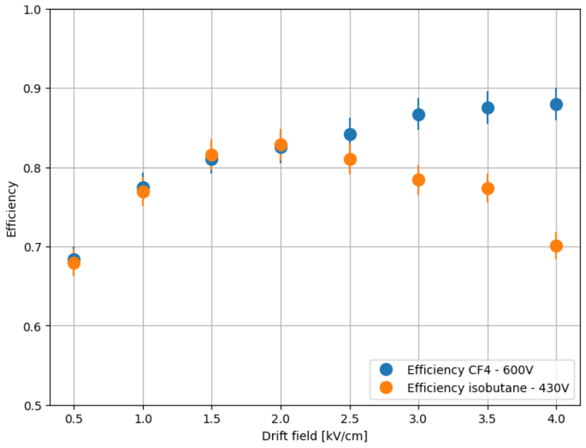
RPWELL

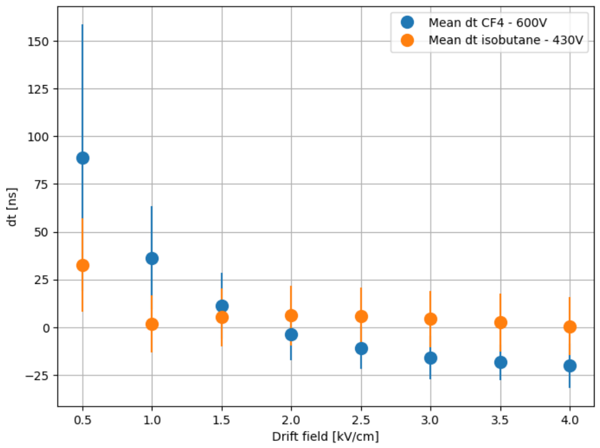


Drift field

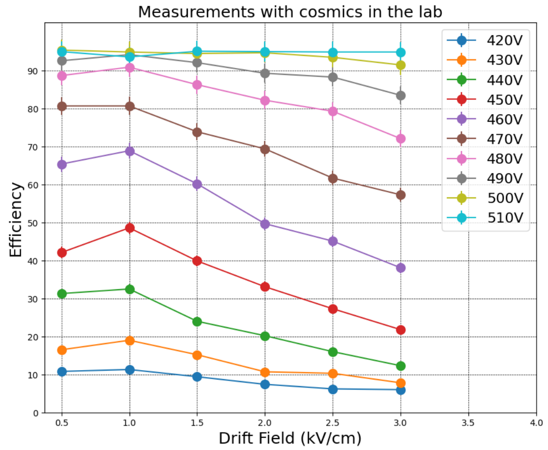
- Drift field values were set according to the optimal values of efficiency (max) and dt_mean (min)

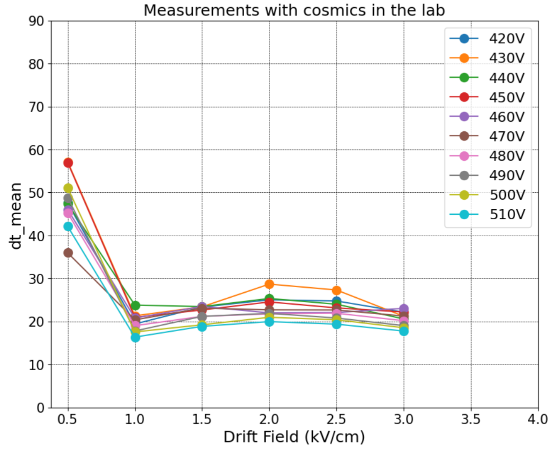
uRWELL



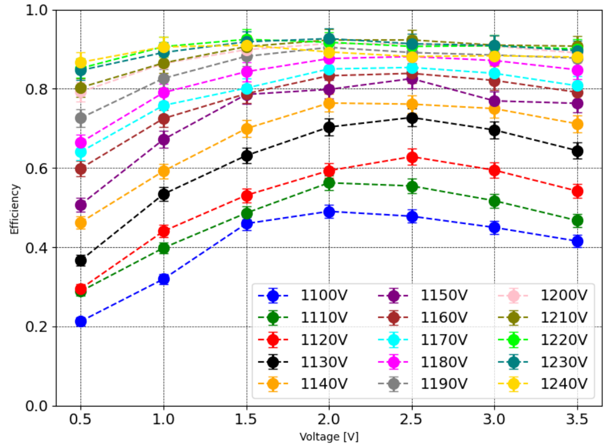


MM





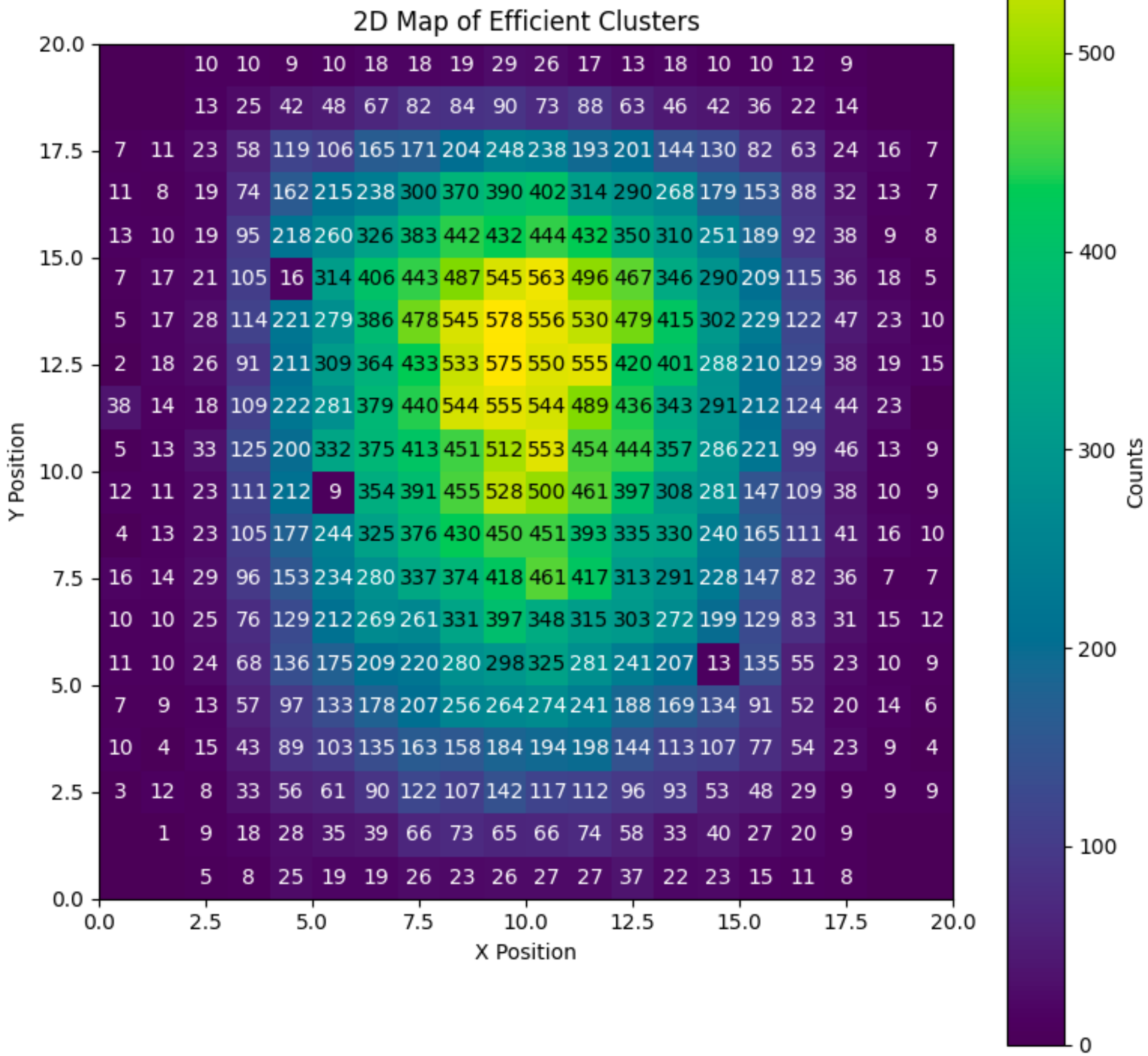
RPWELL



Dead channels

Three dead channels (non-zero counts due to the reconstruction of size>1 clusters with missing pad)

Taking average number of the clusters in the surrounding neighbors, true efficiency is estimated to be 1% higher



Acceptance

With higher statistics it can be seen that the acceptance region od the SCs is not symmetrically positioned.
Lower row of pads has order of magnitude more counts than the highest.
Correcting the values to the asymmetry, is estimated to be 1–2 % higher