Разработка и создание резистивных микроструктурных газоразрядных детекторов (R-MPGD) для экспериментов в физике высоких энергий, проводимых в ОИЯИ

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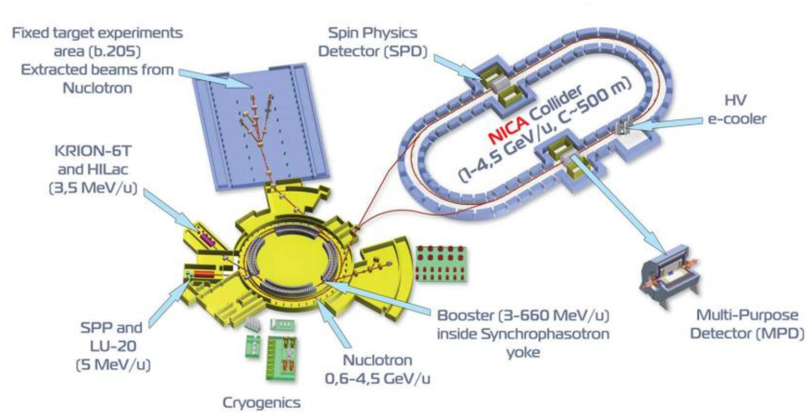
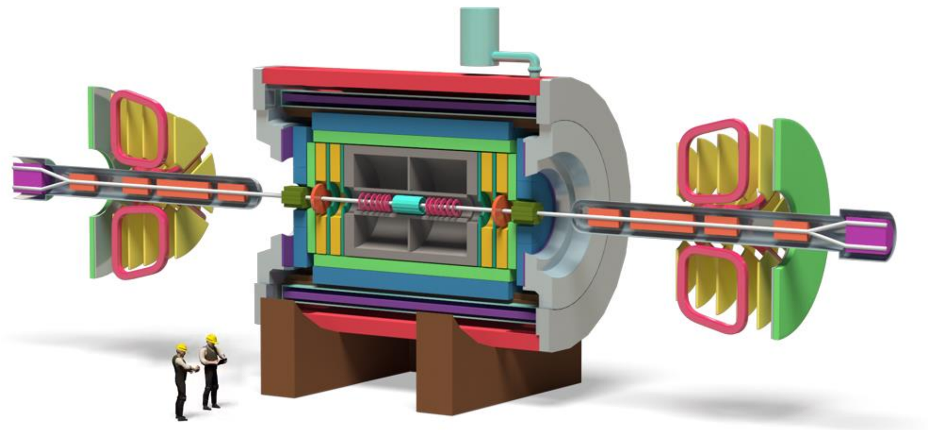
Зав. Сектором научно-технического сотрудничества

Институт энергетики Национальной академии наук Беларуси

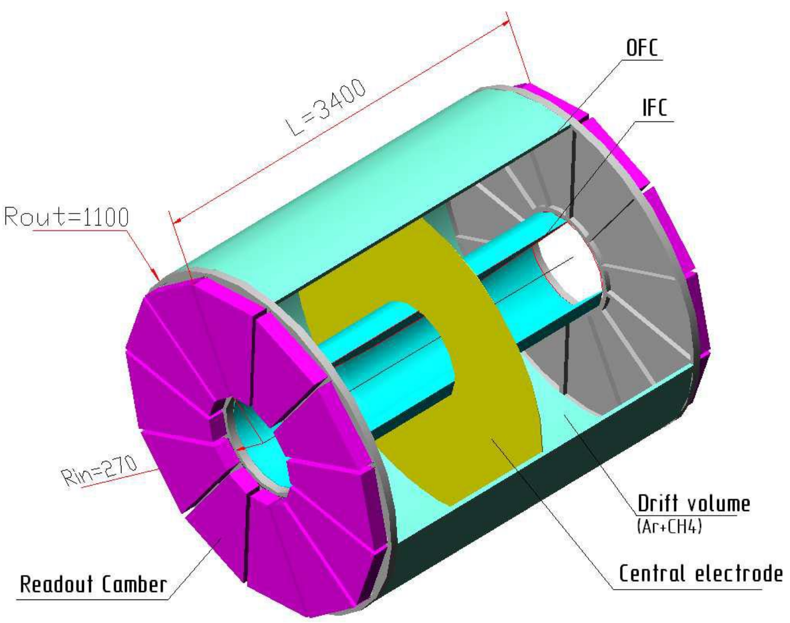
TPC of MPD experiment at Nuclotron-based Ion Collider fAcility (NICA)

Scheduled Launch in 2025





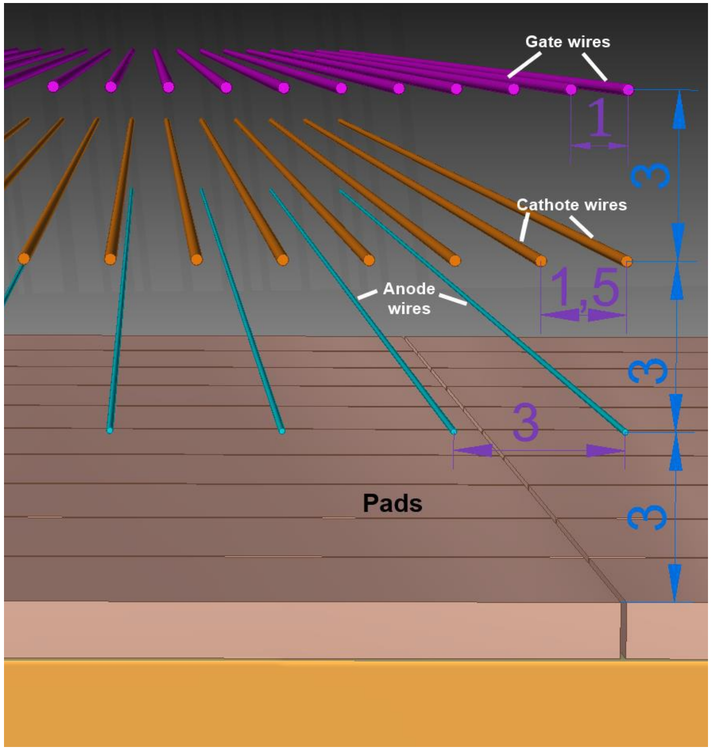
Multi-Purpose Detector (MPD)

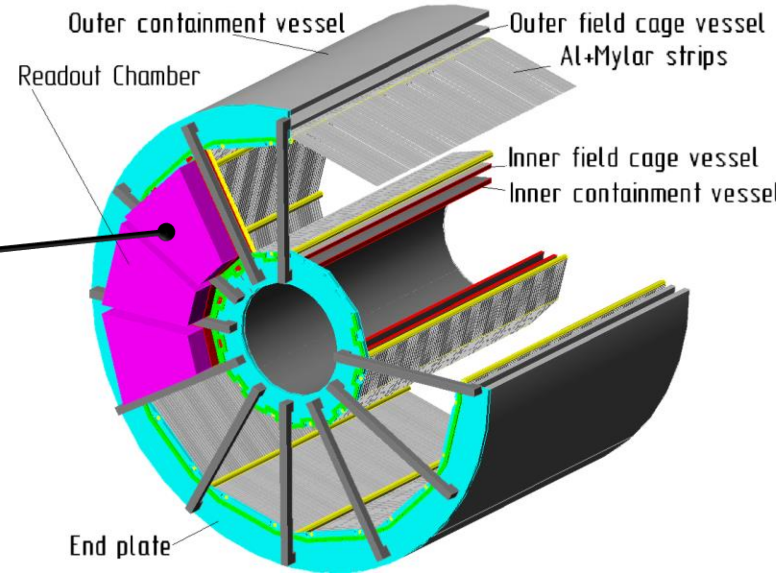


Time Projection Chamber (TPC)

Read-Out Chamber of 1st Stage of NICA MPD Experiment

MultiWire Proportional Chamber (MWPC) with Gating Grid System





Parameter of 1st Stage	Value
Length of the TPC **Outer radius of vessel** **Inner radius of vessel**	**340cm** **140cm** **27 cm**
Maximum beam-beam event rate	**5 kHz**
Luminosity	$1 \cdot 10^{27}$ $cm^{-2}s^{-1}$
Gas amplification factor	**10,000**

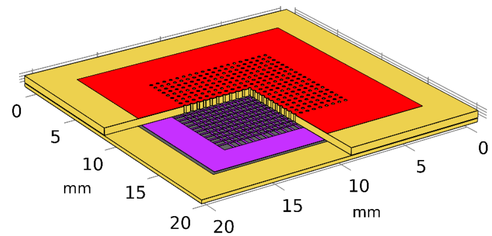
At the 2d Stage of NICA MPD Experiment the Luminosity will be increased. It means that Event Rate of R/O Chambers should be also increased → Upgrade by use of

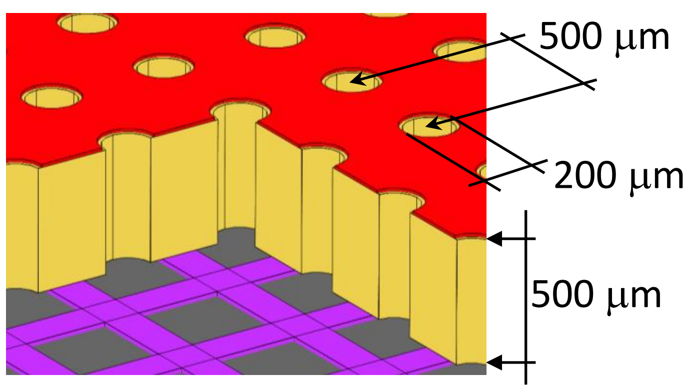
Micro Pattern Gaseous Detectors (MPGDs)

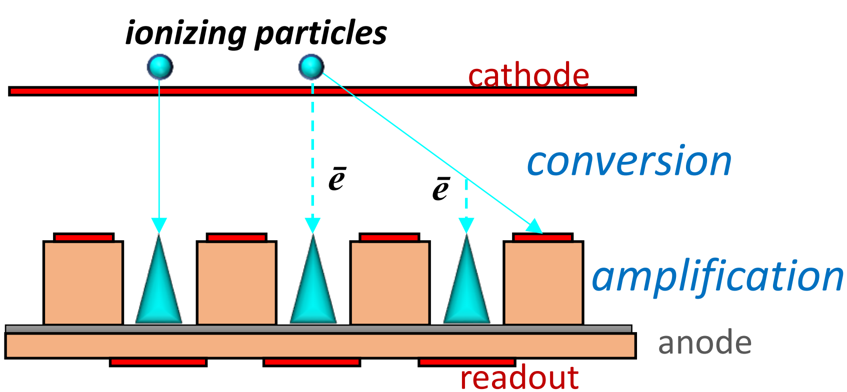
Micro Pattern Gaseous Detectors (MPGDs)

MPGDs is a new generation of radiation detector devices with promising performance not only for the High Energy Physics experiments, but also for many other applications as medical, imaging, dosimetry, muon tomography etc.

Resistive Well Electron Multiplier (R-WEM)

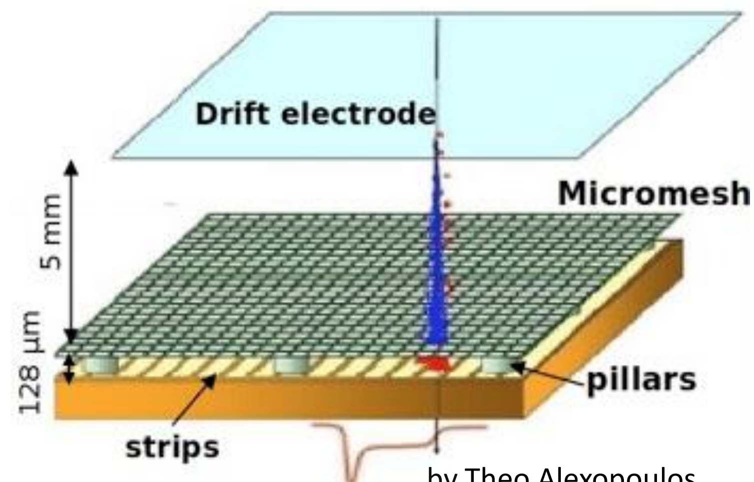




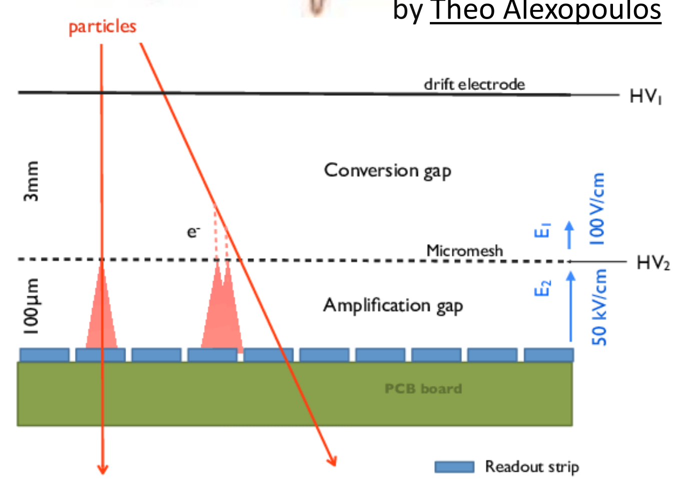


Kashchuk, V. Akulich, K. Afanaciev, V. Bayev, S.A. Movchan ***JINST 2020*** C09018

MicroMegas detector



by Theo Alexopoulos

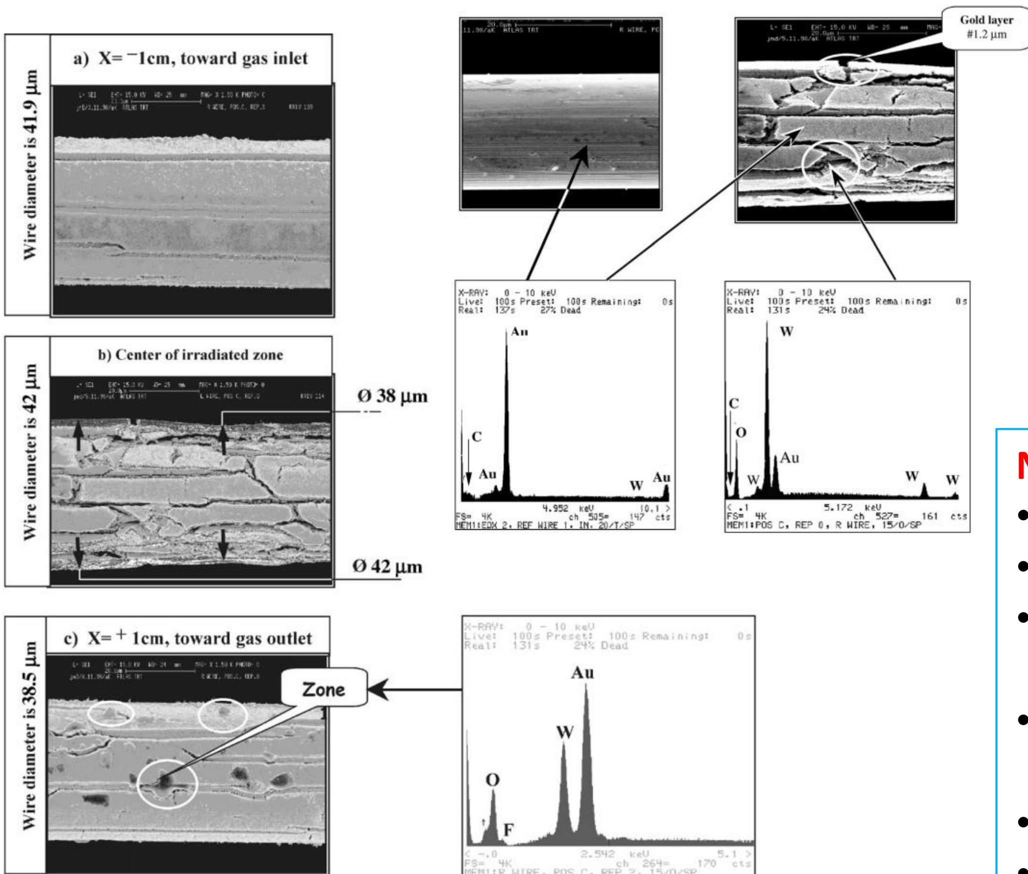


by David Attié

A Key Role of Discharge Robustness

The results of FLUKA simulation of NICA TPC estimate the fluence of highly ionizing particles (ions, recoils) to be up to **10^6 per cm^2** per year

Degradation of wires after discharges



T. Ferguson et al. ***NIMA 483*** (2002) 698–712

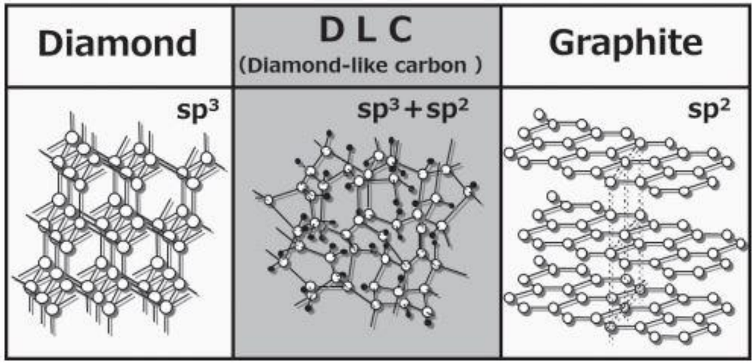
Destruction of resistive strips (resistive paste) in Micromegas chambers for the ATLAS New Small Wheel upgrade

https://cds.cern.ch/record/2712020/files/ATL-MUON-SLIDE-2020-062

Negative consequences of electrical discharges:

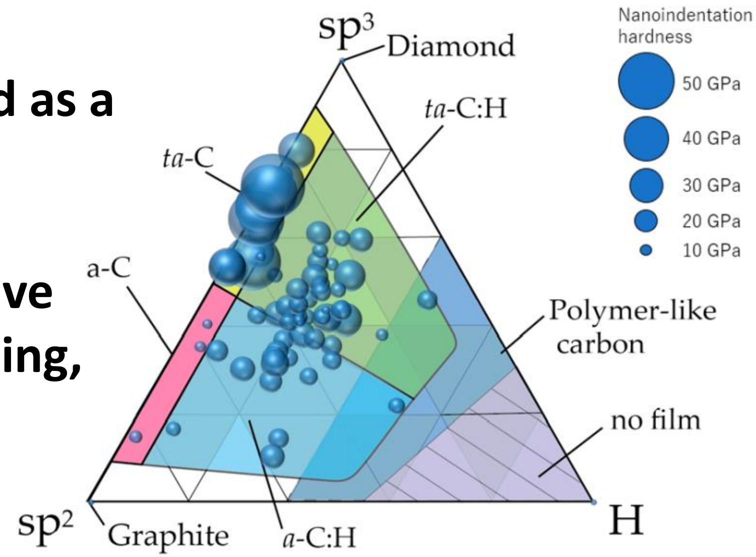
- **material degradation**
- **damage to the amplification structure**
- **reduction of gas gain due to local voltage drop**
- **irreversible changes in the detector parameters (energy resolution, gas gain)**
- **dead time due to local voltage drop**
- **saturation of the readout electronics**

DLC – Diamond-Like Carbon



uploaded from pcs-instruments.com

Widely used as a hardening coating, anti-reflective optical coating, decorative



by Naoto Ohtake ***Materials*** **2021**, *14*(2)

In High Energy Physics is used as a resistive coating for MPGDs

The use of Diamond-Like Carbone Coating as a Resistive Anode in Micro Pattern Gaseous Detectors for High Energy Physics

- ***Joint Institute for Nuclear Research***
- ***Institute of Power Engineering of National Academy of Sciences of Belarus***
- ***Physical-Technical Institute of National Academy of Sciences of Belarus***

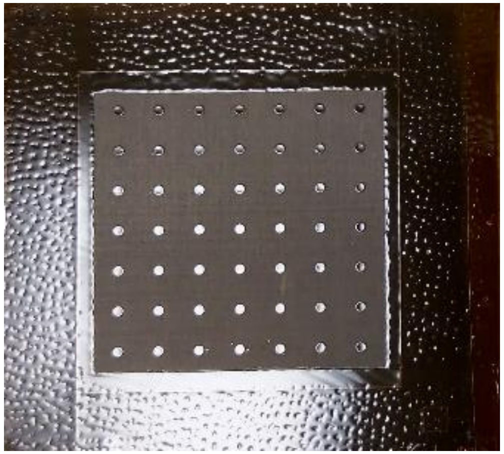
Development and research of Micro Pattern Gaseous Detectors with resistive DLC anode for MPD and SPD experiments of accelerator complex NICA

DLC coating is used in R&D of:
MicroMegas detector (Micromesh Gaseous Structure)
R-WEM detector (Resistive Well Electron Multyplier)
Straw-detector with cathode read-out

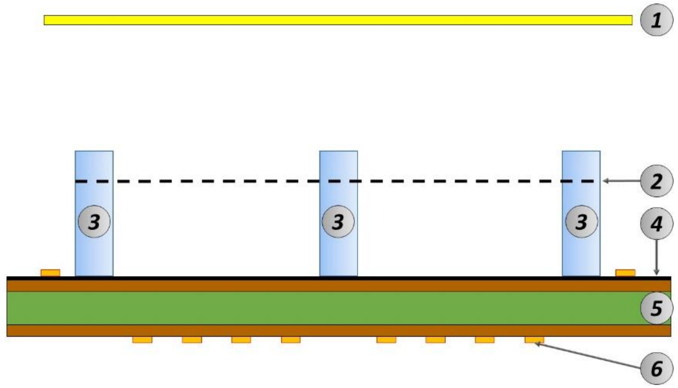
- **DLC coating** (of thickness about **100 nm**) increase the robustness to discharges by highly ionizing particles (ions, recoils).
- **Sheet resistance** is varied from *500 kΩ per square* to *1 GΩ per square* (**Resistivity 0.1 Ω·cm – 5 kΩ·cm**).
- **Uniformity** is 85% at the area 20cmX20cm and 90% at the area 10cmX10cm.
- **Stable parameters** of Micro Pattern Gaseous Detectors after more than 10M discharges at the area 10cmX10cm
- **The maximum area** is 400 mm X 800 mm

Cooperation agreement N332 between **Joint Institute for Nuclear Research** and **Institute of Power Engineering of the National Academy of Sciences of Belarus**

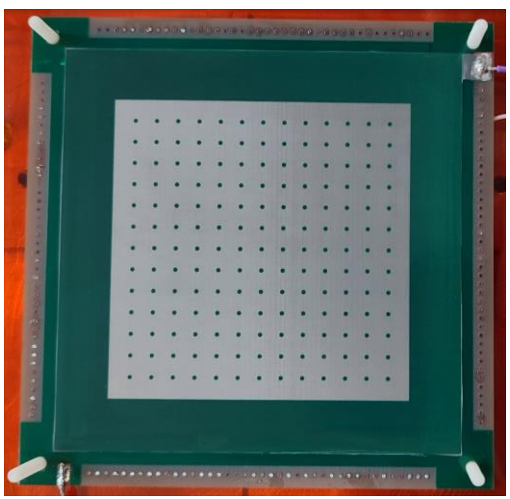
MicroMegas detector with the resistive DLC anode



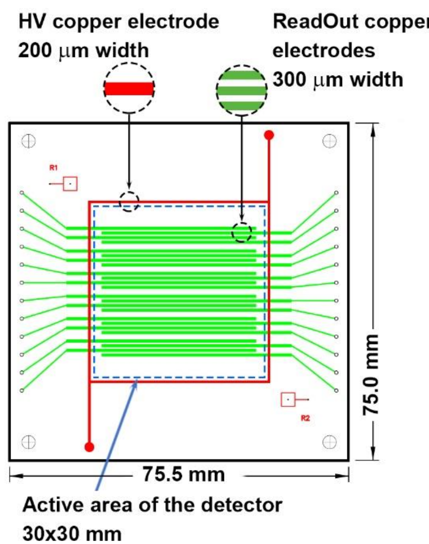
Prototype with active area 30mm x 30mm

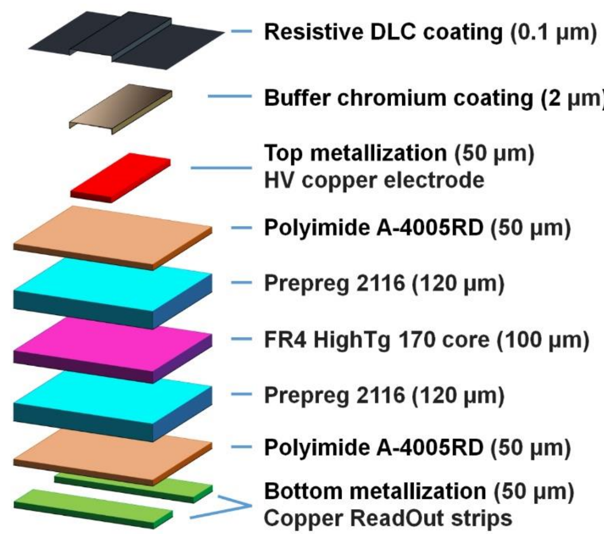


- (1) cathode
- (2) stainless steel mesh with wire of 18 µm in diameter and the pitch of 63 µm
- (3) support pillars
- (4) resistive DLC layer anode
- (5) multilayered printed circuit board (PCB)
- (6) readout copper strips



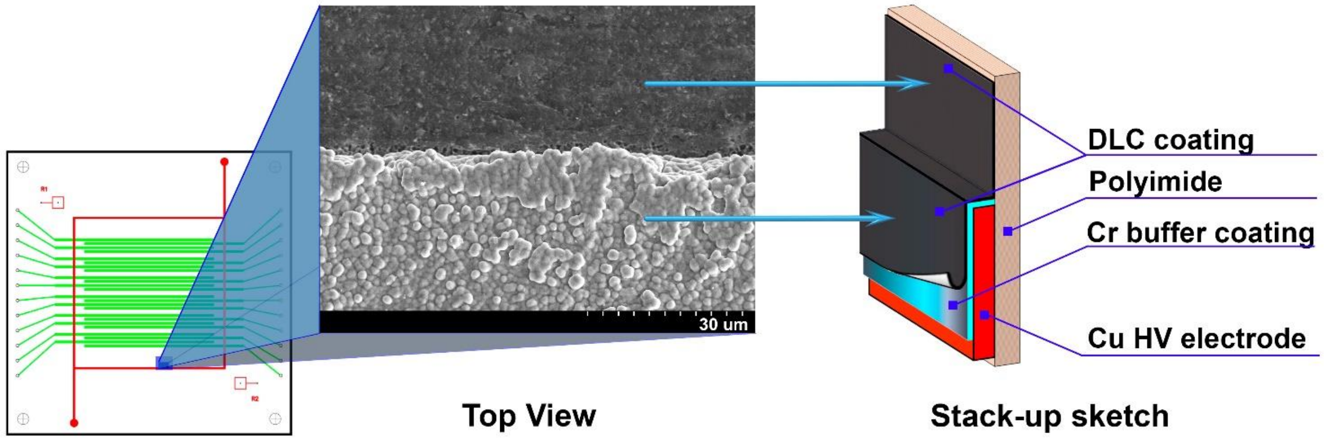
Prototype with active area 80mm x 80mm

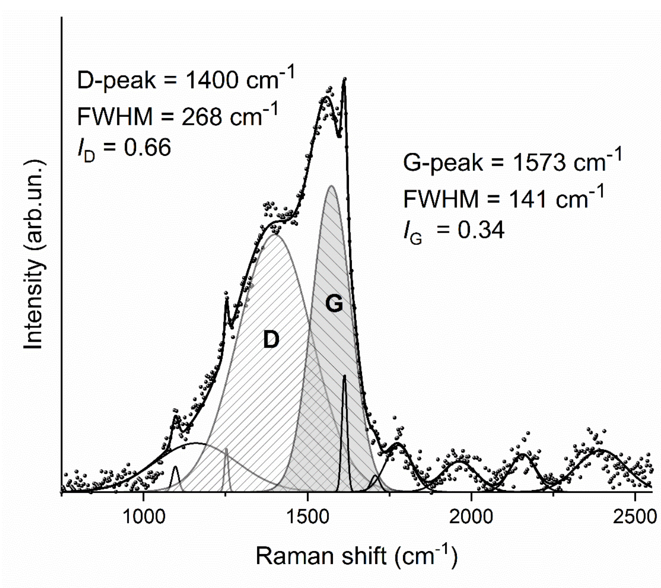




<u>V.G. Bayev</u> et al., ***NIMA 1031*** (2022) 166528

MicroMegas detector with the resistive DLC anode





Raman spectrum of DLC layer reveals that **the content of sp^3-hybritized carbon bonds close to 34 %**

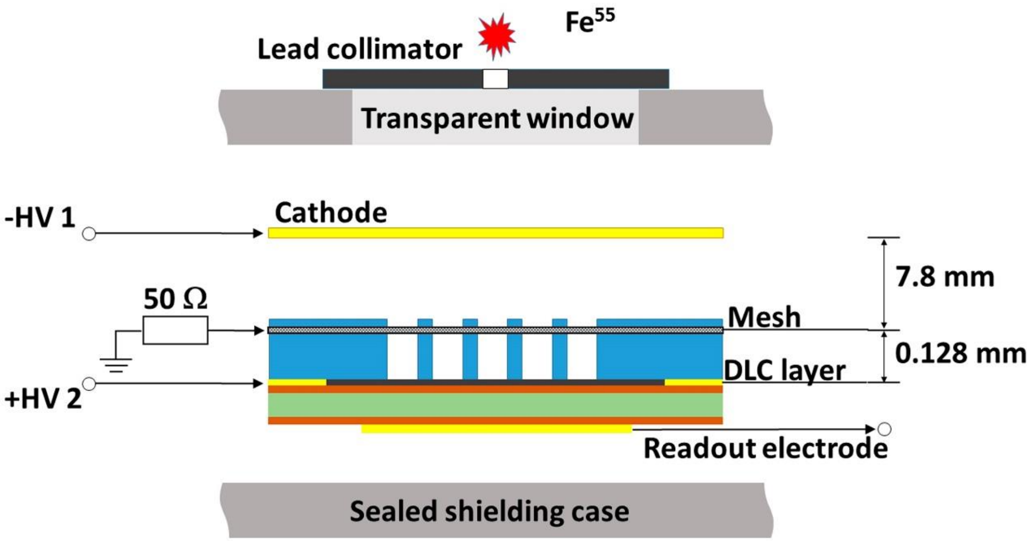
G peak – sp3 – diamond-like

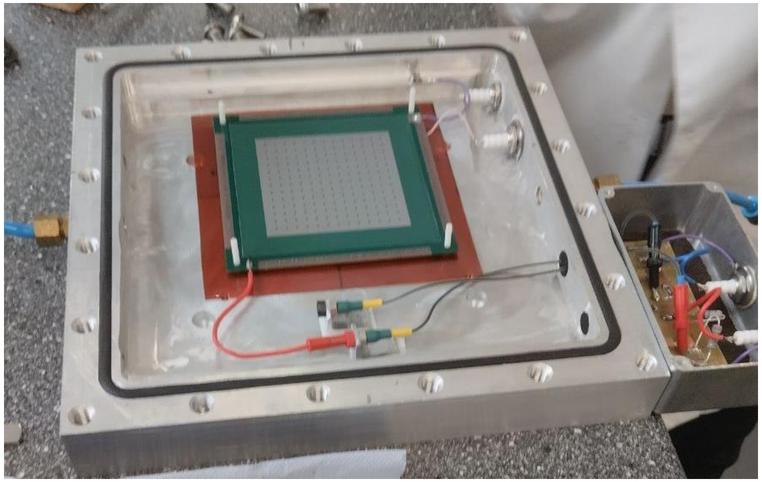
D peak – sp2 – graphite-like

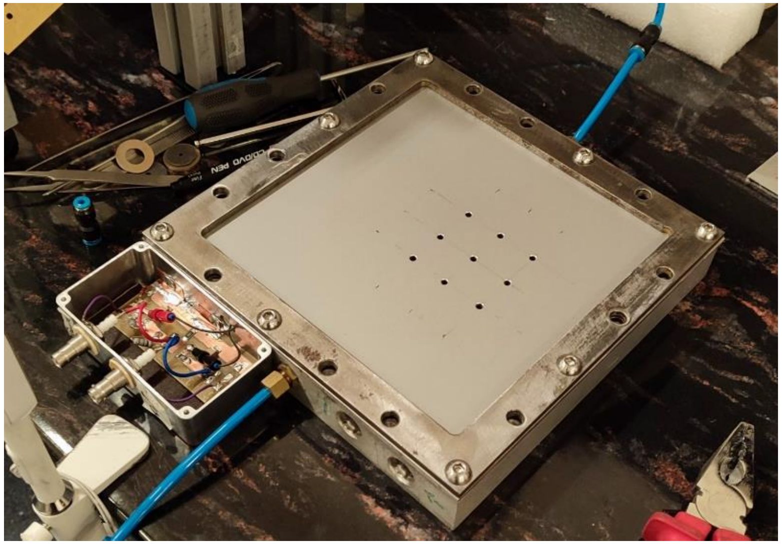
V.G. Bayev et al., ***NIMA 1031*** (2022) 166528

Test of MicroMegas detector with the resistive DLC anode

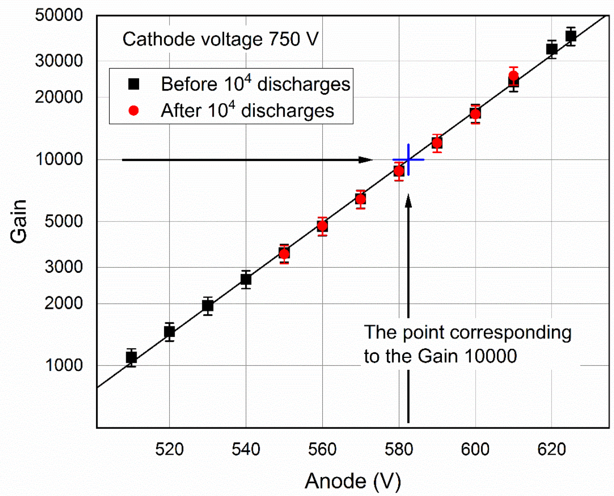
Test Setup:



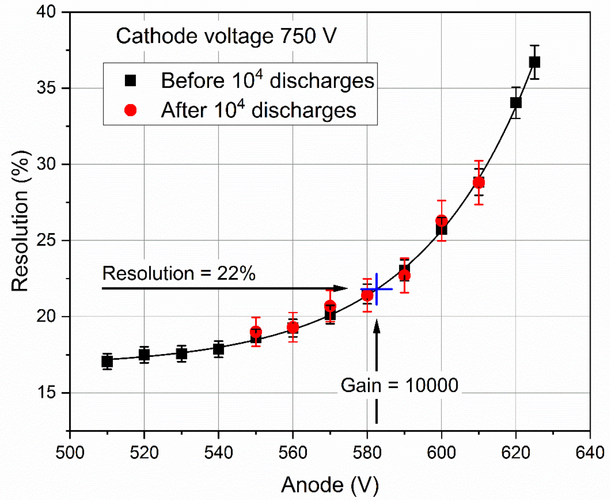




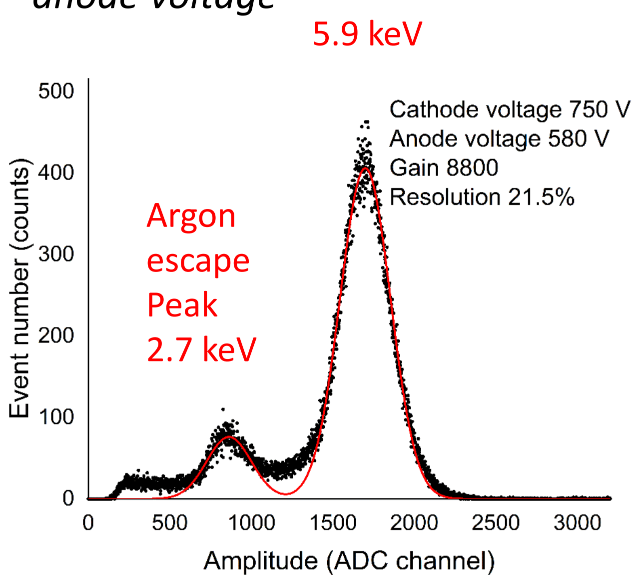
Test of MicroMegas detector with the resistive DLC anode



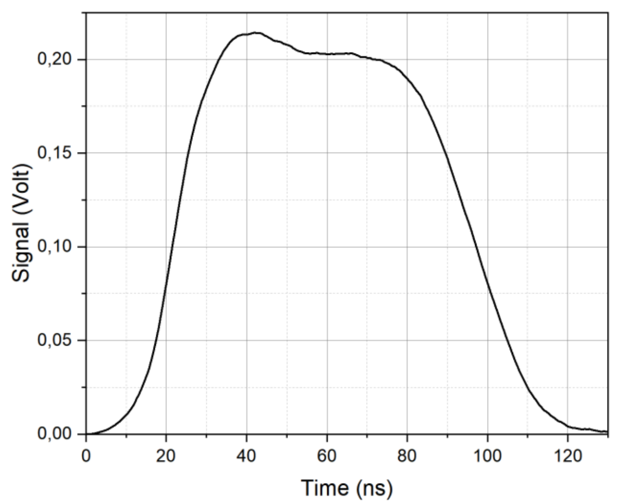
The dependence of gas gain on anode voltage



The dependence of energy resolution on anode voltage



Amplitude spectrum of the ^{55}Fe radioactive source



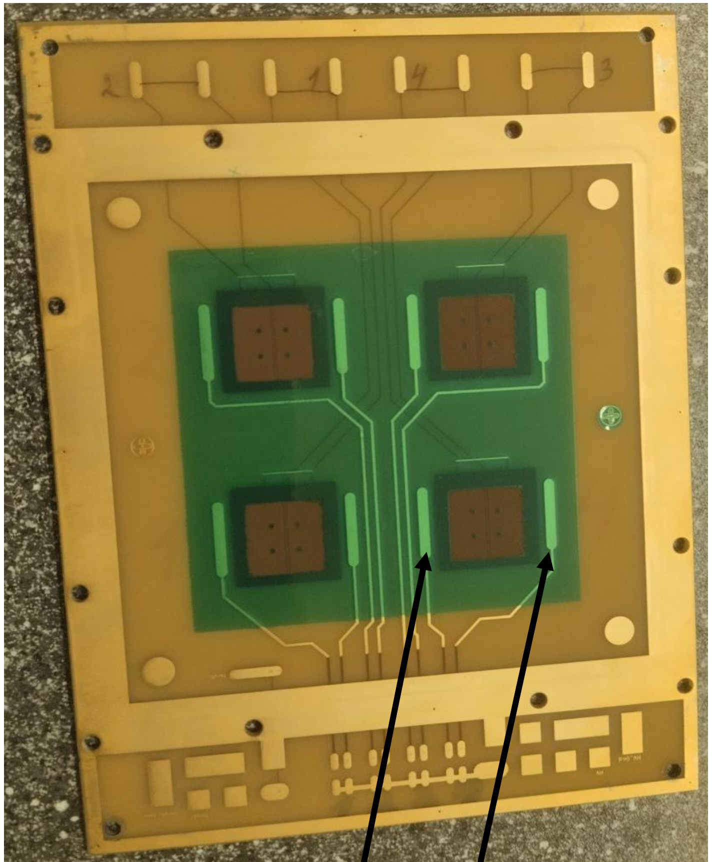
20mV/fC

signal rise time 5 ns

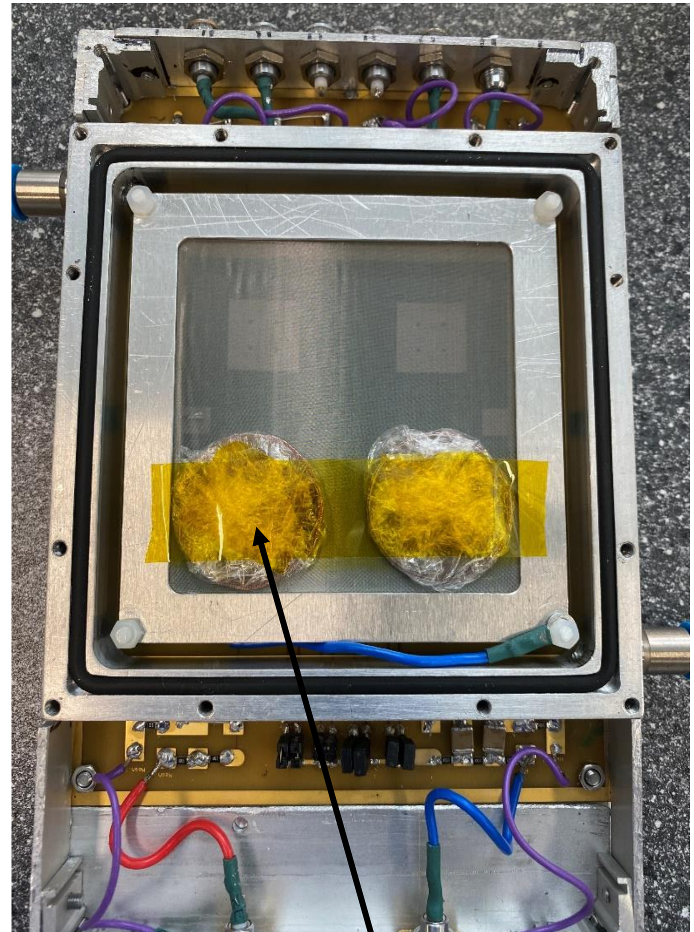
signal formation time 10 ns

Discharge Robustness of the DLC Anode

Special MicroMegas chamber
with DLC anode. 4 active areas.

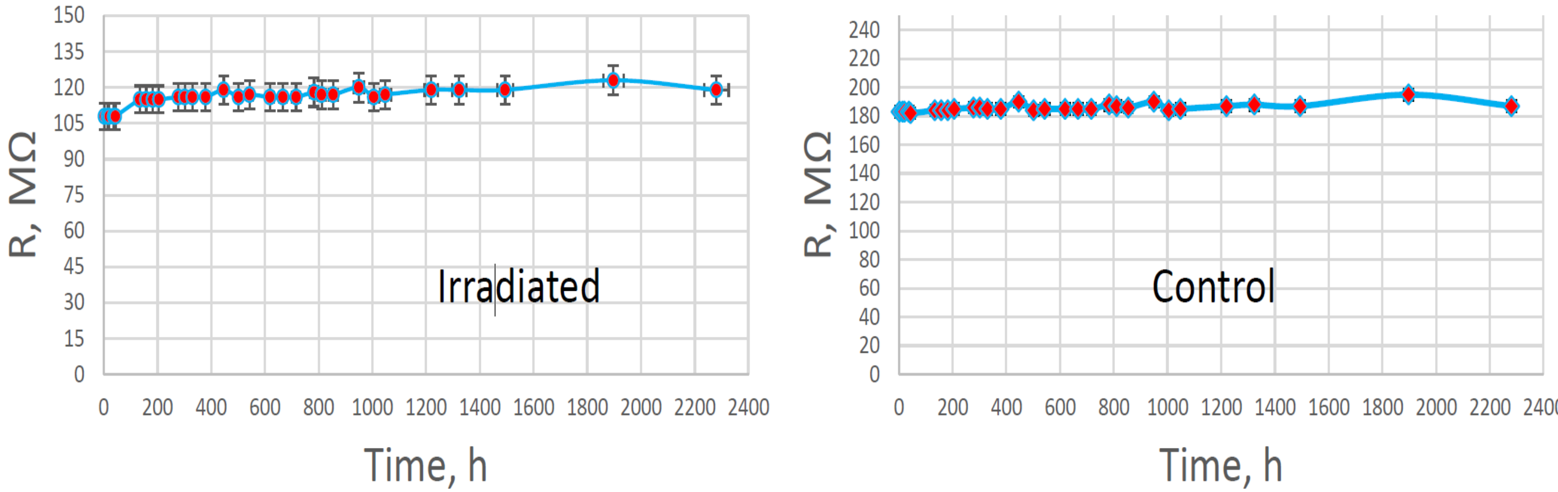


Contacts to apply HV and measure Resistivity



Alpha source to induce electrical discharges
(Pu-238 and Pu-239)

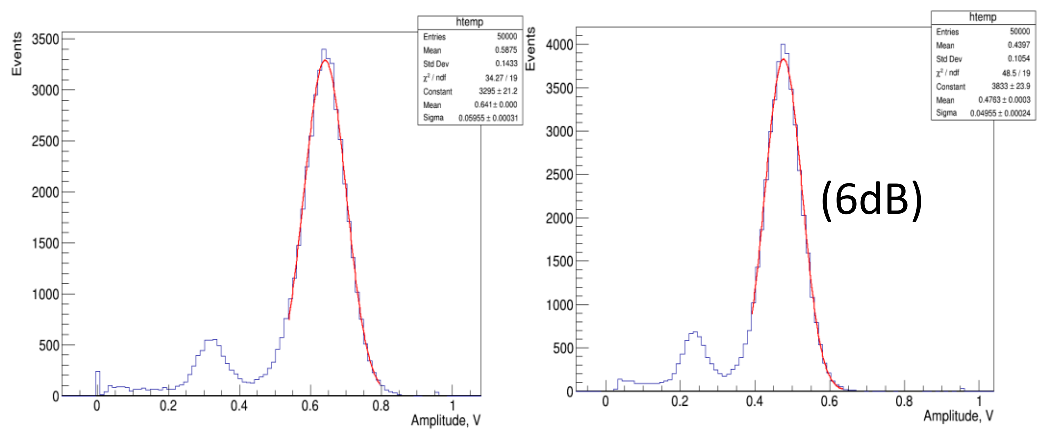
Discharge Robustness of the DLC Anode



Resistivity Dependence of DLC layer on time of irradiation by alpha source

Total number of discharges 9E8 during 2300 hours

No significant signs of degradation are observed



Control energy spectra of X-ray source Fe-55

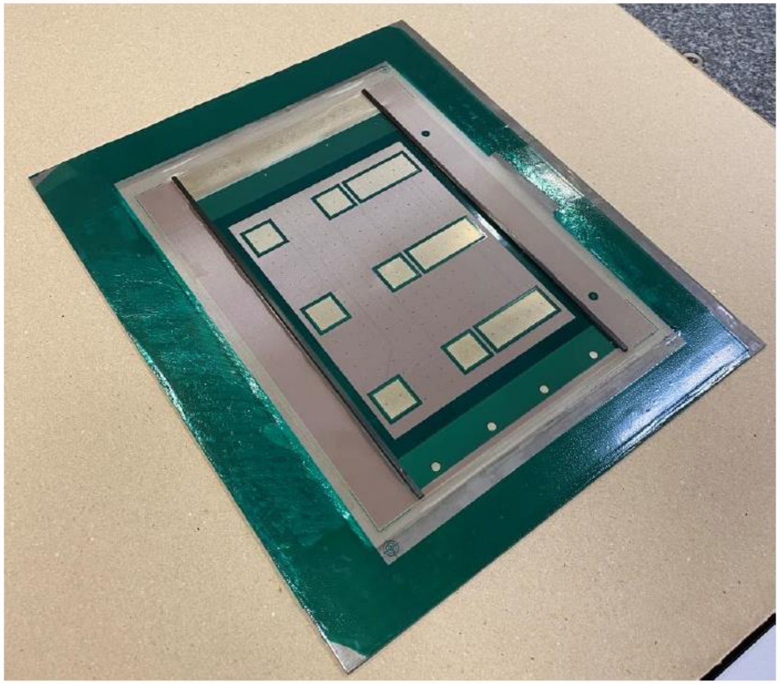
2024

Д.В. Дедович "Центральный трекер для эксперимента SPD на основе детекторов Micromegas"

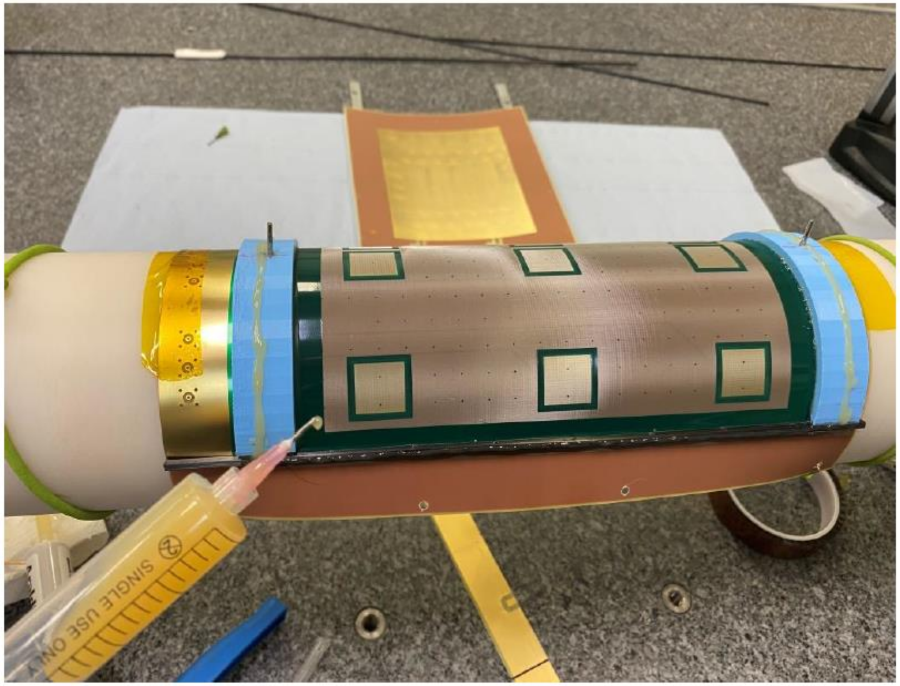
вторник 28 мая 2024 г., 11:00 → 13:00 Europe/Moscow

Первый прототип цилиндрической камеры

MM module (anode PCB + mesh) before bending



MM module bended on assembling table before cathode gluing



Signal electrodes shaped as 9 pad to check gain (⇔ gap) uniformity after bending

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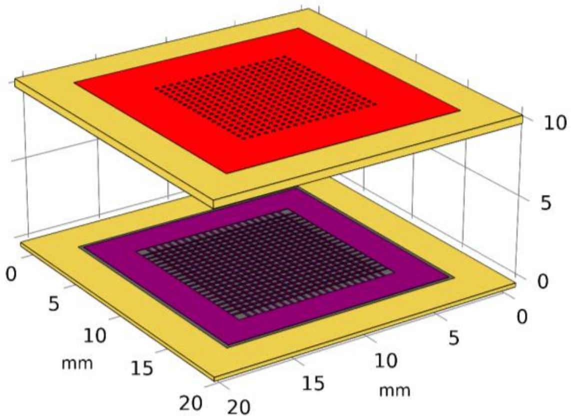
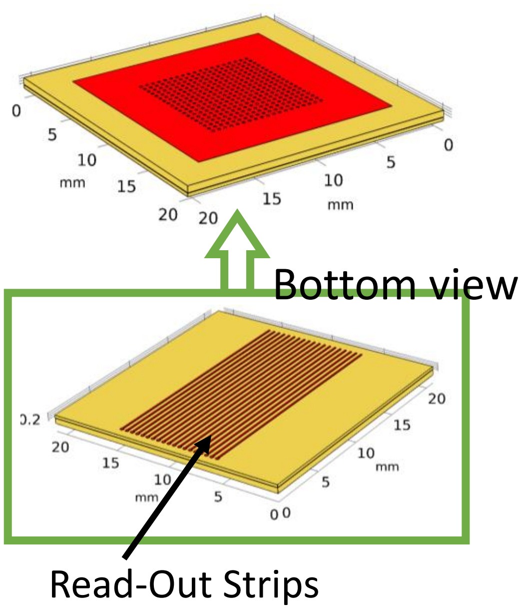
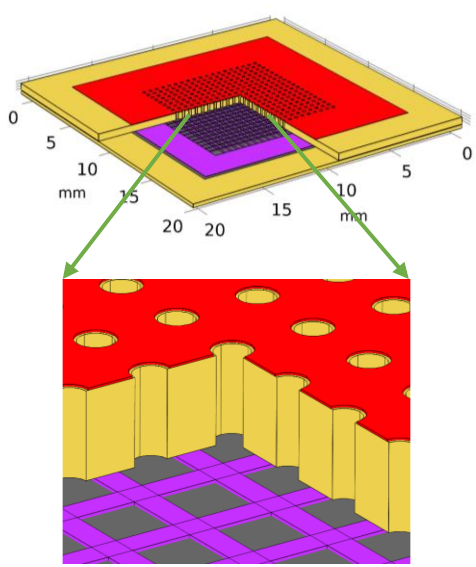
Resistive Well Electron Multiplier (R-WEM) with DLC anode



The R-WEM detector is composed of two parts.

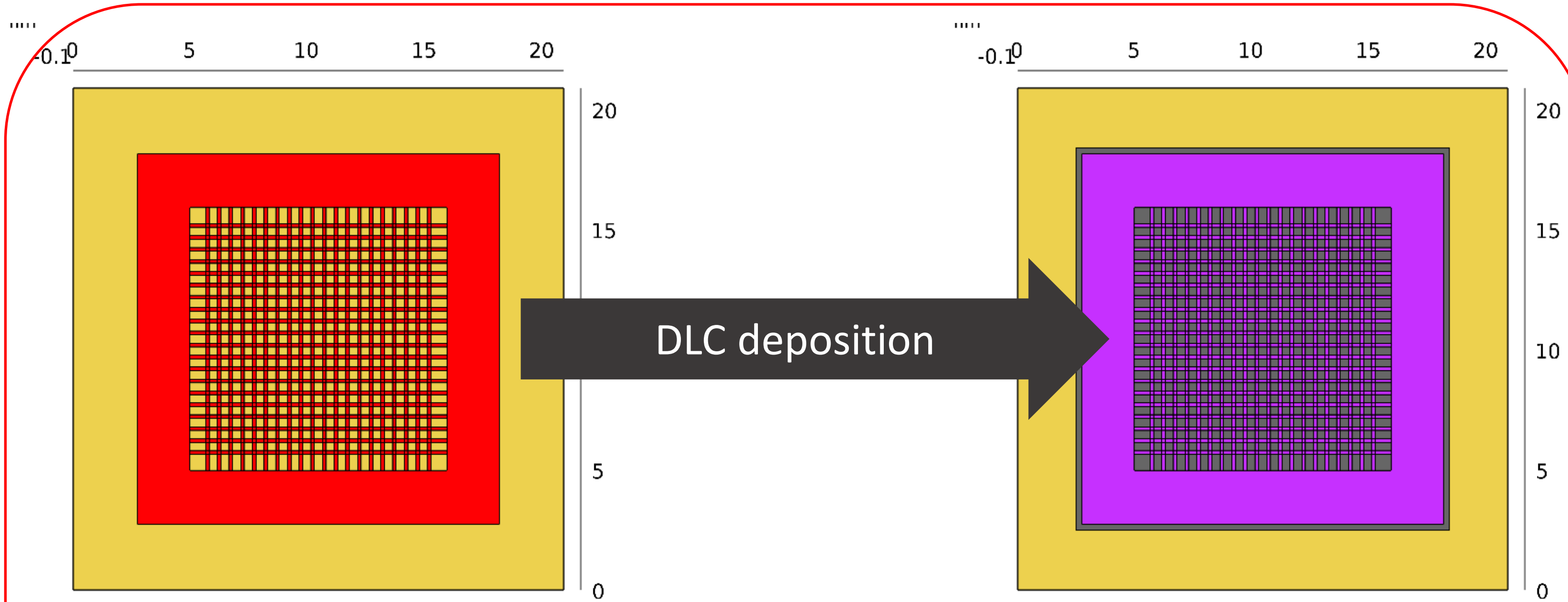
1. 500 µm thick FR4 board metallized on one side with drilled holes of 200 µm in diameter and 500 µm in pitch.
2. FR4 board contains copper HV-grid metallization and DLC layer on top side and readout electrodes at the bottom side





Two boards were combined together into a single multilayer board in such a way that the grid conductors are located between the holes of the perforated board and the DLC coating inside the grid cell is below the holes.

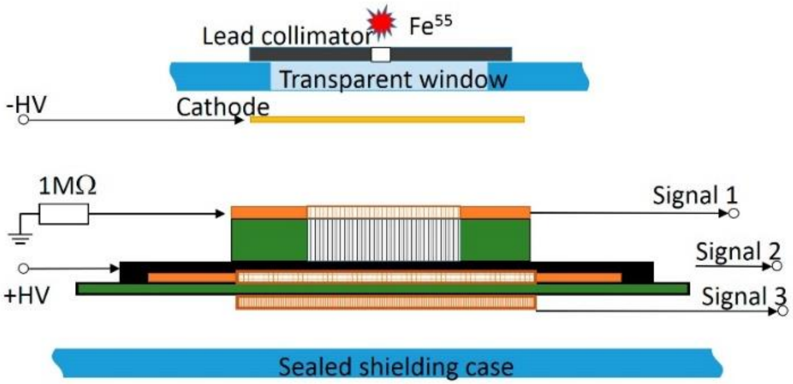
Resistive Well Electron Multiplier (R-WEM) with DLC anode



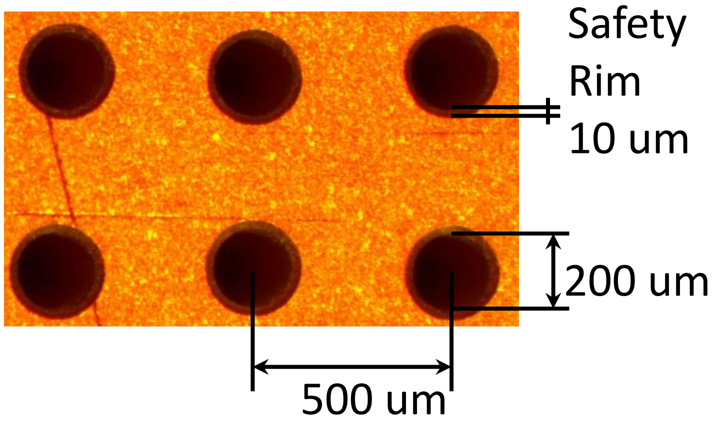
Anode FR4 board with HV grid electrode and DLC coating

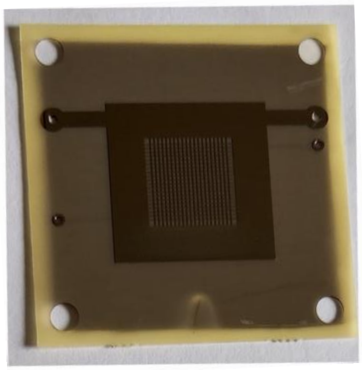
- The anode HV-grid is used to improve avalanche electron evacuation from DLC (ultra high rate capability)
- The resistive DLC layer with a sheet resistance of 30 MOhm/square is supposed to limit the electrical current of discharges produced by highly ionizing particles

Resistive Well Electron Multiplier (R-WEM) with DLC anode

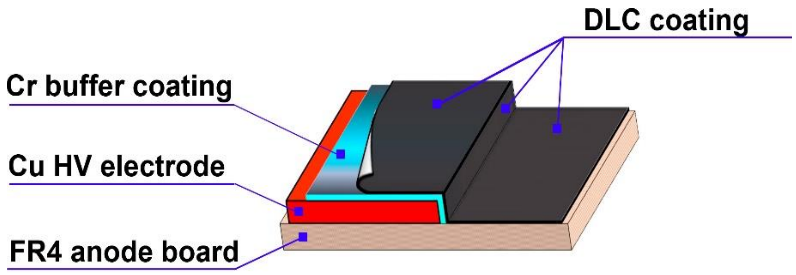


Perforated FR4





Anode board
with
HV-grid and
DLC coating



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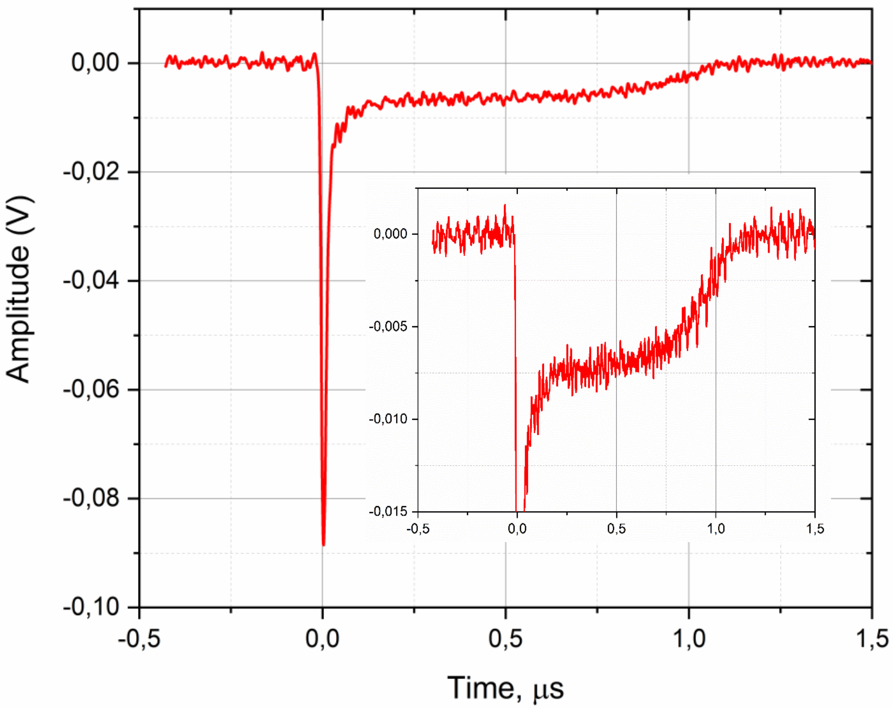
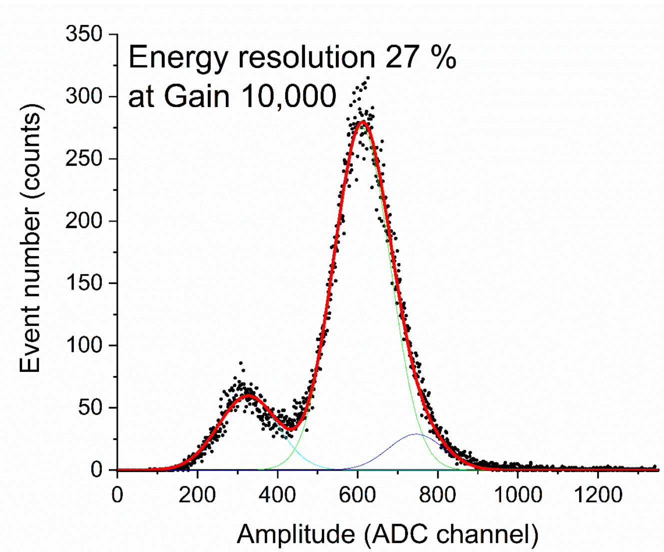
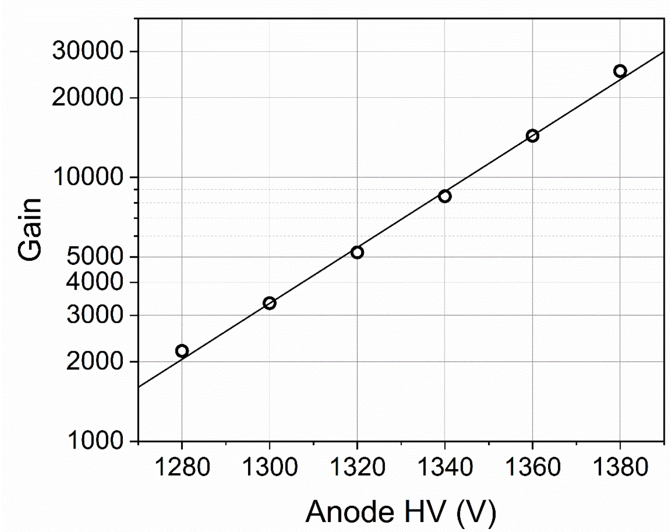




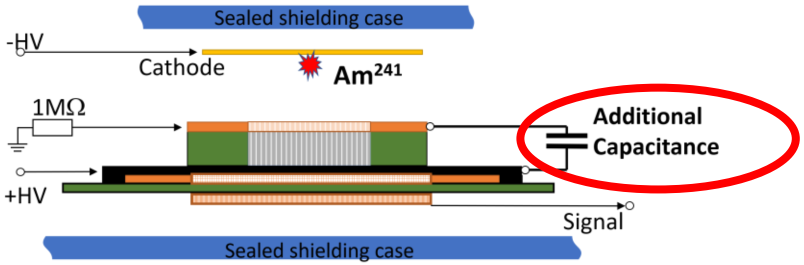
Amplitude spectrum of the ^{55}Fe radioactive source



20mV/fC
signal rise time 5 ns
signal formation time 10 ns

Electron component 20 ns
Ion component 1 us

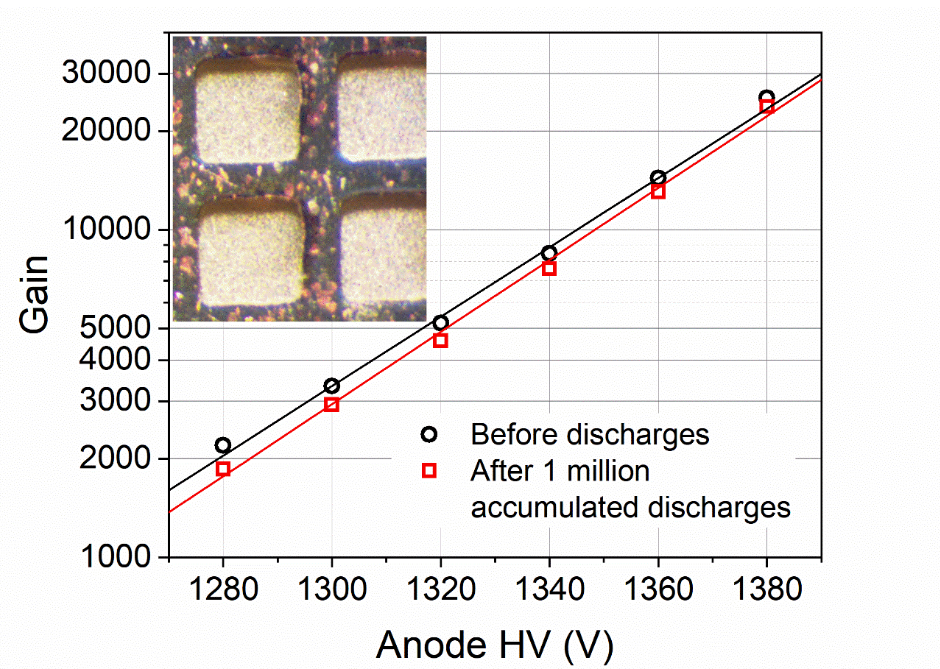
Effect of Multiple Discharges on Accumulated Damage in R-WEM with DLC Anode

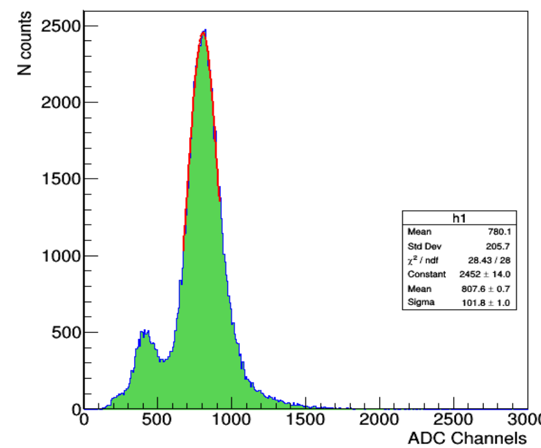


To simulate a large area R-WEM we used an Additional Capacitance, in parallel with R-WEM anode and top electrode

The discharge events initiated by an **Am^{241} alpha** source.
The circular alpha source 3 mm in diameter, activity of **33 Bq**

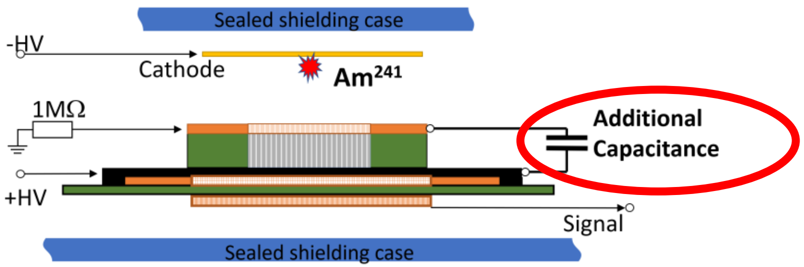
Active Area	Capacitance with the frame	Energy of discharges	Number of discharges
10 x 10 mm²	**34 pF**	**29 μJ**	**1,000,000**
60 x 60 mm²	**360 pF**	**0.3 mJ**	**100,000**
100 x 100 mm²	**1 nF**	**0.9 mJ**	**100,000**





No damage is observed after **1,000,000 discharges** for active **area 10 x 10 mm²**

Effect of Multiple Discharges on Accumulated Damage in R-WEM with DLC Anode



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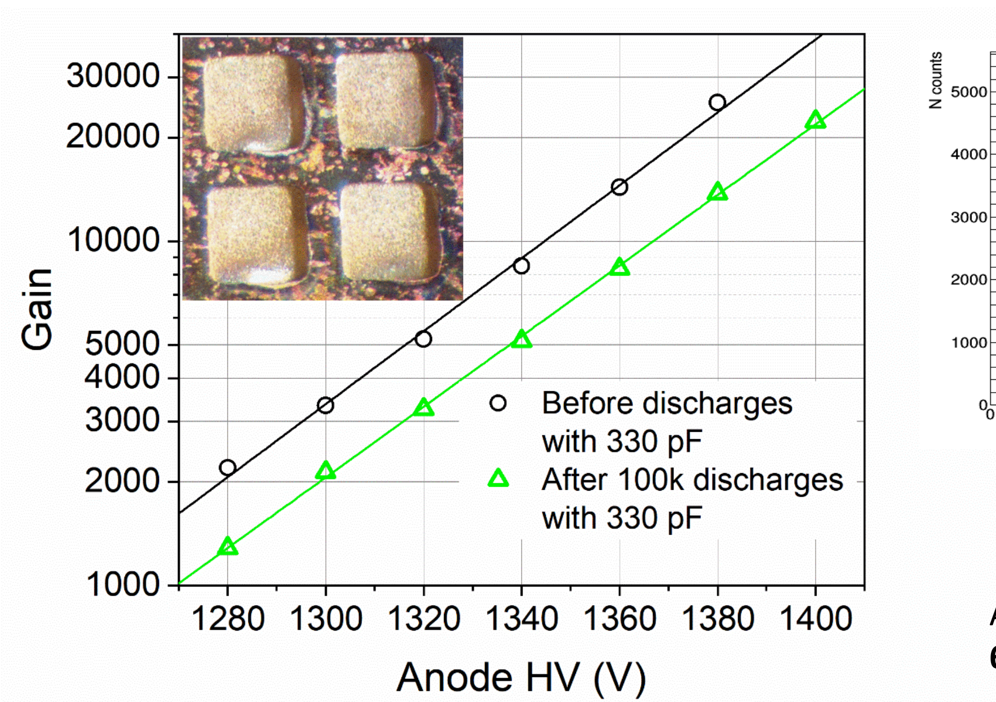
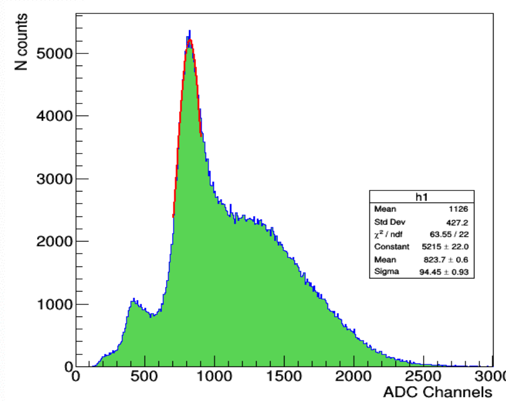
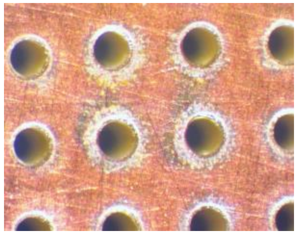
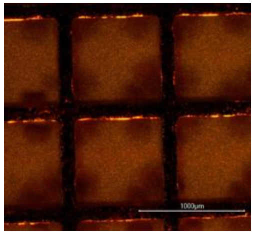


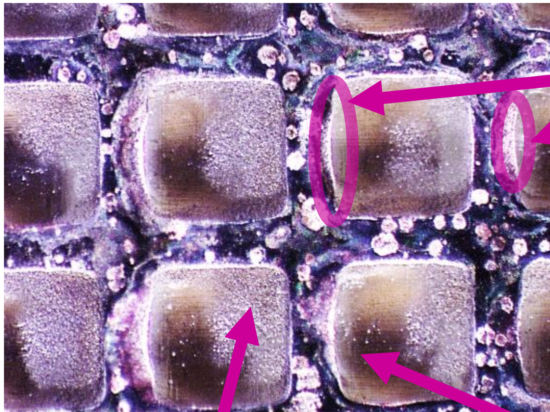






After **100,000 discharges** for active **area 60 x 60 mm^2** a slight visible damage was observed

Effect of Multiple Discharges on Accumulated Damage in R-WEM with DLC Anode

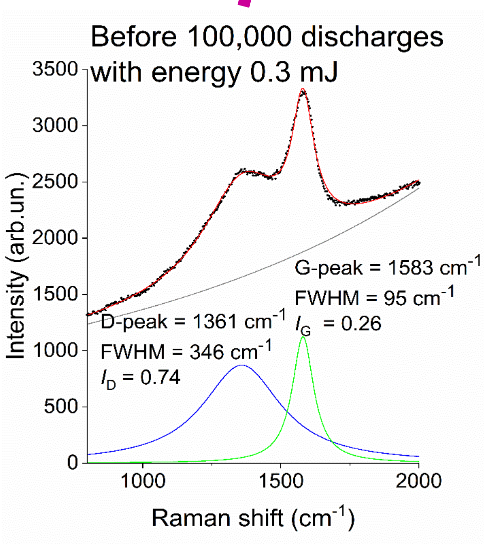


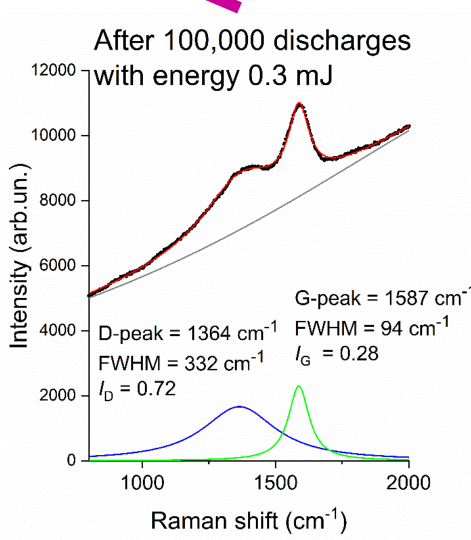
Damaged HV-grid

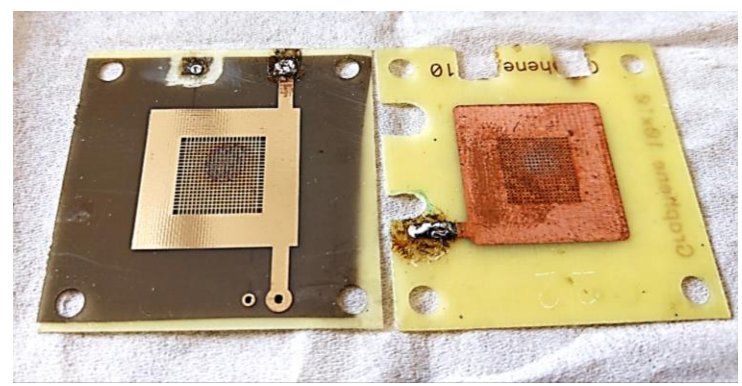
Raman confirm the presence of DLC layer with lower thickness

The discharge events initiated by an **Am^{241} alpha** source.
The circular alpha source 3 mm in diameter, activity of **33 Bq**

Active Area	Capacitance with the frame	Energy of discharges	Number of discharges
10 x 10 mm^2	34 pF	29 µJ	1,000,000
60 x 60 mm^2	360 pF	0.3 mJ	100,000
100 x 100 mm^2	**1 nF**	**0.9 mJ**	**100,000**

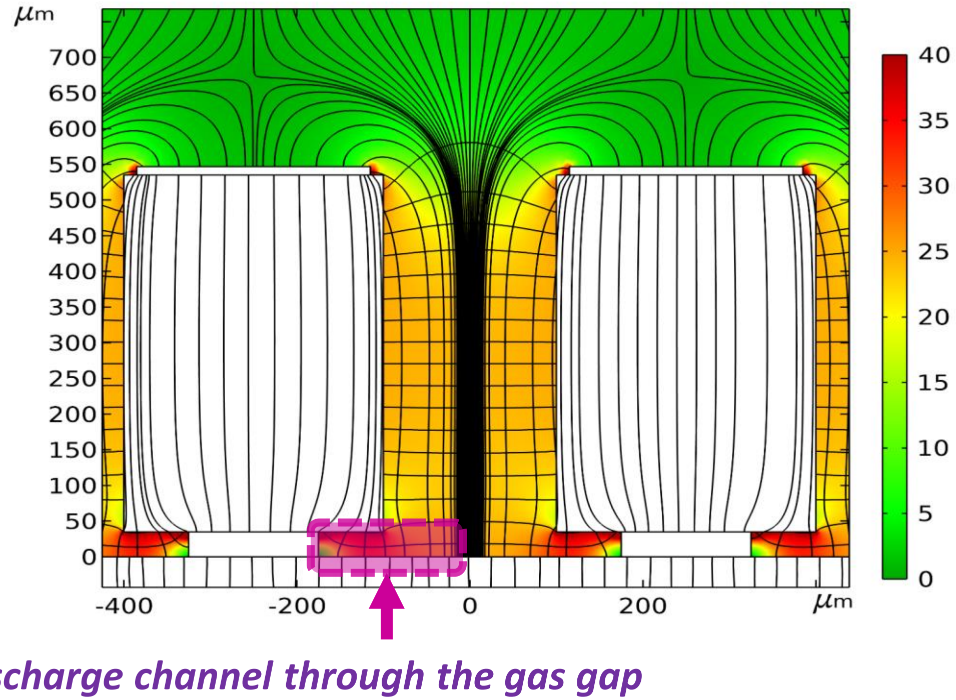






The further increase of the discharge energy by adding a capacitance up to C = 1 nF (active area **100 x 100 mm^2**) resulted in a significant damage to the DLC layer and the perforated FR4 board after **100,000 discharges**.
Both plates of the detector were significantly damaged

Effect of Multiple Discharges on Accumulated Damage in R-WEM with DLC Anode

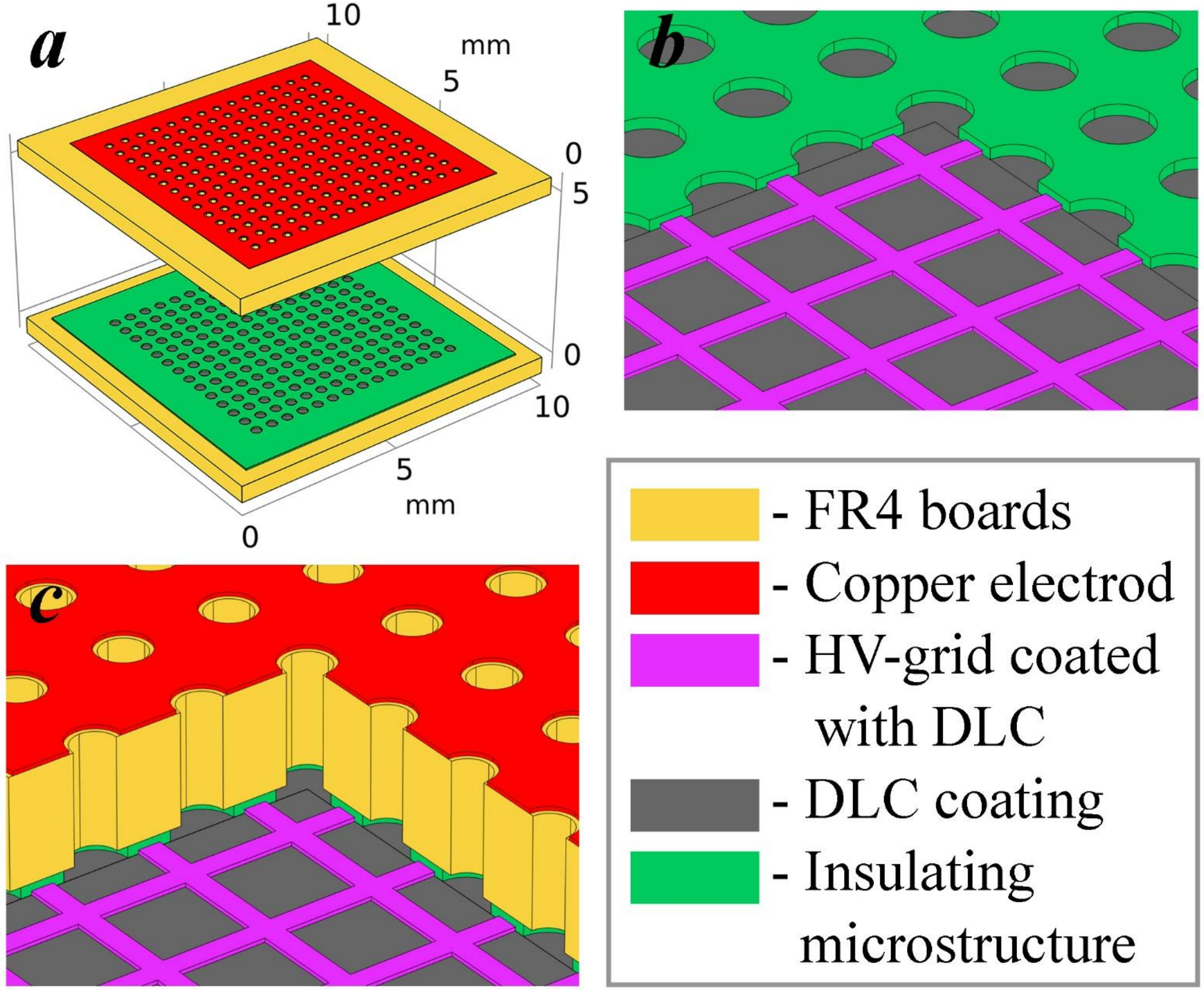


- The HV-grid has a thickness of 35 μm and this results in a gap between the Perforated FR4 board and the Anode board.
- The electric field strength in this gap has a local maximum relative to the center of the multiplication hole.
- When the discharge occurs, the discharge channel does not terminate on the resistive layer directly under the multiplication hole but instead goes above the resistive layer through the gas in the gap and terminates into the metal of the charge evacuation grid.

The damage of DLC layer itself is small, because the discharge current pass through the gas gap

R-WEM with DLC Anode and isolated HV-grid

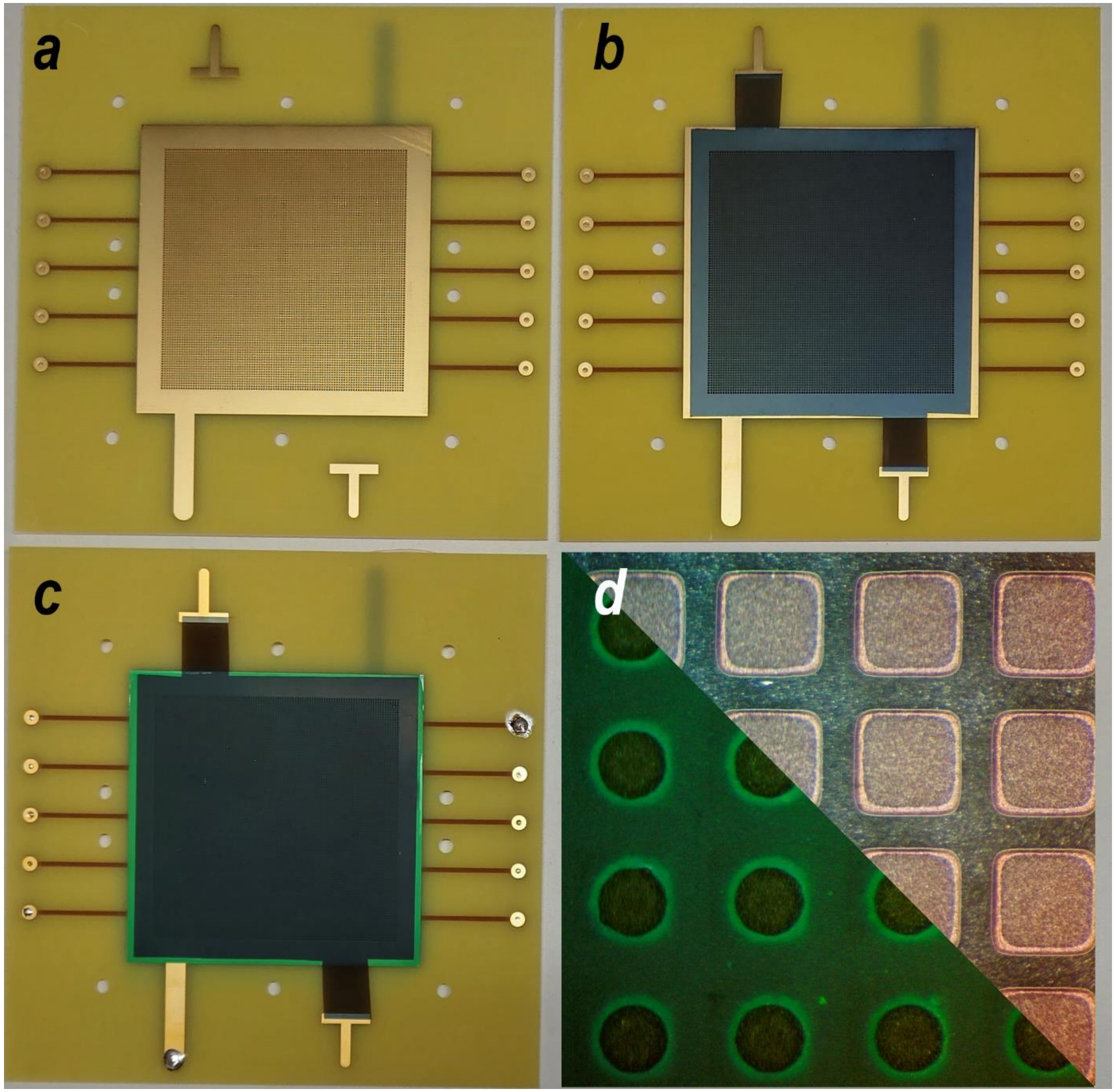
The Insulation of HV-grid avoid discharges from top electrode to HV-grid and allows to make R-WEM detectors with large active areas



a. *Sketch of the WEM detector consisting of two boards*
b. *Enlarged sketch of the insulating microstructure on the resistive DLC anode with a high voltage grid alone*
c. *Combined with perforated FR4 board*

R-WEM with DLC Anode and isolated HV-grid

The Insulation of HV-grid avoid discharges from top electrode to HV-grid and allows to make R-WEM detectors with large active areas



A photographic image of

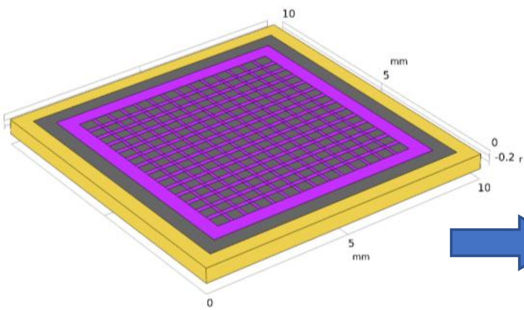
(***a***) the anode FR4 board with high voltage grid

(***b***, ***d***) the anode FR4 board with high voltage grid coated with DLC

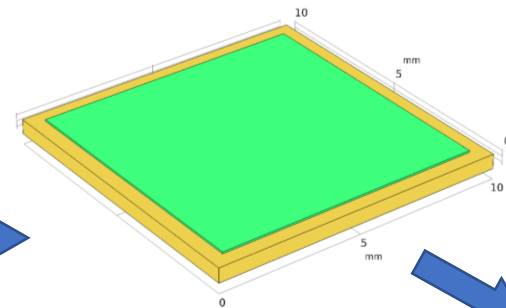
(***c***, ***d***) insulating structure.

R-WEM with DLC Anode and isolated HV-grid

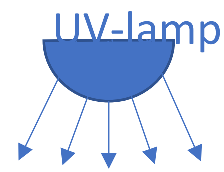
To isolate HV-grid electrode we used liquid photoresistive solder mask



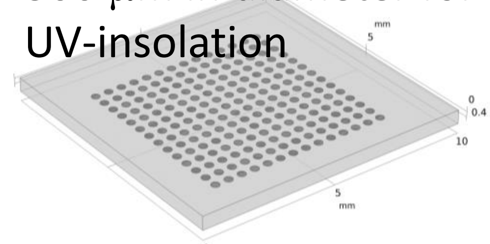
Anode FR4 board with HV-grid and ***DLC coating***

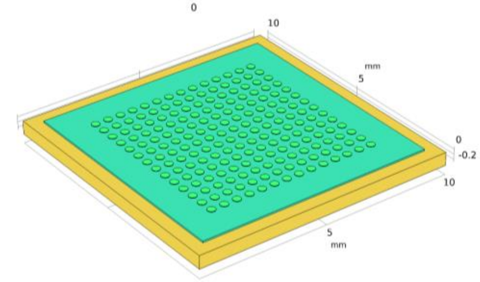


Covering with solder mask layer (50 μm thickness) using screen-printing

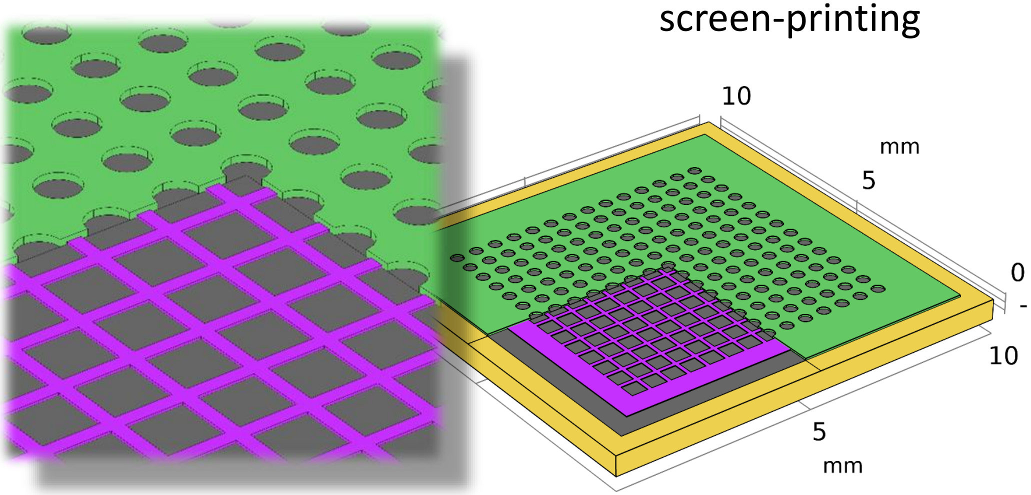


Photomask with circles of 300 μm in diameter for UV-insolation



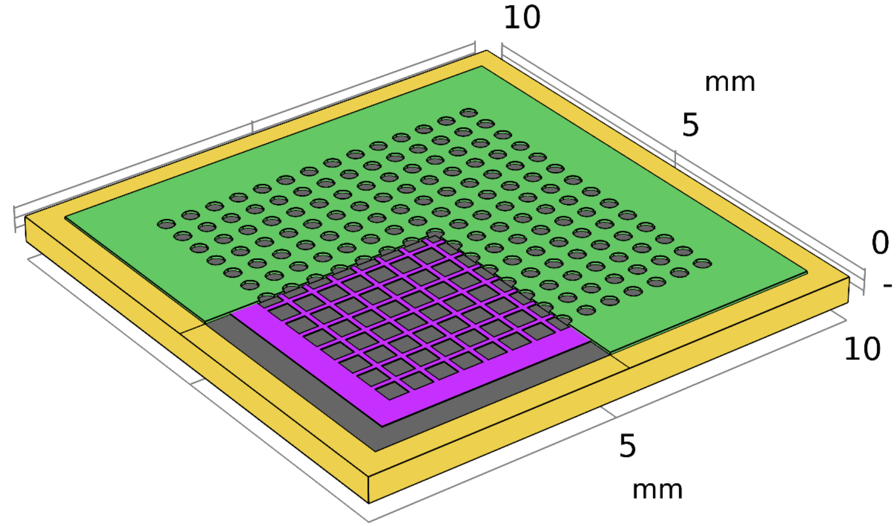


Insolated solder mask at Anode board



Anode FR4 board with isolated HV-grid and DLC coating

R-WEM with DLC Anode and isolated HV-grid

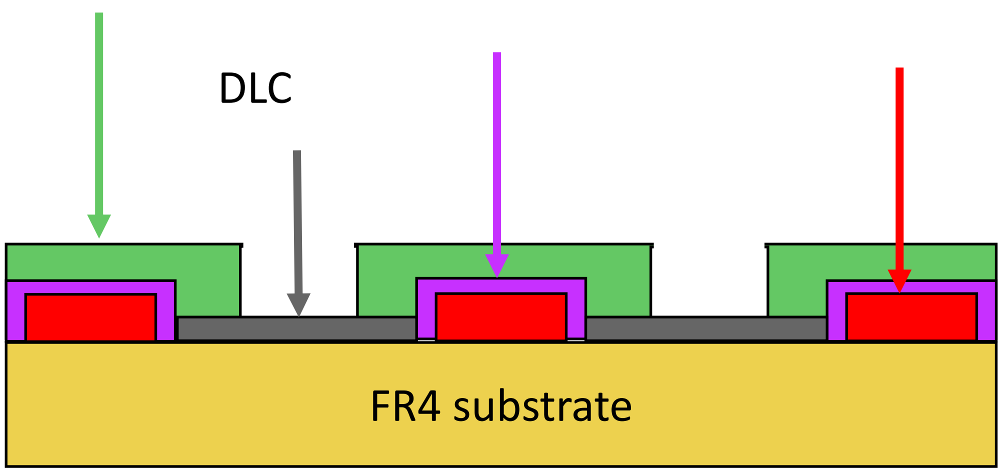


Copper HV-g
covered with
DLC

Copper HV-grid

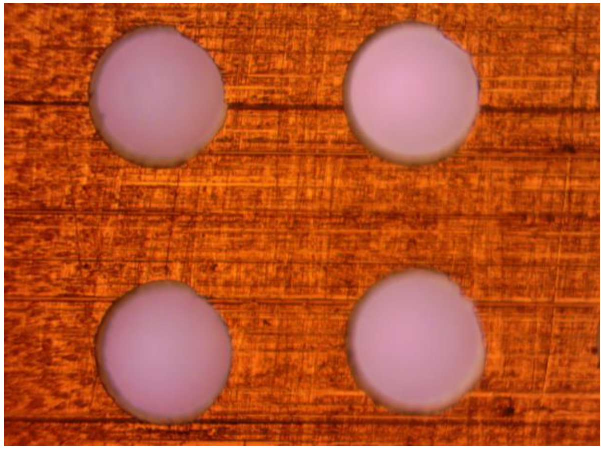
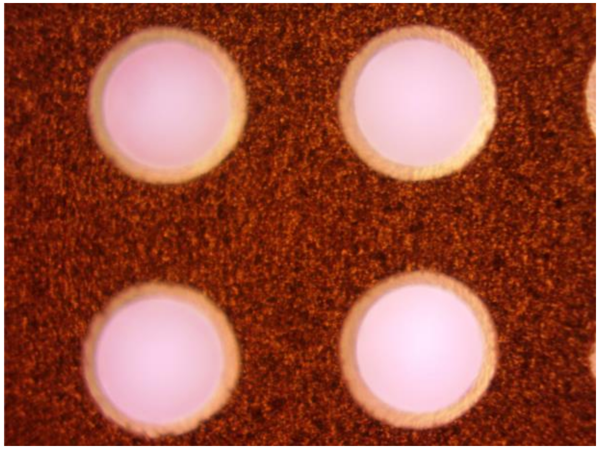
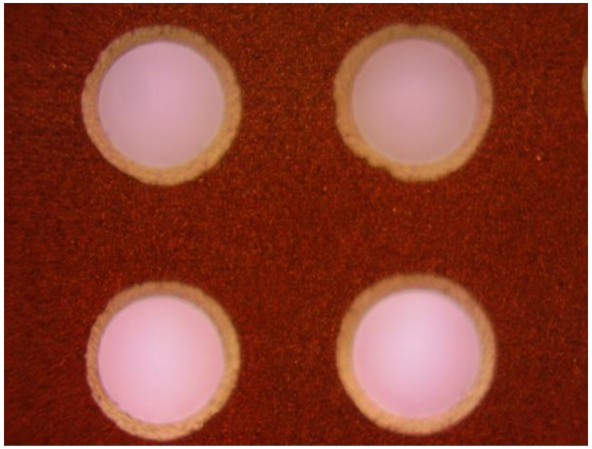
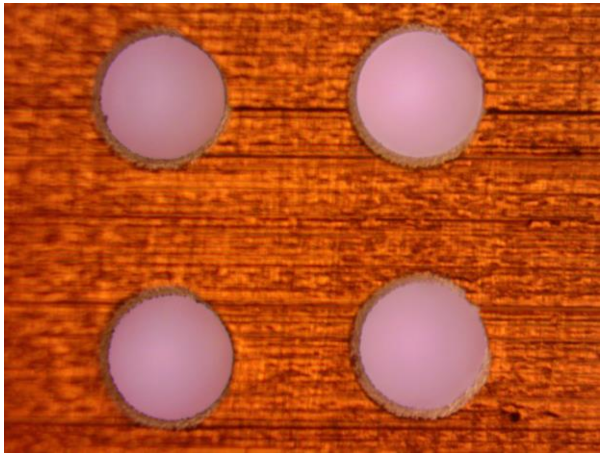
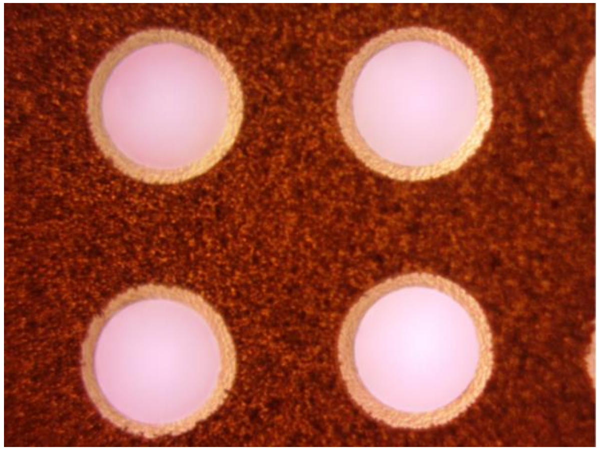
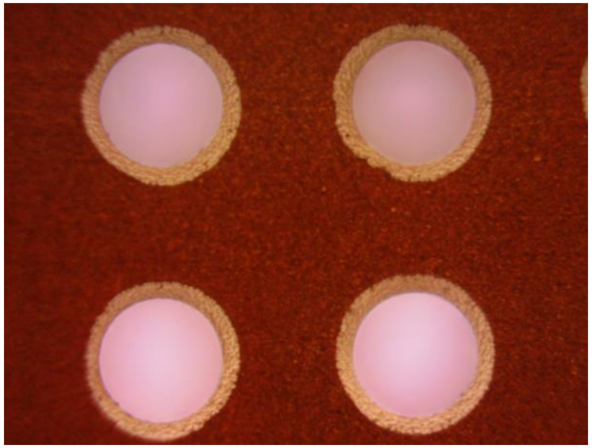
Isolator

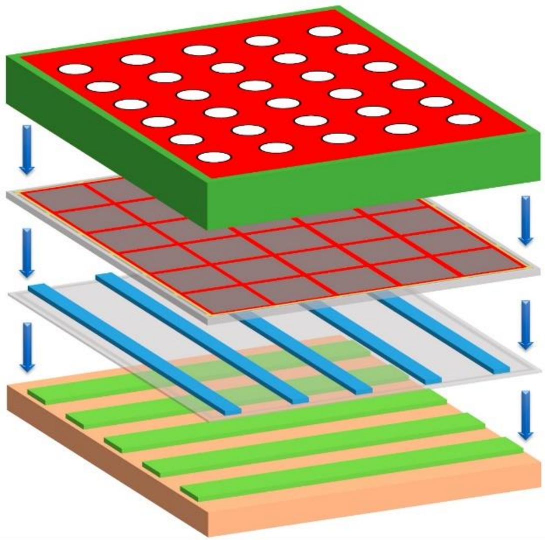
DLC

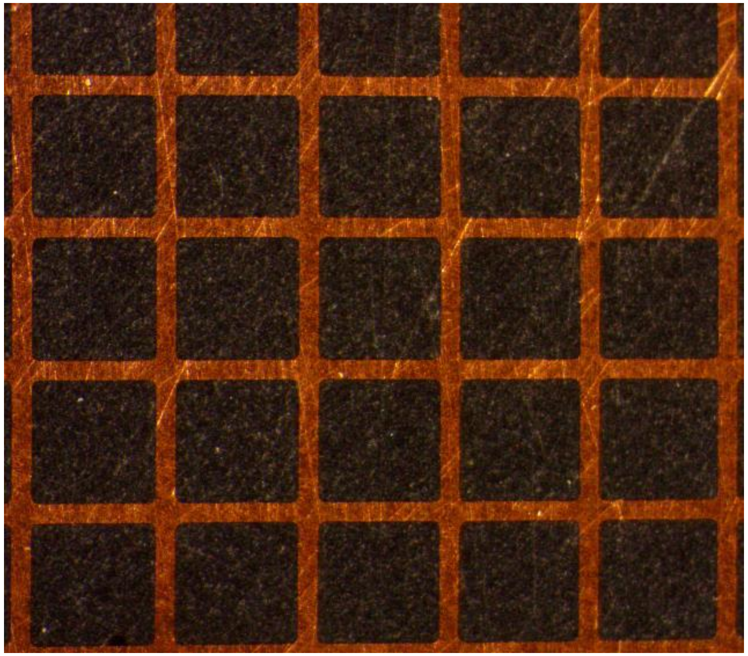


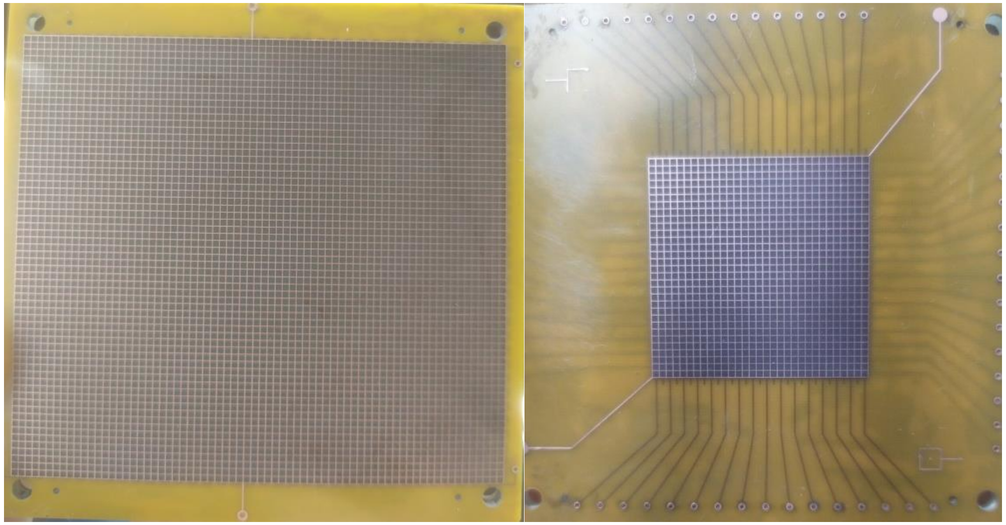
Resistive Well Electron Multiplier (R-WEM) with DLC anode

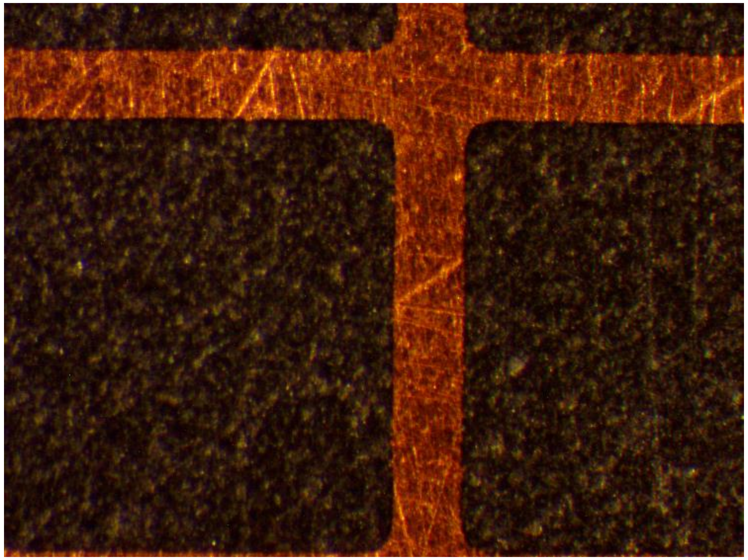
500 µm thick FR4 board metallized on one side with drilled holes of 200 µm in diameter and 500 µm in pitch

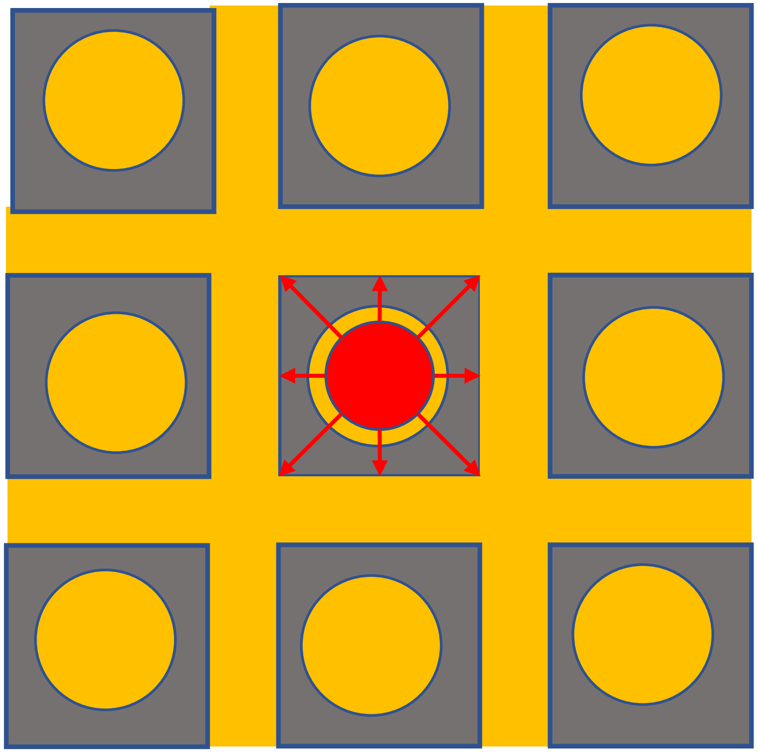


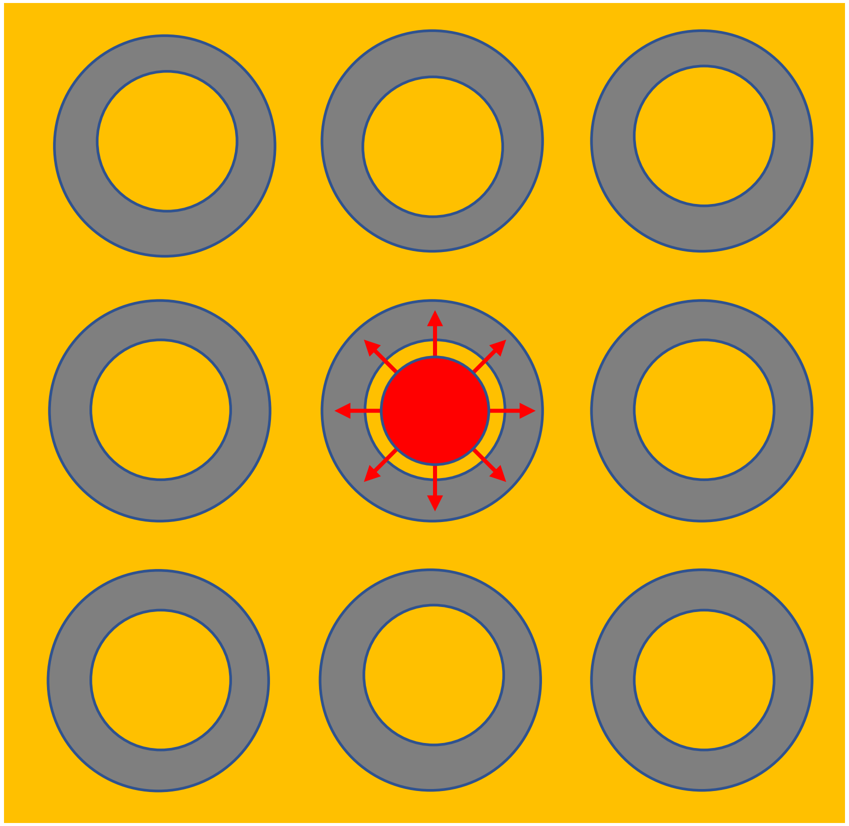


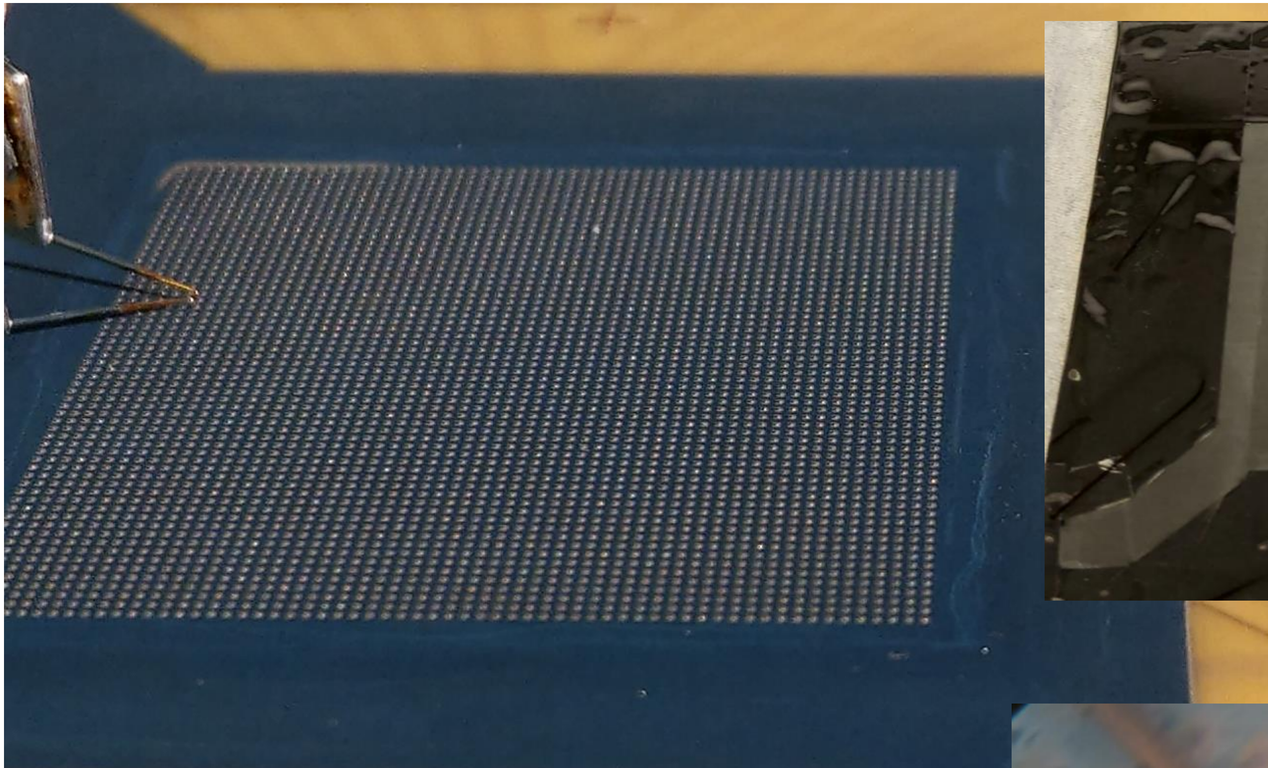


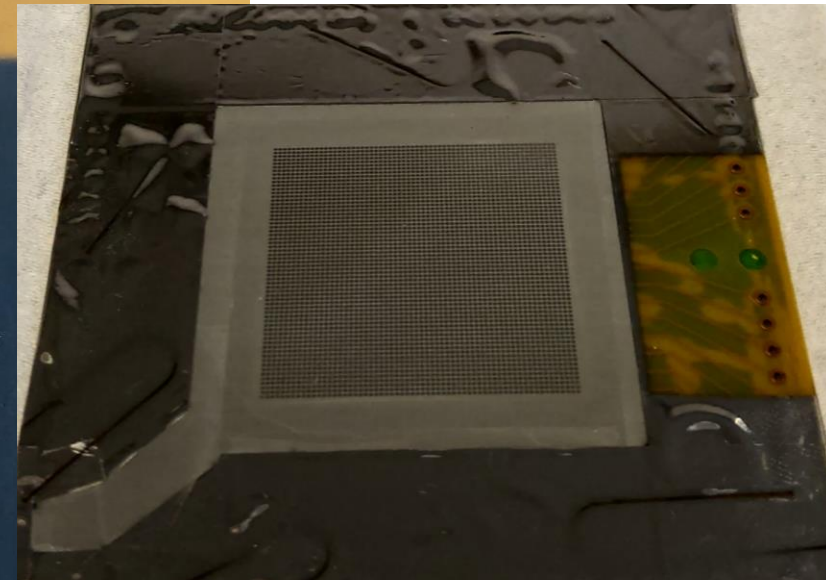


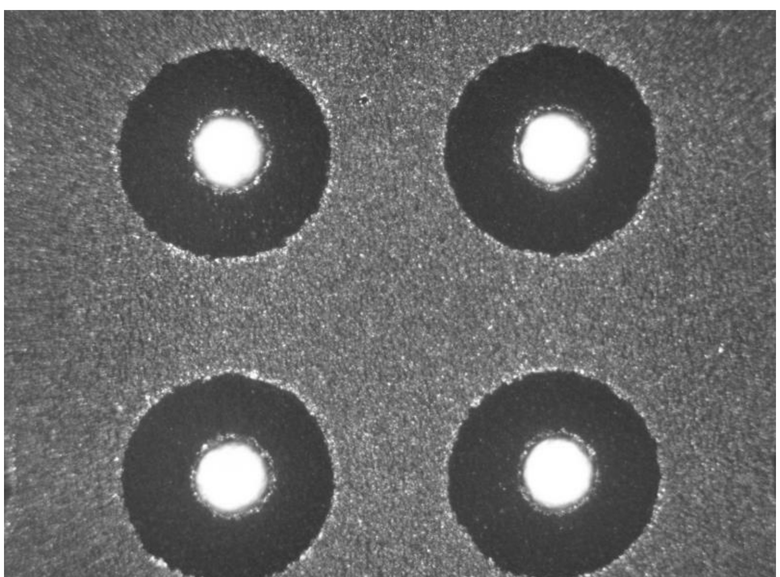
Анод с медным дном, связанный с сеткой, на которую подается напряжение, через слой DLC

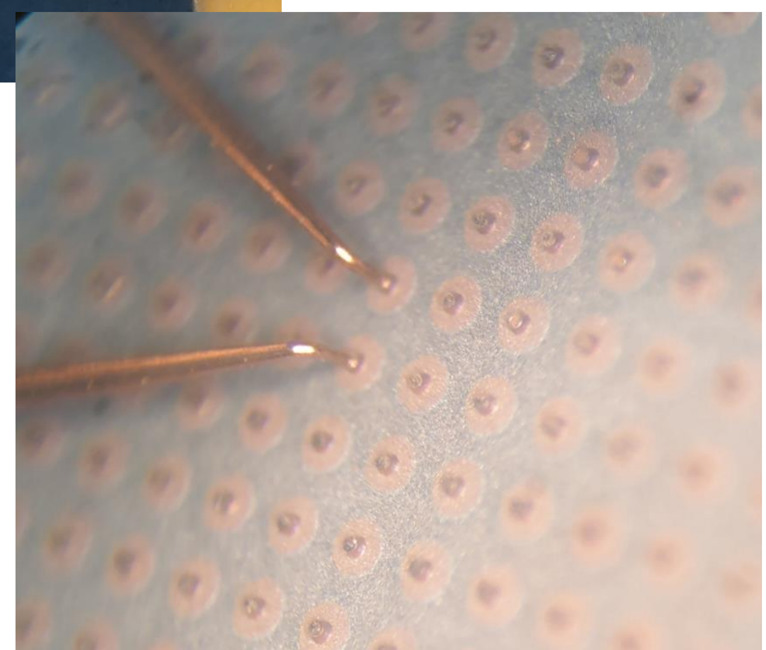


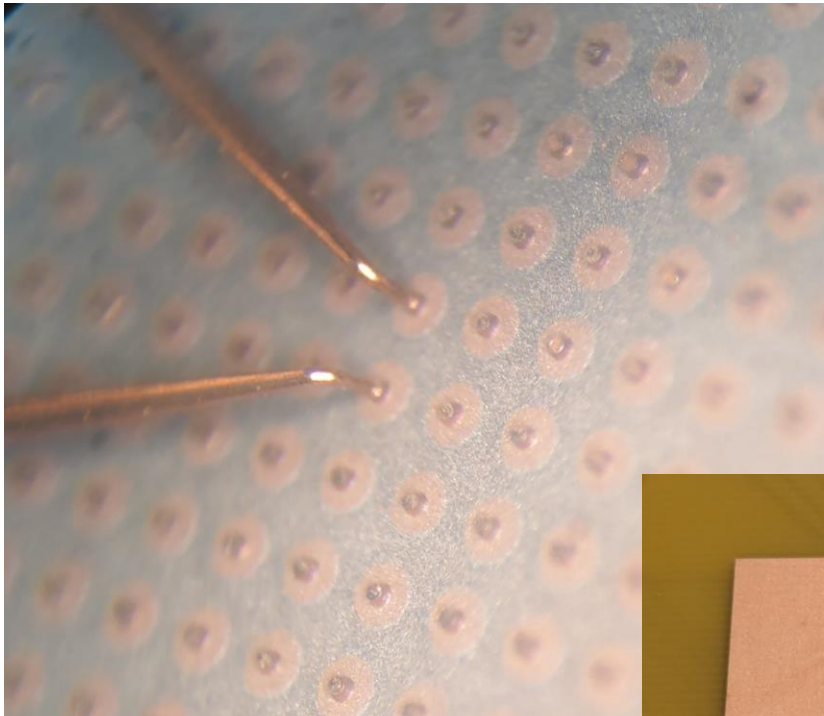
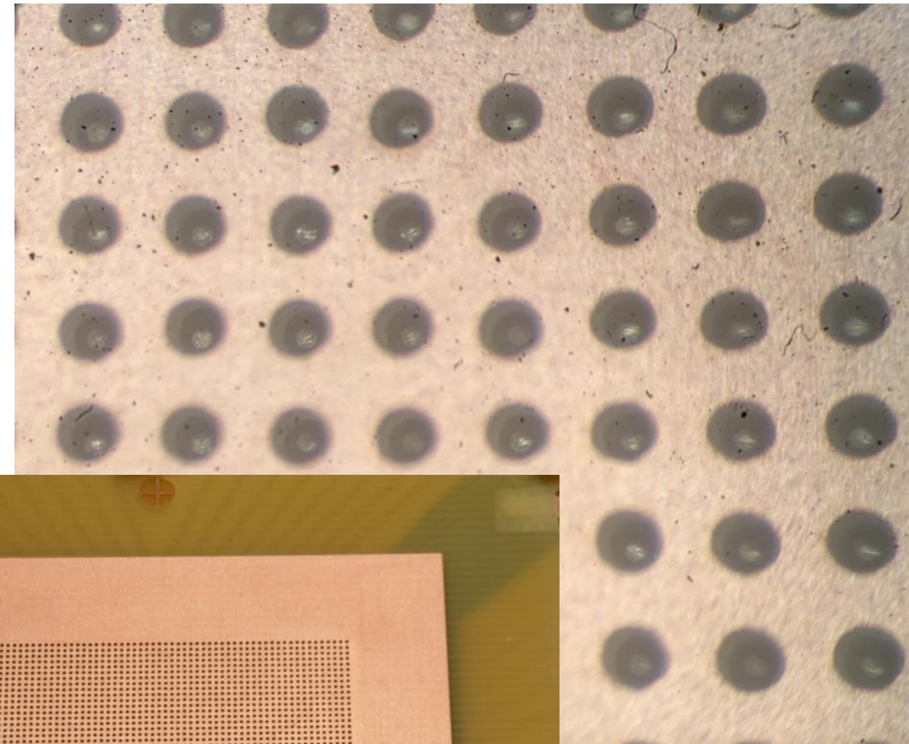
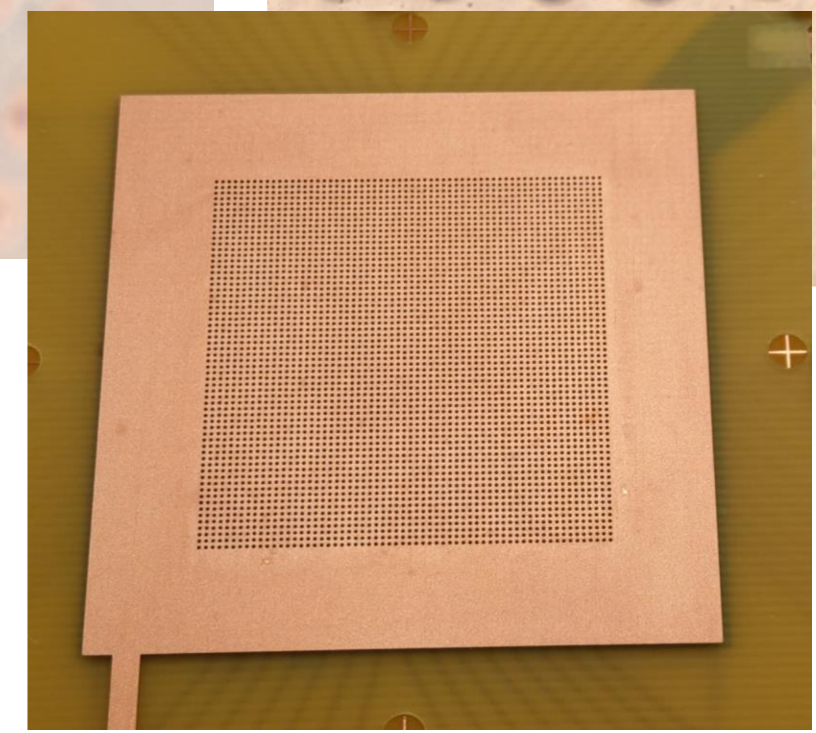


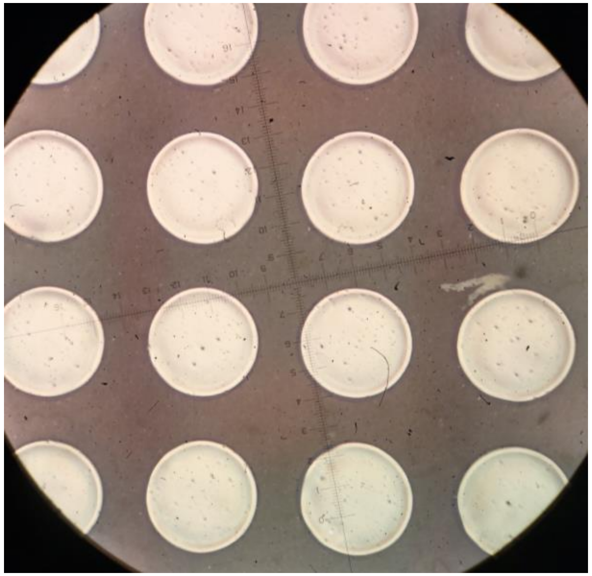


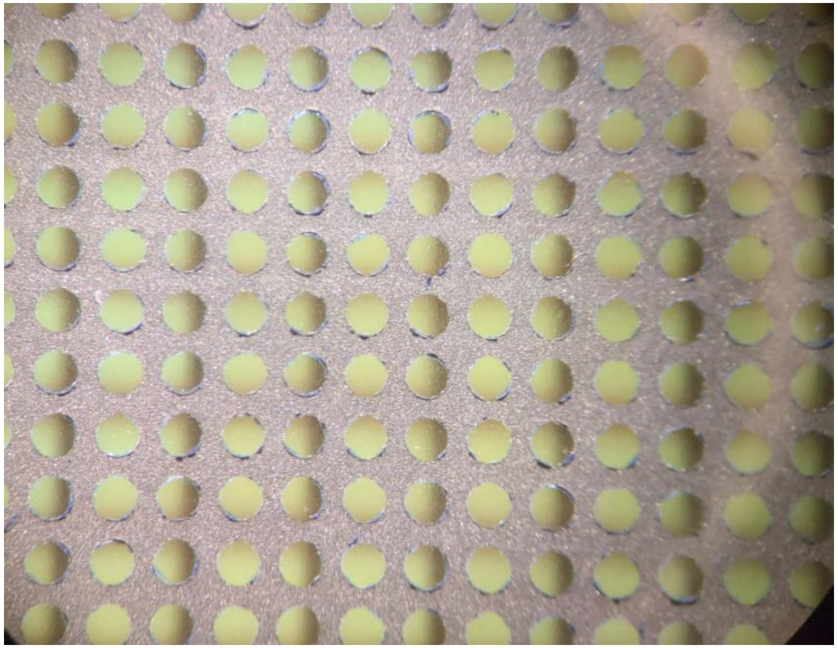


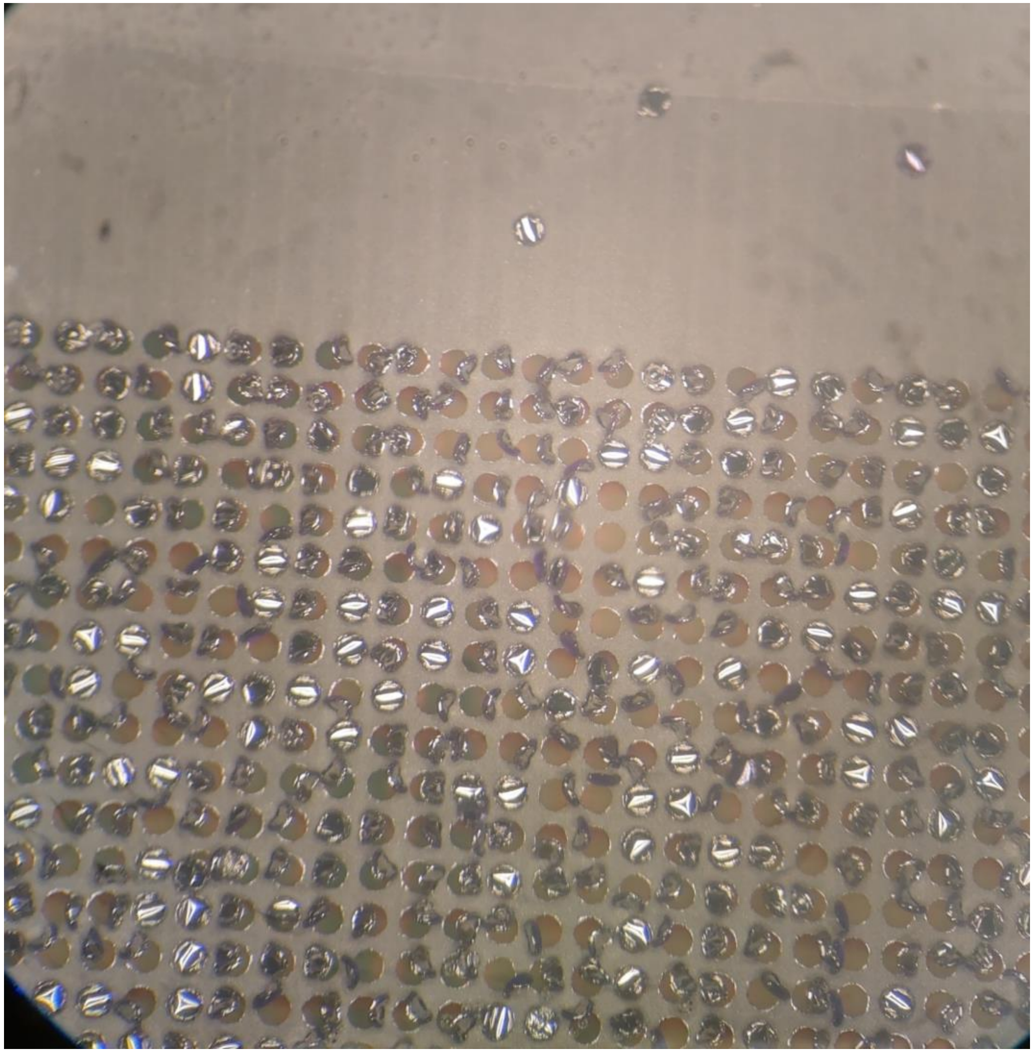




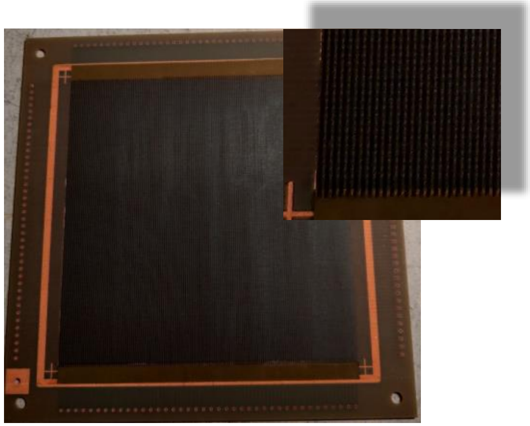




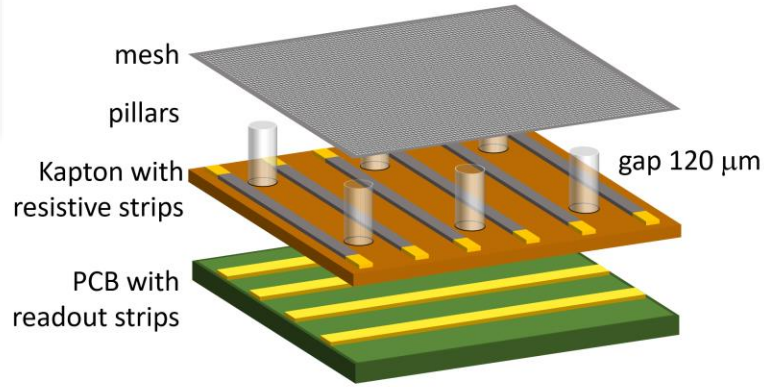


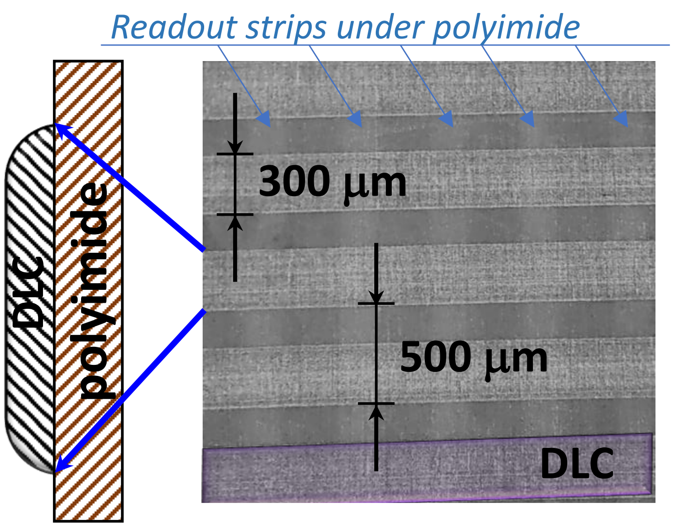


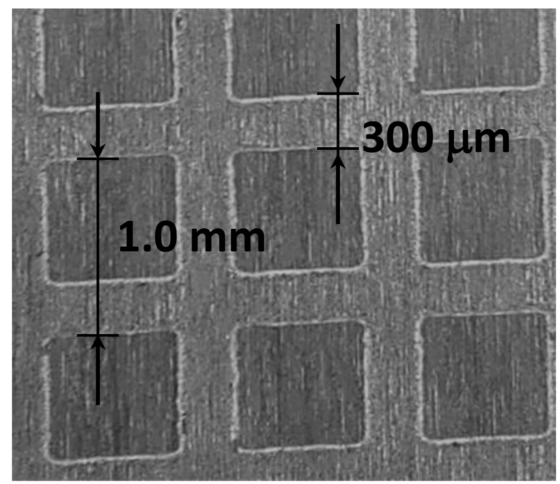


Structured DLC anode for MicroMegas





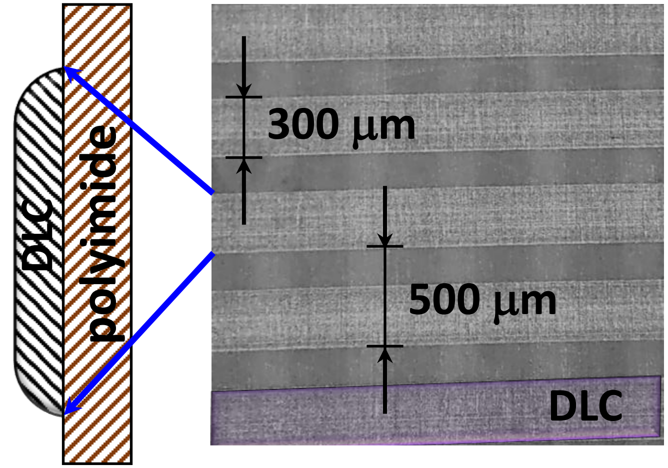


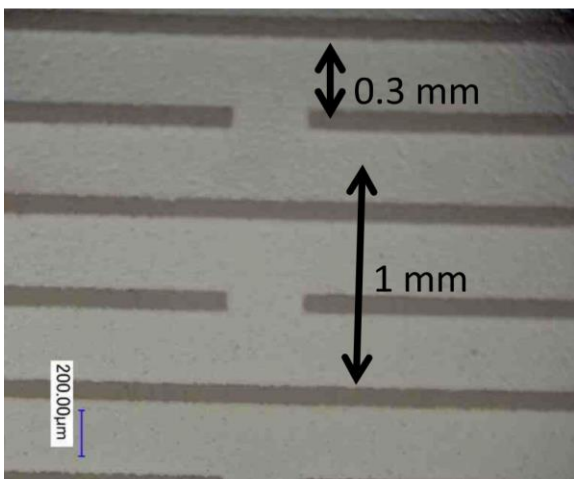


Structured DLC anode (photo-lithography assisted PVD deposition of carbon) – thin coating (100 nm) deposited in ***National Academy of Sciences of Belarus*** for Micromegas R&D for TPC MPD NICA

Structured DLC anode for MicroMegas

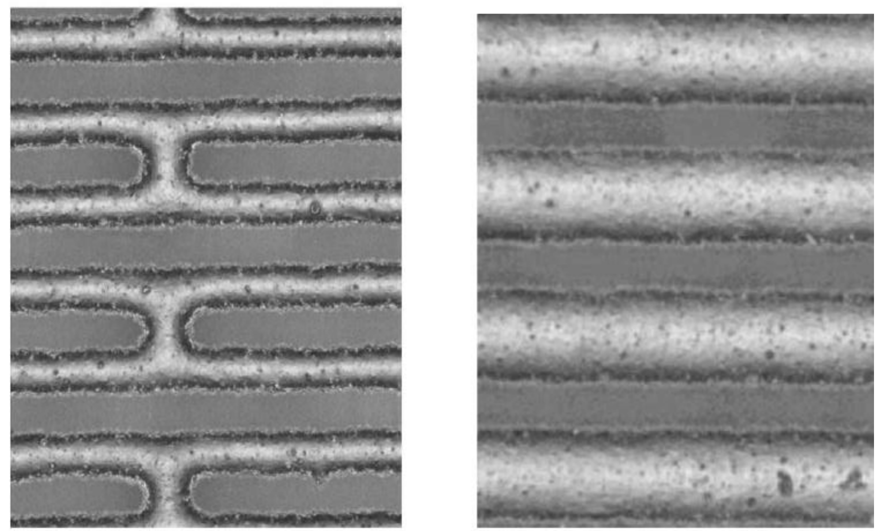
Structured resistive anode (screen-printing of resistive paste) in Micromegas chambers for the ATLAS
New Small Wheel





Structured DLC anode made in Japan (OCHI Atsuhiko KOBE university)

https://agenda.infn.it/event/7618/contributions/69161/attachments/50258/59384/DeOliveira.pdf

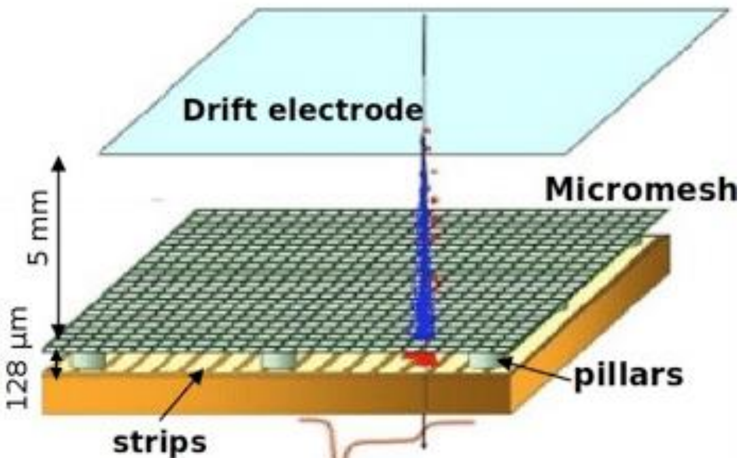


Structured DLC anode for MicroMegas R&D for muon imaging (CEA - Irfu, University Paris-Saclay)

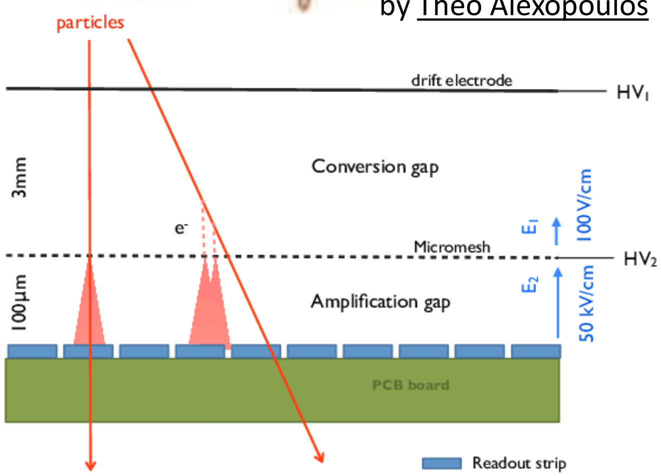
https://indico.cern.ch/event/676702/contributions/2812723/attachments/1575460/2487710/Micromegas_RD_for_muon_imaging_activities_at_Saclay.pdf

Current Activity

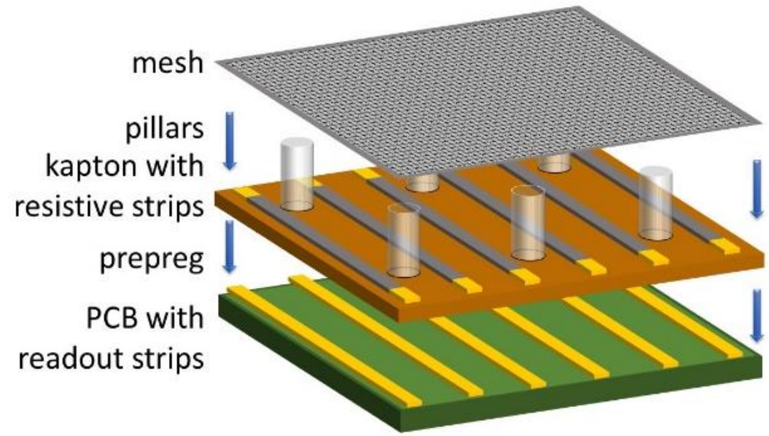
- Improving of arc-PVD method for DLC deposition (sheet resistivity, large area, composite structure)
- Bulk MicroMegas detector with resistive DLC anode for R/O Chambers of TPC @ NICA MPD experiment (Phase II)
- Cylindrical MicroMegas detector with resistive DLC anode for Vertex Detector @ NICA SPD experiment (Phase I)
- R-WEM detector with DLC anode and isolated HV-grid for R/O Chambers of TPC @ NICA MPD experiment
- Hybrid R-WEM & MicroMegas (Double MM) detector with extra low Ion Back Flow
- Ultra Thin MicroMegas detector for diagnostics of the secondary beam at the ACCULINNA-2 fragment separator for the Dubna SuperHeavy Element Factory
- Meta-structures for MPGDs adaptation to R/O Chambers of TPC for MPD experiment
  - ✓ Principe of Large Pads with Capacitive Sharing: Charge-to-Digital-Converter (**QDC**)
  - ✓ Composite anode-readout pad plane structures with patterned resistive layer for Charge Dispersion method of signal readout: Time-to-Digital-Converter (**TDC**)
  - ✓ QDC-TDC Hybrid Meta-Structures

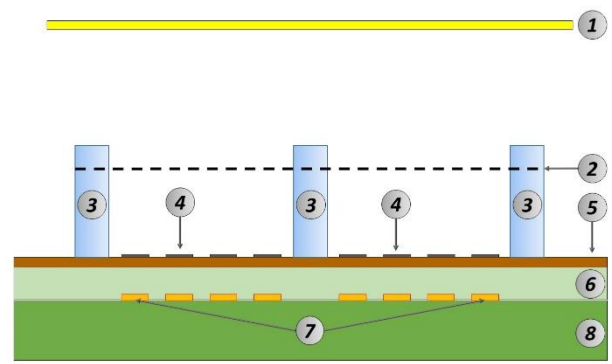


by Theo Alexopoulos



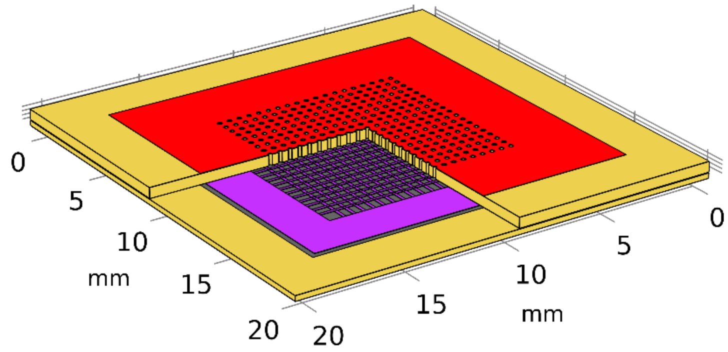
by David Attié

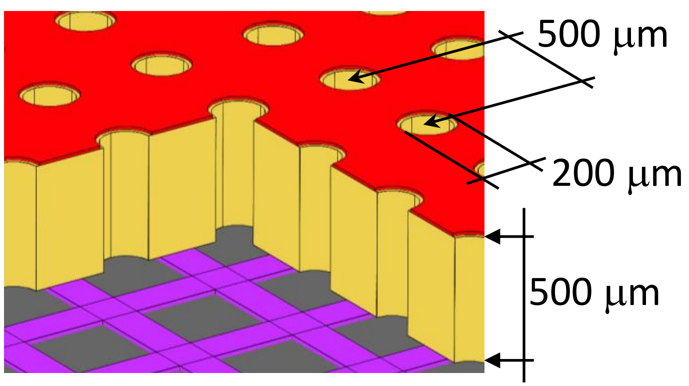


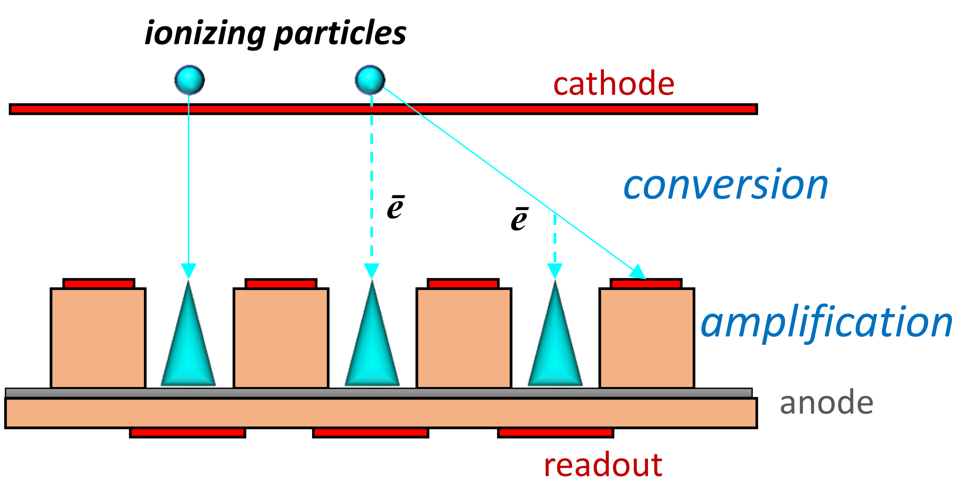


(1) – катод, (2) – металлическая сетка,
(3) – поддерживающие столбики (пиллары),
(4) – резистивные полосы из износостойкого углерода,
(5) – слой полиимида,
(6) – слой препрега,
(7) – считывающие электроды на печатной плате (8)

Resistive Well Electron Multiplier (R-WEM)



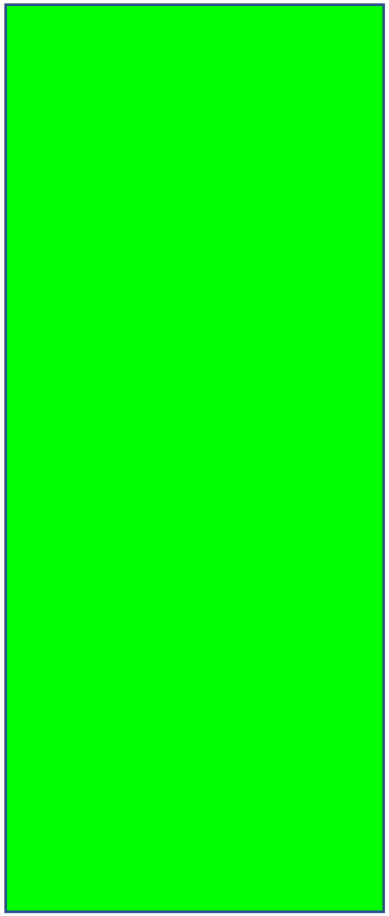


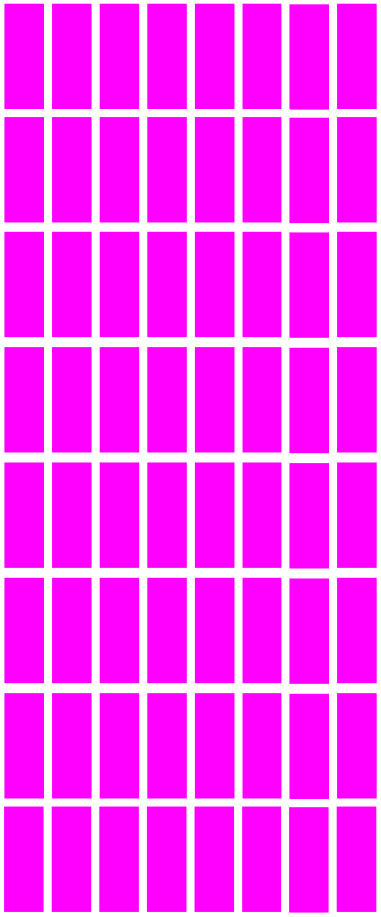


Kashchuk, V. Akulich, K. Afanaciev, V. Bayev, S.A. Movchan ***JINST 2020*** C09018

Pad 5mm X 12 mm

Pad 0.625mm X 1.5mm





For Pads

625μm X 1.5mm

(spatial resolution ~200μm)

Number of channels X 64

Number of Channels in TPC of MPD – 95,232

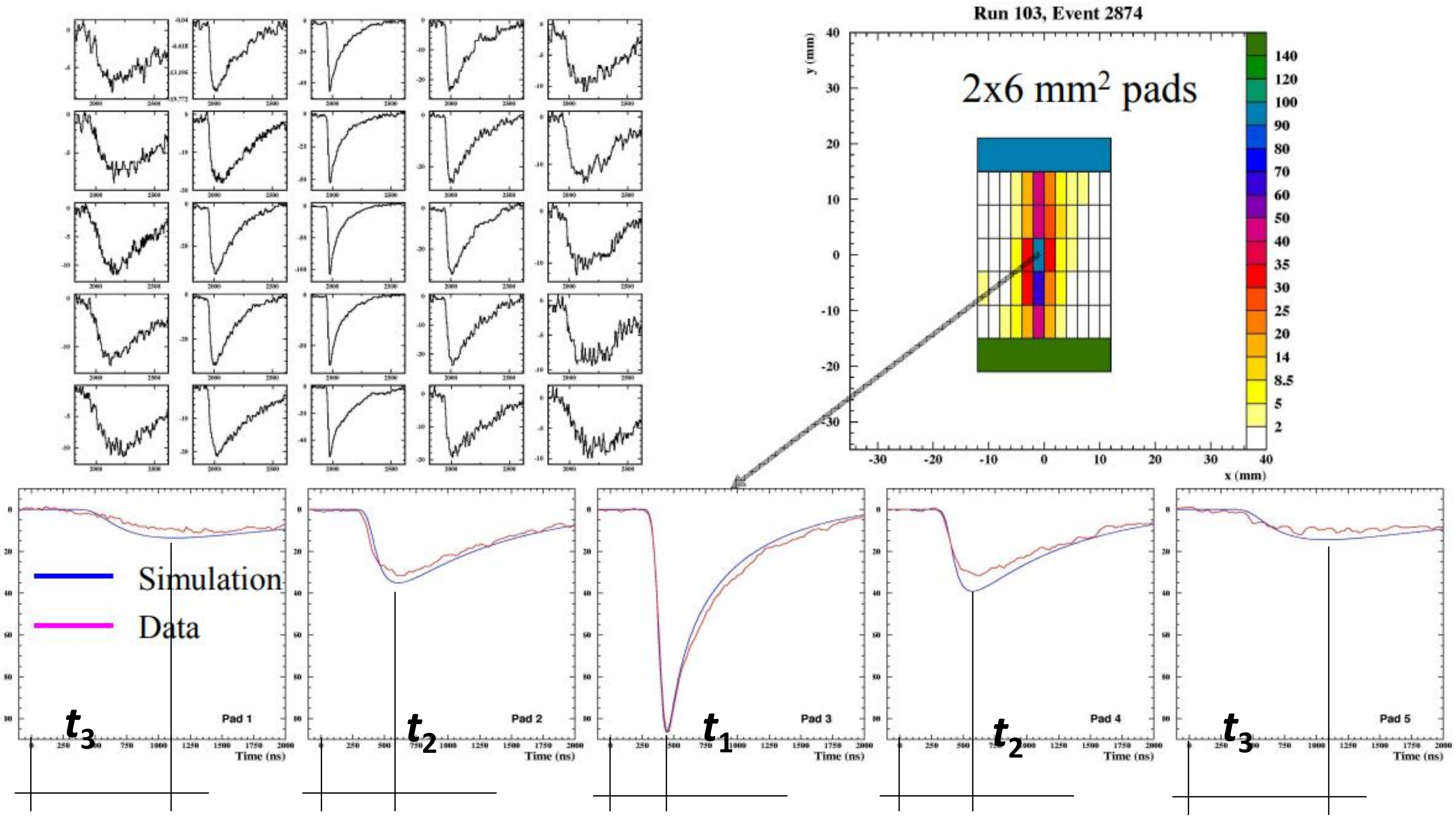
For Pads 300μm X 750μm

Number of channels X 256

Charge Dispersion Signal in Resistive Anode

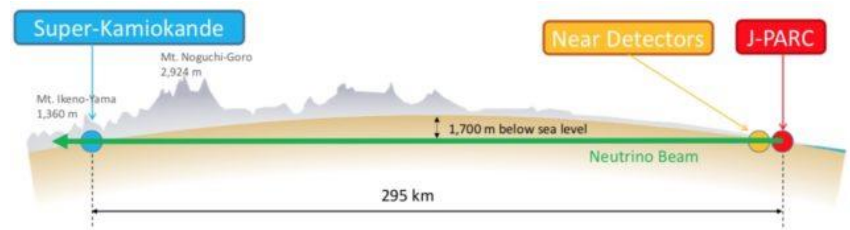
M.S. Dixit et al. Position sensing from charge dispersion in micro-pattern gaseous detectors with a resistive anode. ***NIMA*** **518** (2004) 721

Madhu Dixit Carleton University & TRIUMF, Canada

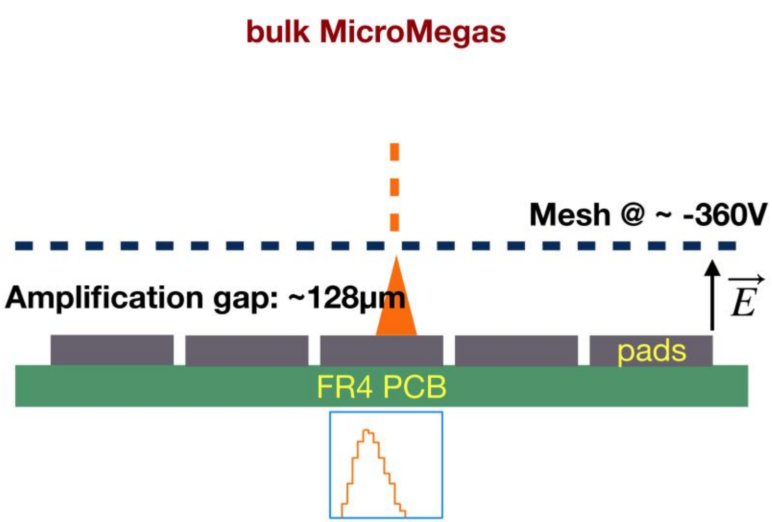


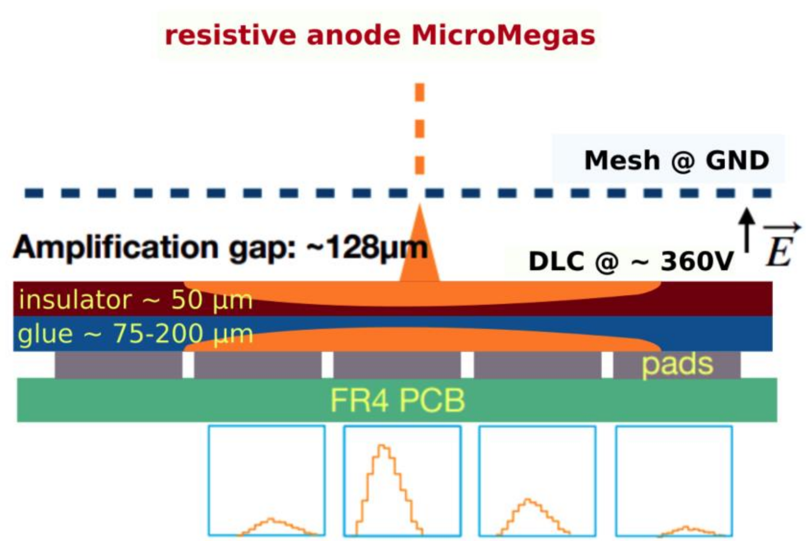
Charge Dispersion Signal in Resistive Anode

The approach of charge dispersion
will be used for the upgrade of the
Near Detector (ND280) in
neutrino T2K experiment (Tokai to Kamioka), Japan



Resistive Micromegas detectors for the upgrade of the
T2K Near Detector Time Projection Chambers.
Spatial resolution up to 200 µm for 0.97x0.69 cm^2 pads





David Attie et al. ***NIMA* 1025** (2022) 166109

Capacitive Sharing Large Pad Readout

Photo from The 6th International Conference on Micro Pattern Gaseous Detectors, MPGD19

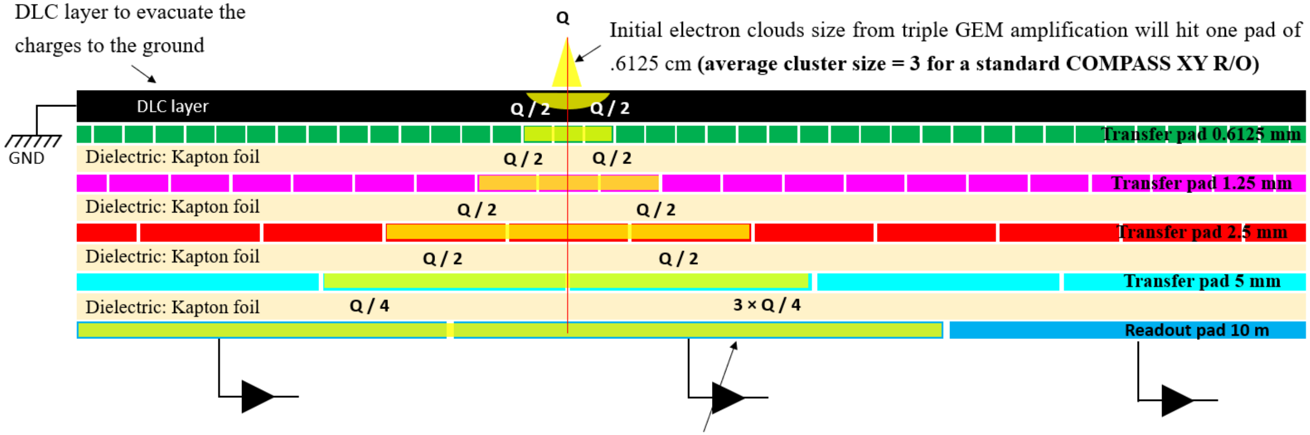
The idea was proposed in **2020** by ***Kondo Gnanvo***, University of Virginia, Charlottesville, VA, USA

Jefferson Lab

Capacitive Sharing Large Pad Readout is supposed to be implemented in:

- **CLAS12 experiment** - Upgrade for High Luminosity Operations, **CEBAF Large Acceptance Spectrometer,** Jefferson Laboratory, Newport News, Virginia, United States
- **The Electron-Ion Collider** that will be build on the base of **Brookhaven's Relativistic Heavy Ion Collider (RHIC)**, Upton, New York, United States

Capacitive Sharing Large Pad Readout

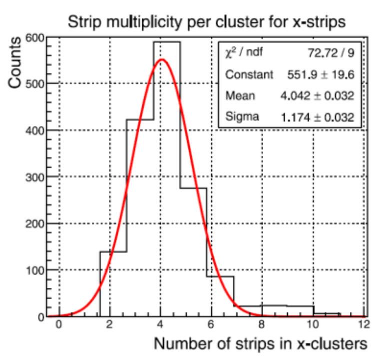


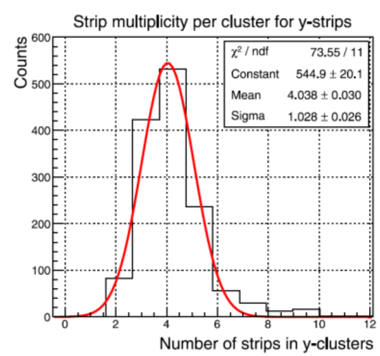
2 large pads (1 cm^2) share the initial charges: position is the weighted average of the pads ⇨ expected similar performances in spatial resolution as a COMPASS X/Y strip readout but with only 100 pads to read out instead of 512 for a COMPASS XY readout

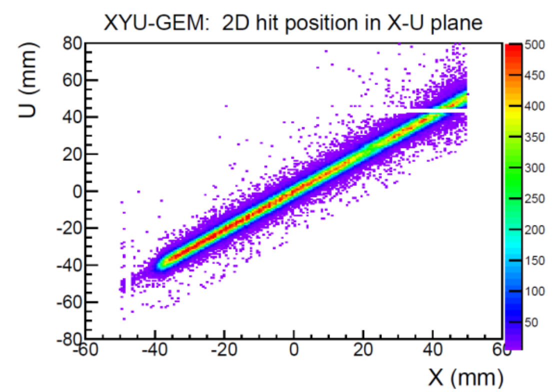
RD51 Collaboration, 06/26/2020

First Results:

K. Gnanvo, N. Liyanage, B. Mehl, Rui de Oliveira ***NIMA 1047*** (2023) 167782
K. Gnanvo et al. ***NIMA 1066*** (2024) 169654







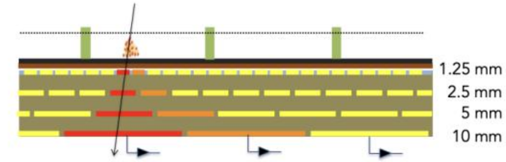
For two transfer layers of pads with pitch of 400 and 800 μm spatial resolution is 56.2 ± 0.9 μm

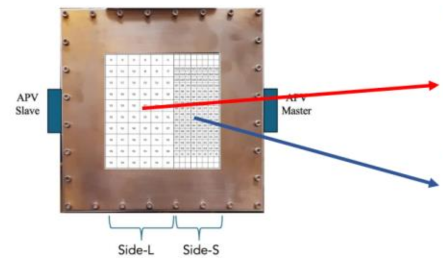
Capacitive Sharing Large Pad Readout

Medium/Low-rate Version – Capacitive Sharing

Concept from R. De Oliveira and K. Gnanvo et al., NIMA 1047 (2023) 167782)

- First implementation of the capacitive sharing principle in a single layer DLC resistive Micromegas
- Charge shared in large readout pads through the capacitive coupling between stack of layers of pads.
  - Good spatial resolution and reduction of the readout channels
- Suitable for low- medium- rate applications



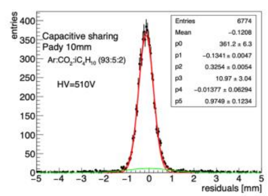


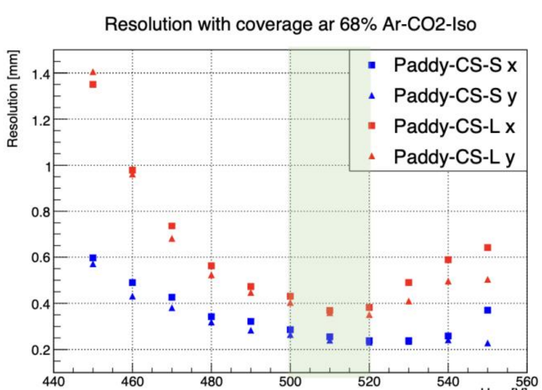
- Pad size of "top-layer" (signal induction): 1.25x1.25 mm2
- **Side-L:** Four layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2 → 10x10 mm^2
- **Side-S:** three layers capacitive sharing: 1.25x1.25 mm^2 → 2.5x2.5 mm^2 → 5x5 mm^2

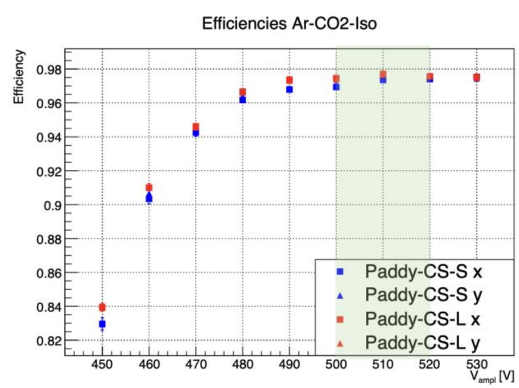
Capacitive Sharing Test-Beam Results

Spatial Resolution and Efficiency

Resolution: half-width of the distribution retaining 68% of the events







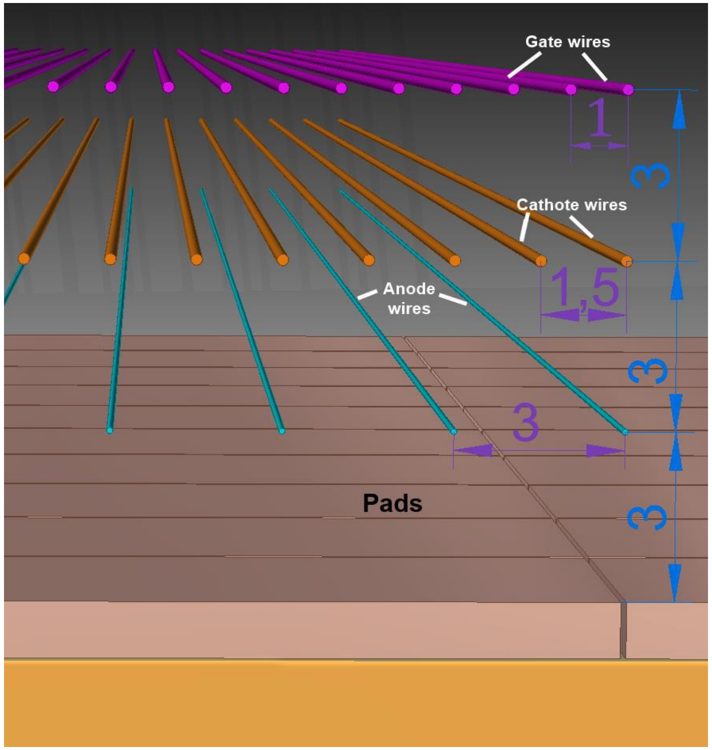
REACH ~380 μm with 10x10 mm² pads

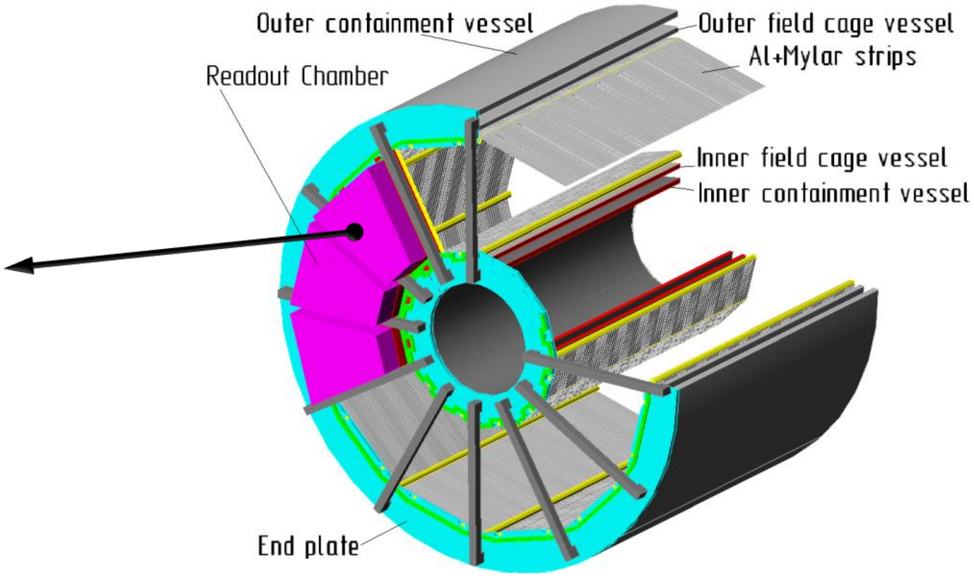
→ A factor 1/26 of the pad size

~220 μm with 5x5 mm^2 pads (1/23 of the pad size)

Read-Out Chamber of 1st Stage of NICA MPD Experiment

MultiWire Proportional Chamber (MWPC) with Gating Grid System





Parameter of 1st Stage	Value
Length of the TPC **Outer radius of vessel** **Inner radius of vessel**	**340cm** **140cm** **27 cm**
Maximum beam-beam event rate	**5 kHz**
Luminosity	$1 \cdot 10^{27}$ cm^{-2}s^{-1}
Gas amplification factor	**10,000**

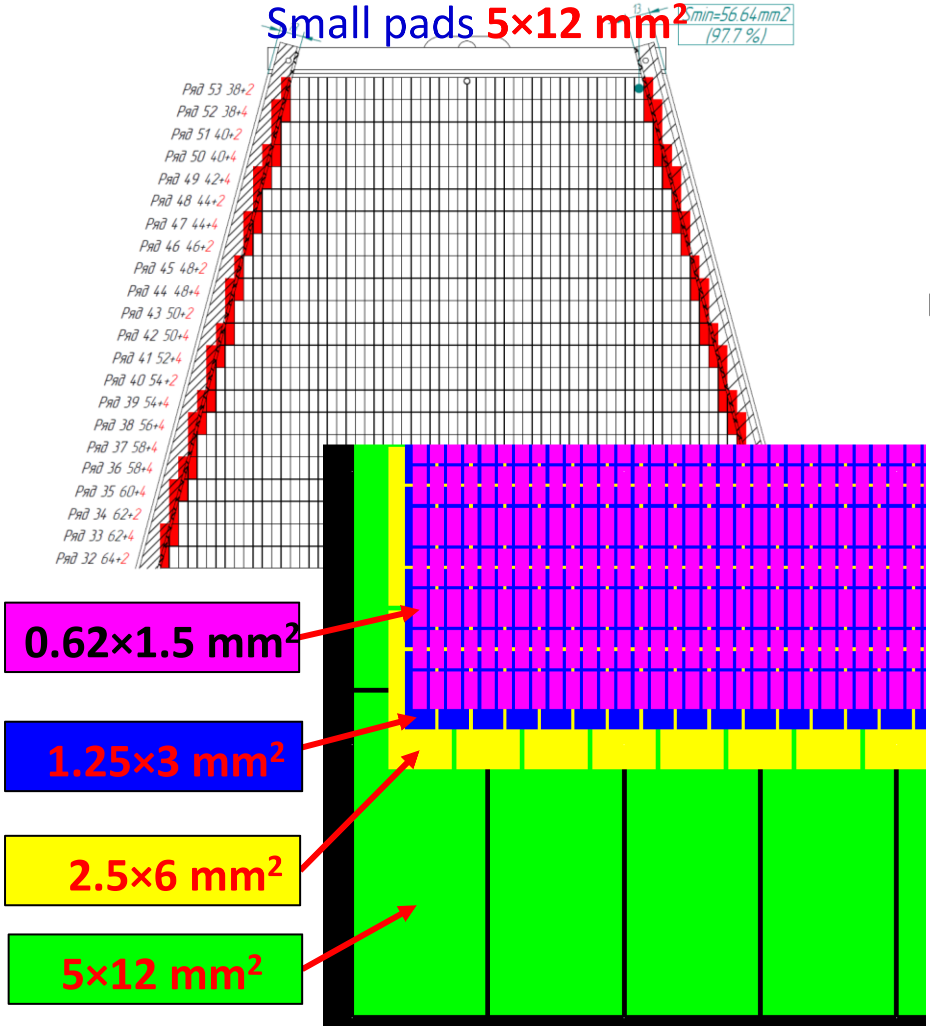
At the 2d Stage of NICA MPD Experiment the Luminosity will be increased. It means that Event Rate of R/O Chambers should be also increased → Upgrade by use of

Micro Pattern Gaseous Detectors (MPGDs)

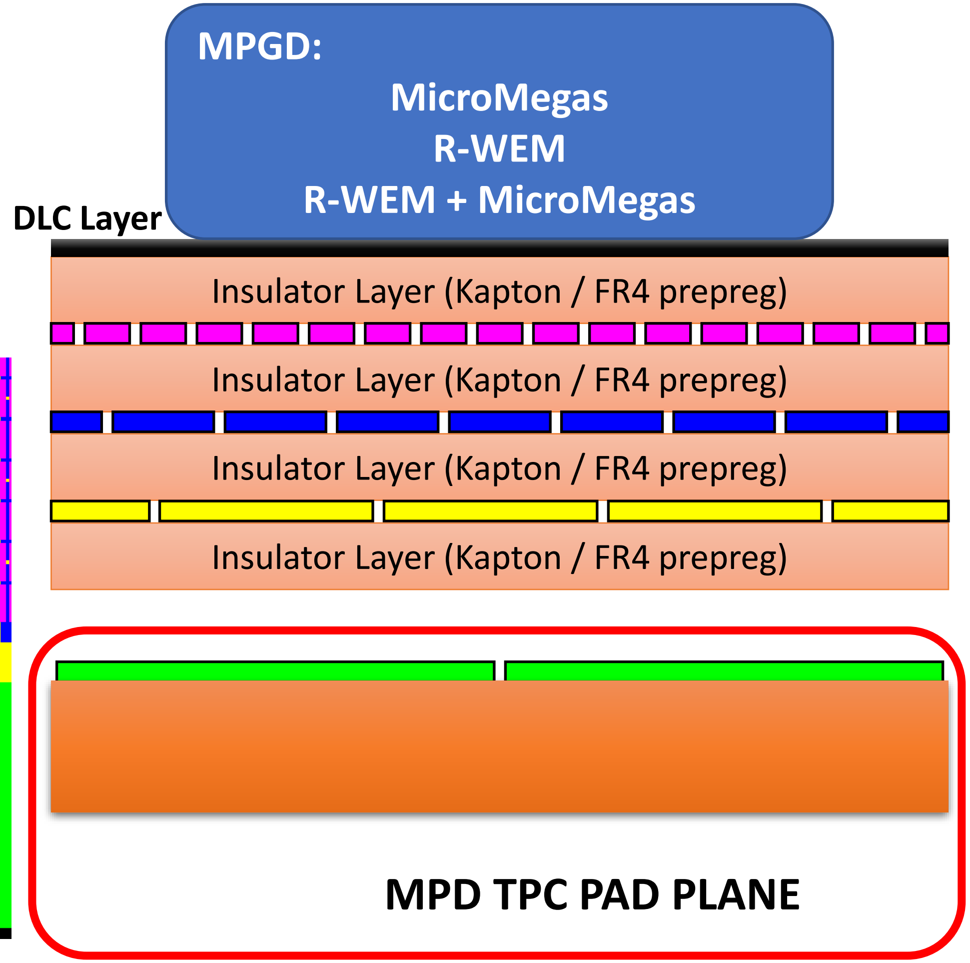
MPGD adaptation to R/O Chambers of TPC of MPD experiment

MPD TPC PAD PLANE

Small pads **5×12 mm²**

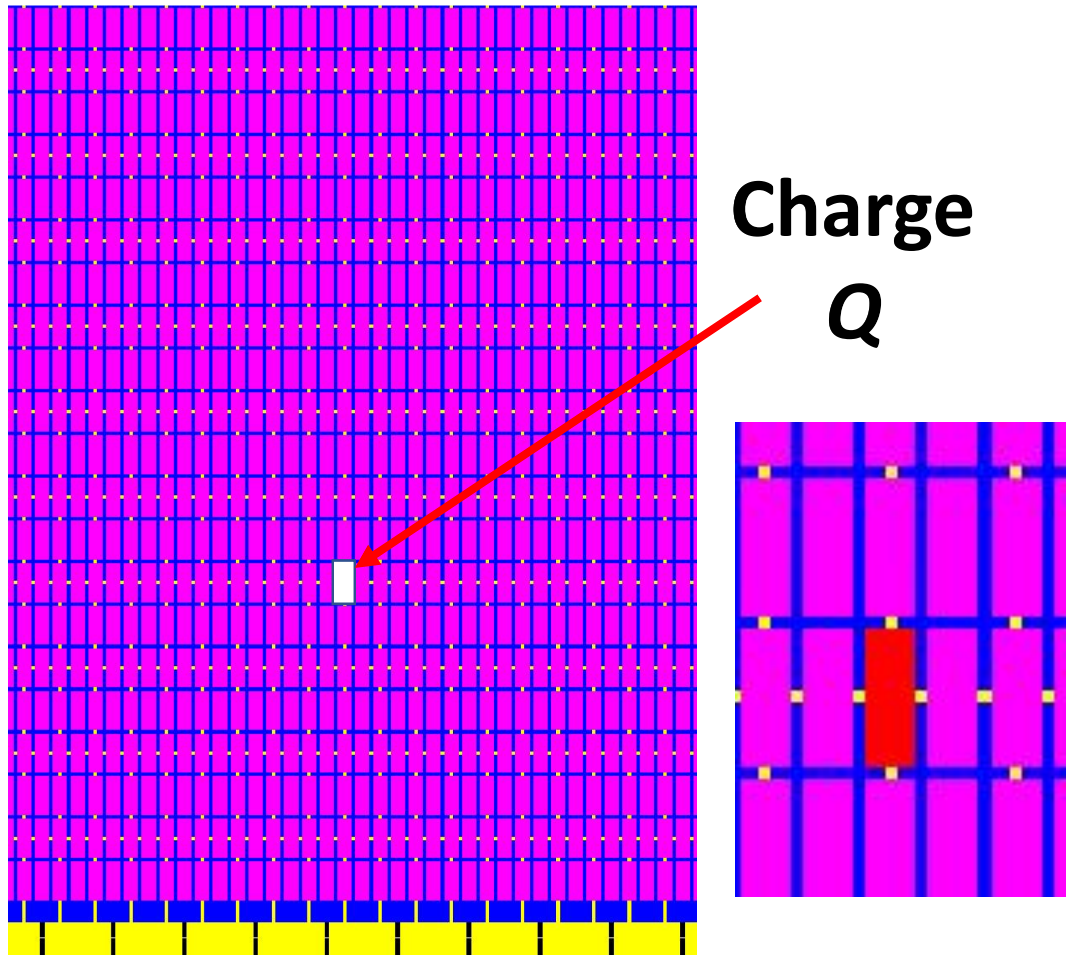


Capacitive Sharing readout PCB



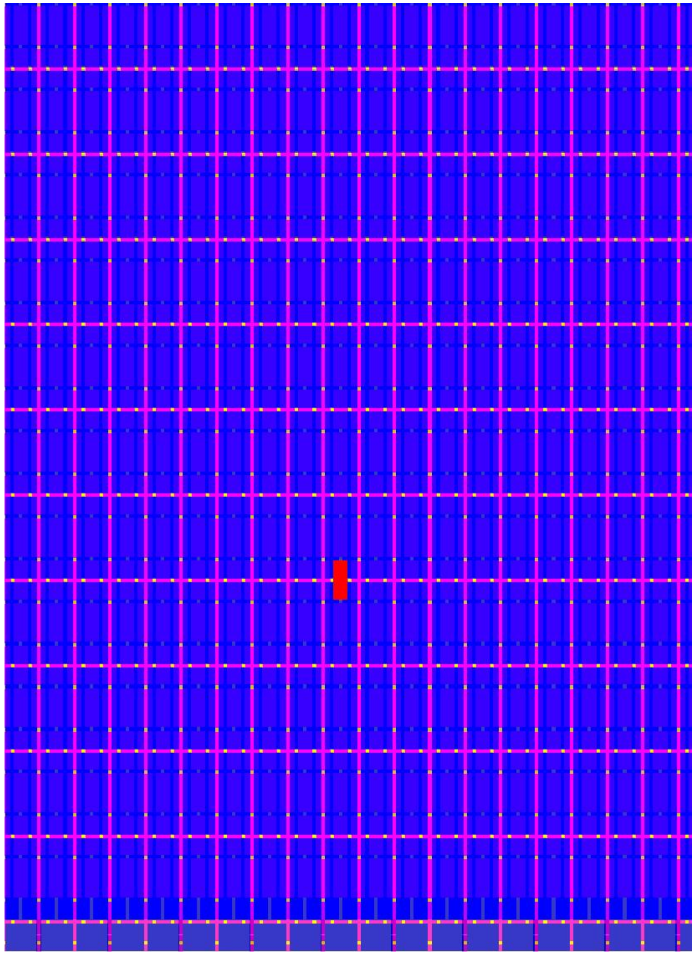
How the Principe of Large Pads with Capacitive Sharing Works

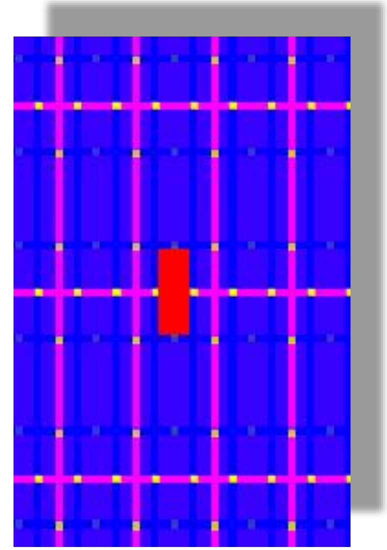
0.62×1.5 mm^2



How the Principe of Large Pads with Capacitive Sharing Works

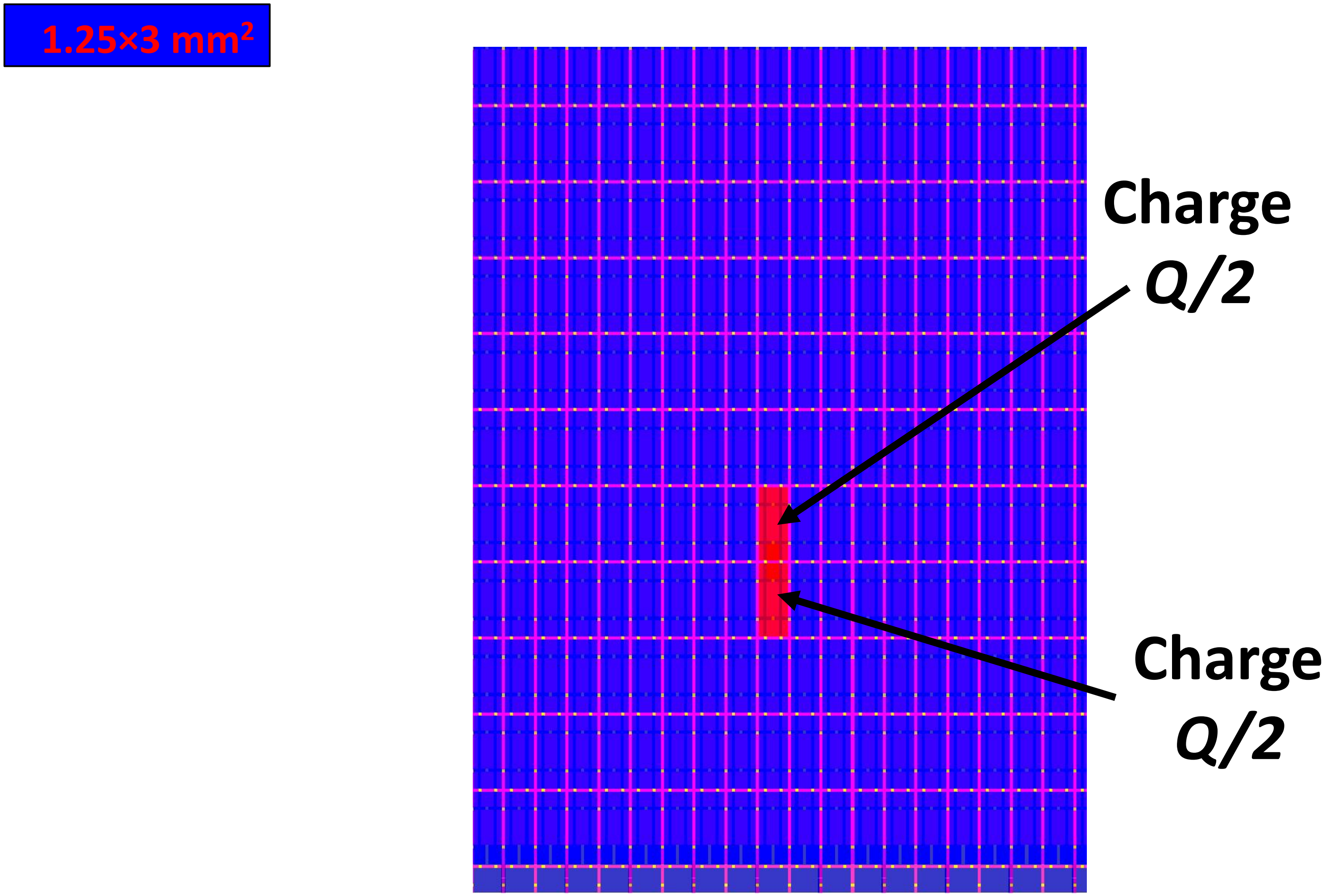
1.25×3 mm^2





Capacitive Sharing with 2 pads at next Layer

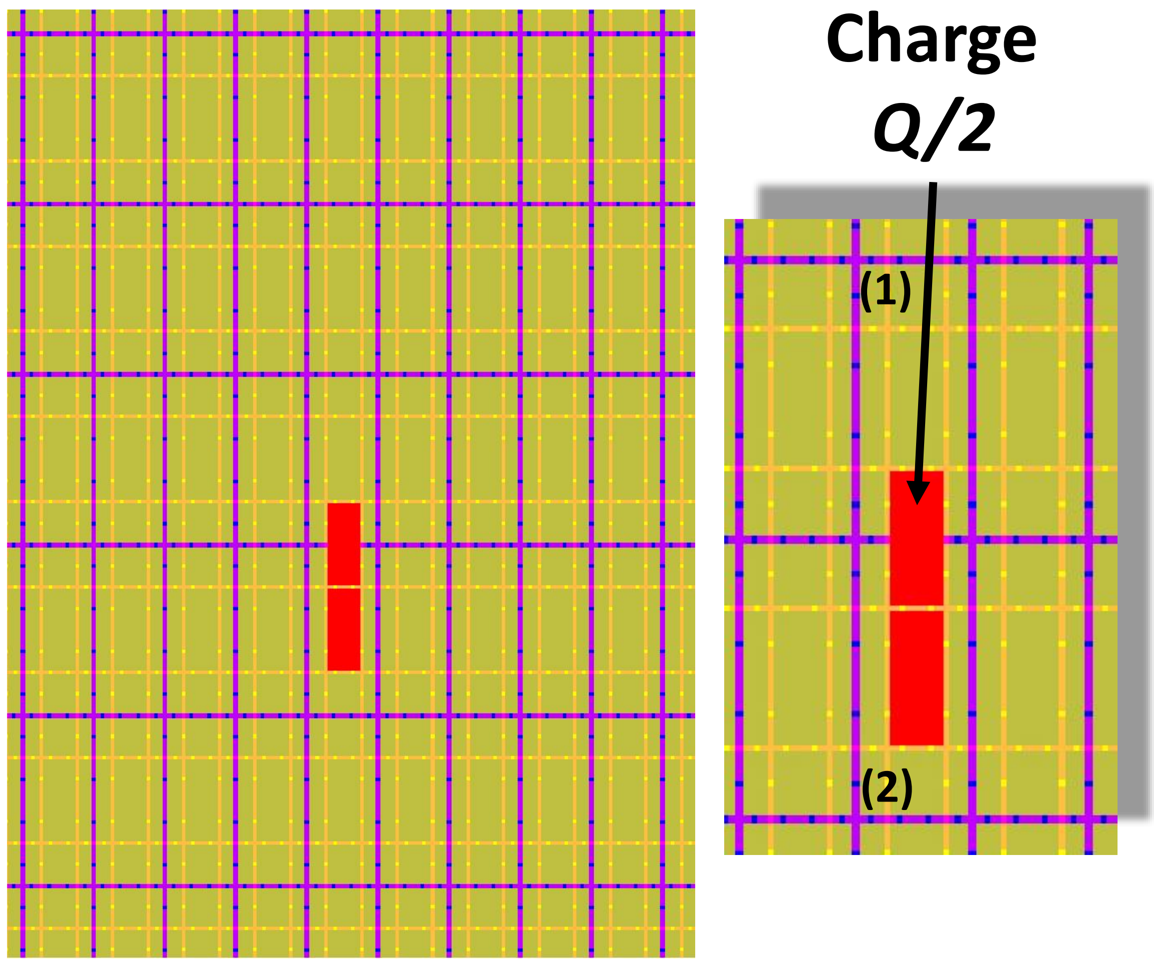
How the Principe of Large Pads with Capacitive Sharing Works



Each pad at 2d Layer with charge Q/2

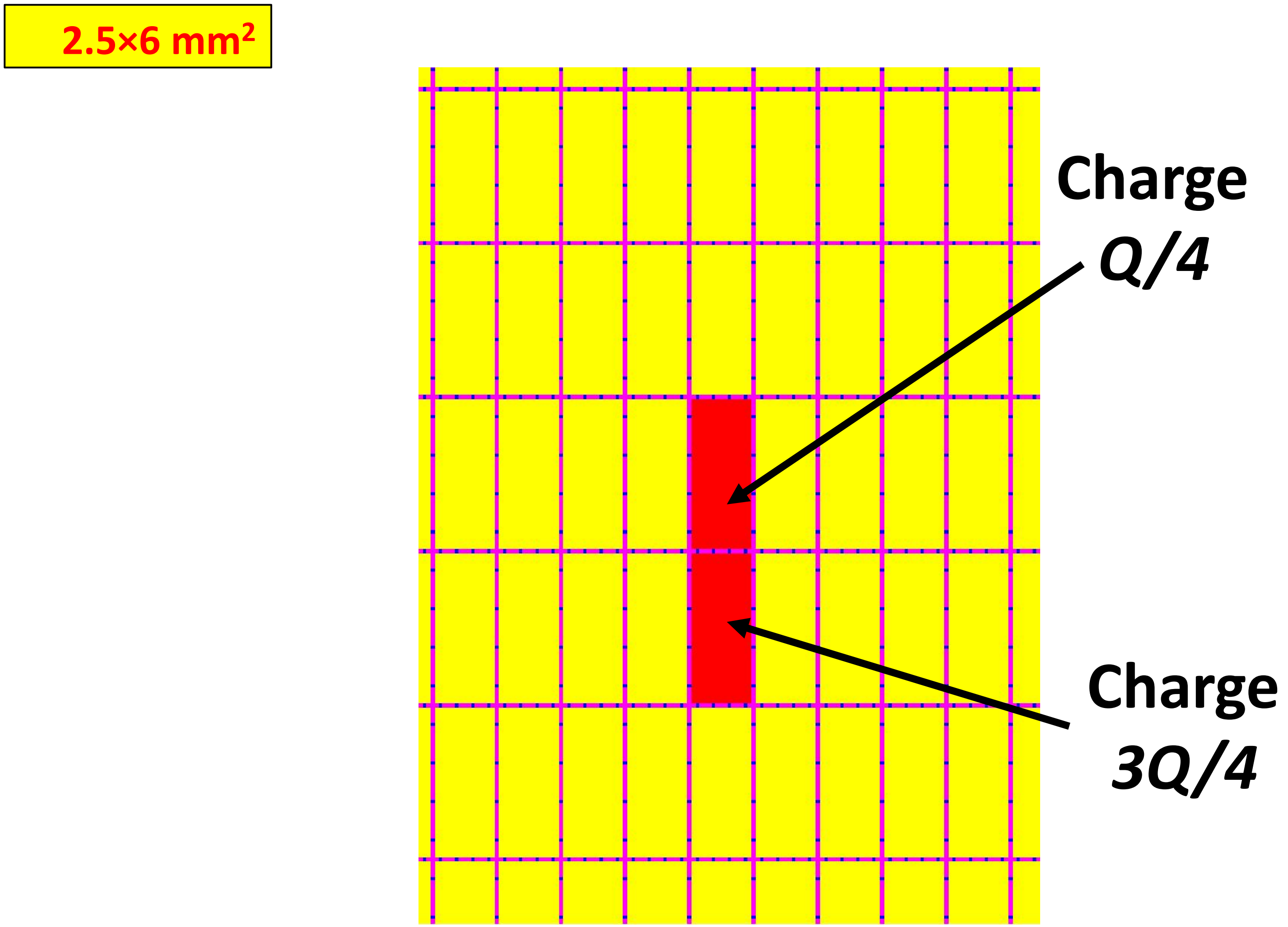
How the Principe of Large Pads with Capacitive Sharing Works

2.5×6 mm^2



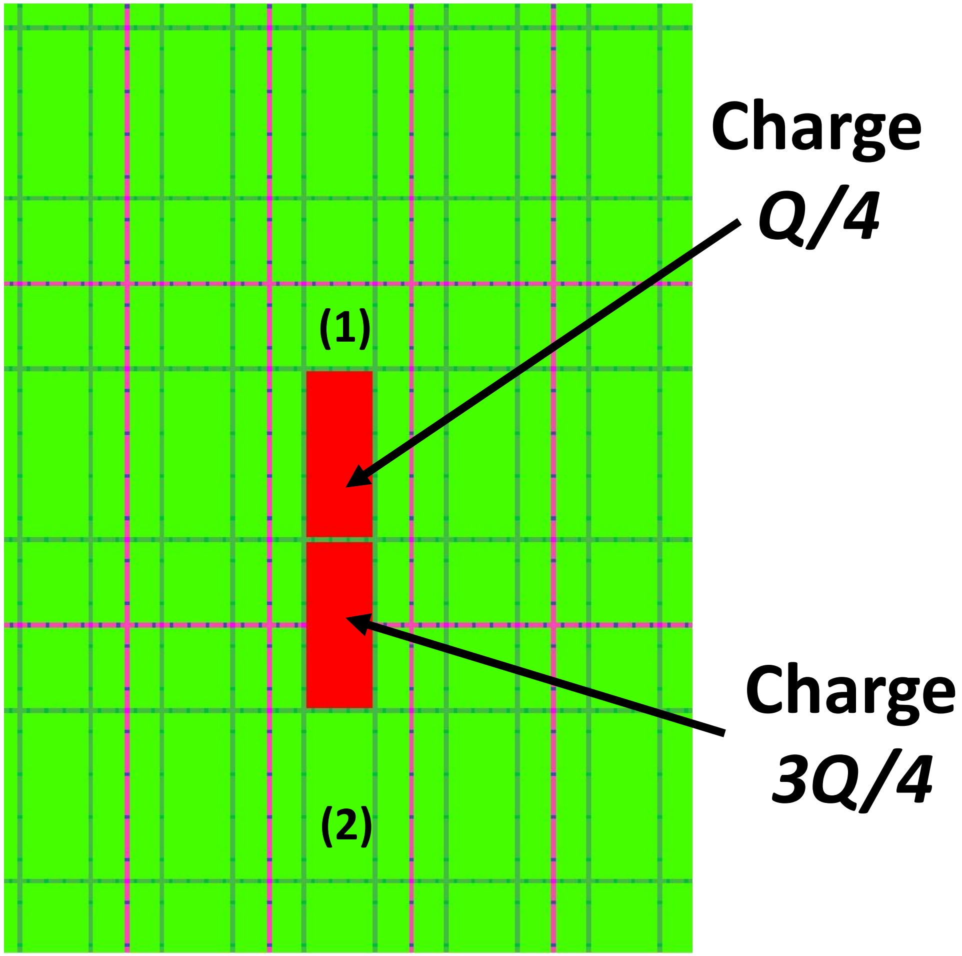
One pad at 3d Layer will be charged with (Q/2)/2
The second as Q/2+ (Q/2)/2

How the Principe of Large Pads with Capacitive Sharing Works



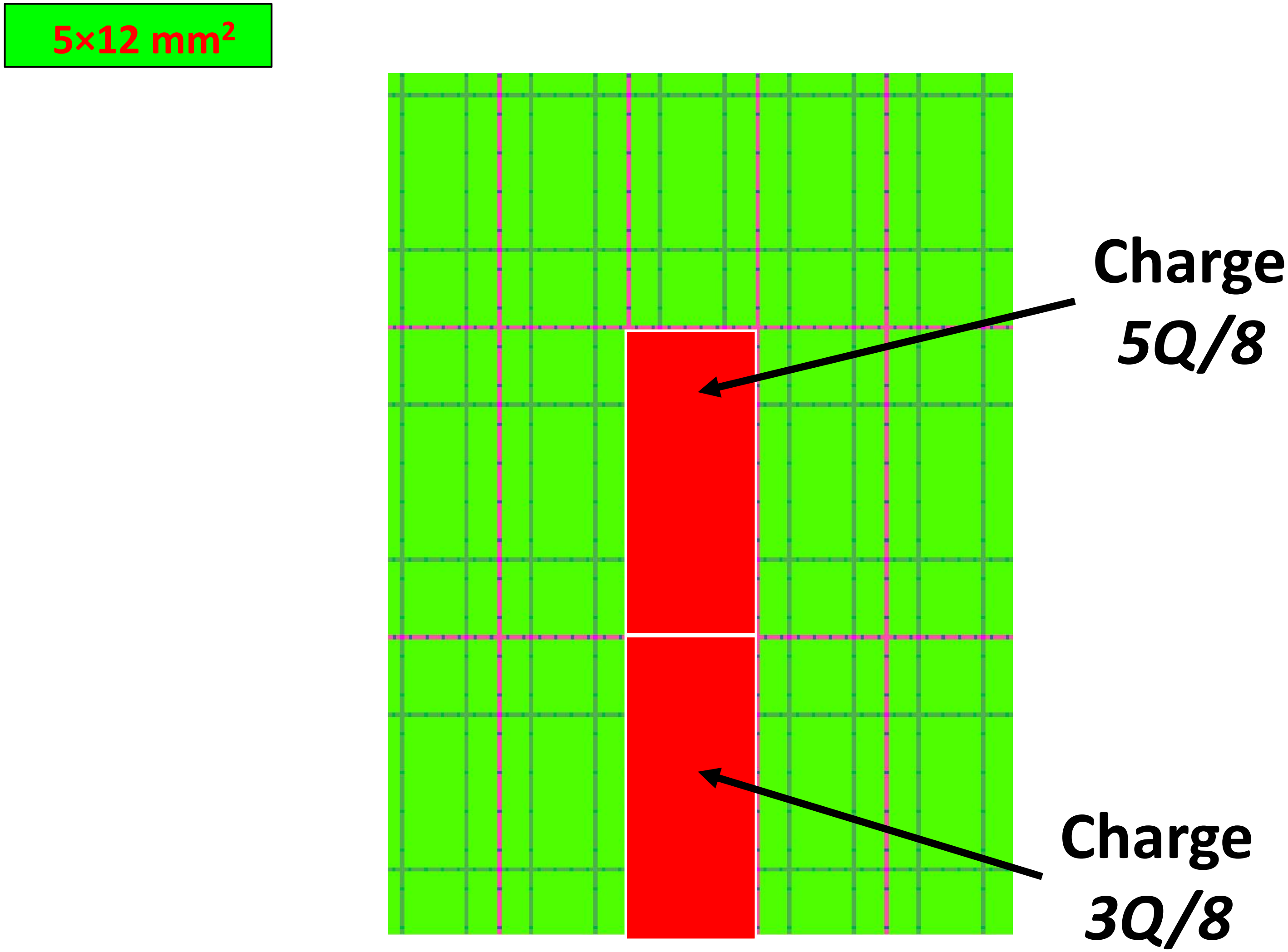
How the Principe of Large Pads with Capacitive Sharing Works

5×12 mm^2

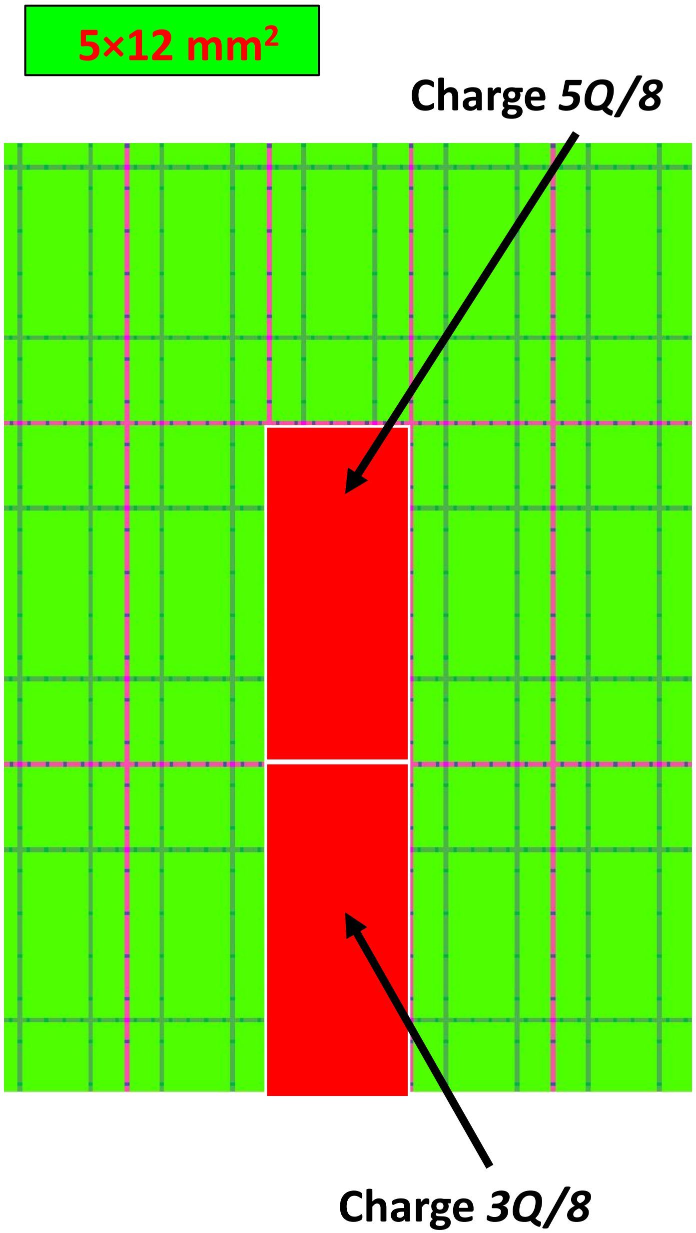


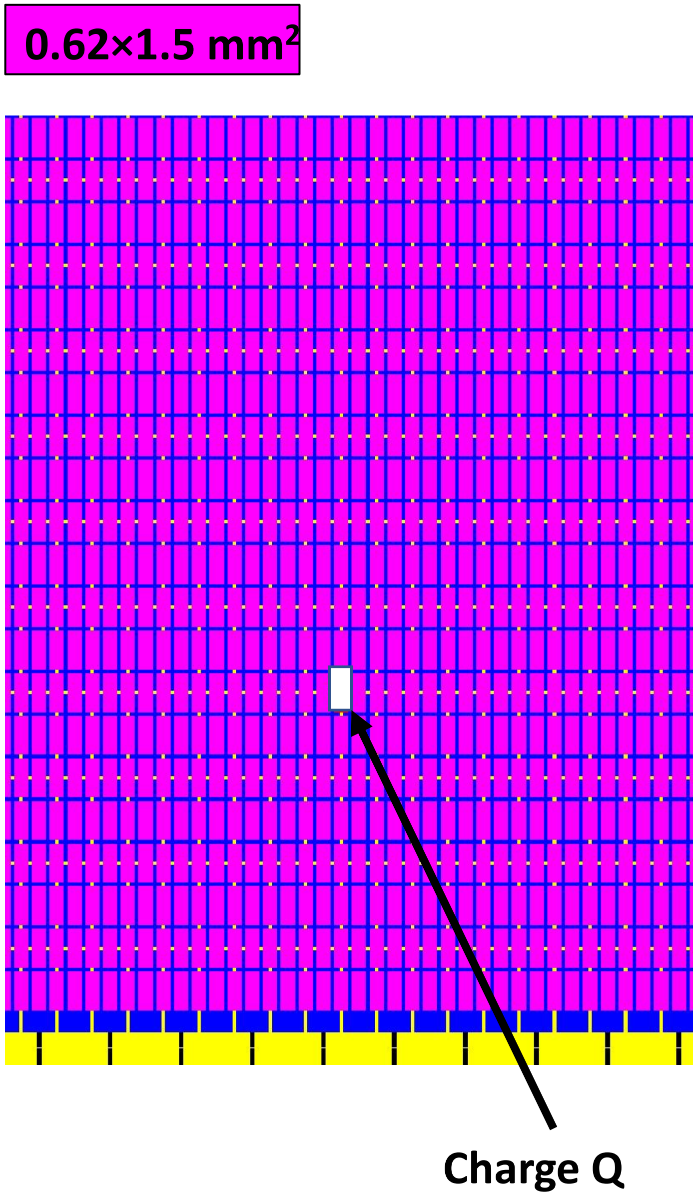
1) First pad at MPD TPC PAD PLANE will be charged with (Q/4) + (3Q/4)/2
2) The second as (3Q/4)/2

How the Principe of Large Pads with Capacitive Sharing Works



How the Principe of Large Pads with Capacitive Sharing Works

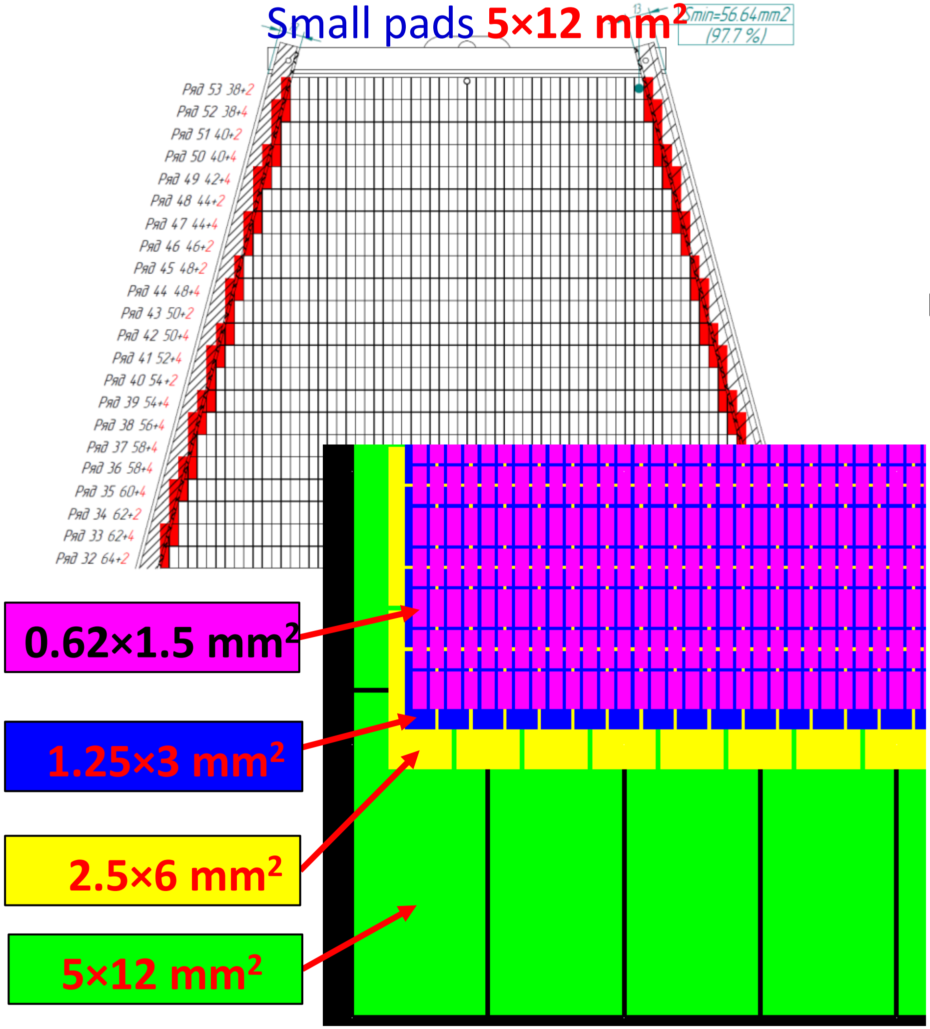




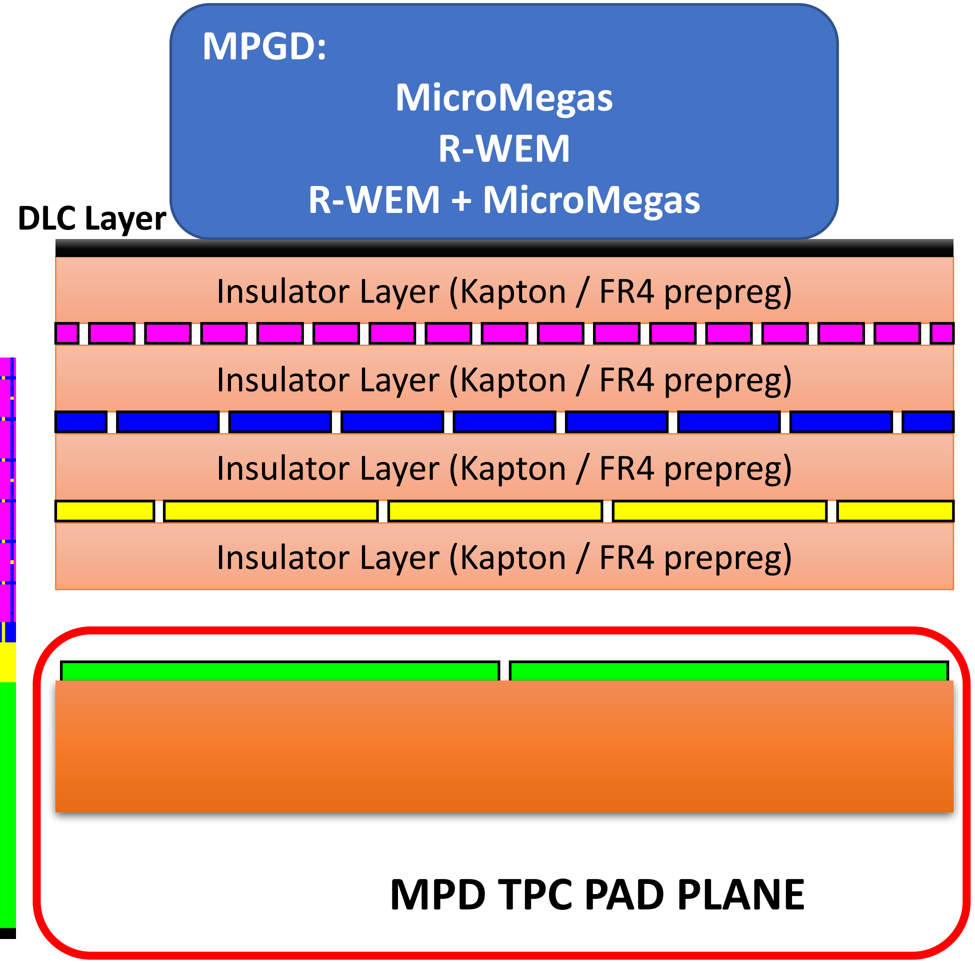
MPGD adaptation to R/O Chambers of TPC of MPD experiment

MPD TPC PAD PLANE

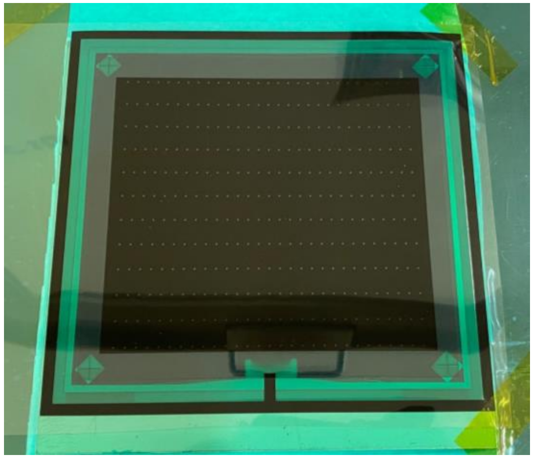
Small pads **5×12 mm²**

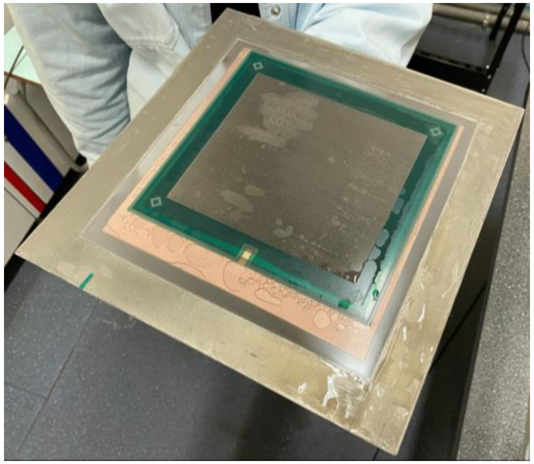


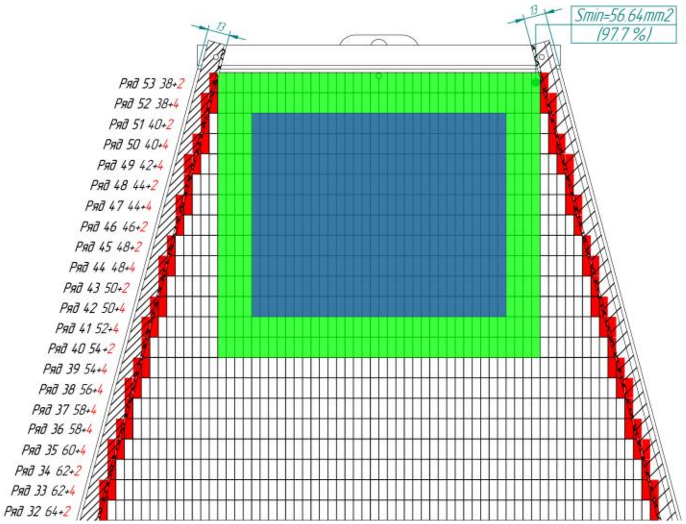
Capacitive Sharing readout PCB

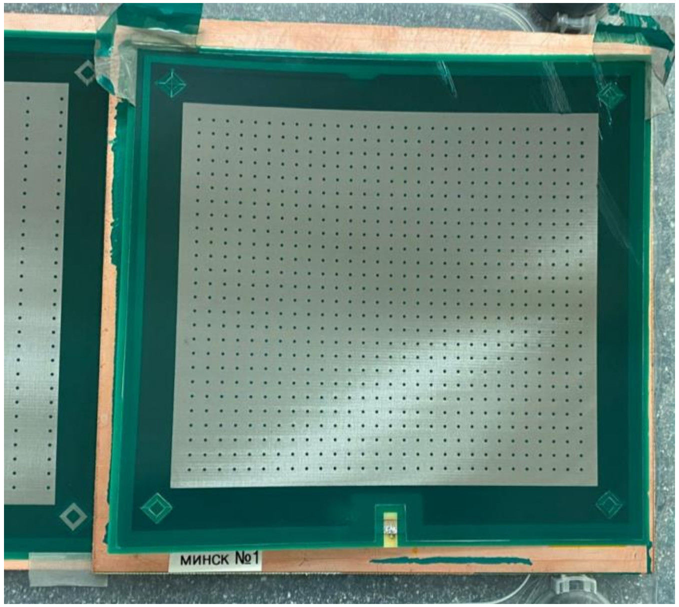


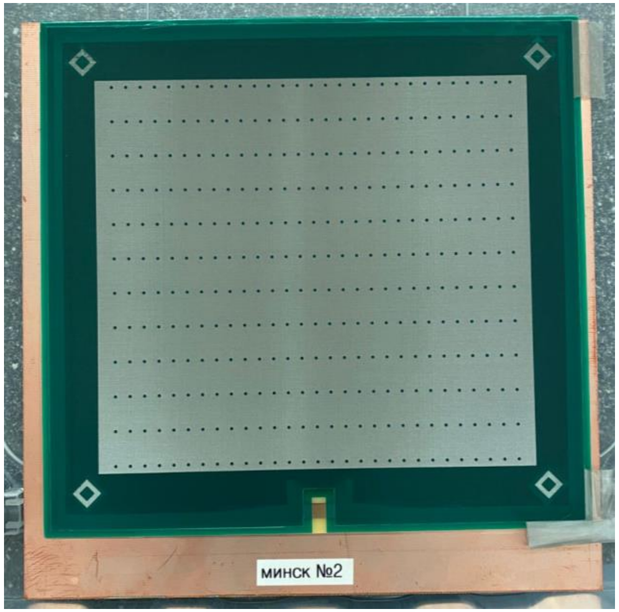
Prototypes of MicroMegas detector with Capacitive Sharing Pad Readout for TPC @ MPD experiment at NICA











Active area
137mm X 152mm