Development of high-performance DLC resistive electrodes for MPGDs

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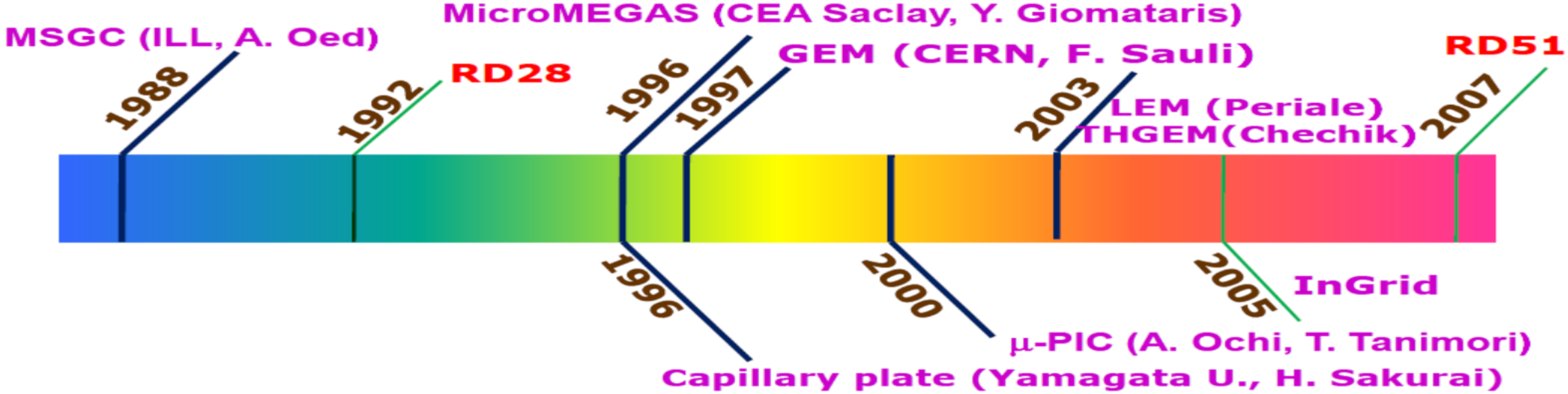
Outline

- Introduction
- R&D on DLC resistive electrodes
- Application of DLC coating
  1. Low-rate μRWELL
  2. high-rate μRWELL
  3. Charging-up free THGEM
- Summary

Development of MPGDs



Advantages of MPGDs :

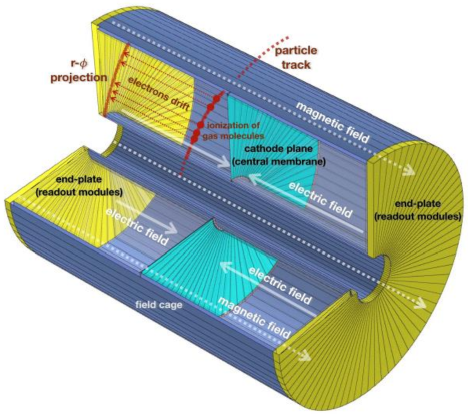
- High rate capability (>> 1 MHz/cm^2)
- Space resolution, mainly depending on the readout segmentation and FEE capability, easily below 200 μm
- Time resolution below 10 ns
- Larger area (m^2/single detector), lower cost

MPGD technology are well established after more than 20 years of production at CERN, and it have already been widely studied and used in nuclear and particle physics experiments.

MPGDs applied in CEPC

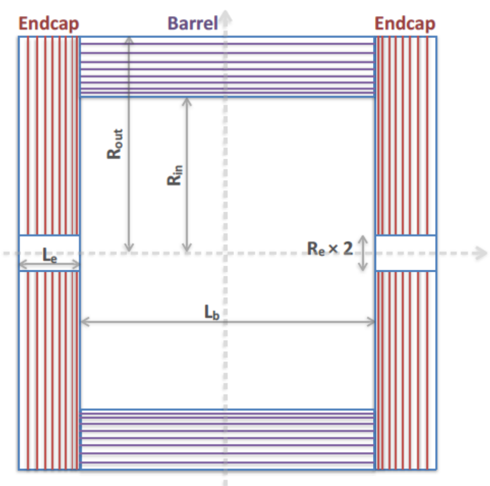
◆ Gas amplification detector module for CEPC TPC readout

- Baseline detector: GEM & MM
- Gain: 10^3–10^4
- Spatial granularity: 1 mm^2
- Position resolution: 100 μm in r - ϕ



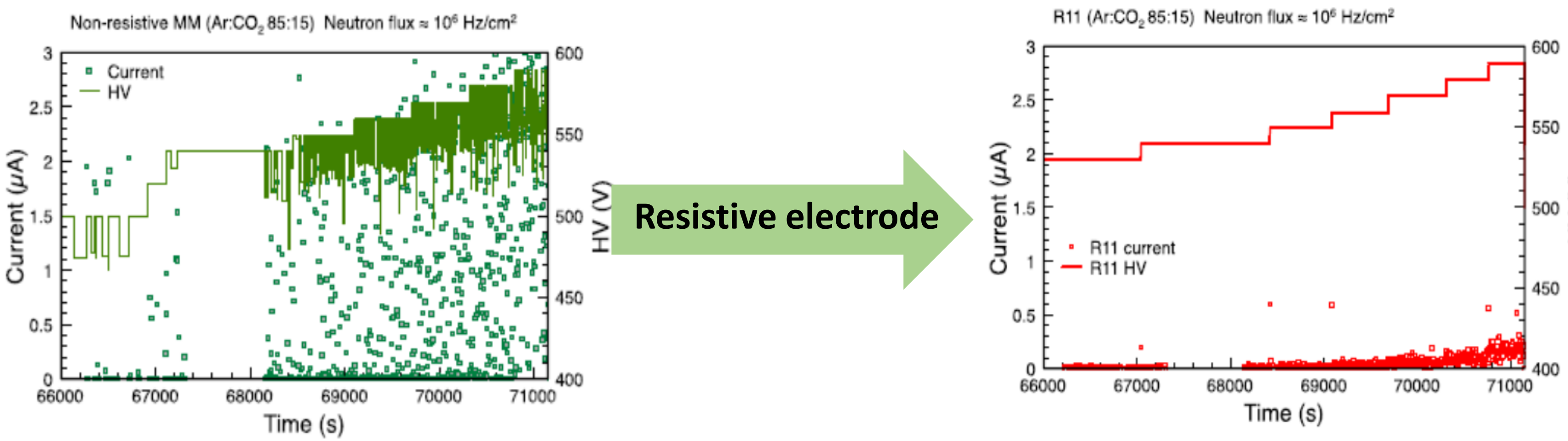
◆ CEPC muon detector system

- Candidate MPGD detector: μ-RWELL
- Sensitive area: 8600 m^2
- Time resolution: 1-2 ns
- Detector efficiency: 95% (P_μ >5GeV)
- Rate capability: ~ 60 Hz/cm^2



Challenge in MPGDs

MPGDs: suffer discharge due to a large amount of avalanche charge created in a very narrow multiplication region.



*Resistive electrode based on **Carbon loaded pastes** have already been used in MPGDs to suppress the discharges and reduce the damaging effects on MPGDs*

- × ***Resistivity sometimes out of control in manufacture;***
- × ***Unable to make fine structures;***
- × ***Difficult to make conductive route on it precisely;***
- × ***Can not open opportunities for new micro-structures;***

New reliable resistive materials and preparation methods needed

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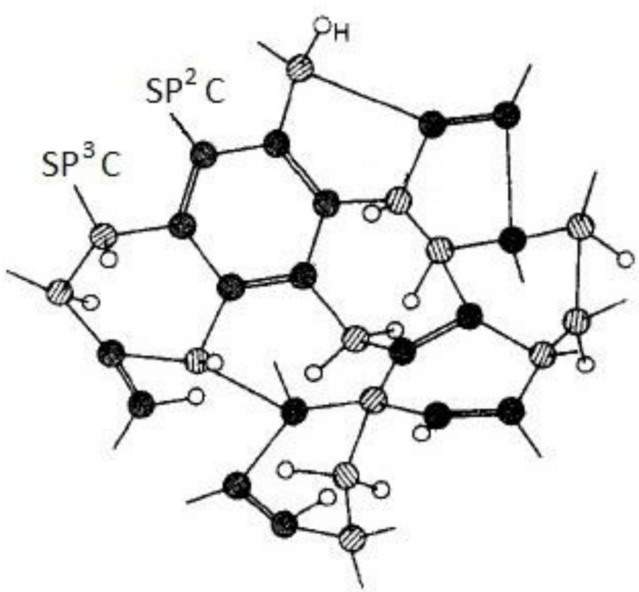
Diamond-like Carbon

Diamond-like Carbon (DLC): a class of metastable amorphous carbon material that contains both the diamond-structure and graphite-structure.



Atom structure of DLC

N·H
ELSEVIER
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Letter to the Editor

High rate operation of micro-strip gas chambers on diamond-coated glass

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Abstract

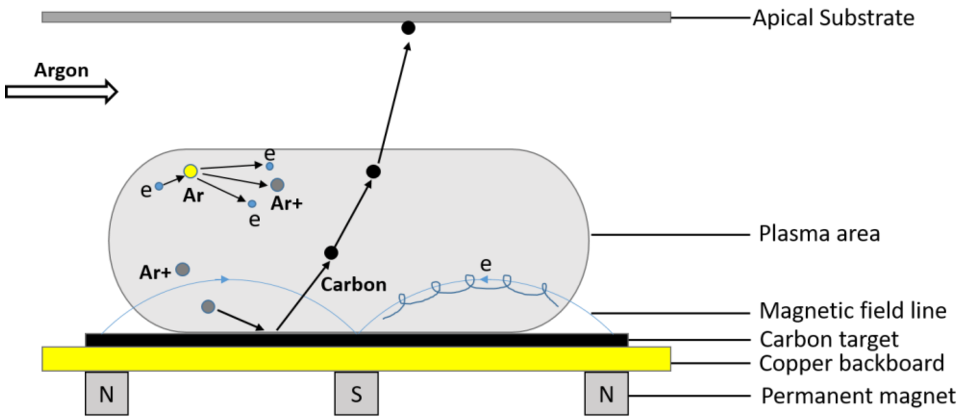
Very high rate operation of micro-strip gas chambers can be achieved using slightly conducting substrates. We describe preliminary measurements realized with detectors manufactured on boro-silicate glass coated, before the photo-lithographic processing, with a diamond layer having a surface resistivity of around 10^{14} Ω/□. Stable medium-term operation, and a rate capability largely exceeding the one obtained with identical plates manufactured on uncoated glass are demonstrated. If these results are confirmed by long-term measurements, the diamond coating technology appears very attractive since it allows, with a moderate cost overhead, to use thin, commercially available glass with the required surface quality for the large-scale production of gas micro-strip detectors.

DLC coating was firstly used in MSGC in 1995 to resolve the charging-up effect

- DLC coating shows good stability in surface resistivity and good chemical stability.
- Resistive electrodes based on DLC are very resistant to discharge and radiation, and able to withstand chemical or physical manufacturing processes.

R&D on DLC resistive electrodes

Magnetron sputtering technique: an effective way for DLC coating at low-temperature, which ensures both accurate surface resistivity and uniform thickness of the coating.



Schematic of magnetron sputtering technique

Magnetron sputtering system (LICP Teer 650)

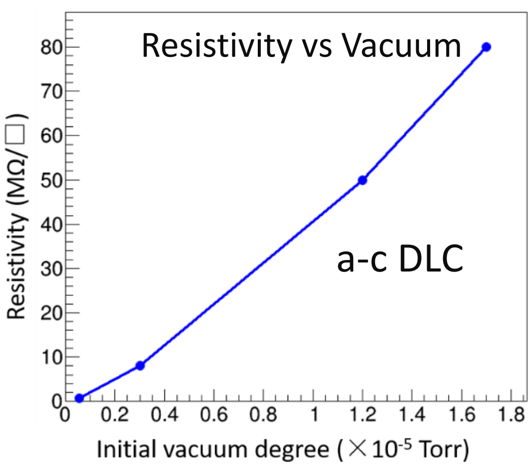
1. Voltage between substrate and target ramping up
2. Glow discharges appear, producing primary electrons and ions
3. Ions hitting targets and sputtering carbons
4. Ejected atoms depositing on substrate

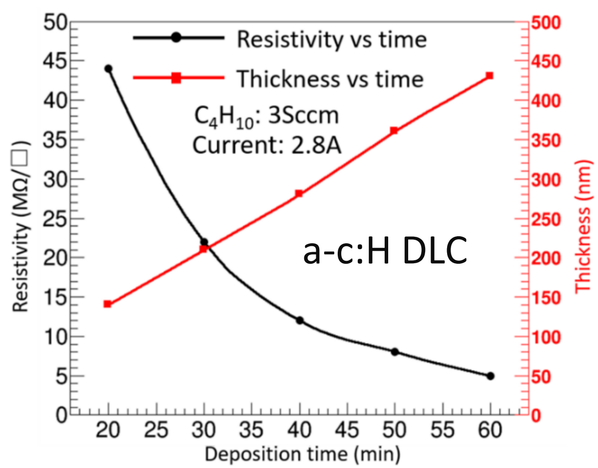
DLC coating deposited by Magnetron sputtering shows good adhesion and good uniformity.

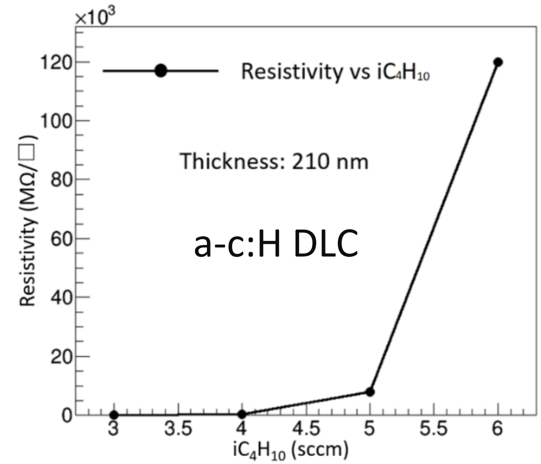
Surface resistivity of DLC coating

a-C DLC: pure DLC
Surface resistivity: MΩ/□ — GΩ/□
Thickness: 50nm —100 nm

a-C:H DLC: Hydrogen doping DLC
Surface resistivity : MΩ/□ —TΩ/□
Thickness: 50nm — 1μm



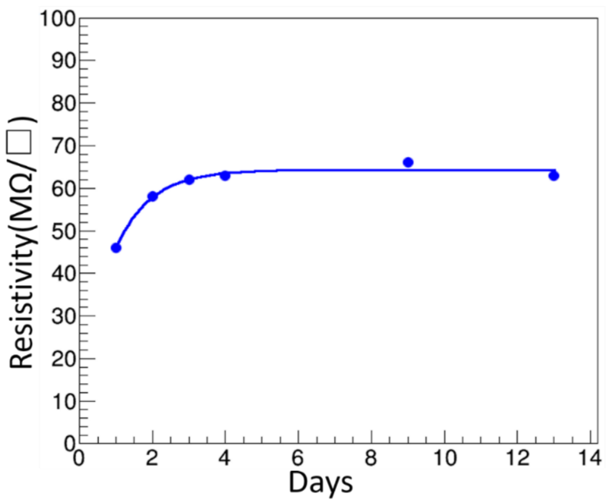


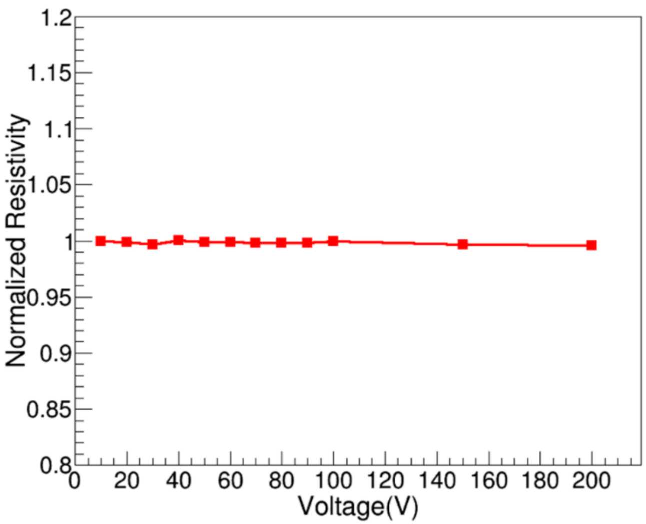


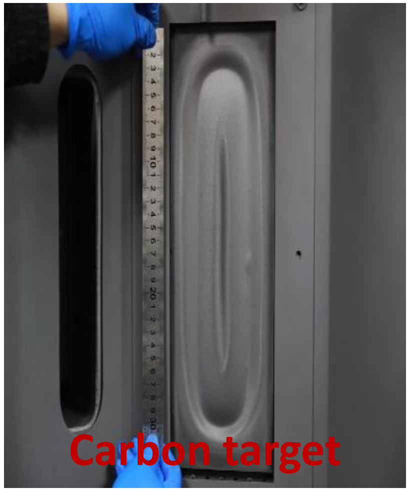
- a-C DLC: Surface resistivity can be adjusted by initial vacuum degree and DLC thickness.
- a-C:H DLC: The surface resistivity is sensitive to hydrogen, it can be adjusted in a very wide range by adjusting the ratio of hydrogen, and more precise by controlling deposition time.

Stability & uniformity

- Surface resistivity increase about 30% in 4 days (exposure to air), and then kept stable.
- Resistivity is independent with the voltage, showing the ohmic behavior.







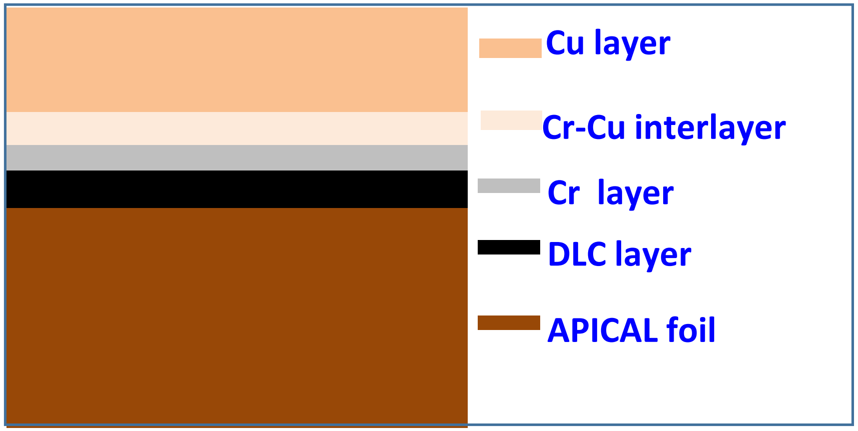
- The resistivity uniformity better than 15% for 15cm×15cm sample size, and 44% @30cm × 30cm DLC sample.

- The height of carbon target is about 30 cm almost same as our large sample size.
- DLC thickness showing difference at different region of the large DLC sample, which result to the bad uniformity.

210	200	178	176	200
105	93	96	82	102
68	70	72	71	68
78	77	78	81	77
135	130	120	135	126

Copper-coated DLC

A copper-coated DLC is developed to extend the application of DLC coating in MPGDs.



Substrate/DLC/Cr/Cr-Cu/Cu

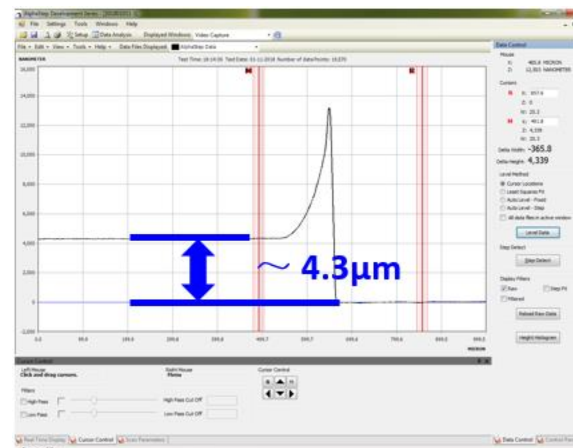
Copper-coated DLC

Good adhesion

1. Deposit DLC on APICAL/Cu substrate
2. Deposit copper on DLC/APICAL/Cu substrate

It shows good adhesion between DLC and copper.
The thickness of copper can be adjusted from 1 μm to 5 μm.

Further processing of the copper-coated DLC can be achieved thanks to the copper layer on the surface of DLC.



Thickness measurment

R&D on larger DLC sample

A new sputtering system (Hauzer 850) is ready to make larger area DLC samples.

Picture of new sputtering system (Hauzer 850)

Chamber size: Φ800mm×900mm

Target size: 600mm×125mm

600mm × 120mm DLC sample

Resistivity uniformity:

25% @400mm×1200mm DLC sample

Resistivity shows good uniformity along the long edge, and bad on the short edge due to the limitation of target size.

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Low-rate μRWELL

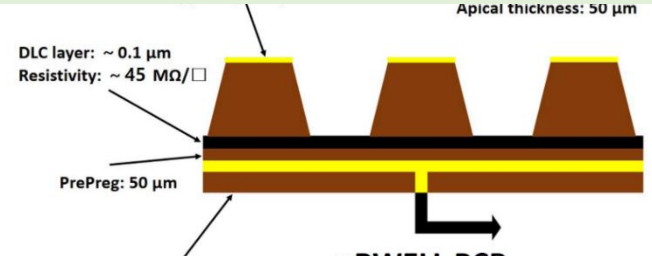
Micro-Resistive WELL (μRWELL): a novel MPGD with resistive electrode and a single stage of well-type gas amplification.

1. Resistive electrode
2. One-stage WELL pattern

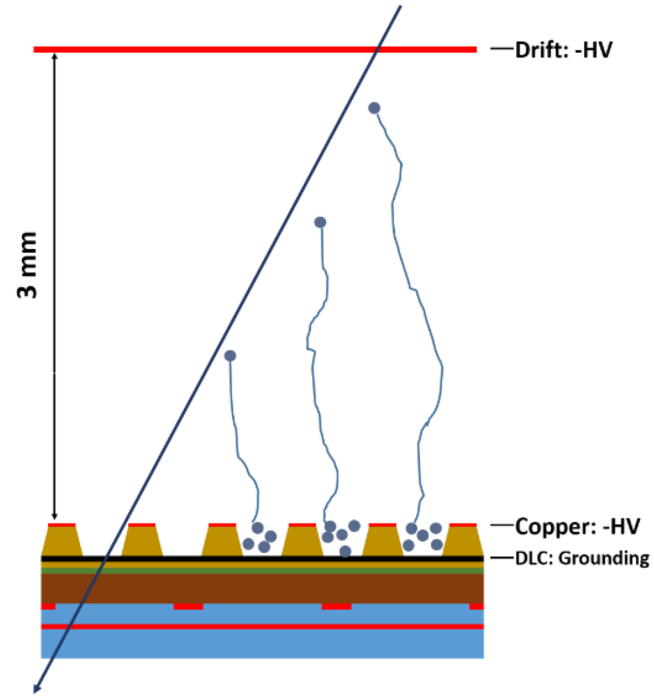
- ✓ Suppress discharge
- ✓ Compact and high granularity
- ✓ Fabrication fast

μRWELL PCB: It is a stack of “readout PCB / insulating pre-preg / DLC resistive layer / well-type amplification” structure.

A critical component of μRWELL PCB is DLC resistive electrode, which is used to suppress the discharge.



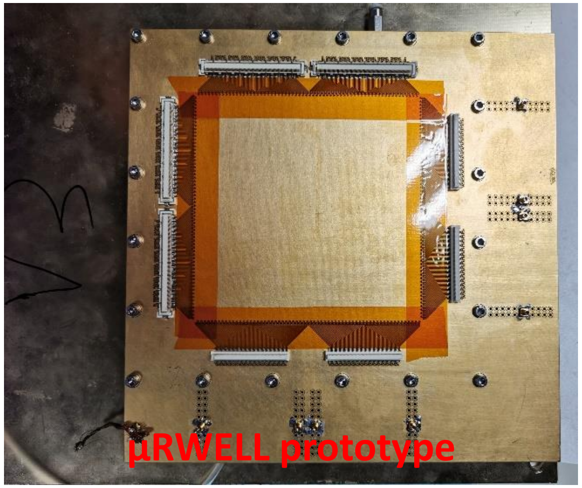
μRWELL PCB



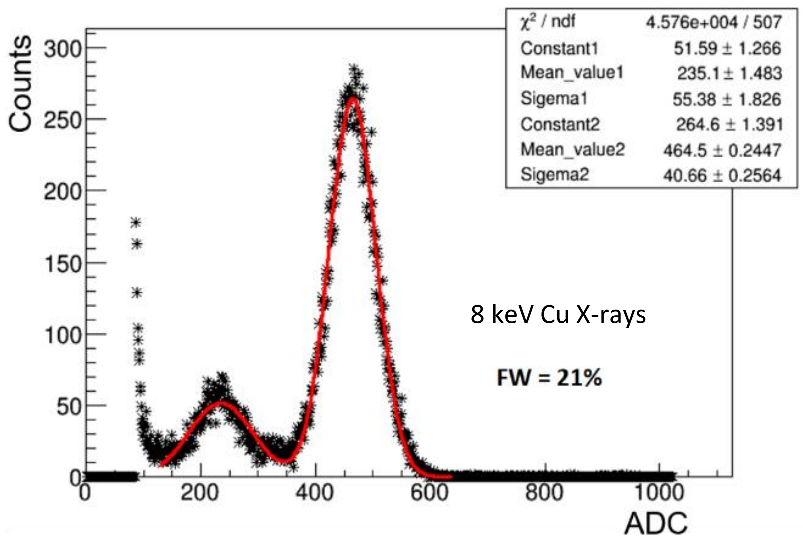
μRWELL detector

2-D µRWELL prototype

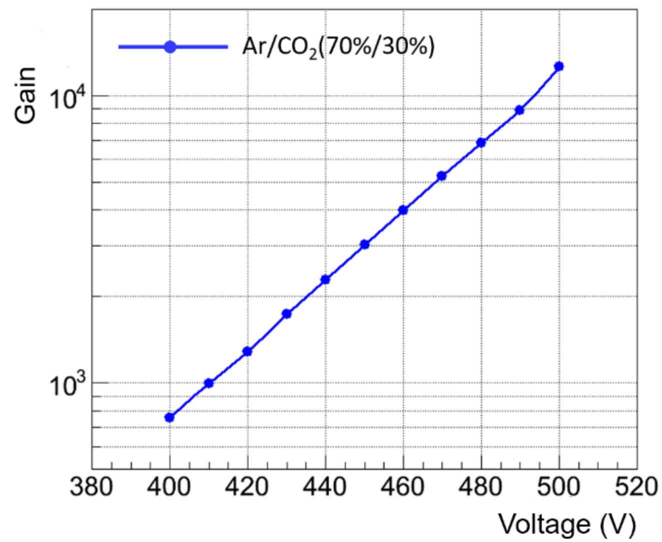
- A 2-D µRWELL detector prototype was designed and fabricated.
- It is composed of a drift cathode and a µRWELL PCB which are fixed in a frame.
- Drift region： 3 mm



The µRWELL detector prototype was fully tested with X-rays/moun beam in Ar/CO_2 (70%/30%) gas mixture.



Energy resolution: 21% @8keV X-rays



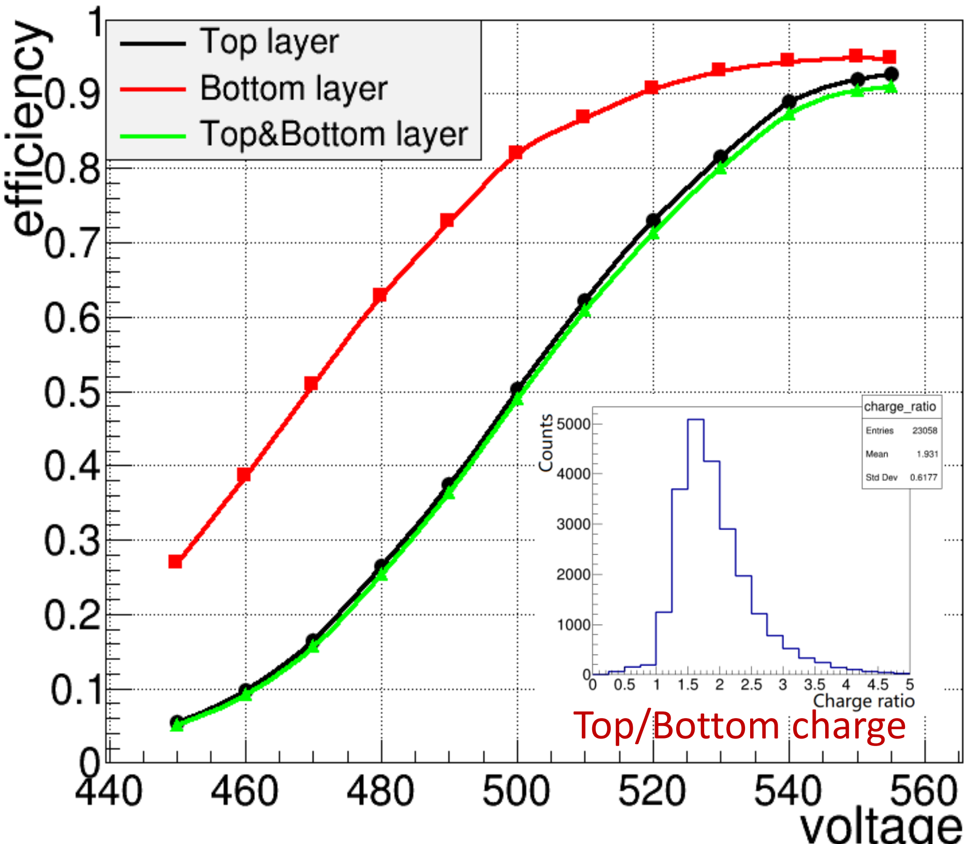
Gas gain: 1.4 × 10^4 @500V

Efficiency & position resolution

Detection efficiency VS Voltage

- Top layer: ~95%, Bottom layer: ~92%
- Top & Bottom efficiency: ~90%

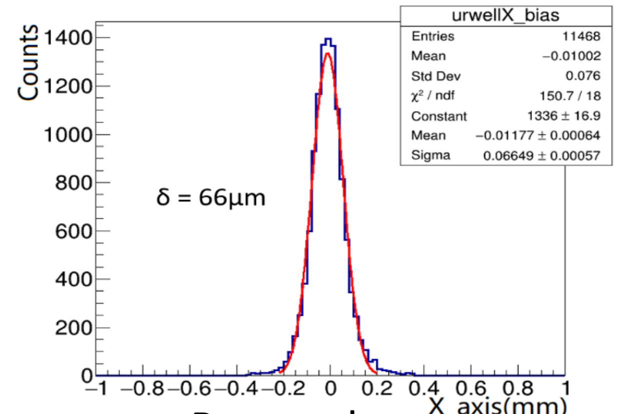
Top induced charge is 1.9 times of Bottom



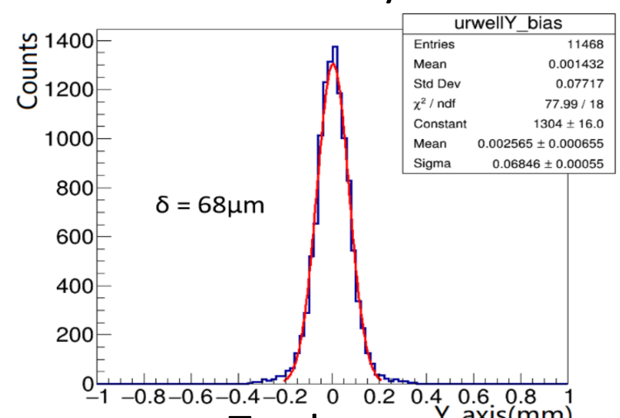
Efficiency vs Voltage

Position resolutions: Charge-weighted center of gravity method.

Position resolution better than 70 μm achieved on both readout directions.



Bottom layer



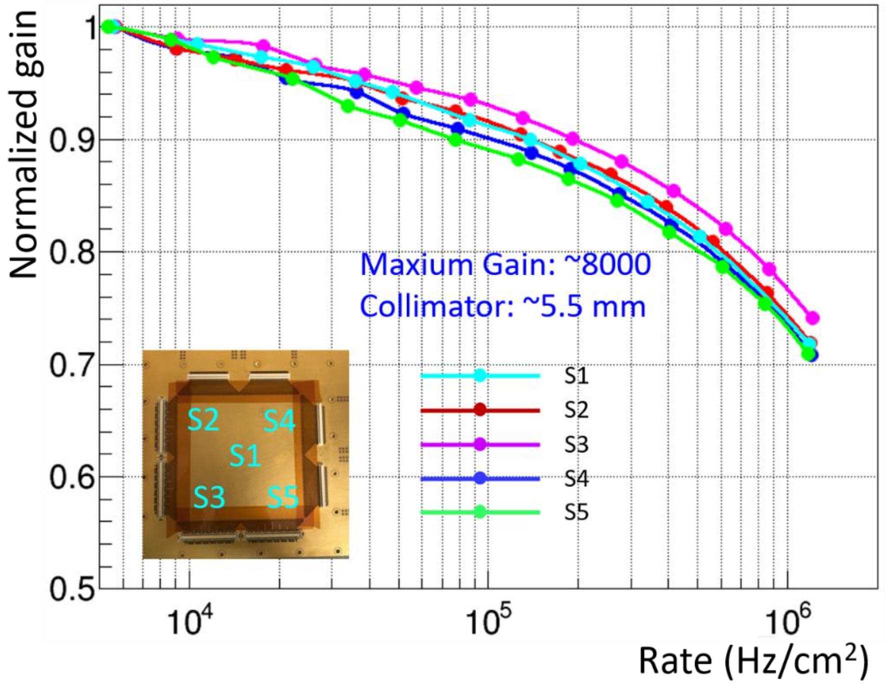
Top layer

Rate capability

The rate capability is assessed by measuring the detector gain as a function of counting rate per unit area.

X-ray gun

Source: 8keV Copper x-ray
Collimator: 5.5mm-diameter



Normalized gain vs. Rate at different region

Gain decreases about 10% @100 kHz/cm^2. Gain drop is still modest (<30%) @1 MHz/cm^2 .

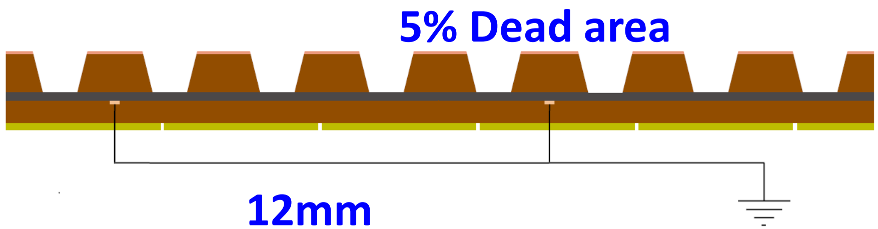
The charge spreads on the DLC resistive electrode, inducing a current flowing through the resistive layer, generating a localized drop of the amplifying voltage, decreasing the gain.

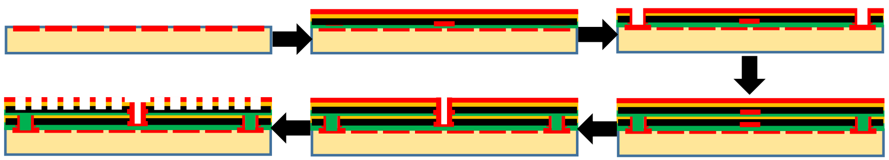
High-rate μRWELL solution

Two types of high-rate μRWELL solution are presented based on copper-coated DLC resistive electrode.

Solution1: 1-DLC layer μRWELL with fast grounding lines.

Solution2: 2-DLC layers μRWELL by SBU (Sequential Build Up).

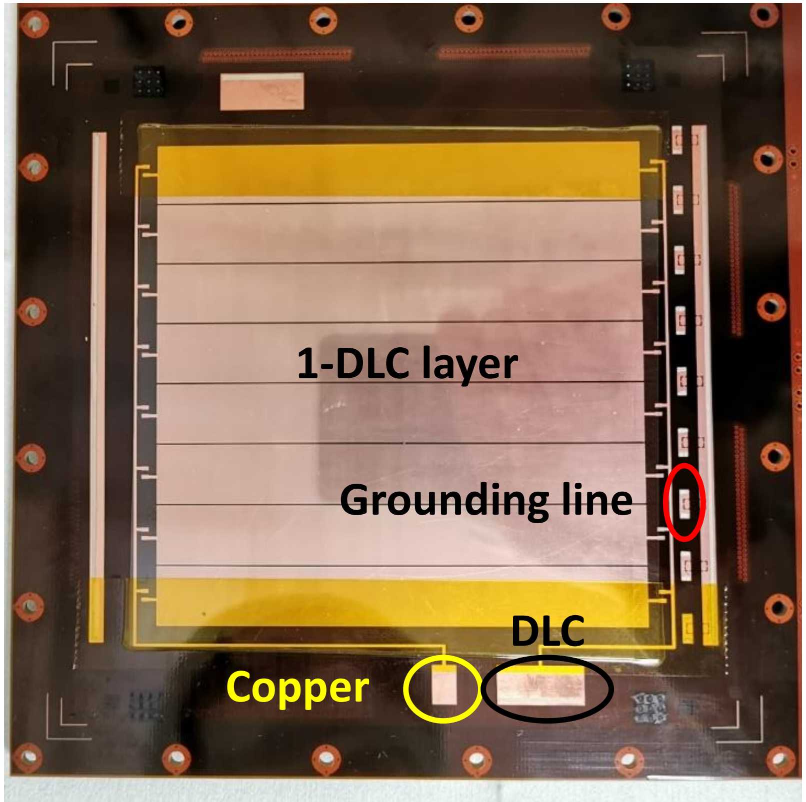


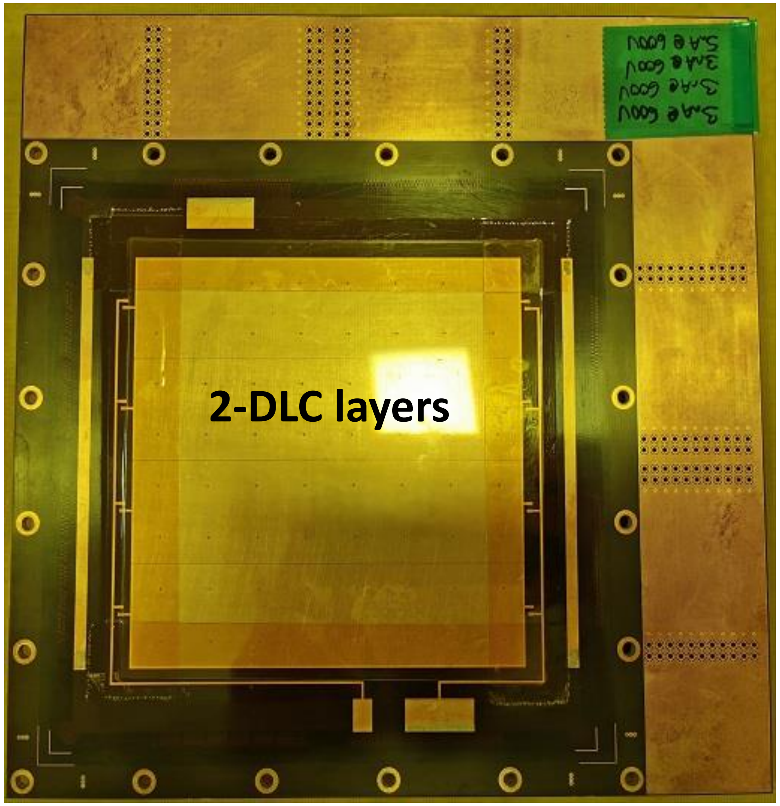


The copper clad on the DLC coating is etched to dash lines (100 μm width) and grounded, the electrons accumulated on DLC electrode can release faster.

Reduce the path of the current on the DLC surface by implementing the first matrix of conductive vias connecting two stacked resistive layers. The second matrix conductive vias connects the second resistive layer to ground through the readout electrodes.

High-rate μRWELL PCB



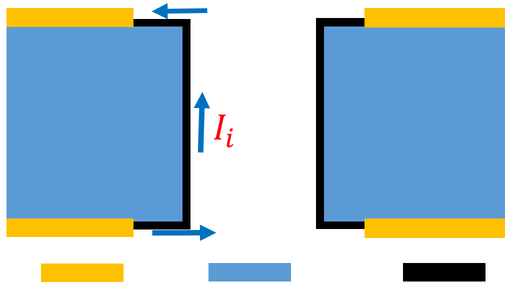


1. Two different high-rate μRWELL prototype have been designed and fabricated.
2. These μRWELL prototype are tested in Ar/CO_2 (70%/30%) gas mixture, showing a good response to X-rays, but a lower gas gain (~1000).

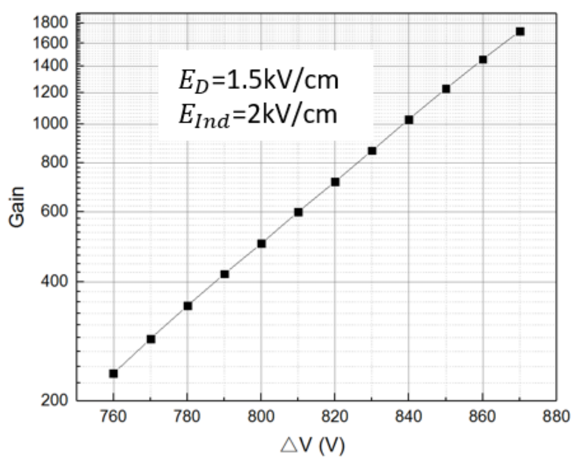
Lower resistivity of DLC resistive electrode, weak suppress to discharge, lower gain.
We are in close collaboration with Rui from CERN to optimize these detectors.

Charging-up free THGEM

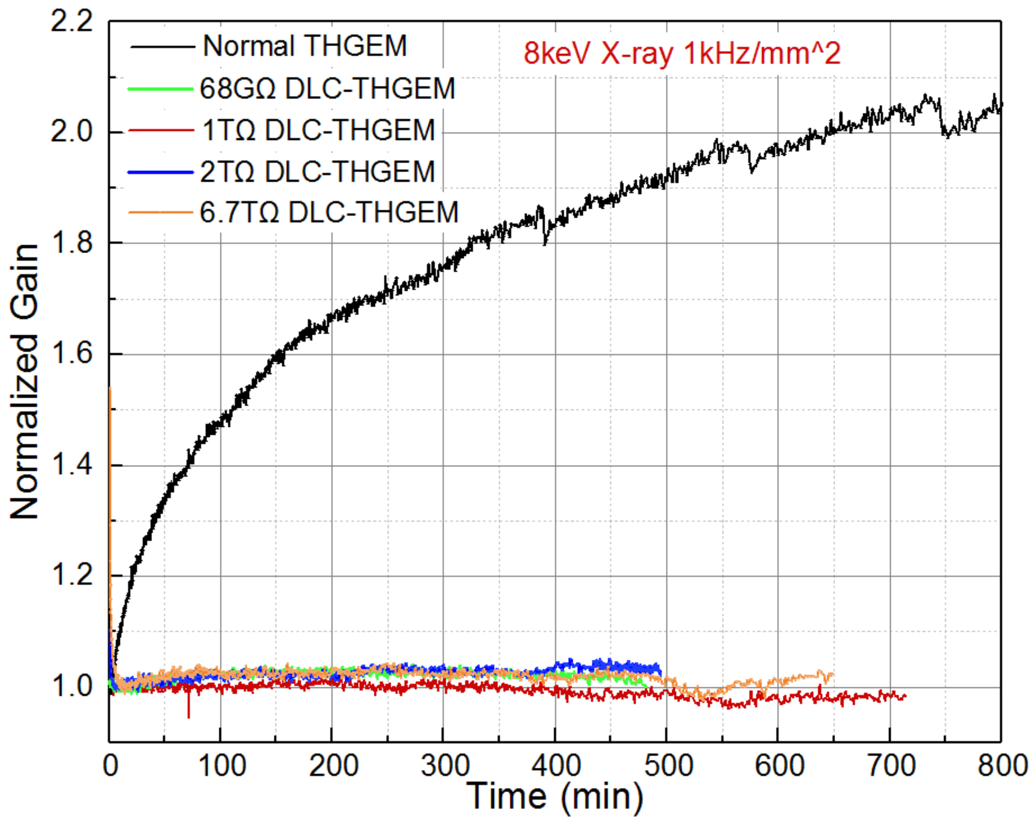
DLC is deposited on the dielectric surface of THGEM foil, in attempt to remove charging-up effect.



DLC THGEM



Gain vs. voltage



Gain vs. time

The long term charging-up effect of DLC-THGEM is removed.

Summary

1. Performance and production process of DLC, as high quality resistive materials, have been studied based on magnetron sputtering technique.
   - ✓ Surface resistivity: 1MΩ/□~100MΩ/□ @a-C MΩ/□~ TΩ/□ @a-C:H
   - ✓ Resistivity uniformity: <15% @15cm×15cm <25% @25cm×25cm
2. The characterization of a 2-D readout μRWELL based on DLC resistive electrode are performed.
   - ✓ Gas gain: $>10^4$ 2-D position resolution: <70 μm @3mm drift region
   - ✓ 2-D detection efficiency: >90% @3mm drift region
   - ✓ Rate capability: Gain drop 10% @100 kHz/cm^2, 30% @1 MHz/cm^2
3. Two different types of high-rate μRWELL based on copper-coated DLC and the DLC-THGEM for charging-up free are presented too.

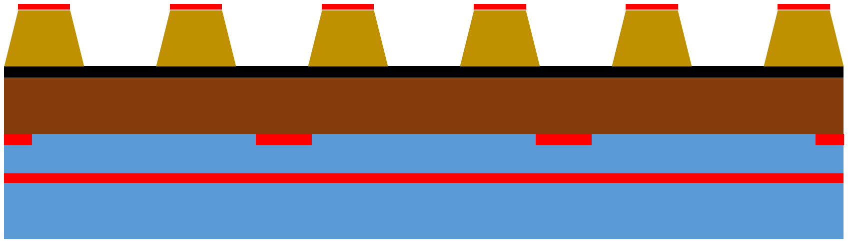
Next step

a) Exploring the larger DLC sample with new sputtering system (Hauzer 850).
b) Optimizing the high-rate μRWELL prototype.

BACKUP

2-D μRWELL PCB

A 2-D μRWELL PCB with 15cm×15cm a-C DLC was designed and fabricated.

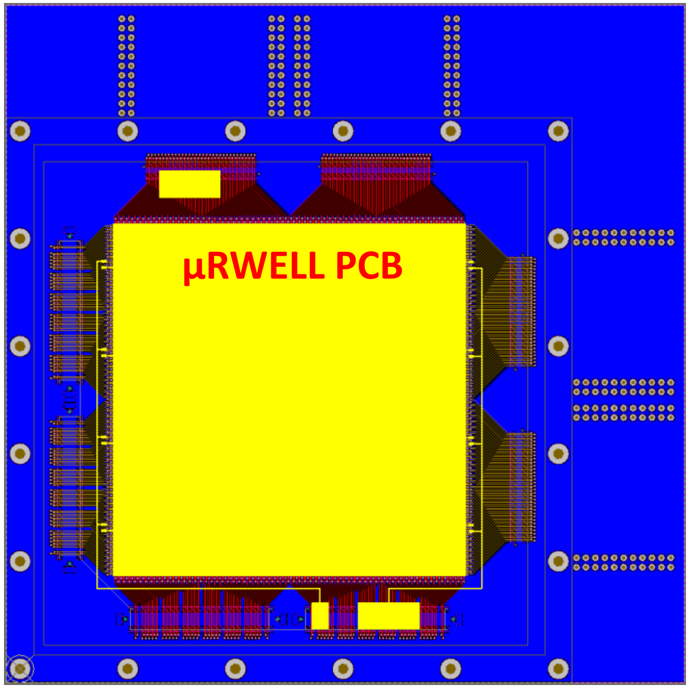


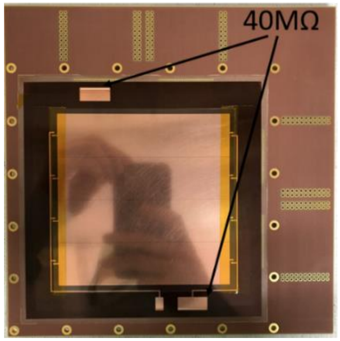
Schematic of μRWELL PCB

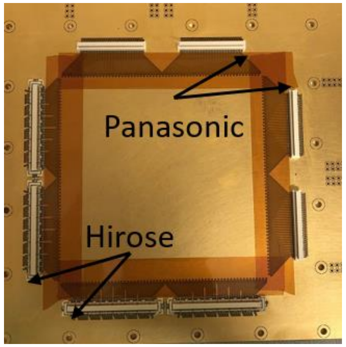
- Readout strip pitch: 400 μm
- Top layer: 80 μm
- Bottom layer: 350 μm
- Readout strip channel: 512
- Distance (Top to Bottom layer): 50 μm

- Sensitive area:
  10cm×10cm divided into 4 sectors
- Well pitch: 140 μm
- Pre_preg (50 μm) isolate the DLC electrode from readout strip

All the readout strips are connected to 4 HIROSE (for laboratory test) and 4 PANASONIC (for beam test) connectors.







Optimization of 2-D readout strip

Achieving an equivalent induced signal on the 2-D readout strips.

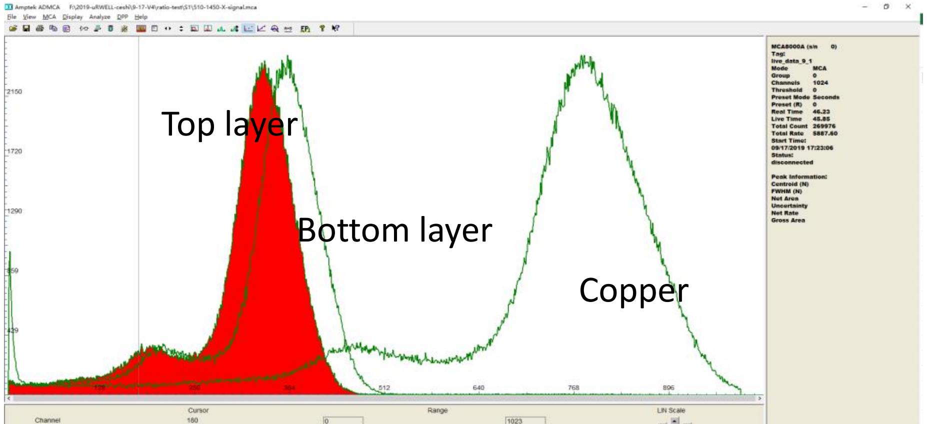
1. Detector's geometry & Electric field map are resolved by ANSYS.
2. Induced signal is exported from GARFIELD++ by simulating single electron avalanching.

Before

- Top layer: 80 μm
- Bottom layer: 350 μm
- Distance : 50 μm

NOW

- Top layer: 60 μm
- Bottom layer: 350 μm
- Distance : 25 μm



Spectrum after optimization of 2-D readout strip

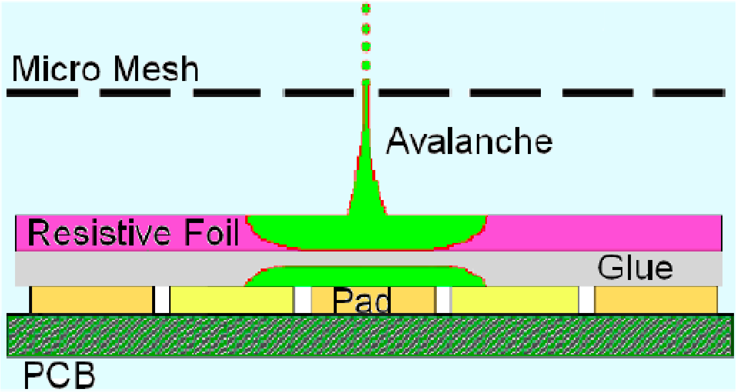
- Increase strip width of bottom layer and decrease strip width of top layer.
- The energy spectrum peak of top layer almost same with bottom layer after optimization.

	Bottom/Top	Copper/Bottom
Sector 1	**1.09**	**2.03**
Sector 2	**1.11**	**1.95**
Sector 3	**1.14**	**2.06**
Sector 4	**1.11**	**1.95**

Peak ratio in different sector

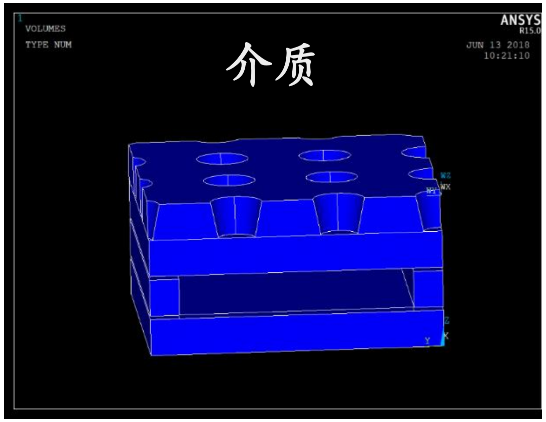
The charge spread on the DLC resistive electrode, inducing a current flowing through the resistive layer, generates a localized drop of the amplifying voltage, decreased the gain.

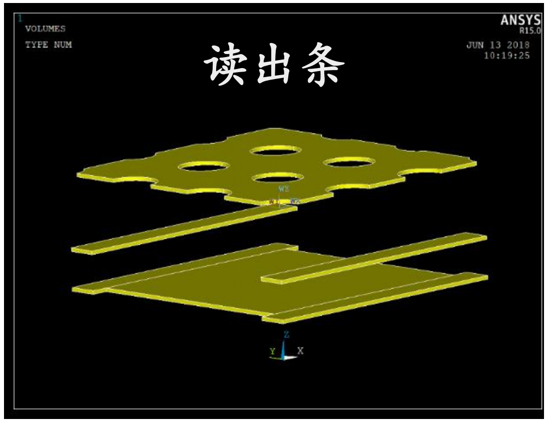
$$\frac{G}{G_0} = \frac{-1 + \sqrt{1 + 4P_0\Phi}}{2P_0\Phi}$$

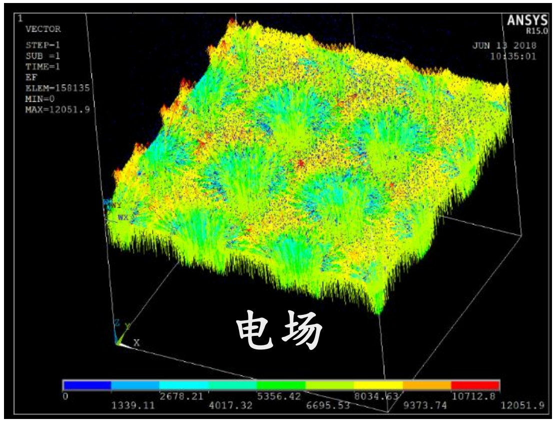


二维读出条感应信号模拟

ANSYS建模，GARFIELD++模拟电子雪崩产生感应信号

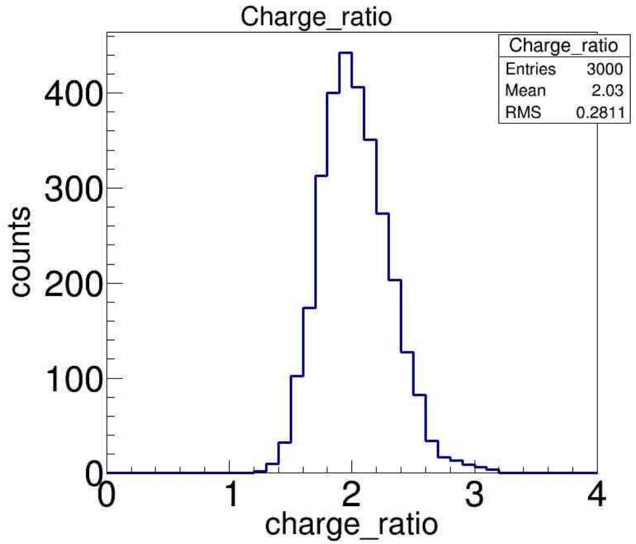




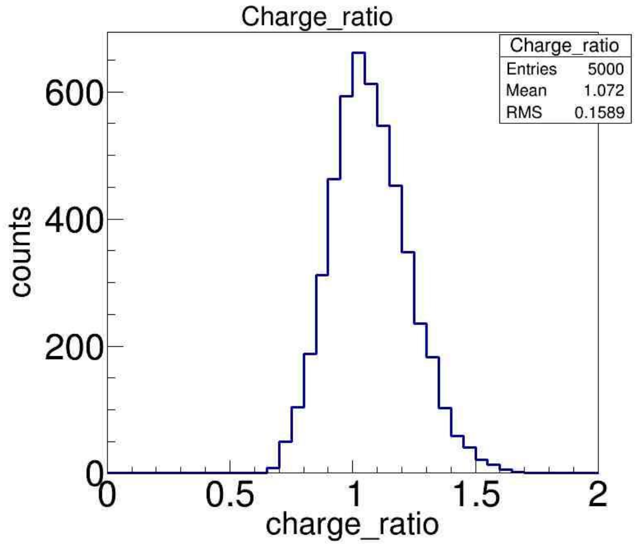


优化前参数：
Top layer: 80 μm
Bottom layer: 350 μm
Distance : 50 μm

优化后参数：
Top layer: 60 μm
Bottom layer: 350 μm
Distance : 25 μm



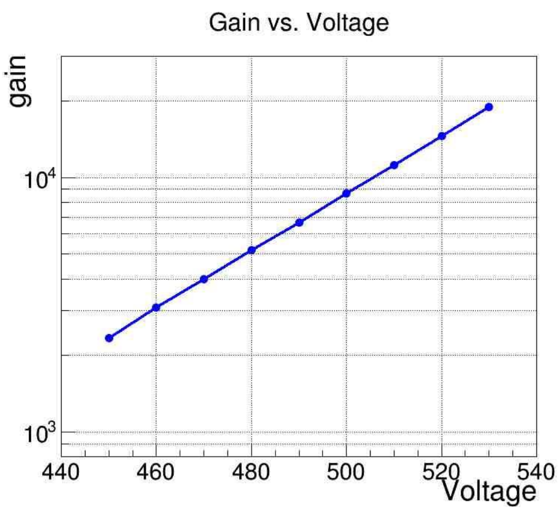
优化前



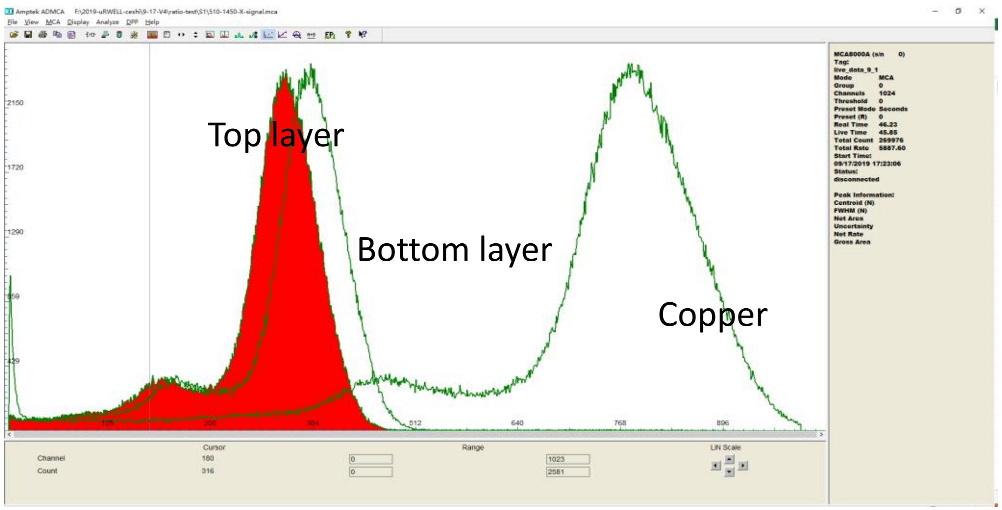
优化后

优化后测试结果

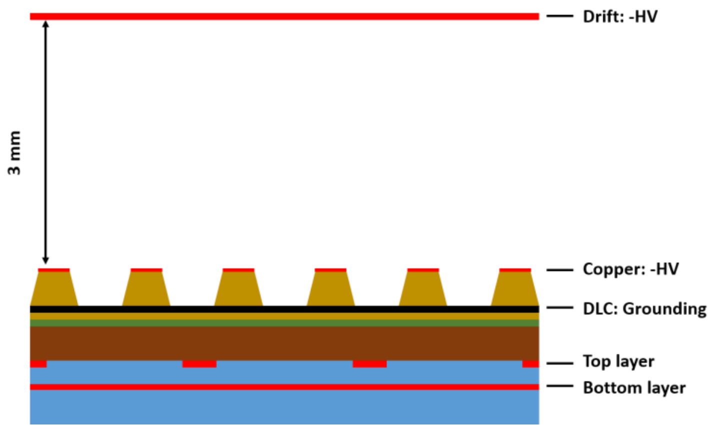
Ar/CO2=70/30 8 keV copper X-rays



Gain

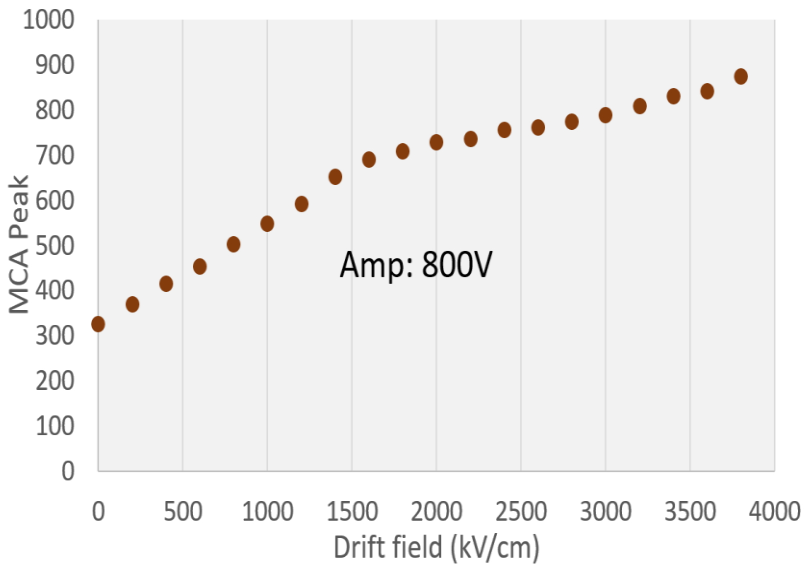


Sector 1能谱



	Bottom/Top	Copper/Bottom
Sector 1	**1.09**	**2.03**
Sector 2	**1.11**	**1.95**
Sector 3	**1.14**	**2.06**
Sector 4	**1.11**	**1.95**

Energy spectrum peak at different sector

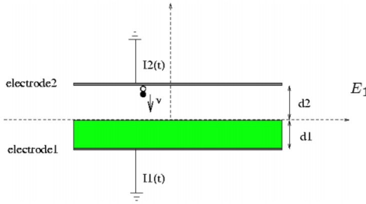


Example, Induced Currents (2,4)

At t=0 a pair of charges q, -q is created at z=d_2.
One charge is moving with velocity v to z=0
Until it hits the resistive layer at T=d_2/v.

$$x_0(t) = \begin{cases} d_2 - vt & t < T \\ 0 & t > T \end{cases}$$

$$\dot{x}_0(t) = \begin{cases} -v & t < T \\ 0 & t > T \end{cases}$$



$$E_{1z}(\vec{x},t) = \frac{\varepsilon_r V_0}{d_1+\varepsilon_r d_2}\left[\delta(t) + \frac{\tau_2-\tau_1}{\tau_1\tau_2}\, e^{-\frac{t}{\tau_2}}\right] \qquad z > 0$$

$$I_1(t) = qv\frac{\varepsilon_r}{d_1+\varepsilon_r d_2}\left[1 + \frac{d_1}{d_2\varepsilon_r}(1 - e^{-\frac{t}{\tau_2}})\right] \qquad t < T$$

$$= qv\frac{1}{d_1+\varepsilon_r d_2}\frac{d_1}{d_2}\left(e^{\frac{T}{\tau_2}} - 1\right)e^{-\frac{t}{\tau_2}} \qquad t > T$$

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