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WEIZMANN INSTITUTE OF SCIENCE

Resistive Plate WELL Detectors as DHCAL sampling elements

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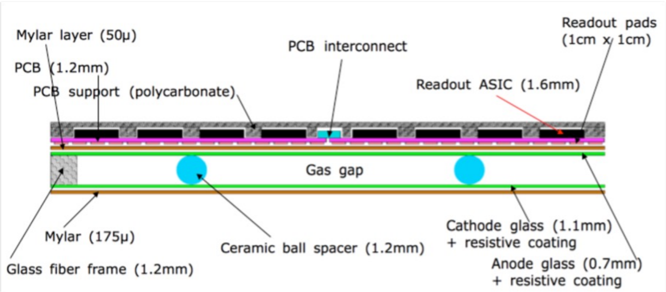
Introduction

- Future accelerator experiments pose stringent requirements on their detectors
  - In particular, unprecendendent jet energy resolution, 30%/√E
- Particle Flow (PF) is a leading approach towards the desired resolution
- Employment of highly granular calorimeters is a key in PFA (both ECAL and HCAL) realization
- High granularity can be provided by using segmented sampling elements
  - Scintilator tiles – ACAL
  - Gaseous detectors – (s)DHCAL

- Requirements for DHCAL sampling elements:
  - Compactness
  - Total volume of 100 m^3 (CEPC TDR)
  - 10^7 – 10^8 readout channels
  - Uniform performance
  - High detection efficiency
  - Low average pad multiplicity

Available gaseous detectors technologies

Resistive Plate Chamber (RPC)

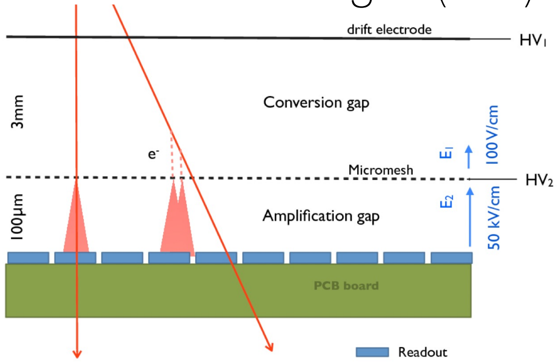


- Technological prototype built and tested
  - 48 layers
  - Fe and W absorbers
- Operated in Flourine based gases

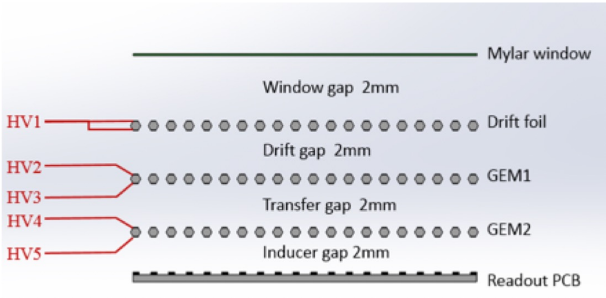
Refs:
G. Baulieu et al 2015 JINST 10 P10039
J Repond 2014 JINST 9 C09034
B. Bilki et al 2015 JINST 10 P05003

Micro-Patern Gaseous Detector (MPGD)

Resistive Micromegas (MM)



Gaseous Electron Multiplier (GEM)



- Operated in environment friendly gases (Ar)

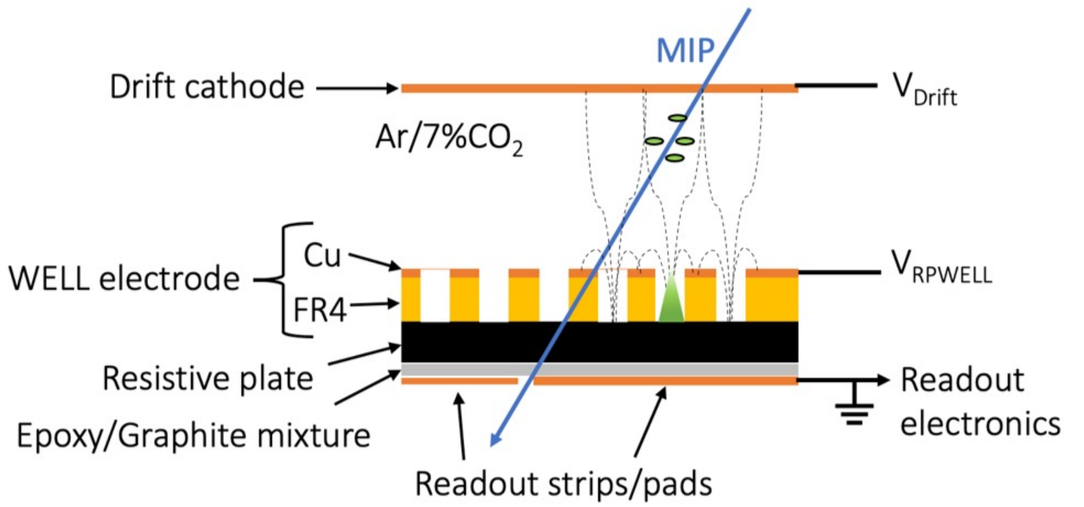
- 1×1 m^2 chambers built and tested
- Response to pions simulated for 100 layers
- Expected resolution is similar to RPC DHCAL

- 30×30 cm^2 chambers built and tested
- 20% gain uniformity
- Low spark probability
- Closed geometry

Refs:
https://doi.org/10.1016/j.nima.2013.06.081
W. You et al 2018 JINST 13 P01020

Resistive Plate WELL Detector

- Single-sided Thick GEM electrode coupled to the readout anode through high bulk resistivity
  - Combining RPC and MPGD concepts
- Ionization induced primary electrons
  - Drift along the field lines into the THGEM holes
  - Undergo charge avalanche multiplication
- Signals induced on a segmented anode by the movement of charges
- Stable operation at the gain up to a few 10^3 and rate up to $100 kHz/cm^2$

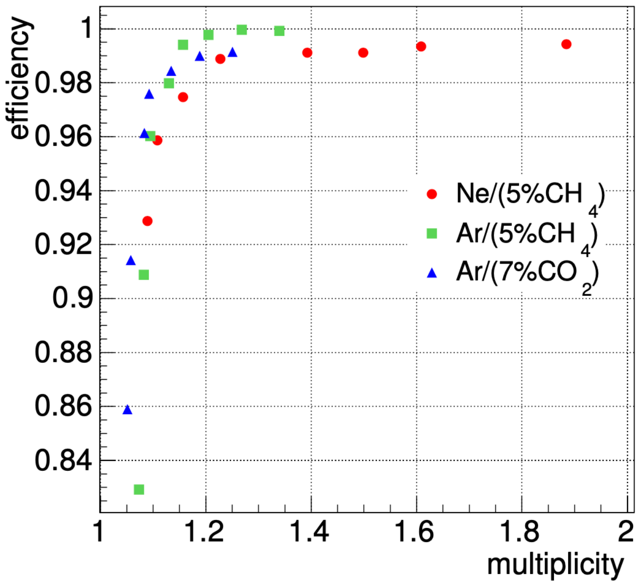


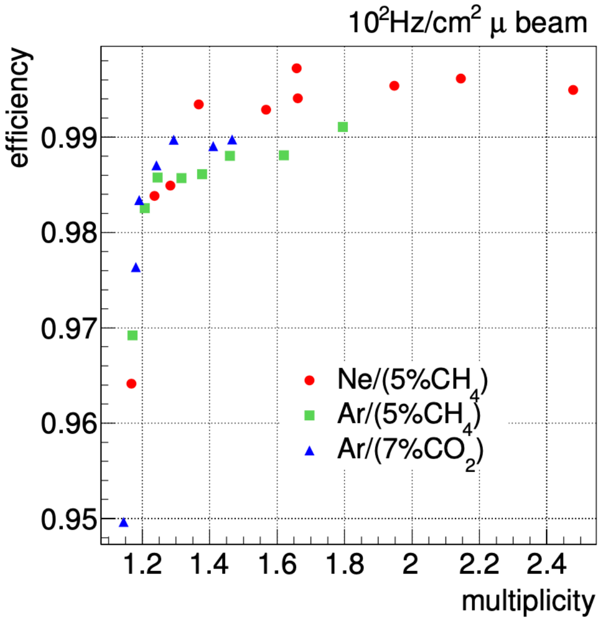
Potential advantages:

- Operation in environment friendly gases (Ar)
- Industrially produced
- Robustness
- Simple assembly procedure
- Closed geometry

Refs:
A Rubin et al 2013 JINST 8 P11004
L. Moleri et al 2017 JINST 12 P10017
L. Moleri et al 2016 JINST 11 P09013
https://doi.org/10.1016/j.nima.2016.06.009

RPWELL Performance – 10×10 cm^2 & 30×30 cm^2





- 1×1 cm^2 readout pads
- APV25 ASIC + SRS readout system

- 0.86 mm thick WELL
- Semitron plastic resistive plate (2×10^9 Ωcm bulk resistivity)

→ Could meet the DHCAL requirements

https://doi.org/10.34933/wis.000321
https://doi.org/10.1016/j.nima.2016.06.009

The challenge: scaling up – 50×50 cm^2

- Tried different techniques:
  - Mechanical pressing
    - Large dead areas
    - Hard to ensure uniformity
  - Gluing by spraying the bottom electrode
    - Hard to prevent glue from penetrating into the holes
    - Not sufficiently strong adhesive properties
  - Spreading epoxy glue with a roller
    - Hard to prevent glue from penetrating into the holes

- Optimized procedure
  - Gluing in dedicated points

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– will be discussed later

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- The version available for test beam campaign in 2018
- Before LHC long shutdown
- Worked with sub-optimized detectors
- Goals:
  - Gain experience in calorimeter setups
  - Collect data to validate simulation

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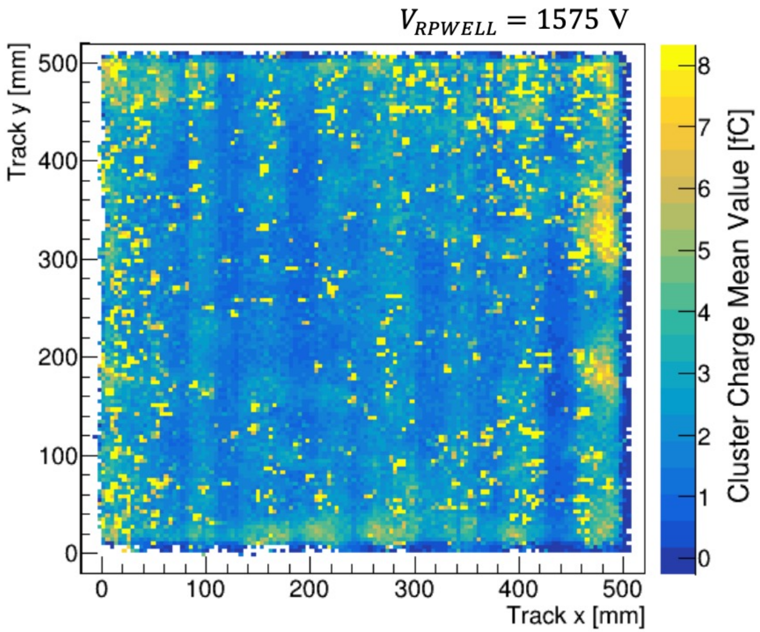

Measurement with analog readout:

- Non-uniform response due to the electrode thickness variations
- Instabilities – high charge events
- Had to work below the efficiency plateau

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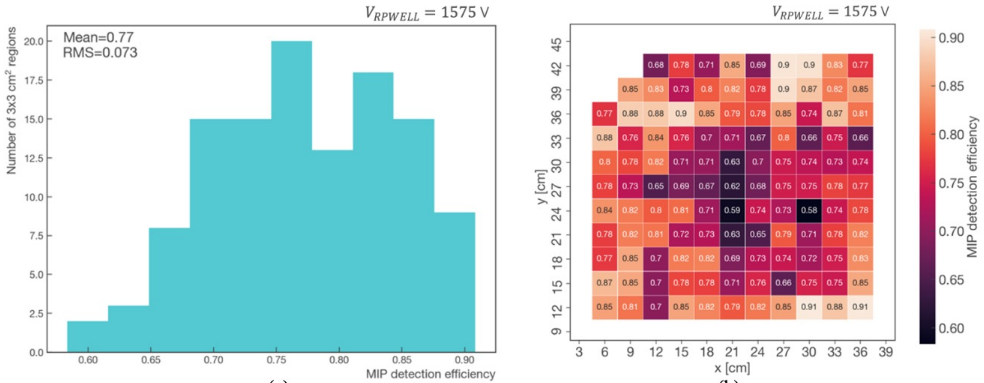
- Before LHC long shutdown
- Worked with sub-optimized detectors
- Goals:
  - Gain experience in calorimeter setups
  - Collect data to validate simulation

Shaked Renous, Dan, DHCAL technical meeting report, 2019.

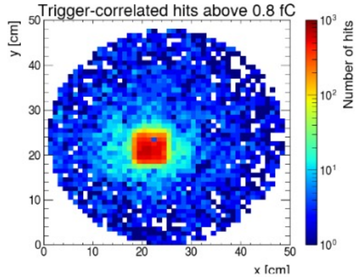
Single sampling element performance

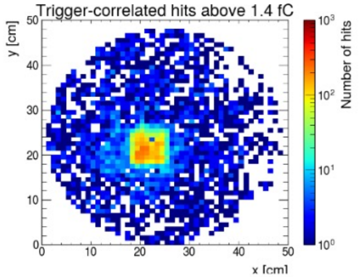
Measurement with semi-digital readout:

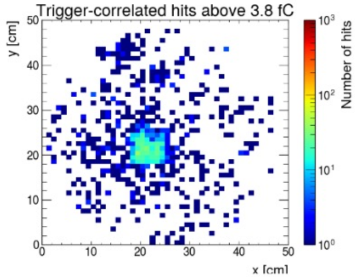
- 50×50 cm^2 area, 1×1 cm^2 readout pads
- MICROROC based semi-digital readout
- 0.8 mm thick WELL
- Adhesive coupling (Epoxy)
- Silicate glass resistive plate (10^9 – 10^{10} Ωcm)



(a) (b)



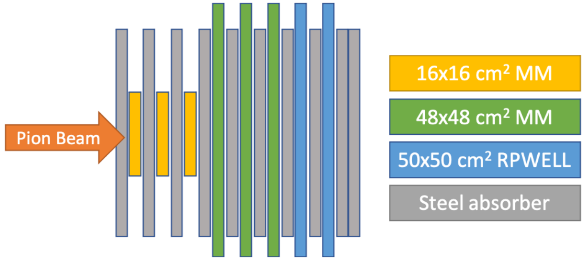




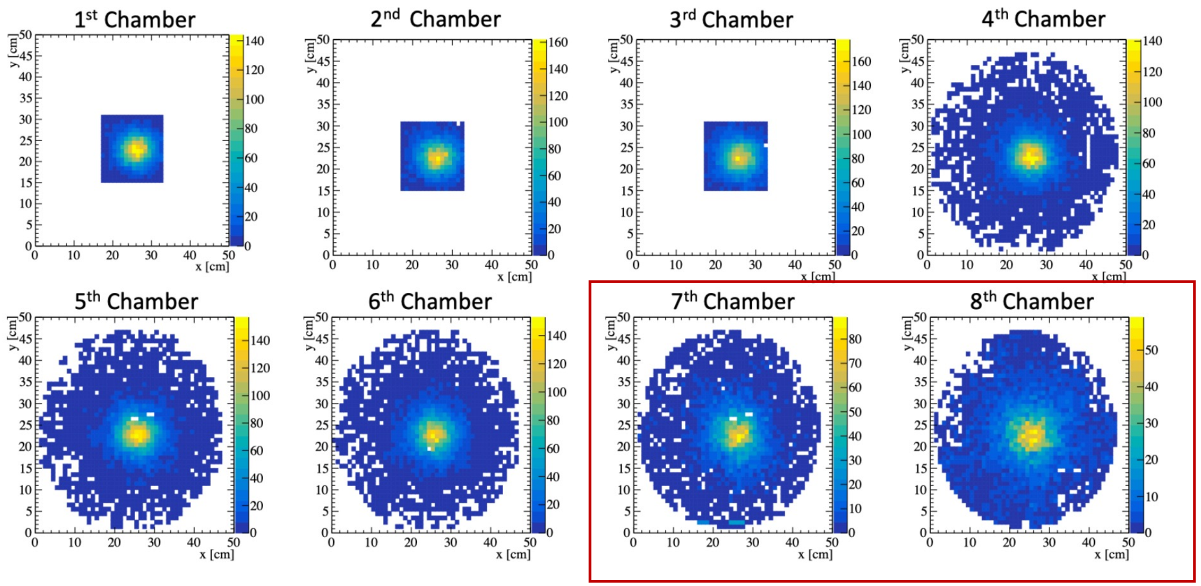
- Large efficiency variations (up to 50%) over the area
  - Thickness variations
- The efficiency plateau not reached
  - instabilities at a relatively low voltage

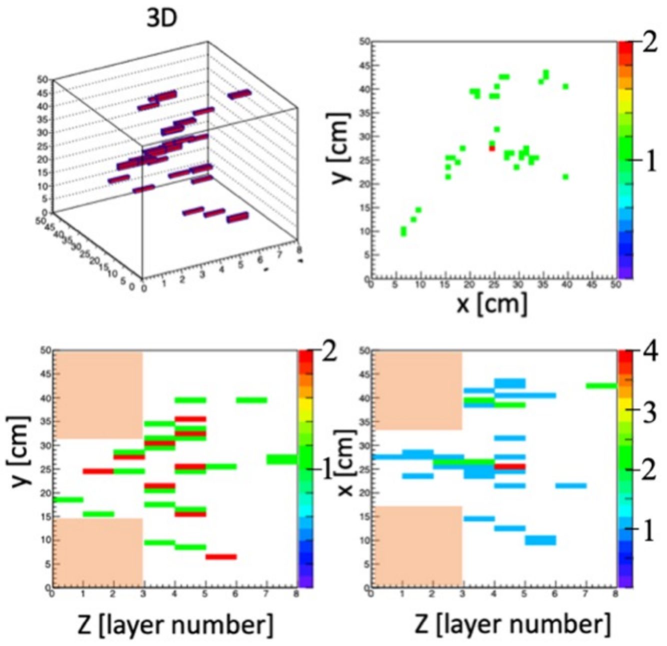
Shaked Renous, Dan. Investigation of RPWELL-based Digital Hadronic Calorimeter. Diss. The Weizmann Institute of Science, 2022.

RPWELL within the small MPGD based DHCAL



- Three 16×16 cm2 resistive Micromegas
- Three 48×48 cm2 resistive Micromegas
- Two 50×50 cm2 RPWELLs
- 2 cm thick steel absorbers



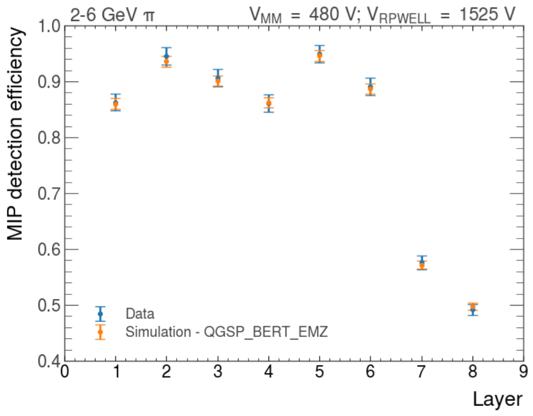


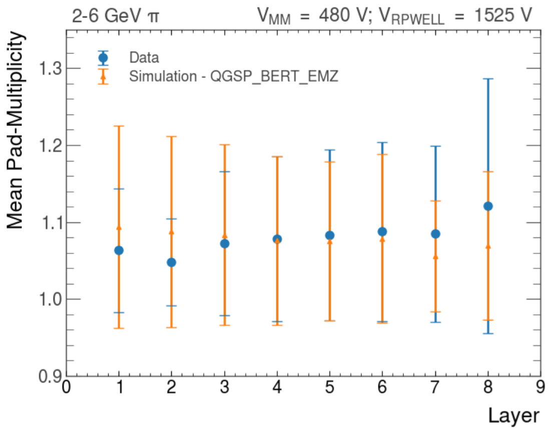
D. Shaked Renous et al 2020 J. Phys.: Conf. Ser. 1498 012040

Monte Carlo simulation & validation

- Geant4 simulation of small DHCAL setup emulating the measured sampling element
  - Modelling 8 sampling layers and absorbers
  - Physics modelling of pion interactions
  - Digitization – energy depositions to signals

- Validation – comparing the simulated response to measured response
  - Verification for each sampling element in terms of detection efficiency, pad multiplicity





Shaked Renous, Dan. Investigation of RPWELL-based Digital Hadronic Calorimeter. Diss. The Weizmann Institute of Science, 2022.

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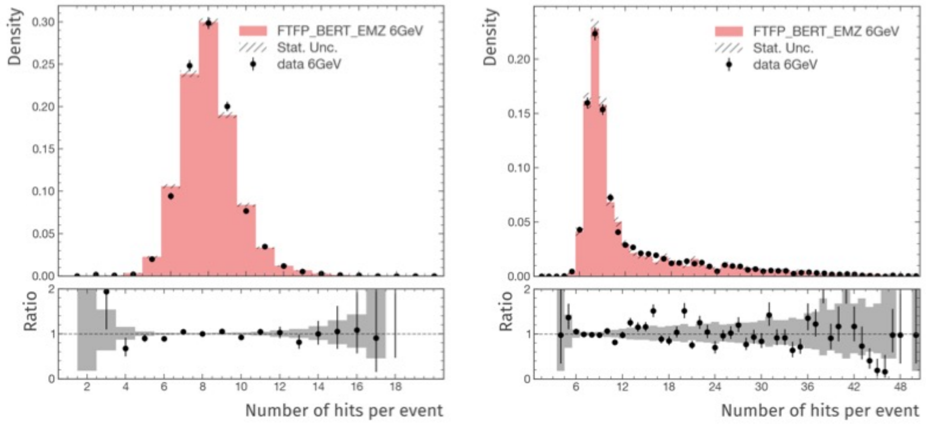
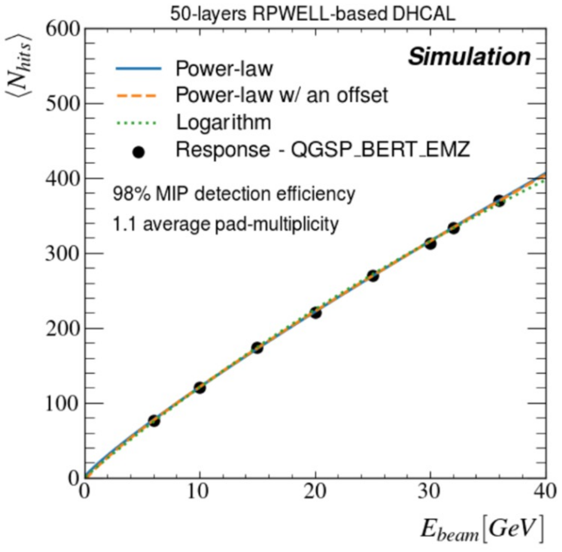
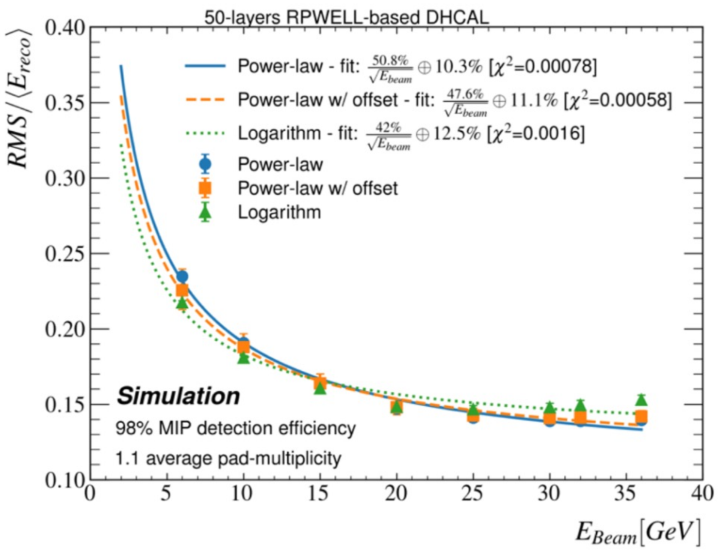
- Validation – comparing the simulated response to measured response
  - Verification for each sampling element in terms of detection efficiency, pad multiplicity
  - Verification for full setup – comparing response to pions
    - MIP-like events (left)
    - Showers and MIPs (right)



Shaked Renous, Dan. Investigation of RPWELL-based Digital Hadronic Calorimeter. Diss. The Weizmann Institute of Science, 2022.

Expected performance of 50 layers RPWELL-based DHCAL





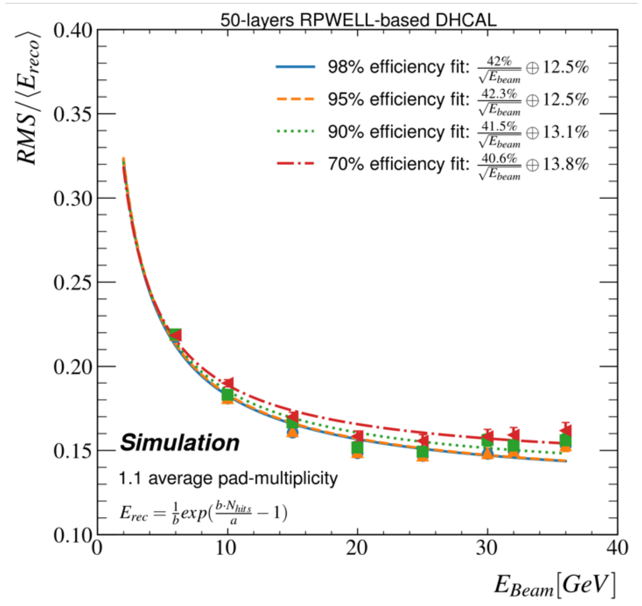
- Assuming:
  - uniform response
  - 98% MIP detection efficiency
  - 1.1 average pad multiplicity

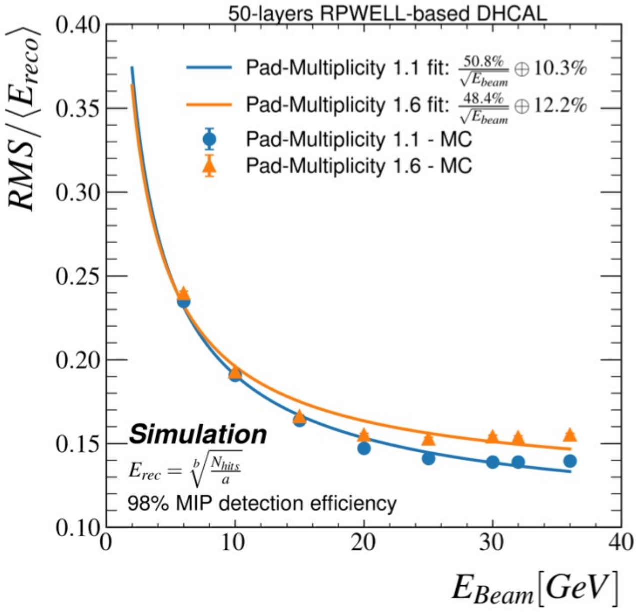
- Left: the simulated calorimeter response (black dots) and the fits with various parametrizations (lines).
- Right: the relative energy resolution as a function of the beam energy obtained with various parametrizations.

Shaked Renous, Dan. Investigation of RPWELL-based Digital Hadronic Calorimeter. Diss. The Weizmann Institute of Science, 2022.

Expected performance of 50 layers RPWELL-based DHCAL

- Not compensating for saturation effects:
  - Left: effect of detection efficiency
  - Right: effect of pad multiplicity

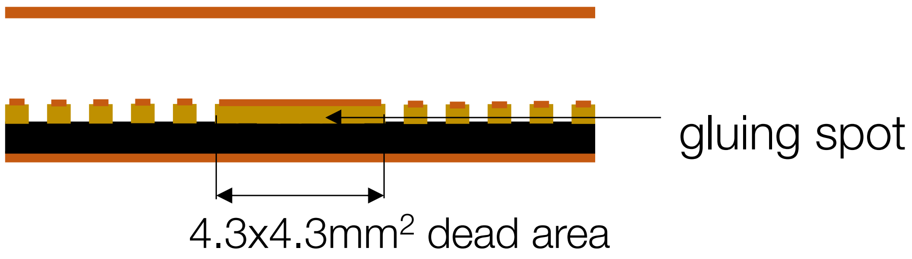


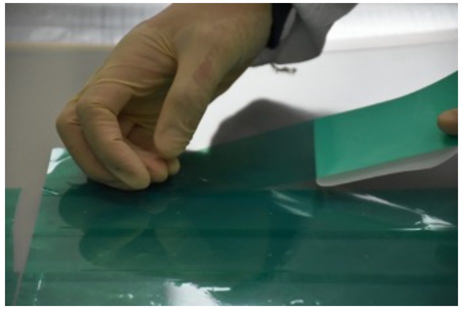


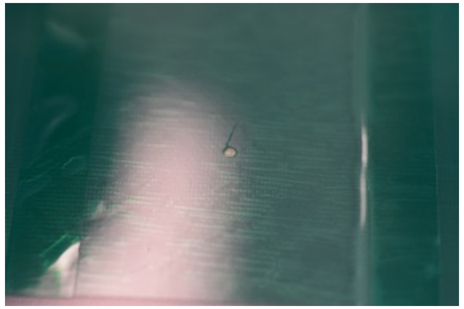
Shaked Renous, Dan. Investigation of RPWELL-based Digital Hadronic Calorimeter. Diss. The Weizmann Institute of Science, 2022.

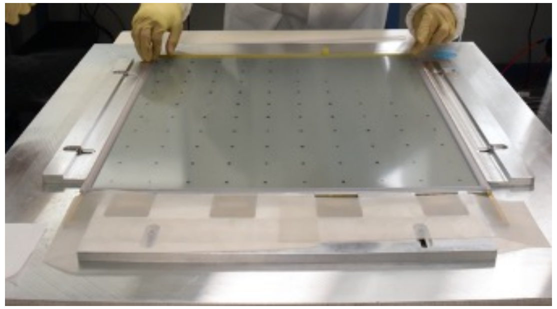
Latest detector prototypes – optimized assembly

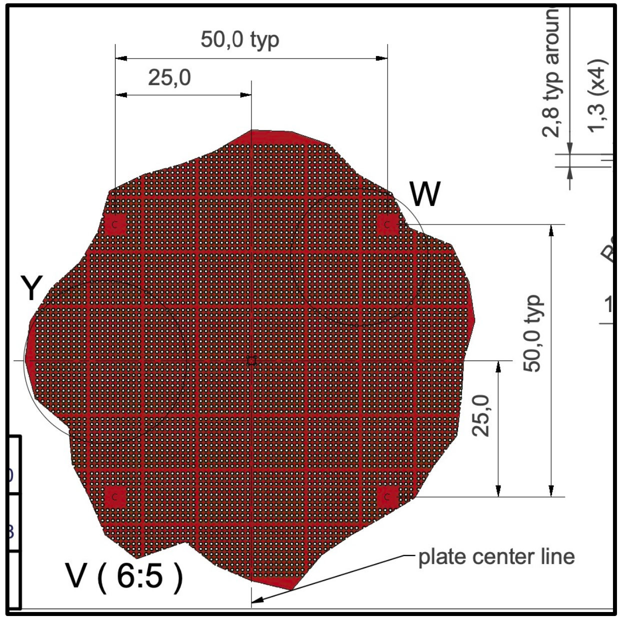
- Stringent QA&QC requirements and procedure
  - less than 5% thickness variations
- New assembly procedure
  - gluing the electrode every 5 cm in a dedicated spots





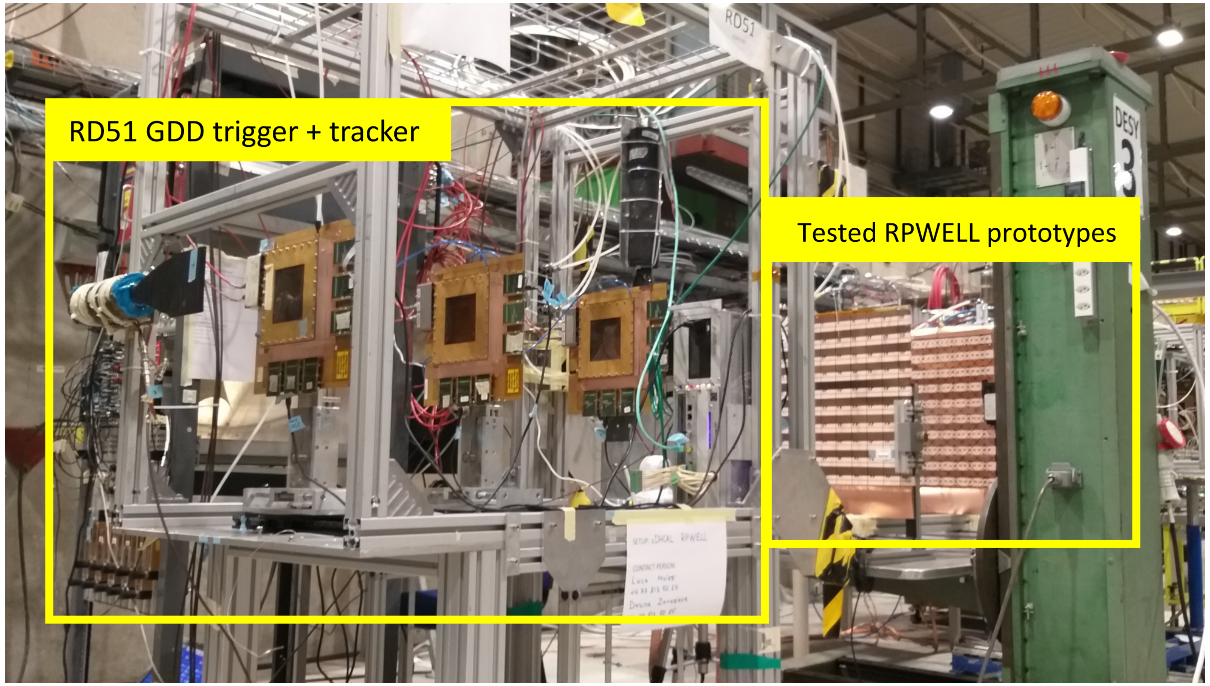






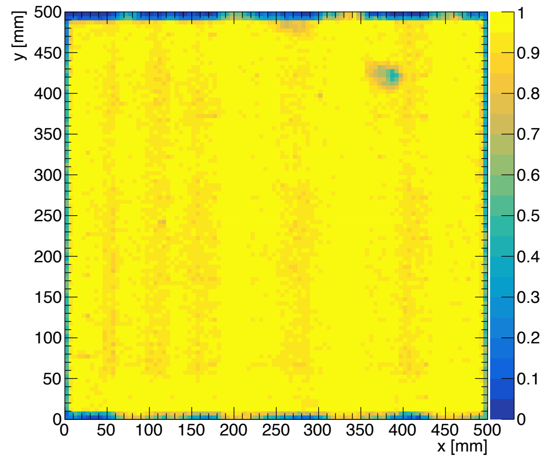
- Dead area is <1%
- 0.4 mm thick THGEM
- 5% thikness variations

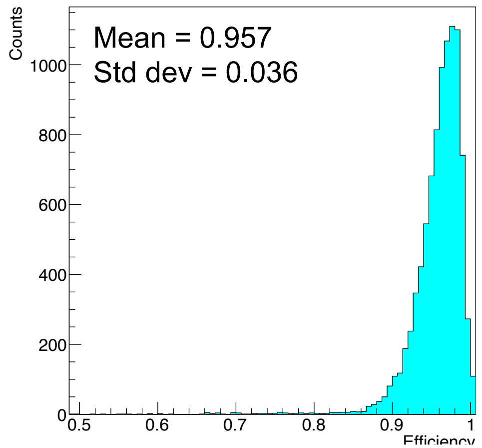
Latest prototypes – test beam at CERN SPS



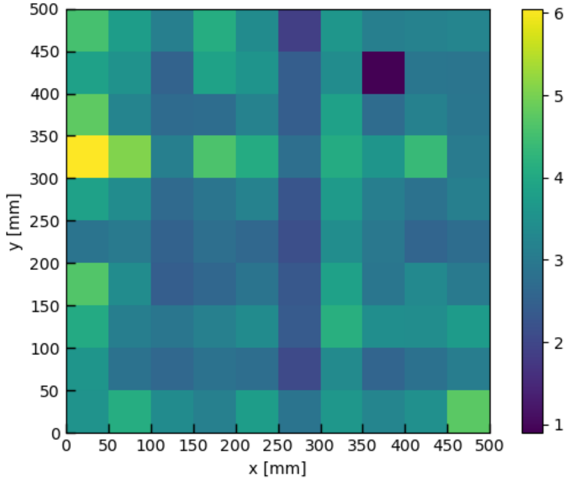
- Muon beam, E = 80 GeV
- RD51 GDD 6 cm^2 trigger + tracker: 3 SCs, 3 Micromegas
- Two 50×50 cm^2 RPWELL prototypes were tested
- DAQ: APV25 SRS
- Readout: 1 mm pitch 1D strips
- The goal was to assess the uniformity of the detectors' performance over the entire area
- 100 points of ≈ 5 cm^2 were scanned

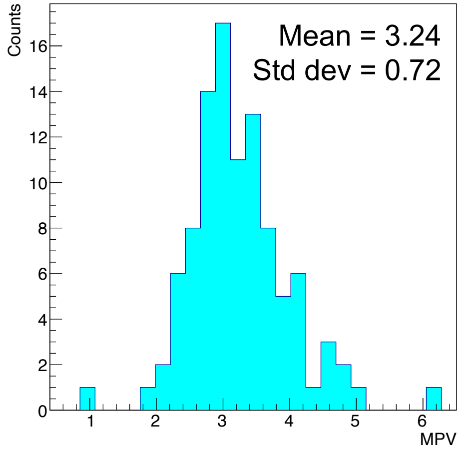
Latest prototypes – better response uniformity





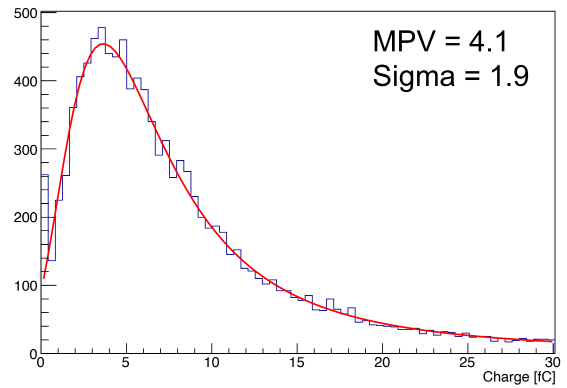
- Left: efficiency map
  - One glue point detached
- Right: distribution of efficiency values
  - 4% variations



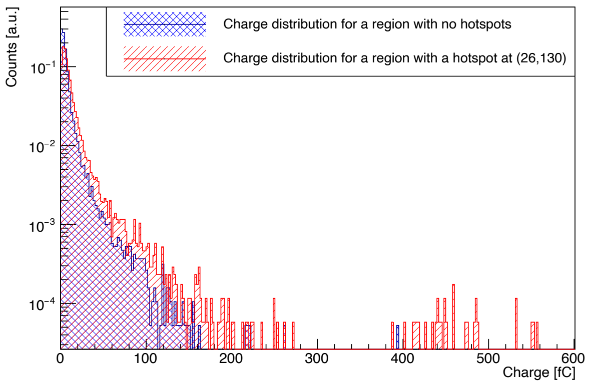


- Left: charge MPV map
- Right: distribution of charge MPV values
  - 22% variations
  - ~ consistent with thickness variations in THGEM-like detectors

Latest prototypes – high charge events

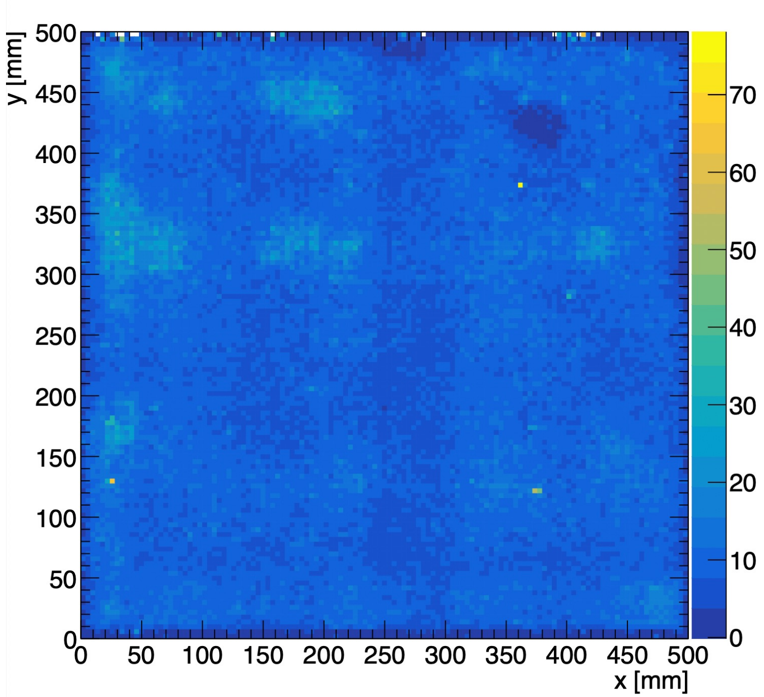


Typical charge spectra fitted to Landau distribution



Presence of high charge signals in some of the runs

Fraction of high charge events: 0.2% relative to 5% in the past



Average cluster charge map

Summary

- MPGDs are good candidates for highly granular HCAL
- RPWELL detector could be suitable in terms of the detection efficiency and average pad multiplicity
- RPWELL-based DHCAL could provide the required hadron energy resolution

- Building large area detectors of high quality is a challenge
- Uniformity of the response should be further optimized
  - Improve assembly procedure
  - Improve raw material
- Remaining source of instabilities should be undersood
- Shielding&grounding could be improved
- Improvement in the electrical coupling between the readout and the RP

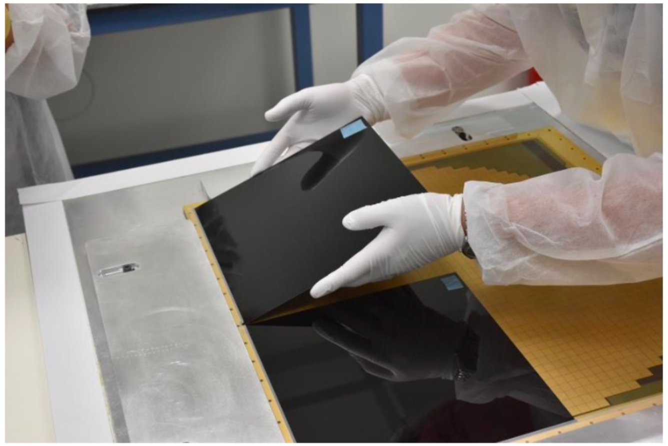
- Outlook: further optimization of design&assembly, scaling up to $1 \times 1 m^2$ chambers, digital readout employment

- High quality large area RPWELL detectors could be attractive for other applications as well

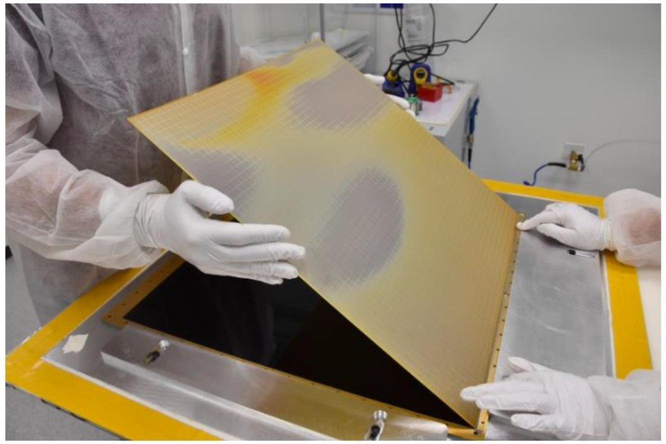
Thank you!

Assembly procedure – past

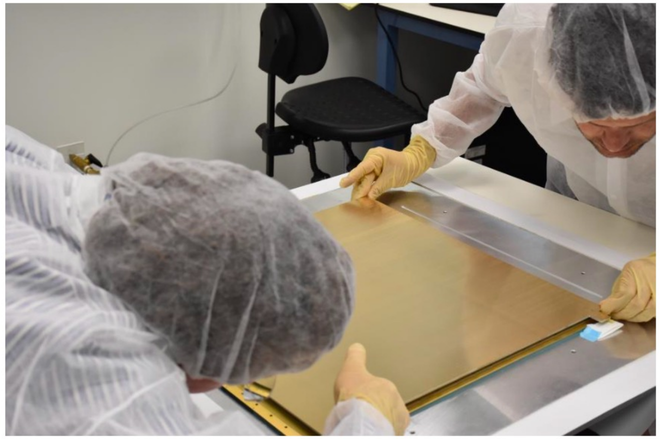
1. Coupling RP tiles to the anode using epoxy/graphite mixture



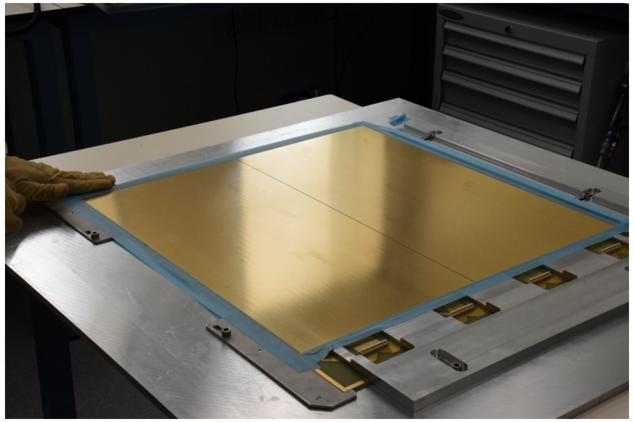
2. Gluing THGEM board to the RP



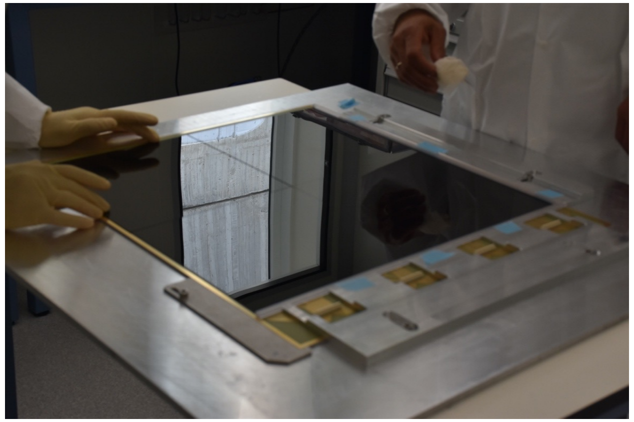
3. HV connections, gluing of the side frames and the cathode



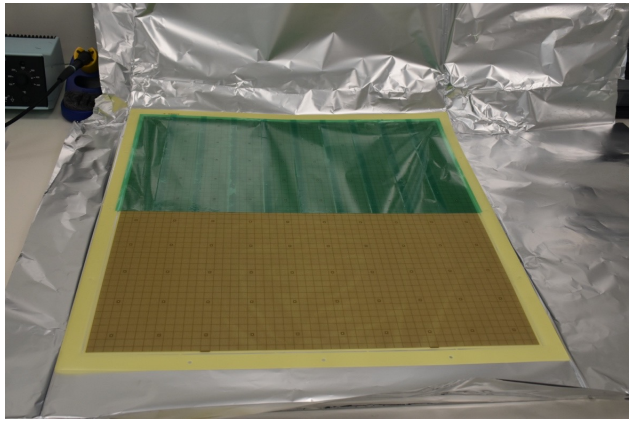
Assembly procedure – present



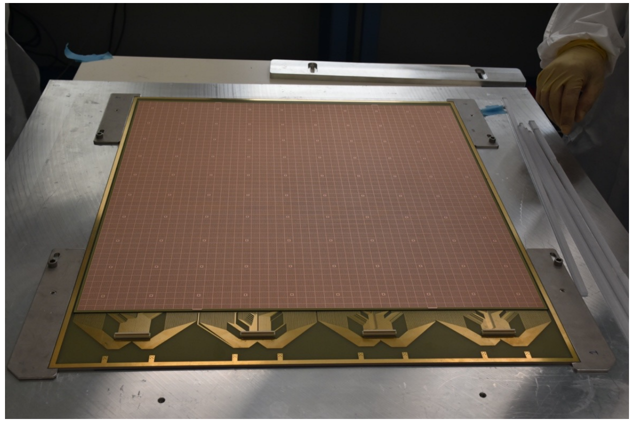
Preparing the readout



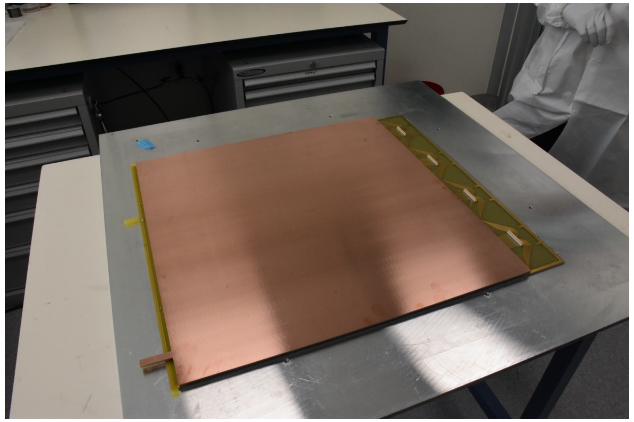
Coupling RP tiles using
epoxy/graphite mixture



Masking bottom of the THGEM, applying
epoxy glue to the dedicated points



Placing the THGEM on the RP and
fixing it by vaccum press



Closing the chamber: gluing the side frames,
providing HV connections, attaching the cathode