Comparative study of resistive MPGD technologies

Darina Zavazieva[1,2], Ilia Ravinovich[2], Luca Moleri[2],
Maryna Borysova[2], Edward Brendan Shields[2], Oz Arie[2],
Michael Kwok Lam Chu[2], Shikma Bressler[2]

[1]Ben Gurion University of the Negev
[2]Weizmann Institute of Science

The 8th International Conference on Micro Pattern Gaseous Detectors (MPGD2024)
October 14— 18, 2024
Hefei, China

Single stage resistive MPGDs

- Single stage amplification
- Lower material budget, thinner structure
- Simpler power supplying scheme

- Resistive material to quench discharges energy and protect R/O electronics from discharge damage

Single stage resistive MPGDs

- Single stage amplification
- Lower material budget, thinner structure
- Simpler power supplying scheme

- Resistive material to quench discharges energy and protect R/O electronics from discharge damage

- Potentially a sampling element for digital hadronic calorimeters with fine 3D segmentation

spin-off from to RD51 Common project, MPGD2024 talk given by Anna Stamerra

Single stage resistive MPGDs

- Single stage amplification
- Lower material budget, thinner structure
- Simpler power supplying scheme

- Resistive material to quench discharges energy and protect R/O electronics from discharge damage

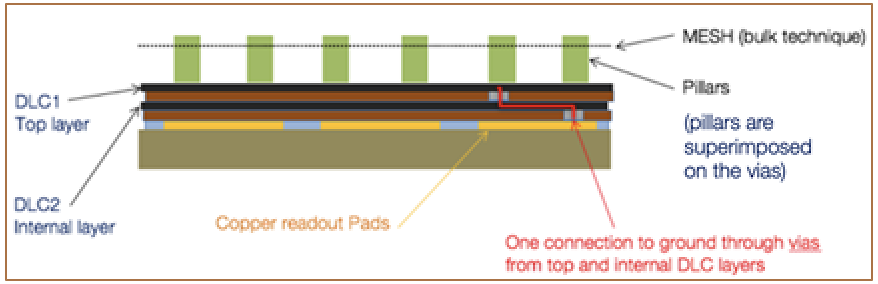
- Potentially a sampling element for digital hadronic calorimeters with fine 3D segmentation

  spin-off from to RD51 Common project, MPGD2024 talk given by Anna Stamerra

- Variety of technologies
- So far, no systematic comparison in similar conditions and controlled environment
  - Same readout
  - Same p/T, humidity
  - Radiation source

Technologies studied

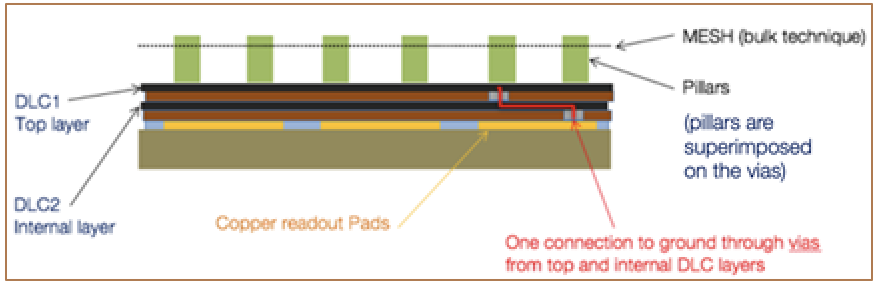
Micromegas, MM



- Double DLC layer
- ~ 50 MΩ/□
- Grounding points through vias under the pillars

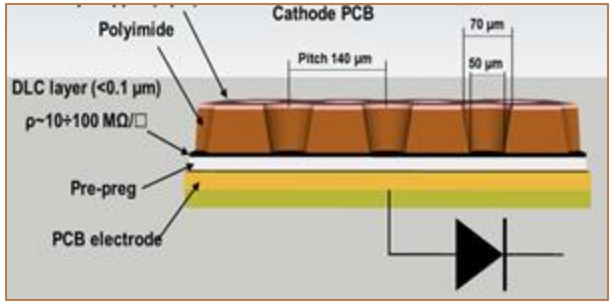
Technologies studied

Micromegas, MM



- Double DLC layer
- ~ 50 MΩ/☐
- Grounding points through vias under the pillars

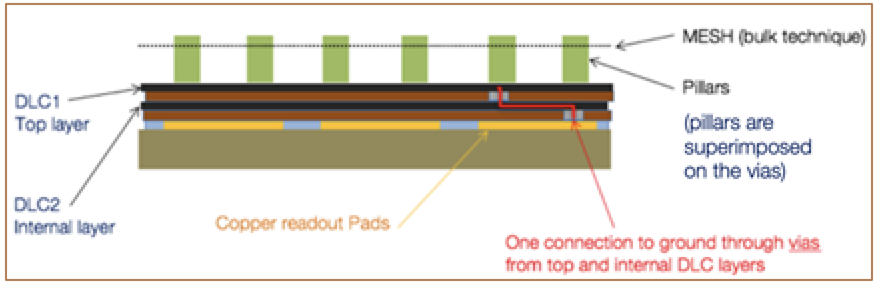
uRWELL



- Single DLC layer
- ~ 100 MΩ/☐
- Gounding lines between GEM HV sectors

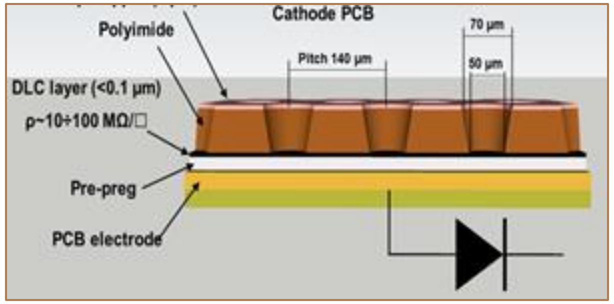
Technologies studied

Micromegas, MM



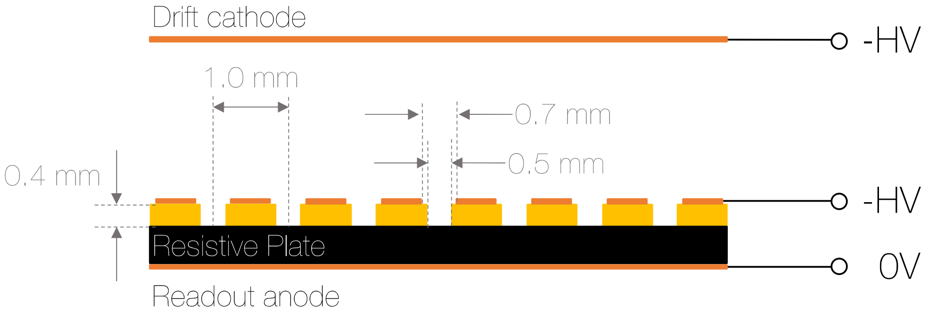
- Double DLC layer
- ~ 50 MΩ/□
- Grounding points through vias under the pillars

uRWELL



- Single DLC layer
- ~ 100 MΩ/□
- Gounding lines between GEM HV sectors

RPWELL



- Fe-dopped glass
- 2 GΩ·cm
- Grounding through pads with epoxy-graphite mixture

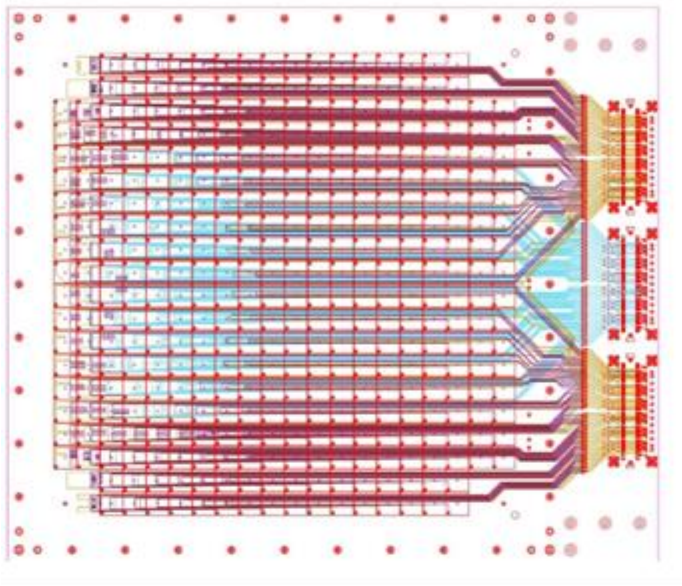
Technologies studied

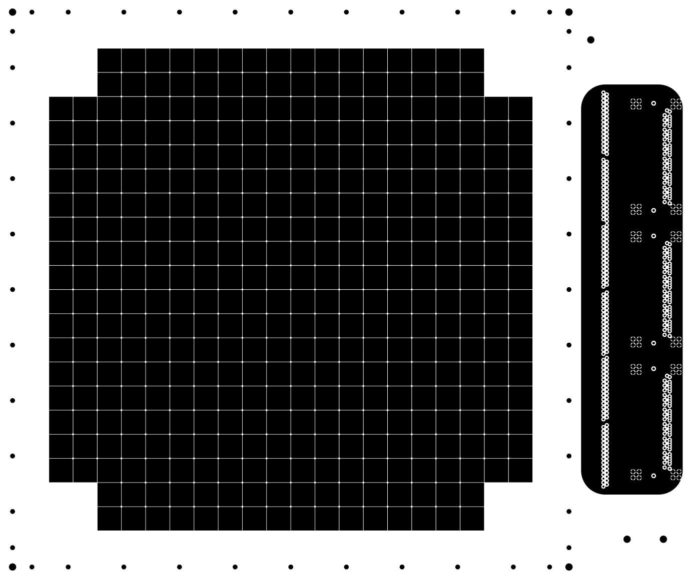
- Pad readout
  - 1×1 cm^2 pad area
  - 384 pads routed to three Hirose connectors

- 6 mm – amplification gap drift

- Optimal* gas mixtures
  - MM, RPWELL: $ArCO_2iC_4H_{10}$ (93/5/2)
  - uRWELL: $ArCO_2CF_4$ (45/15/40)

  *based on previous studies





Methodology

- Common VMM3a/SRS readout system
  - Continuous acquisition mode
  - 3 mV/fC VMM gain
  - 200 ns shaping time
- Common analysis framework
  - Reference timestamp of the trigger, coincidence of three scintillators
  - Cluster timing defined as charge weighted cluster hits time
  - |dt| = |t_cluster – t_trigger|

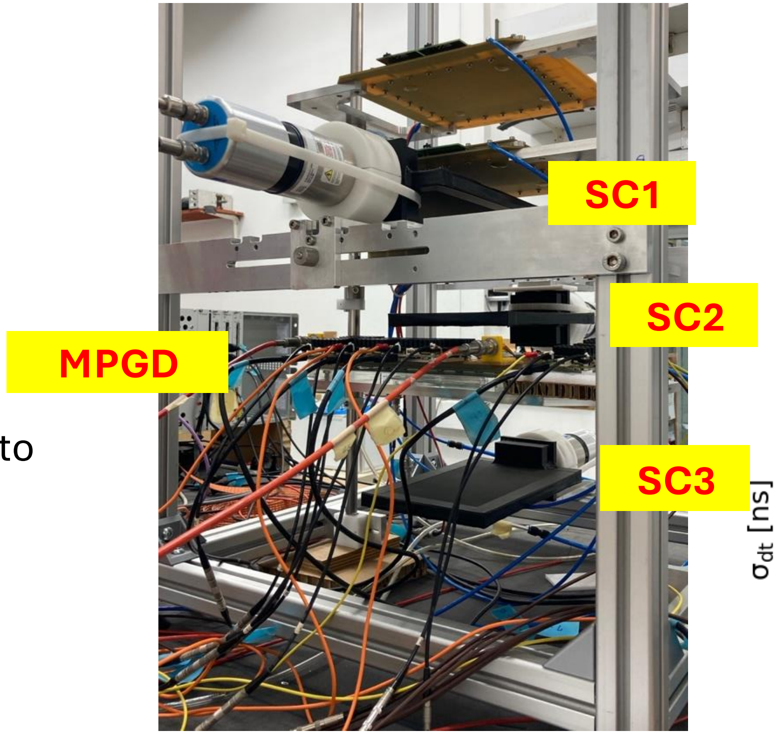
- Cosmic test bench in the lab
  - One detector at a time, power supply from DVMM through HDMIs
  - Efficiency defined relative to trigger time

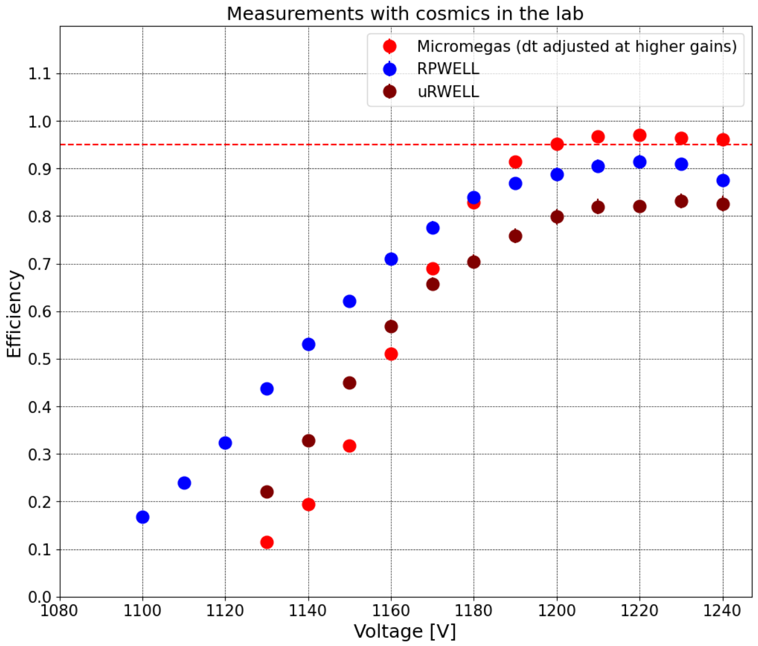
- H4 SPS NA test beam (total 2688 channels)
  - External power supply for VMM hybrids
  - Tracking with RD51 telescope
  - Efficiency defined relative to trigger time and distance from track

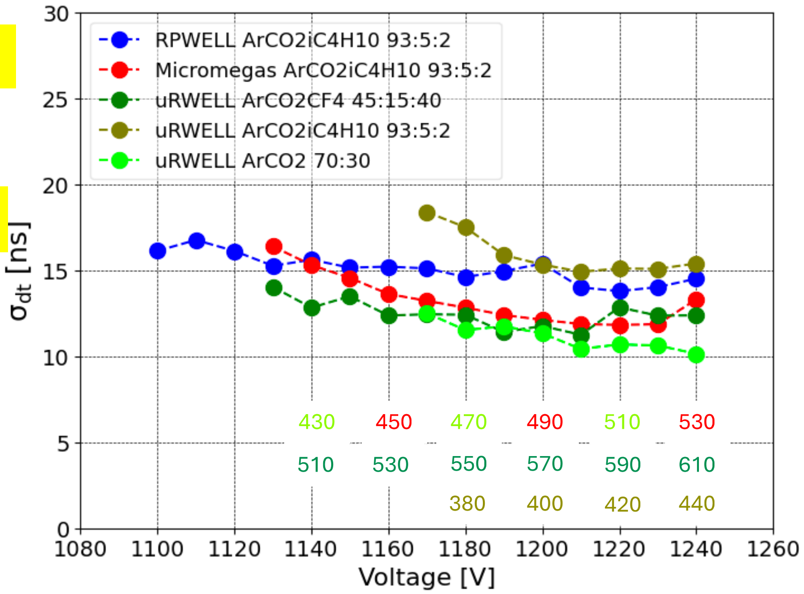
Lab results

[presented in June 2024, at [DRD1 collaboration meeting]]

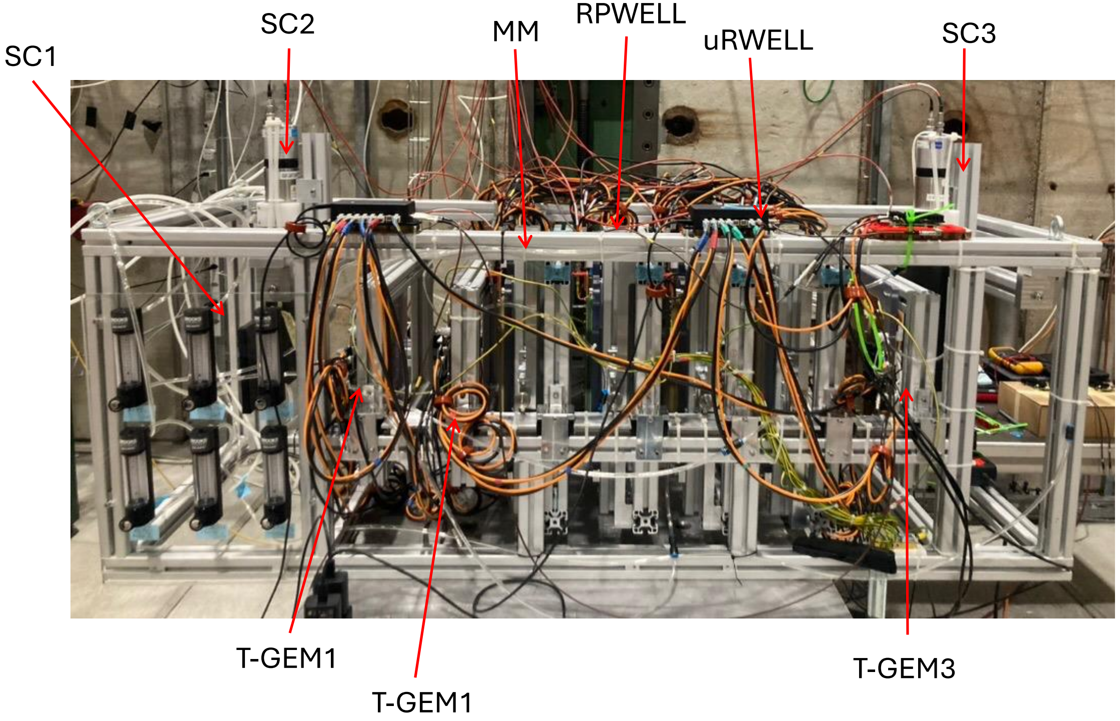
- Efficiency as a function of various parameters, e.g. amplification voltage
  - MM and RPWELL > 90%
  - uRWELL ~ 80%
    - dead area, observed with large statistics in the beam
- Time resolution estimation
  - Similar values for all technologies
  - uRWELL and MM slightly better due to smaller amplification gap
- Saturated signals
  - Imposed electronic dead time and effciency loss
  - Recovered by adjusting dt cut







H4 SPS NA Test Beam

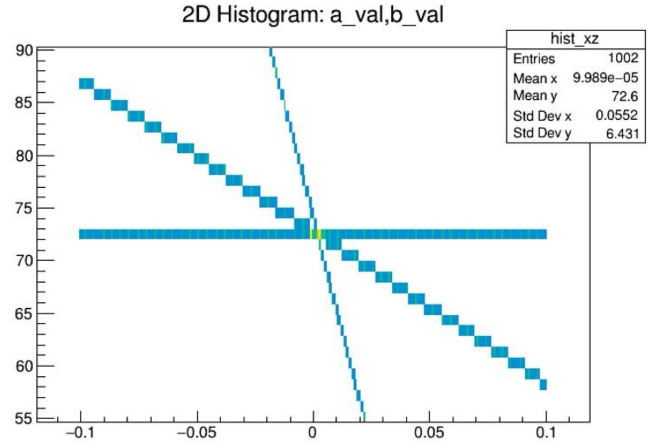


- Common settings
  - 3 mV/fC gain
  - 200 ns shaping time
- Tracking triple GEMs
  - 3-4 mV peak-to-peak noise → 40mV threshold
  - Neigbouring logic enabled
  - Tracking efficiency ~75%
- Tested detectors
  - 1 mV peak-to-peak noise → 10 mV threshold
  - signal amplitude at the efficiency plateau > 220mV
    → factor of 5 above the threshold

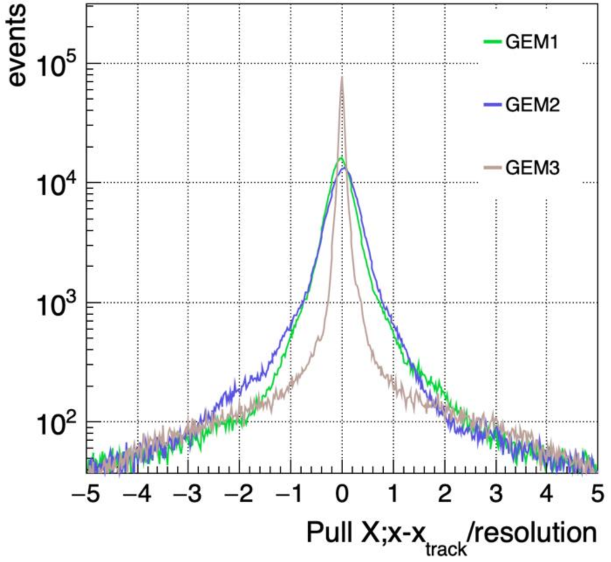
Tracking software

- Two independent packages seeded with clusters
  - Standalone based on Hough Transform ([tb24-tracking]())
  - [Corrryvreckan]()
- Consist of several steps
  - Event building associating cluster to trigger based on dt
  - Track reconstruction
    - Including tracking chambers alignment
  - Track interpolation to tested detectors' plane
- Similar tracking performance
- No effect on measured performance of tested detectors

Example of track accumulation in Hough space



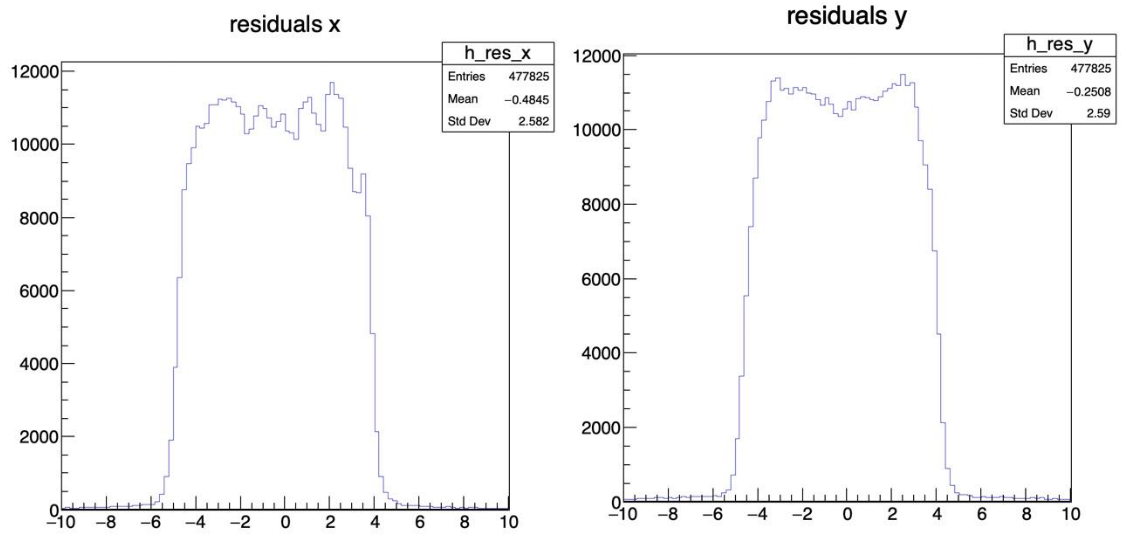
Tracking detectors residuals after alignment and rotation fix in Corry



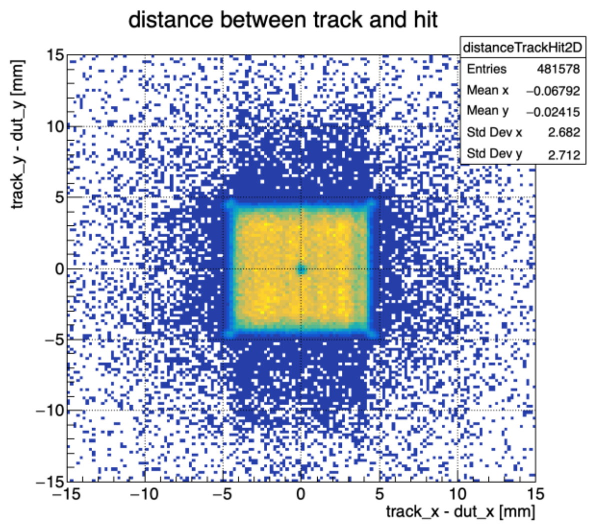
Analysis

- Cluster matching to a track within a given distance
  - Tested detectors residuals dictated by the pad size (1 cm^2)
- In case >1 clusters match, considering the closest (min residual)

Residuals obtained for tested detectors with Python script running on tb24-tracking output



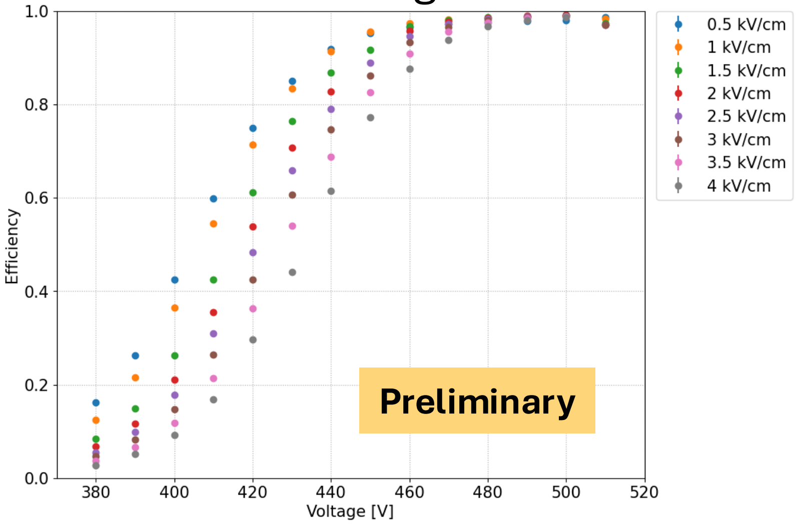
2D plot of residuals obtained for tested detectors with Corry



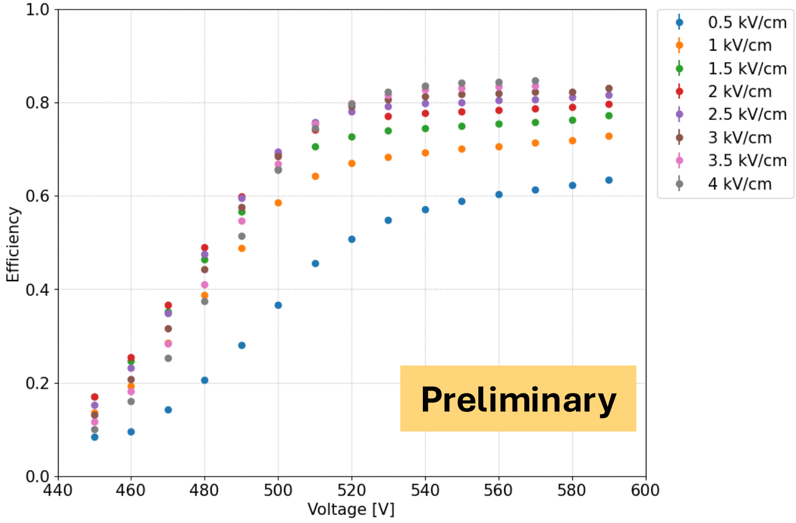
Beam results – Efficiency

- Average efficiency as a function of amplification voltage for different drift fields
- Efficiency = matched clusters / total number of selected tracks
  - Matching distance ±10mm
  - Tracks selection based on slope cut (straight tracks)

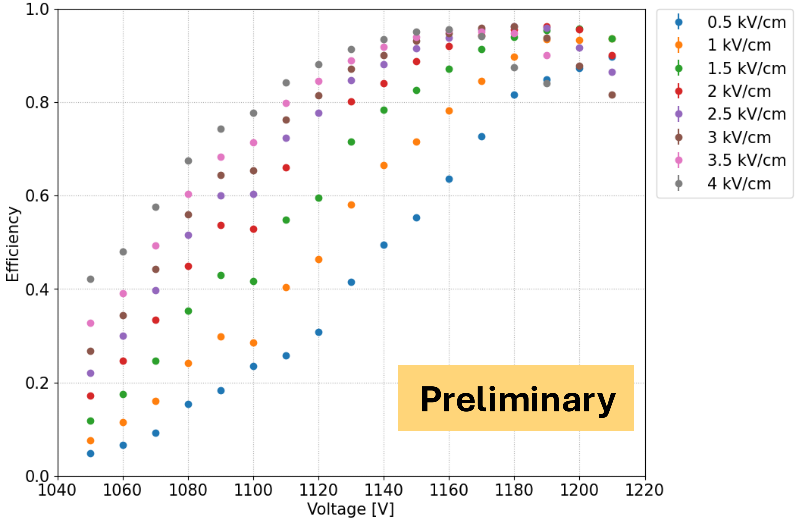
Micromegas



uRWELL

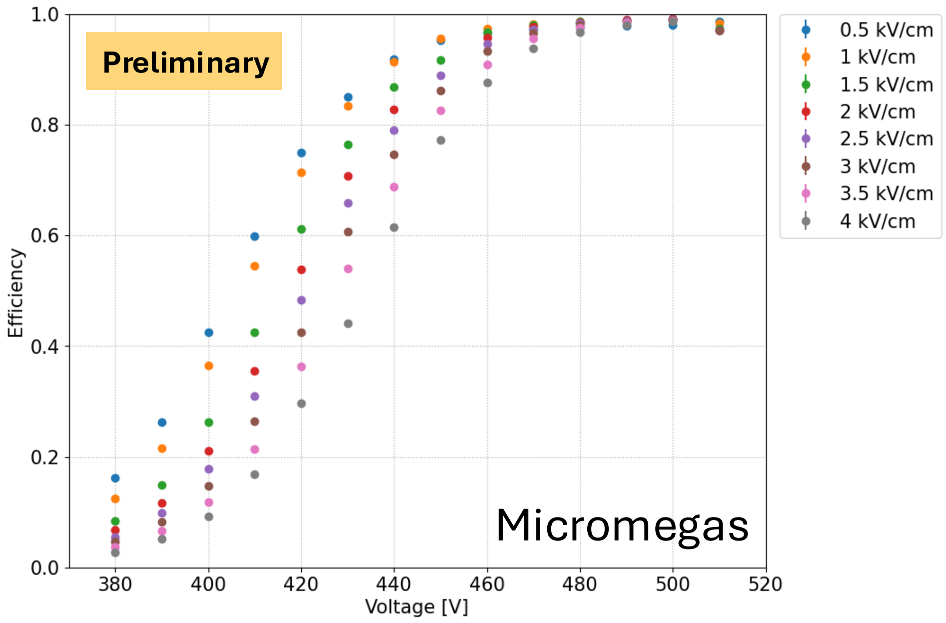


RPWELL



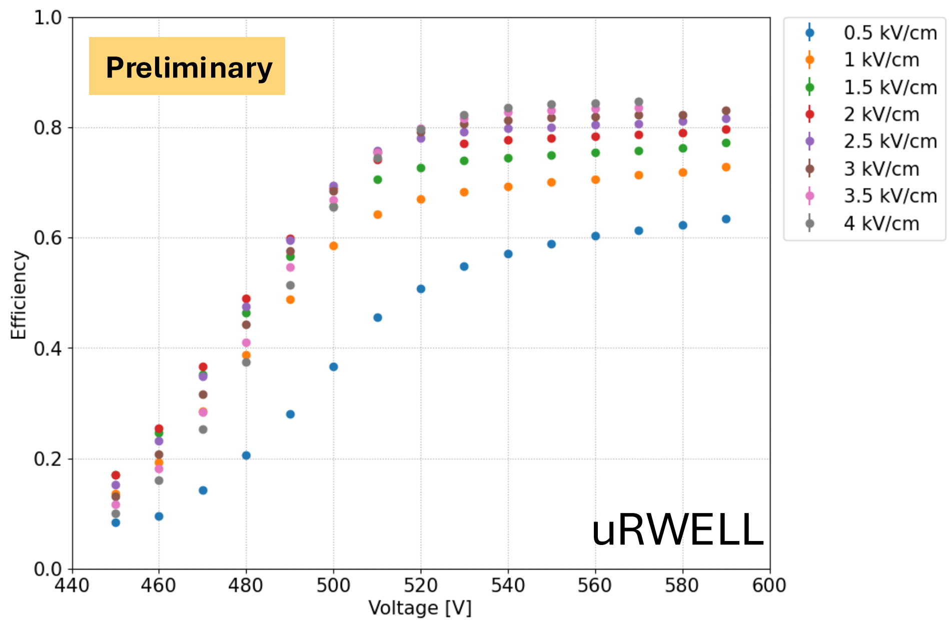
Beam results – Efficiency

- Average efficiency as a function of amplification voltage for different drift fields
- Efficiency = matched clusters / total number of selected tracks
    - Matching distance ±10mm
    - Tracks selection based on slope cut (straight tracks)
- MM
    - Plateau @ 98% efficiency for all drift filed
    - @ low drift field the turn on curve start early
    - @ high drift filed the turn on curve is steeper



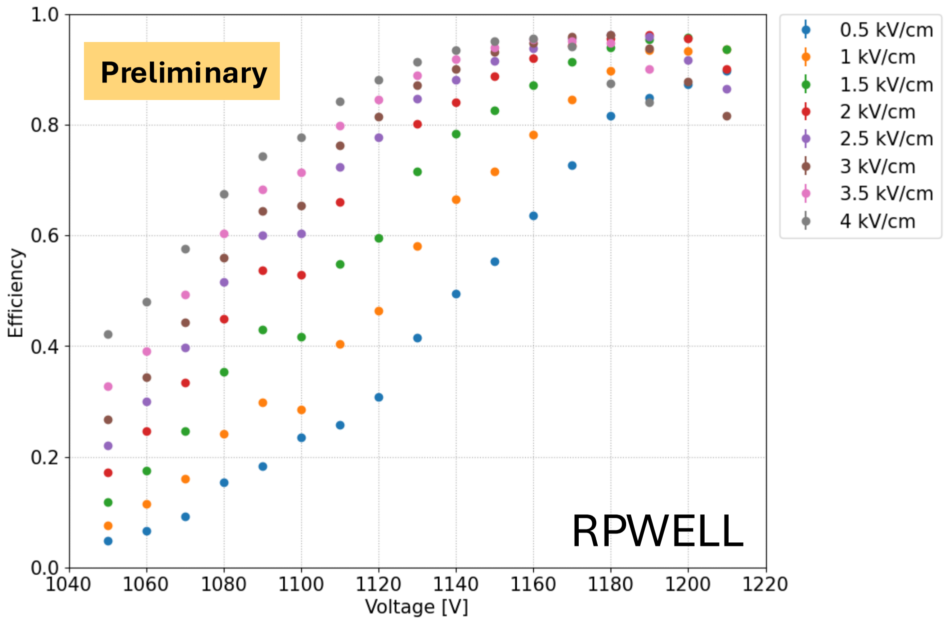
Beam results - Efficiency

- Average efficiency as a function of amplification voltage for different drift fields
- Efficiency = matched clusters / total number of selected tracks
  - Matching distance ±10mm
  - Tracks selection based on slope cut (straight tracks)
- MM
  - Plateau @ 98% efficiency for all drift filed
  - @ low drift field the turn on curve start early
  - @ high drift filed the turn on curve is steeper
- uRWELL
  - Plateau @ 84% due to large dead area
  - Higher efficiency for higher drift fileds



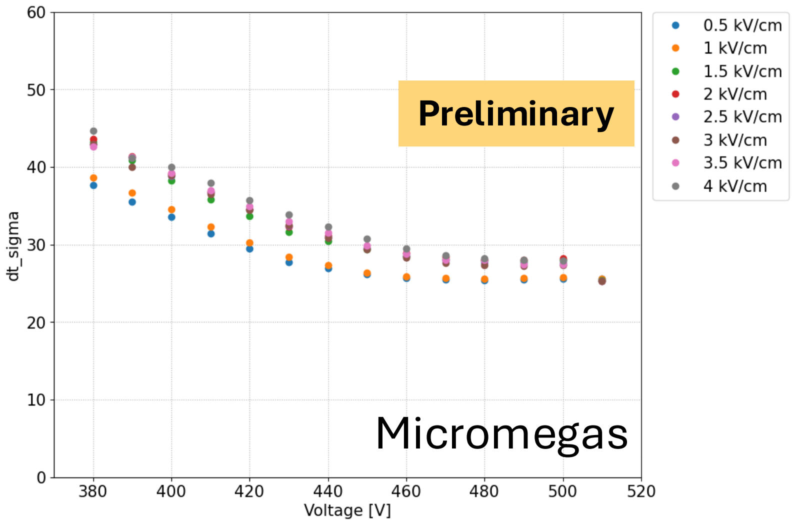
Beam results - Efficiency

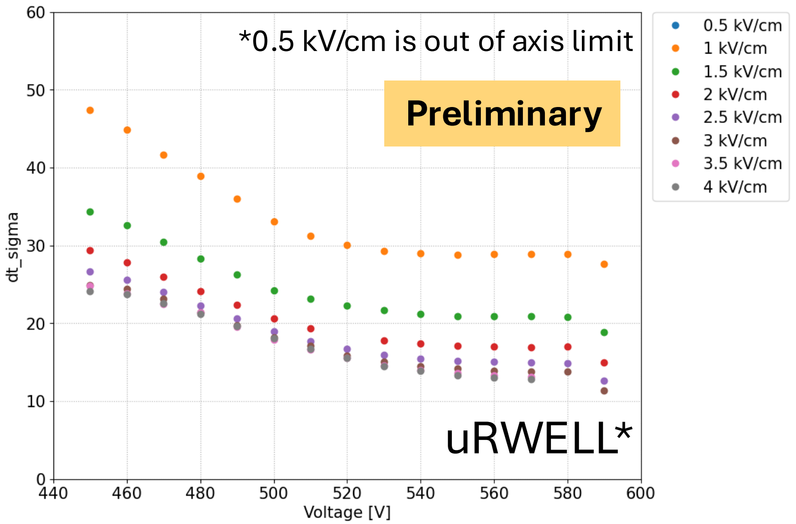
- Average efficiency as a function of amplification voltage for different drift fields
- Efficiency = matched clusters / total number of selected tracks
  - Matching distance ±10mm
  - Tracks selection based on slope cut (straight tracks)
- MM
  - Plateau @ 98% efficiency for all drift filed
  - @ low drift field the turn on curve start early
  - @ high drift filed the turn on curve is steeper
- uRWELL
  - Plateau @ 84% due to large dead area
  - Higher efficiency for higher drift fileds
- RPWELL
  - Plateau @ 96% due to small dead area and a few dead channels
  - Efficiency loss at high gain probably due to staturated signals induing electronic dead time
  - Intermediate (2.5 kV) drift fields are optimal

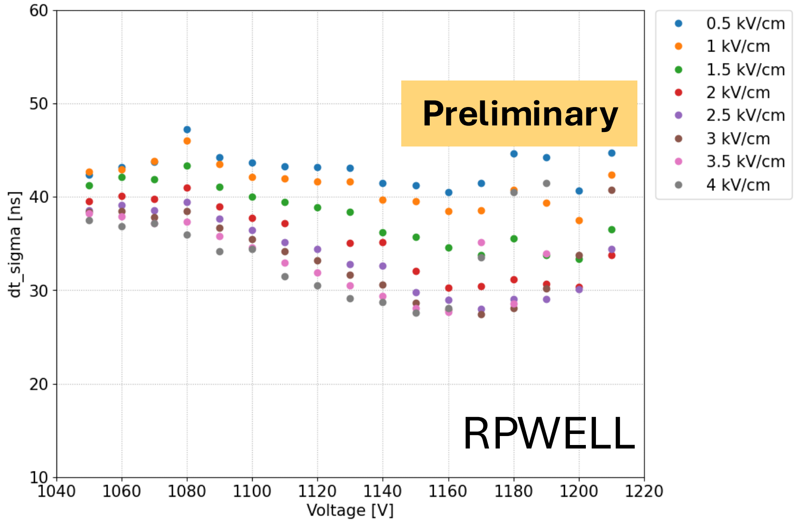


Beam results – Time resolution

- Time resolution as a function of amplification voltage for different drift fields
- Estimated as σ_{dt}

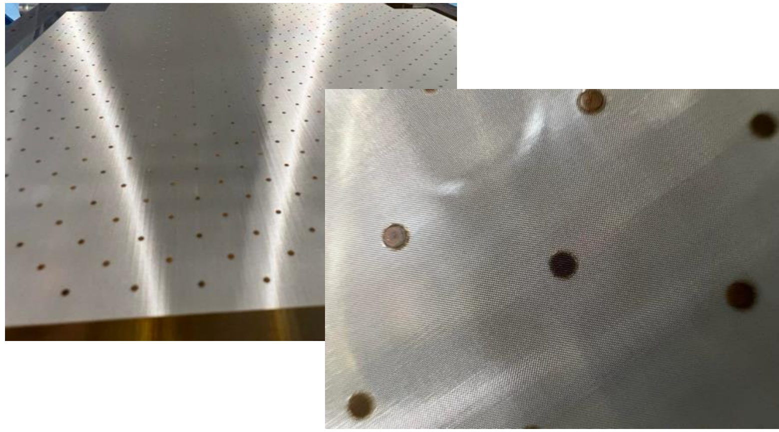






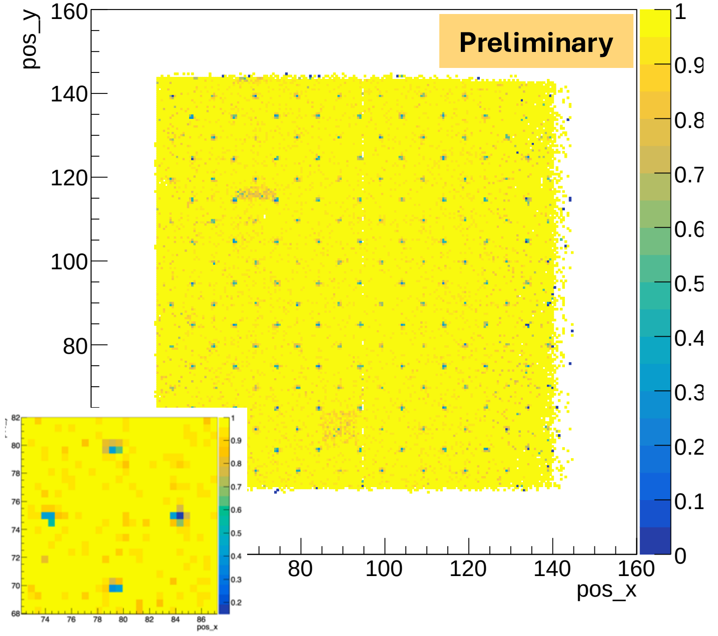
- Time resolution higher than the one measured in the lab (~13ns for MM, uRWELL) – to be understood
- Otimal time resolution and optimal efficiency obtained for similar drift fields

A closer look at the MM

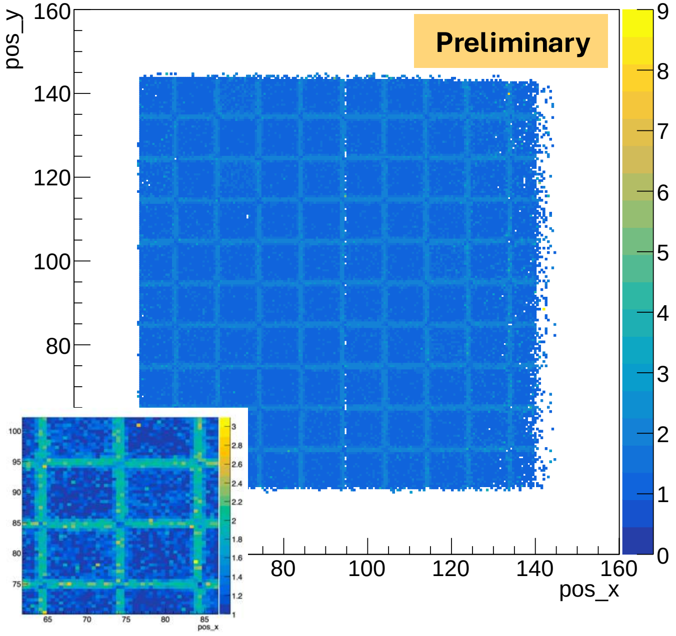


- 490V in $ArCO_2iC_4H_{10}$
- 1.0 kV/cm drift field
- Av. Efficiency = 98%
- Periodical / uniform response

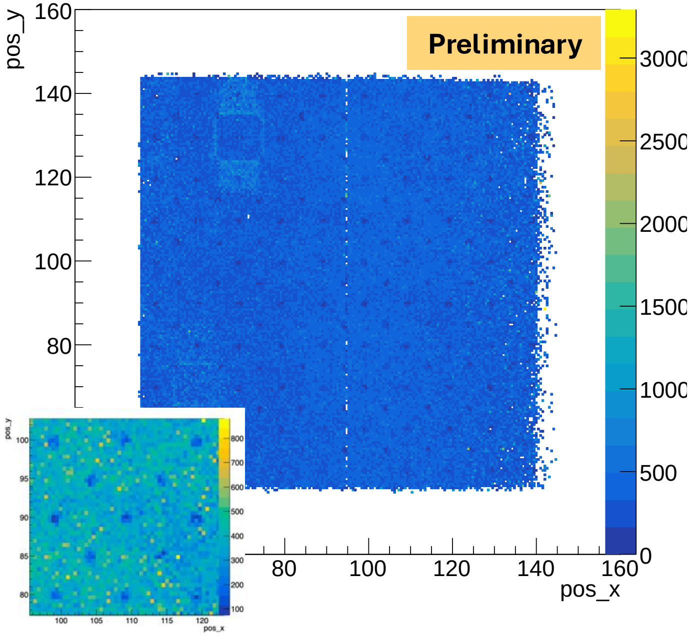
Efficiency Map



Cluster Size Map

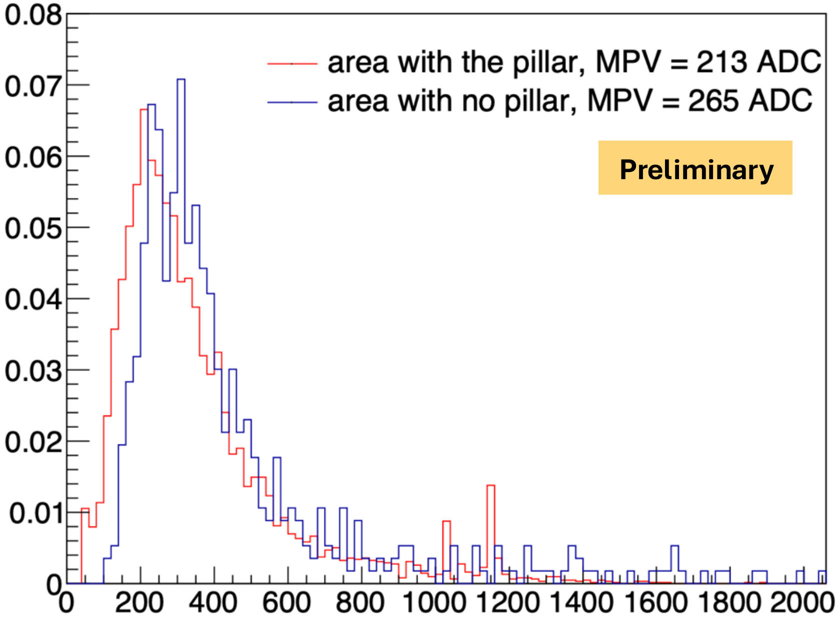


Cluster Charge Map

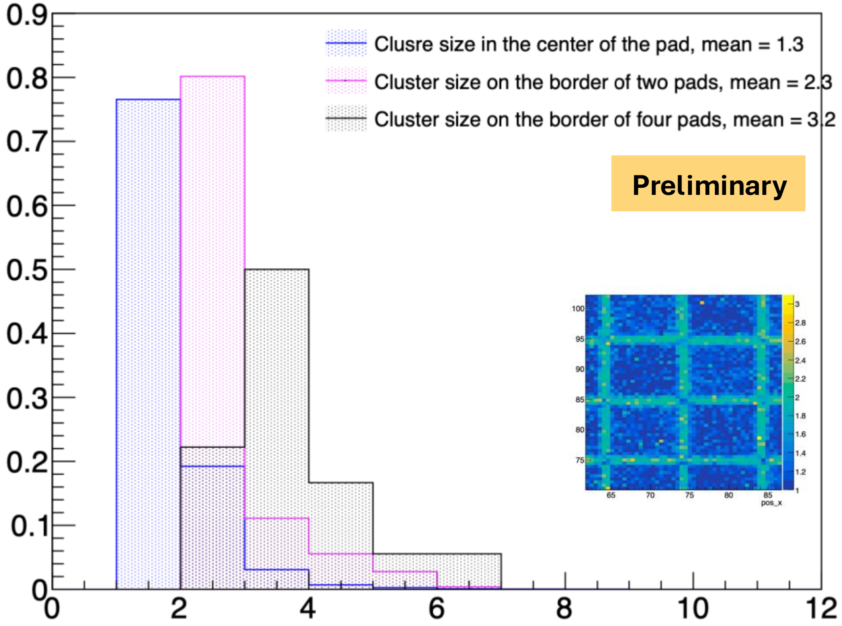


A closer look at the MM

- Charge distribution of 5×5 mm^2 areas
  - Without a pillar
  - With a pillar – MPV drop by 20%



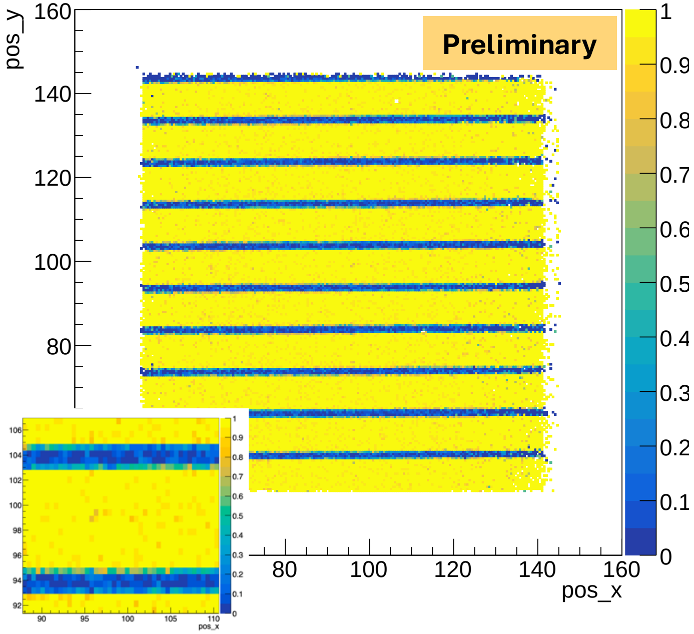
- Cluster size distribution
  - Pad center
  - 2 pads border – 1.5 mm effect 28% of the total area
  - 4 pads corner



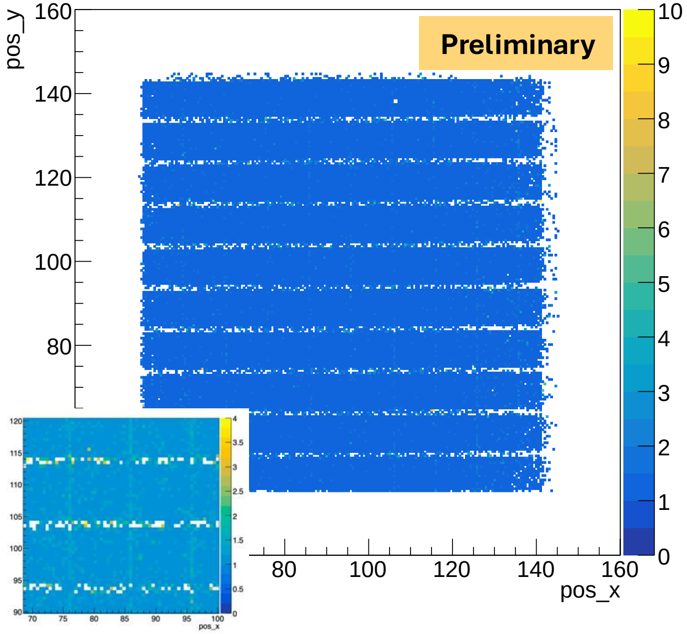
A closer look at the uRWELL

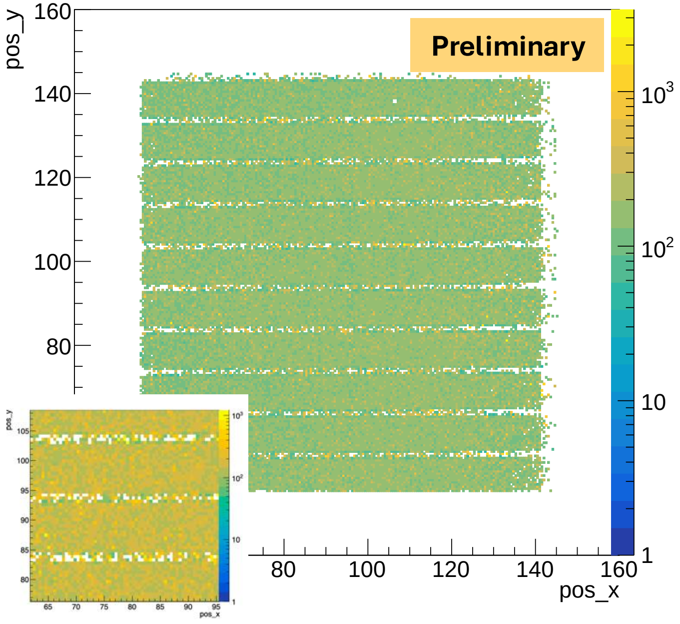
- 560V in $ArCO_2CF_4$
- 4.0 kV/cm drift field
- Periodicity consistent with the DLC grounding lines
- Av. Efficiency = 0.844 (2 mm wide dead horizontal lines, 19% of the tested area)

Efficiency Map



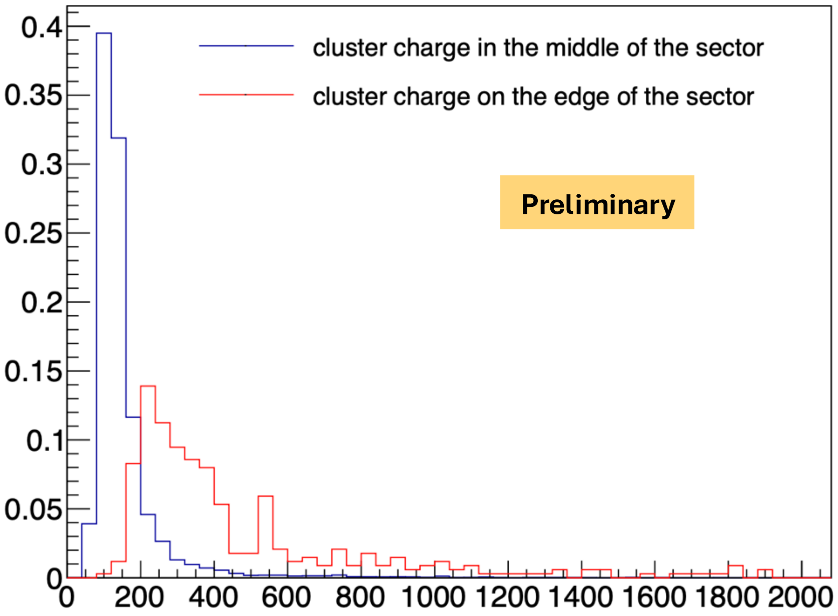
Cluster Size Map



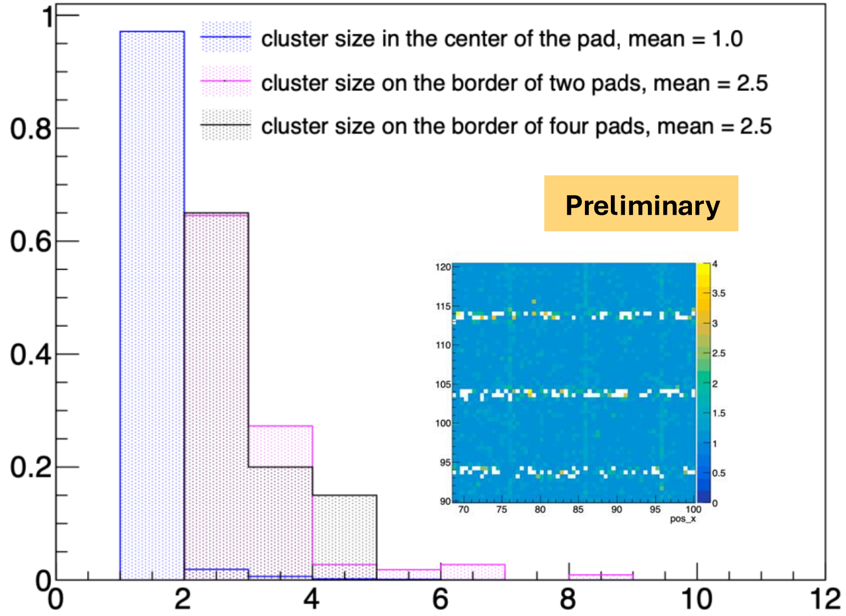


A closer look at the uRWELL

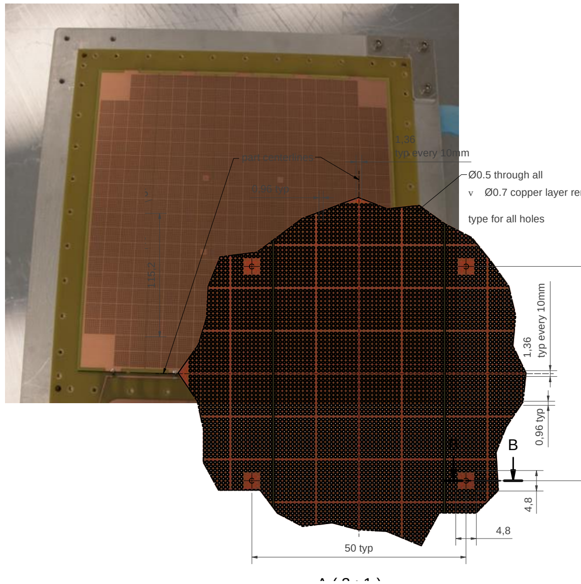
- Charge distribution for two 2 mm wide lines
  - In the middle of HV sector
  - On the edge of the gounding line
    - MPV increases by a factor of two
      To be understood, higher gain on the edge might explain part of the effect



- Cluster size distributions
  - Pad's center
  - 2 pads border – narrow vertical structure is observed
  - 4 pads corner

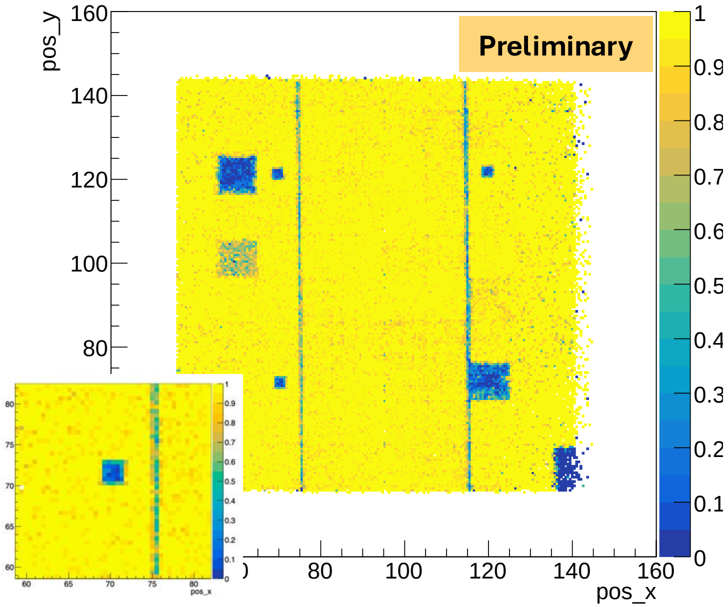


A closer look at the RPWELL

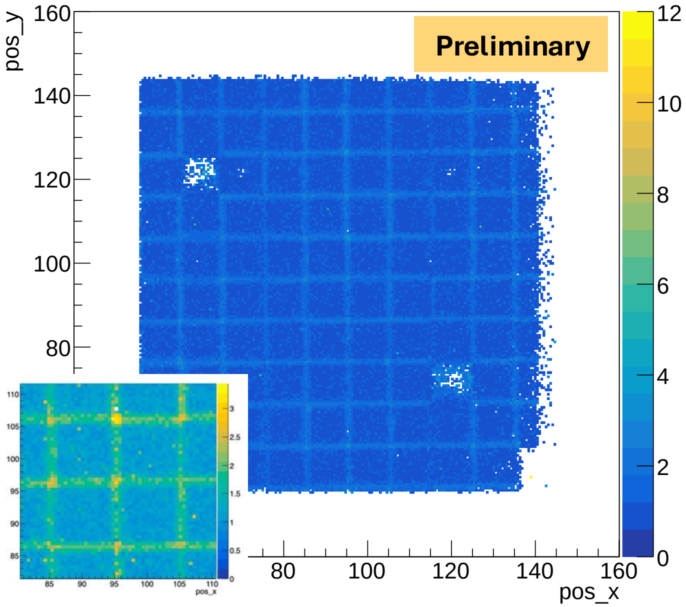


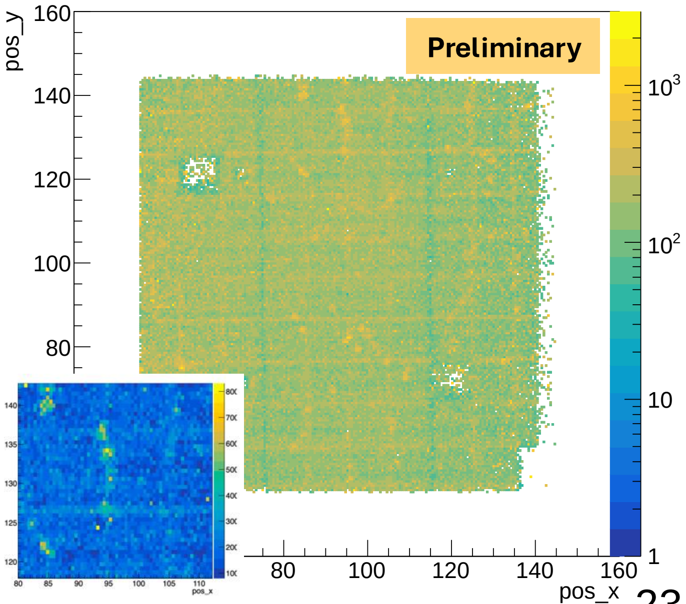
- 1180V in $ArCO_2iC_4H_{10}$
- 2.5 kV/cm drift field
- Av. Efficiency = 96% consistent with ~ 3% dead area
  - 2.5 fully dead channels
  - 3 gluing points
  - 2 lines separating HV sectors

Efficiency Map



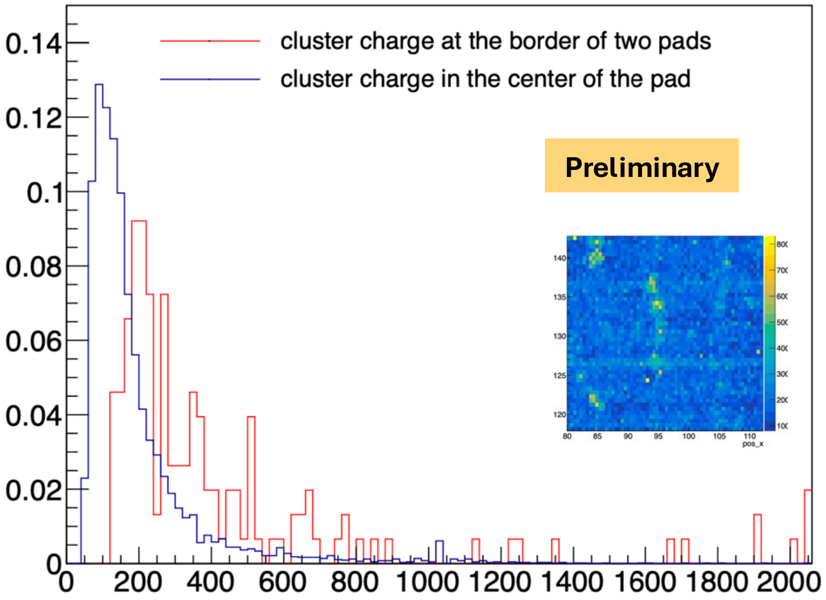
Cluster Size Map

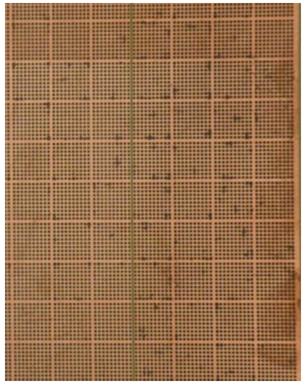




A closer look at the RPWELL

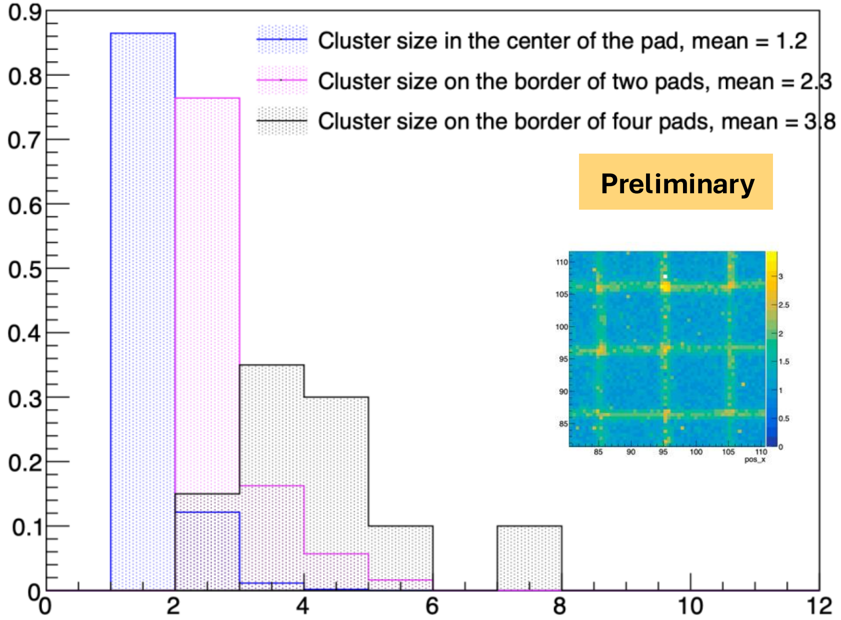
- Charge distribution for two areas
  - Center of a pad
  - Edge of the pad
    Charge saturation due to higher field as reported originally by the Trieste group





Picture of THWELL electrode with holes affected by discharges

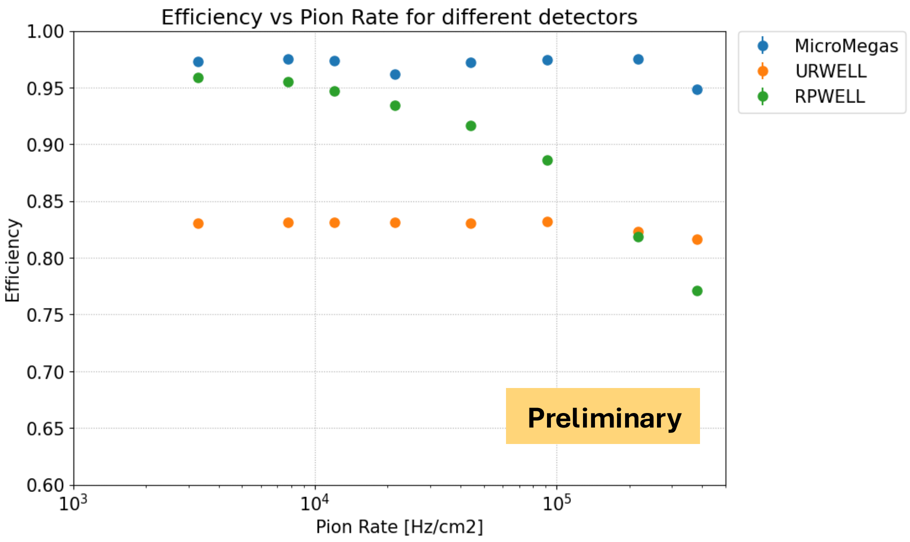
- Cluster size distributions
  - Pad center
  - 2 pads border – 2 mm effect for a total of 38% of the area
  - 4 pads corner

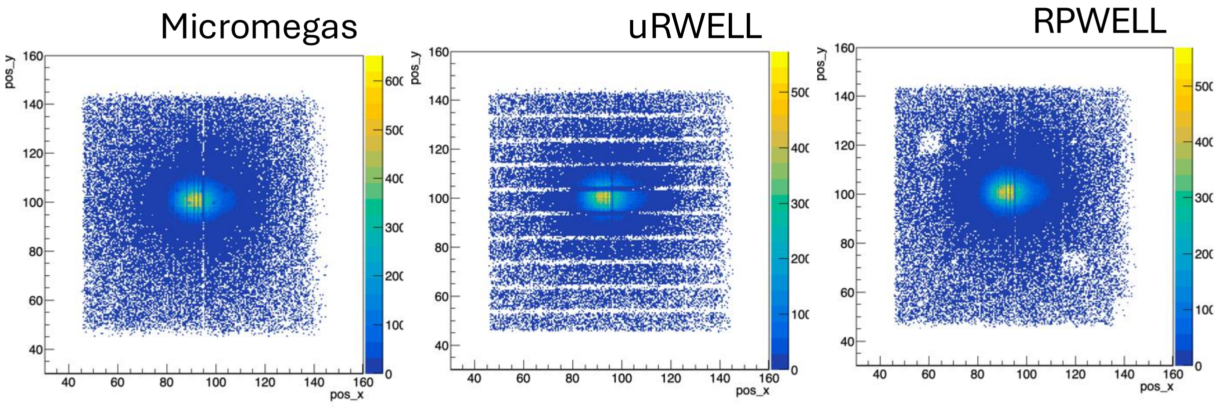


Operation at high pion rate

- Operation conditions
  - MM
    - @ 470V
    - 0.5 kV/cm
  - uRWELL
    - @ 550V
    - 3.5 kV/cm
  - RPWELL
    - @ 1170V
    - 2.5 kV/cm

- RPWELL gain drops earlier due to higher resistivity



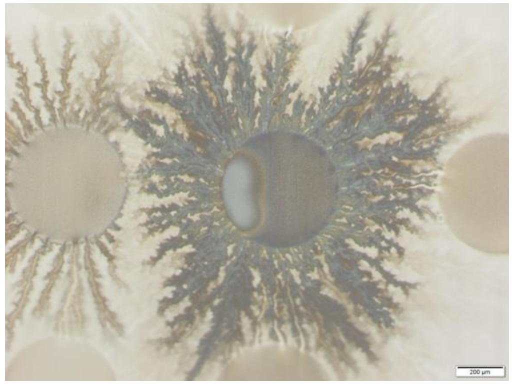


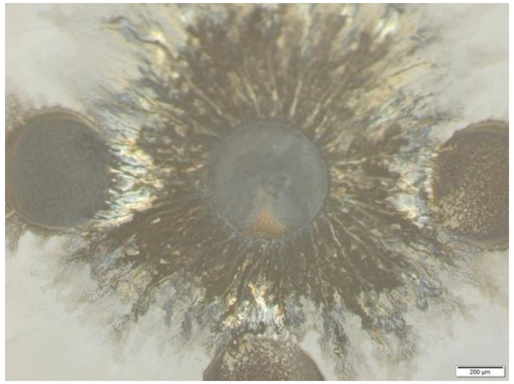
Instabilities

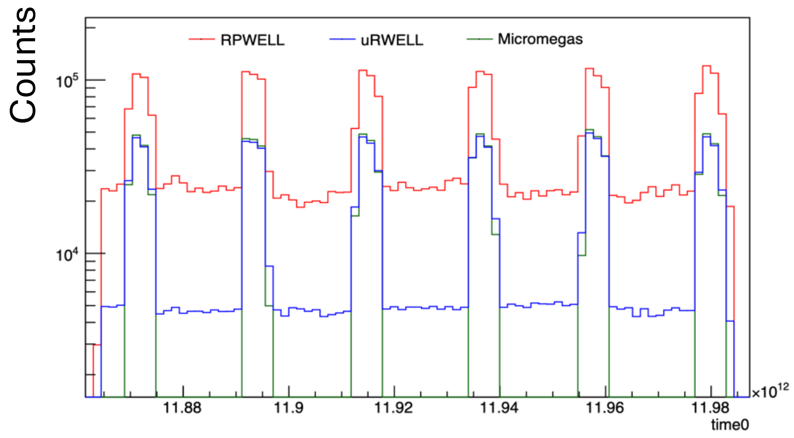
- Out of spill hits observed in all technologies
  - Much higher rate in RPWELL
- Saturated out of spill hits observed in RPWELL and MM

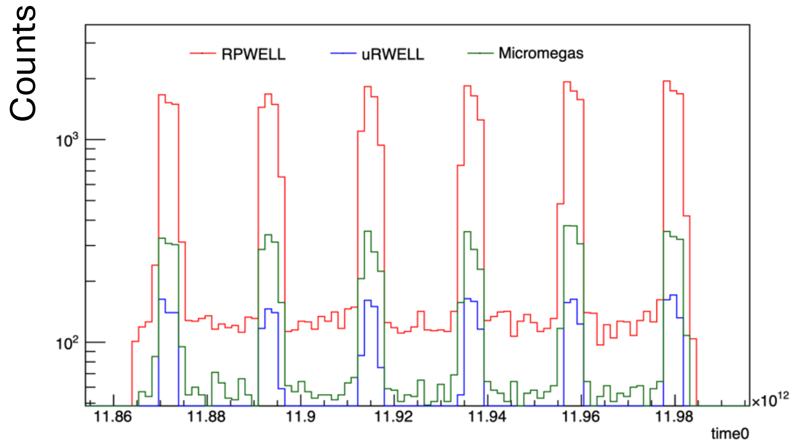
- RPWELL instabilities might be due to the gap between the bottom WELL electrode and the resistive plate
  - Hole shaped patterns are observed on the glass

Glass surface pictures, holes pattern can be seen









Disscussion and outlook

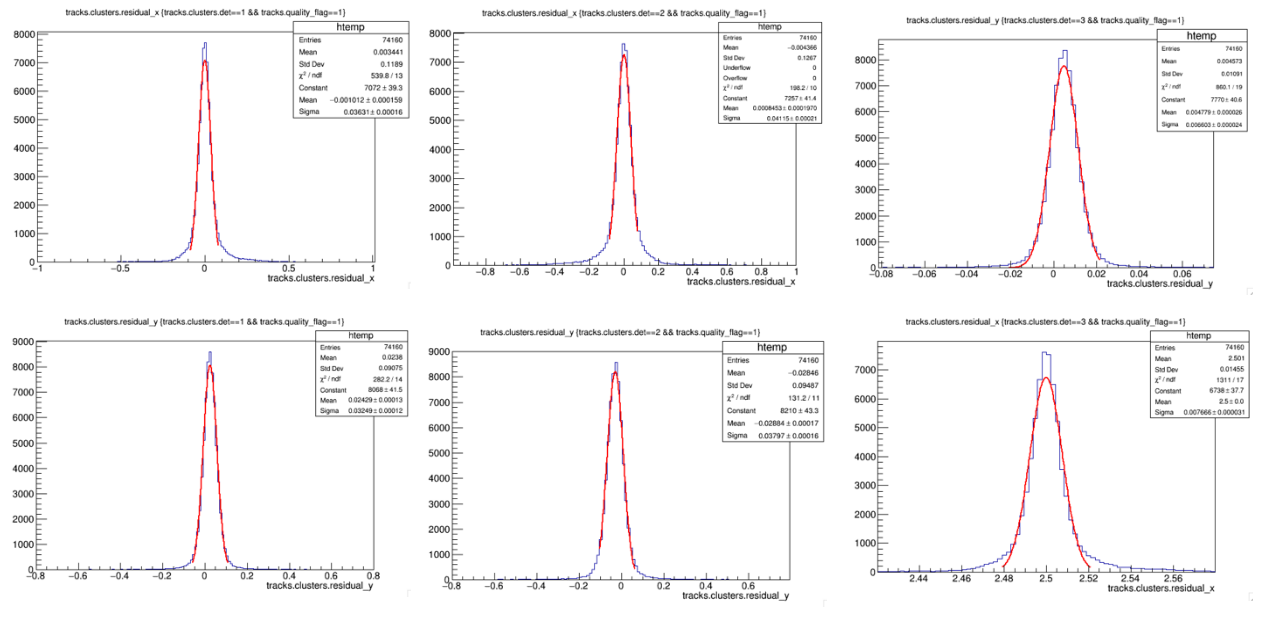
- Measurements with resisstive MM, uRWELL and RPWELL detectors were carried out in similar conditions
  - In the laboratory, in muon and high rate pion beams
  - With 1 cm^2 pad readout with VMM3/SRS readout electronics
- Laboratory and beam results are mostly in agreement

- Preliminary comparison of the performance of the three technologies is reported
- Efficiency plateau is reached with all technologies
  - Actual values point out towards the need to optimize the design of some of the components
- Observed gain and cluster size variations are consistent with the design of all technologies
- Sources of instabilities needs further investigation
  - RPWELL is mostly affected

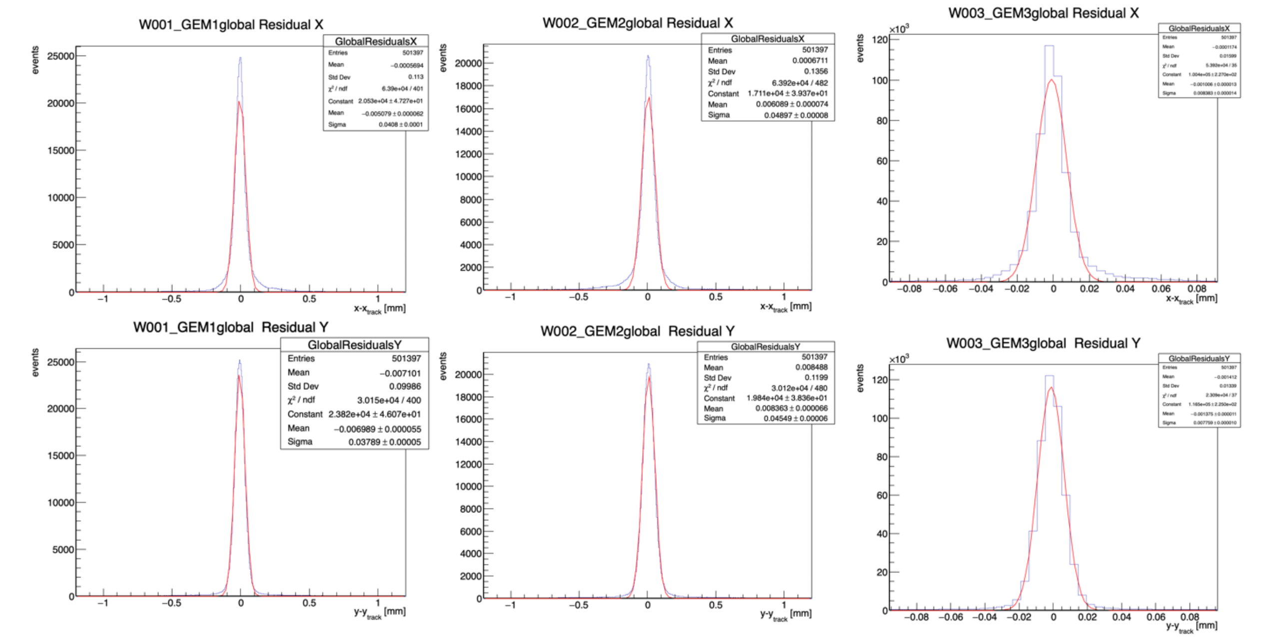
Thank you!

Tracking algorithms

tb24-tracking



Corry



Tracker resolution ~ 40 um obtained with both algorthms
Third tracking station is ~85 cm far from the first station → most weight, biased residuals