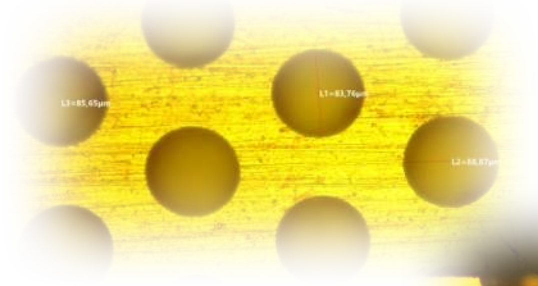
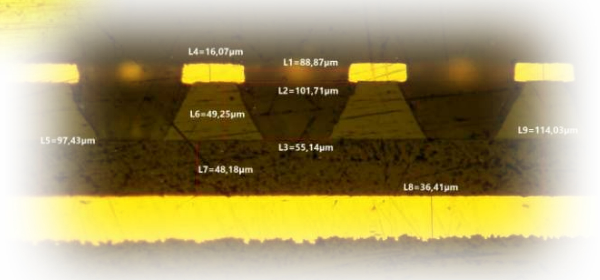
AIDAinnova-WP7.3.2

Industrial engineering of high rate µ-RWELL





Matteo Giovannetti [LNF-INFN]

on behalf of
LNF-INFN (leading group)
Bologna-Ferrara INFN teams
R. De Oliveira – CERN-EP-DT-MPT Workshop
R. Pinamonti, M. Pinamonti – ELTOS S.p.A.

AIDAinnova 3nd annual meeting, Catania, March 18th-21th 2024

WP7.3.2: Task objectives

Future HEP experiments *(LHC upgrades, FCC-ee …) require the development of particle* ***detection technologies easily engineered*** *and compatible with* ***industrial-scale*** *production.*

The ***µ-RWELL****, a resistive MPGD based on* ***sequential build-up technology, effectively meets these requirements.***

DELIVERABLE – December 2023[*]

- **D7.3:** µ-RWELL prototypes co-produced by industry under the guidance and supervision of the research team.
  Discussed on 7/12/23 & report submitted

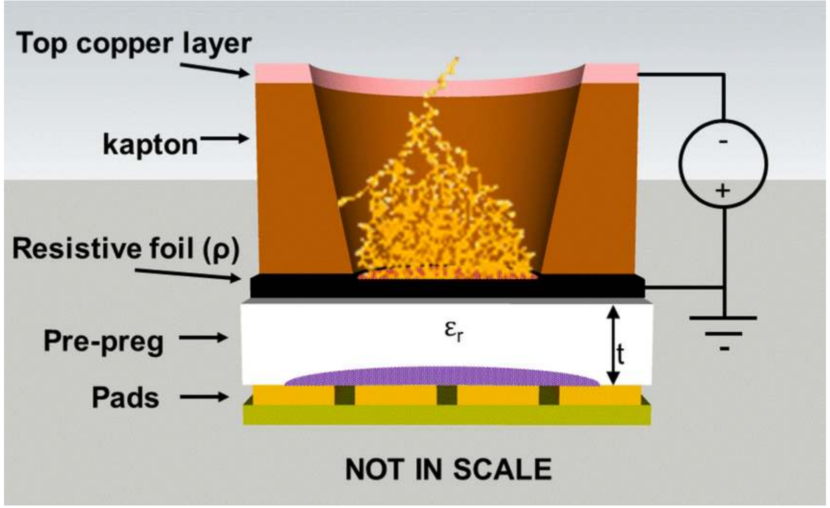
MILESTONE – June/July 2024[*]

- **MS28:** build a 0.3×0.3 m^2 prototype and the readout plane,
  with the new structure

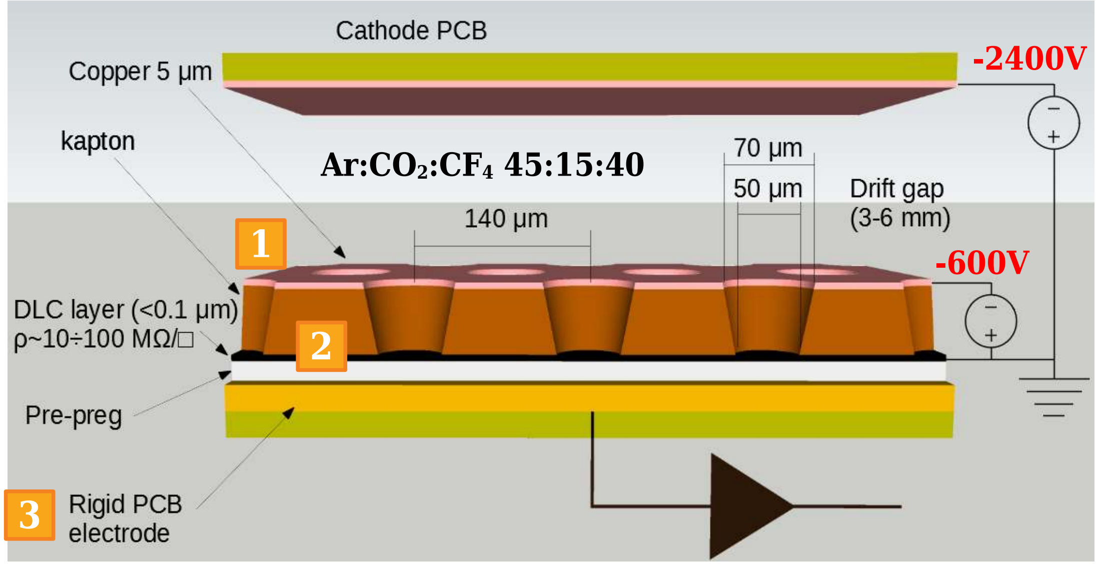
[*] *Postponed both by 3 months due the production time required by the final construction steps*

The µ-RWELL detector (reminder)

The µ-RWELL is a Micro Pattern Gaseous Detector (MPGD) composed of only two elements: the µ-RWELL_PCB and the cathode. **The core is the µ-RWELL_PCB**, realized by coupling three different elements:



Applying a suitable voltage between the **top Cu-layer and the DLC** the WELL acts as a **multiplication channel for the ionization** produced in the conversion/drift gas gap.



1. **a WELL** patterned kapton foil acting as **amplification stage** (GEM-like)
2. a **resistive DLC layer (Diamond-Like-Carbon)** for discharge suppression with surface resistivity ~ 50÷100 MΩ/□
3. a standard readout PCB

WP7.3.2: Operative Meetings

21st Sept. 2021 - joint INFN-ELTOS-CERN meeting
- standardizing manufacturing procedures of µ-RWELL layout

1st-3rd Dec. 2021 - CERN-INFN meeting
- status of the R&D on the High Rate layout

7th-10th Dec. 2021 – 1st test batch in ELTOS
- DLC patterning + PCB planarizing tests

7th–8th Mar. 2022 - 2nd test batch in ELTOS
- Kapton DLCed foil coupling with PCB-readout

28th-31th Mar. 2022
1st AIDAinnova
Annual meeting

31st Oct. 2022 - joint INFN-CERN meeting
- Result discussion + Planning 2023 production

5th Dec. 2022 - joint INFN-ELTOS meeting
- Planning 2023 production

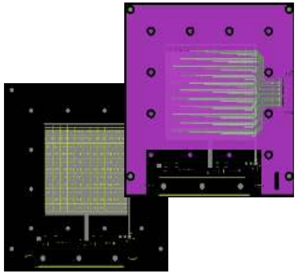
20th-22th Mar. 2023 - 1st production batch in ELTOS
- DLC patterning
- PCB palnarizing (prepreg thickness scan)

24th-27th Apr. 2023
2nd AIDAinnova
Annual meeting

Nov-Dec. 2023 – INFN test
- D7.3 – testing the detector produced
- Submission of the deliverable report

WP7.3.2: Technology Transfer [flow chart]

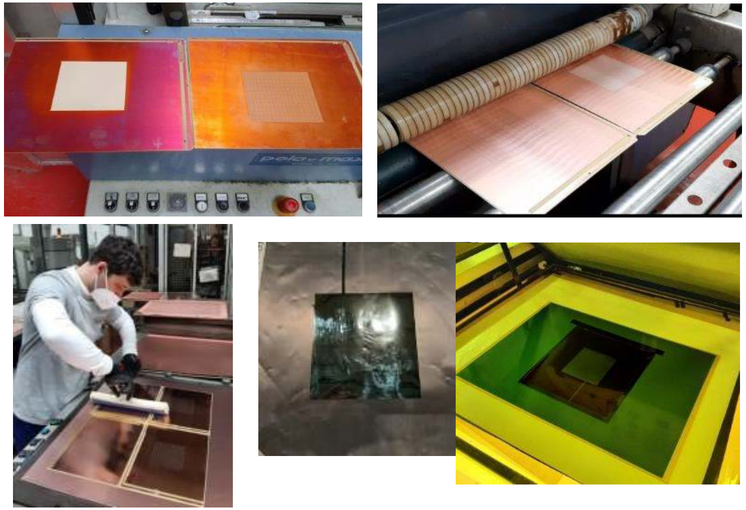
LAYOUT design



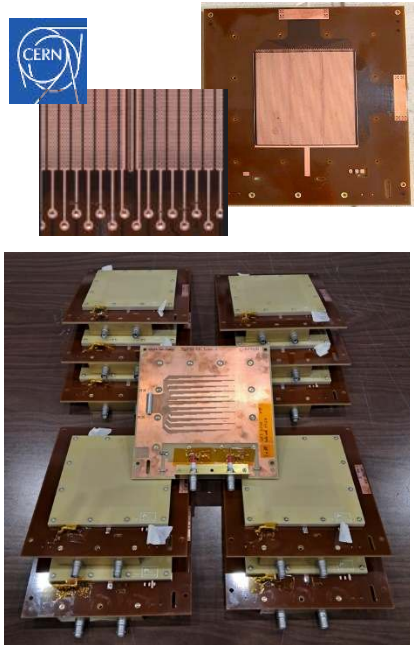
Feedback from tests

PCB production

ELTOS



Final detector manufacturing



DLC foil production[*]

[*] DLC Magnetron Sputtering machine co-funded by INFN- CSN1

WP7.3.2: Technology Transfer 2023

Step 0 – Detector **PCB design** @ LNF + CERN-MPT

Step 1 – CERN_INFN **DLC sputtering machine** @ CERN (+INFN)
- In operation since Nov. 2022
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- pad/strip readout

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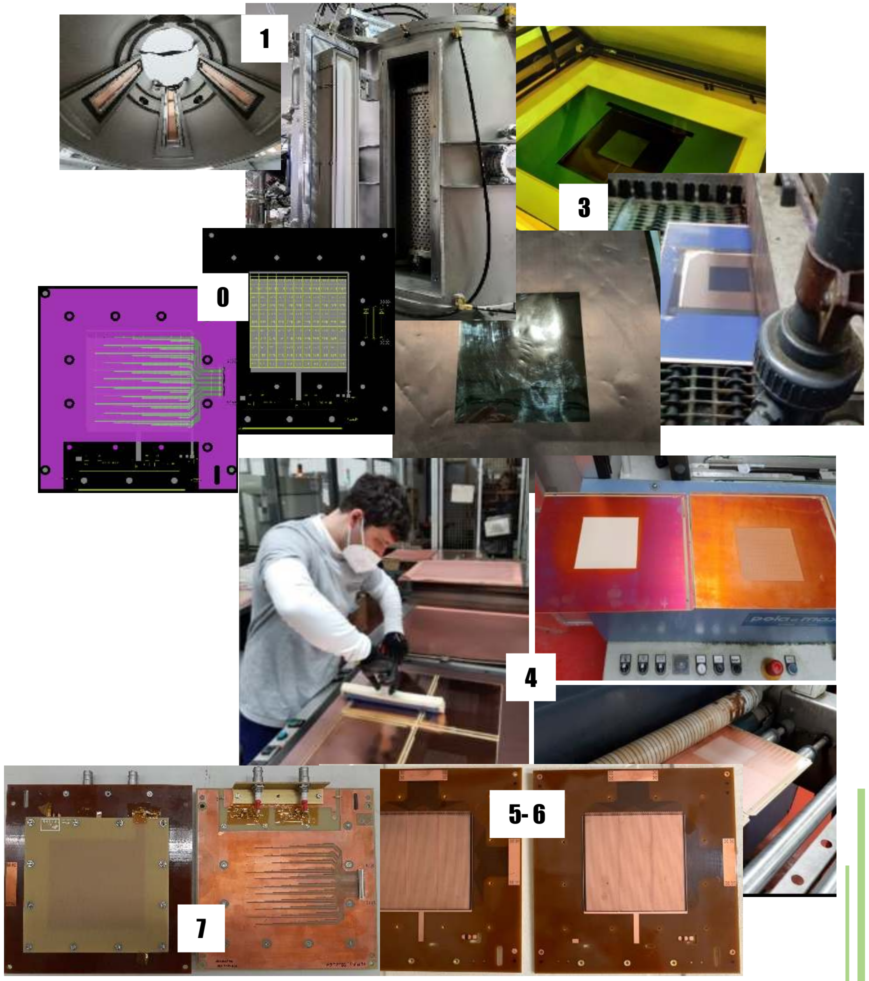
Step 4 – **DLC foil gluing** on PCB by ELTOS
- Large press available, up to 16 PCBs workable at the same time

Step 5 – **Ground network connections** creation by CERN
- **PEP** layout: Cu **P**atterning → PI **E**tching → Cu **P**lating

Step 6 – **Amplification stage** patterning by CERN
- Cu amplification holes image and HV connections by Cu etching
- PI etching → plating → amplification-holes

Step 7 – **Electrical cleaning** and detector closing @ CERN



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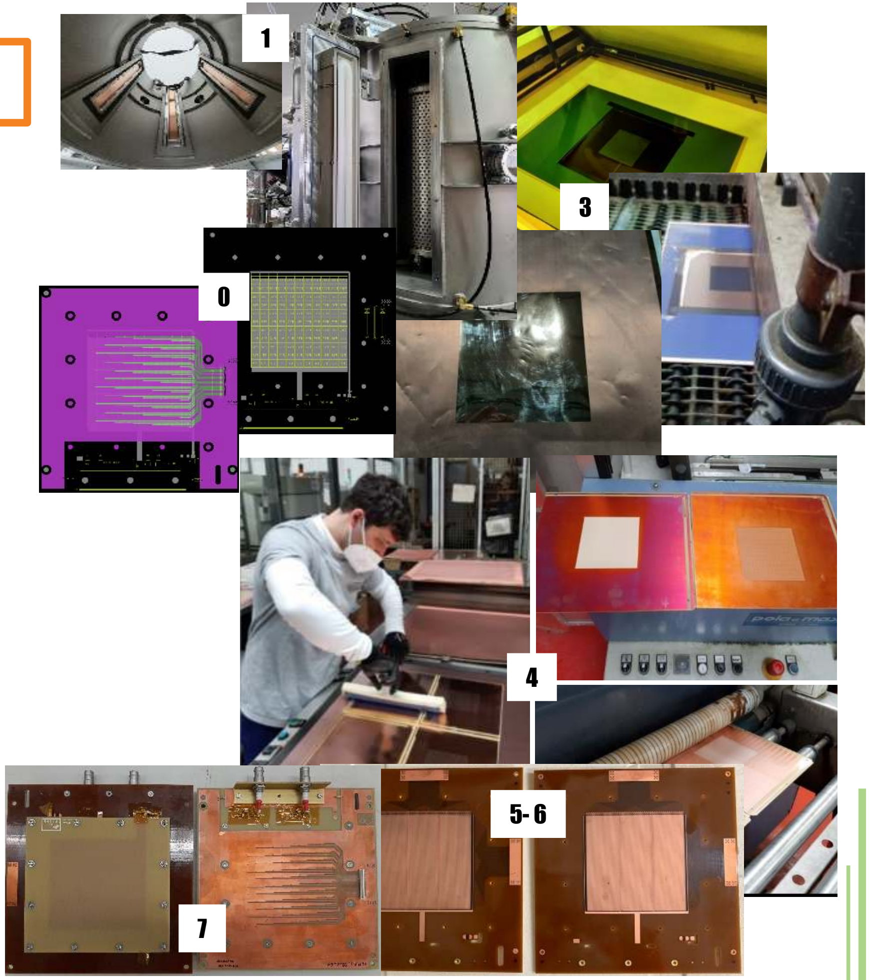
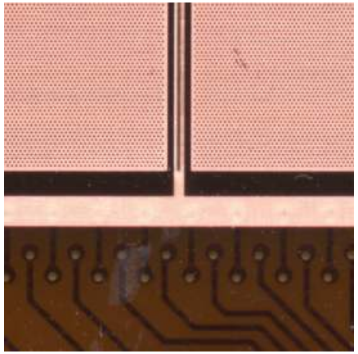


WP7.3.2: High-rate layout optimization

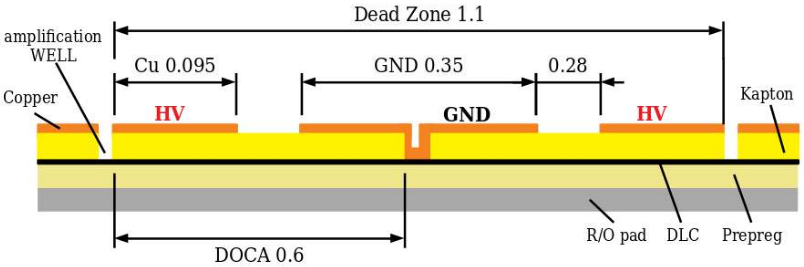
The GOAL: **minimizing** the average **path towards the ground** connection by introducing a **high-density grounding network** on the DLC layer. In **PEP** (Patterning-Etching-Plating) layouts the top Cu layer is connected to the DLC, plating through the APICAL foil.

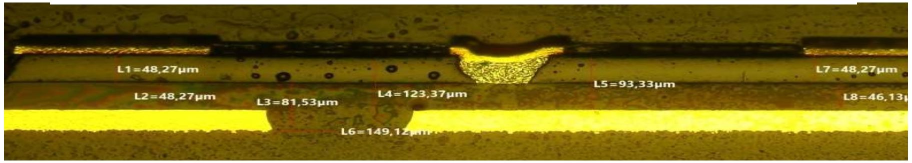
2022 – PEP-groove

DLC grounding by
conductive groove
Pad R/O = 9×9cm^2
Grounding: - pitch = 9.0 mm
- width = 1.1 mm



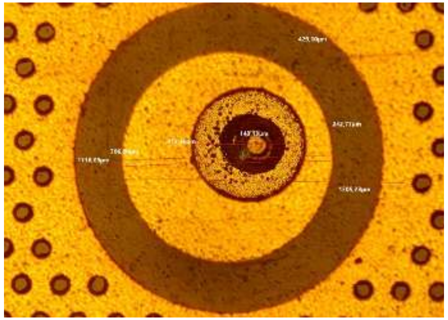
→ **84% geometric** acceptance



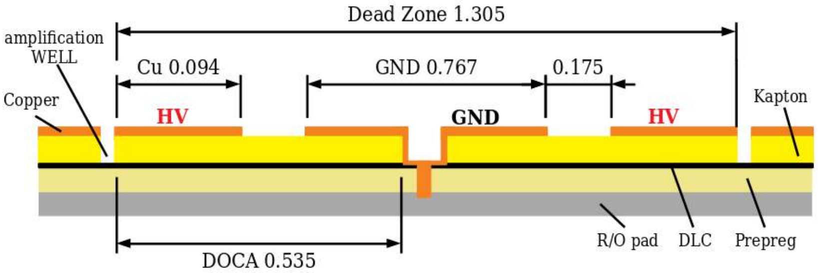


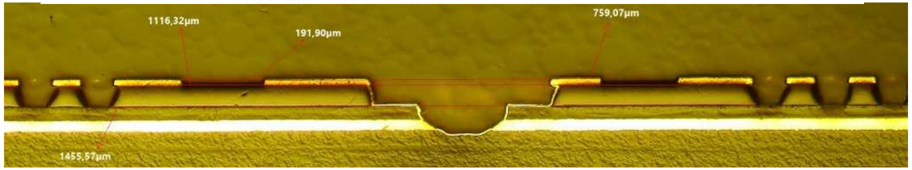
2023 – PEP-dot

DLC grounding by
conductive DOT
Pad R/O = 9×9cm^2
Grounding: - pitch = 9.0 mm
- rim = 1.3 mm



→ **97% geometric** acceptance





WP7.3.2: High-rate layout optimization

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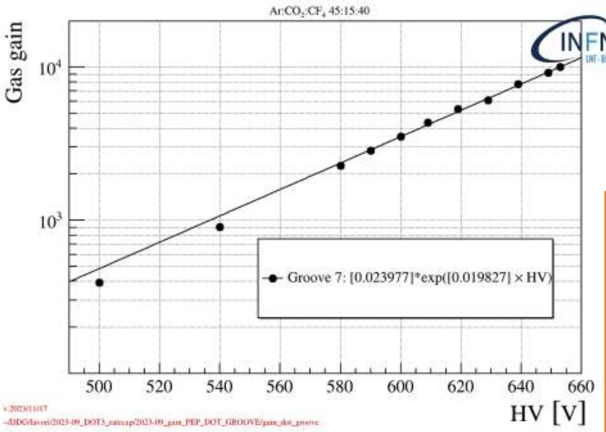
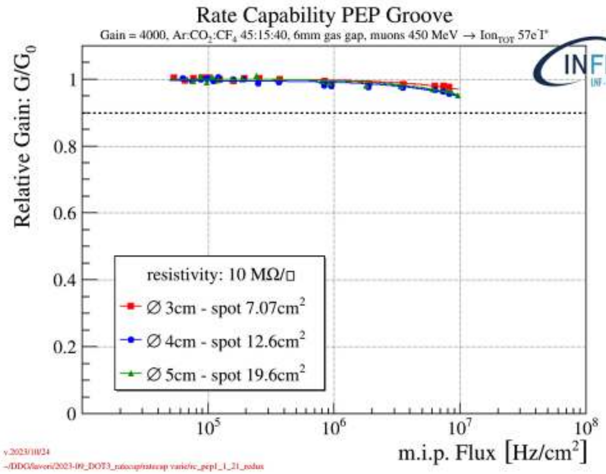
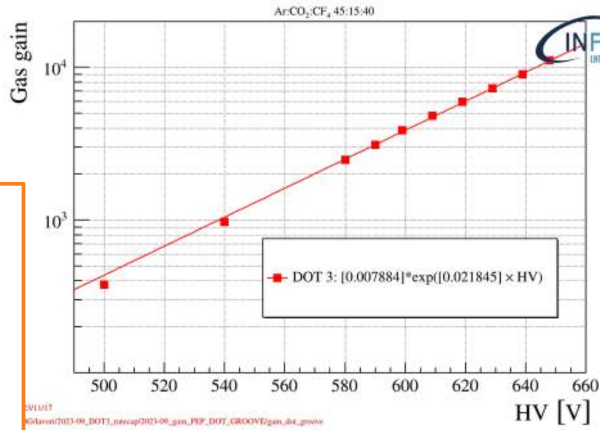
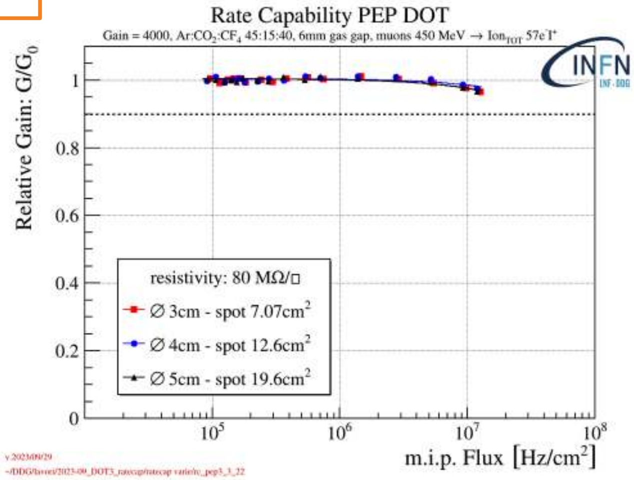
PEP-groove





2023
PEP-dot



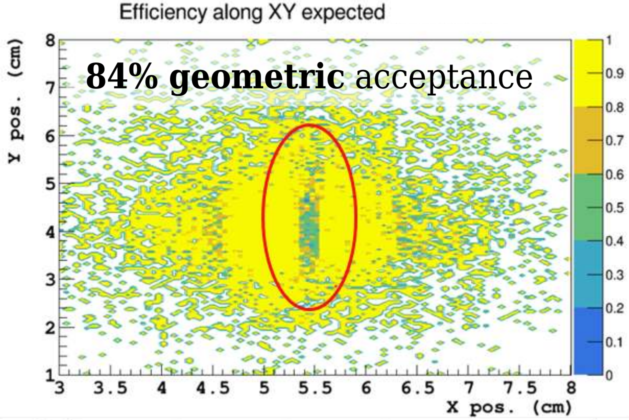


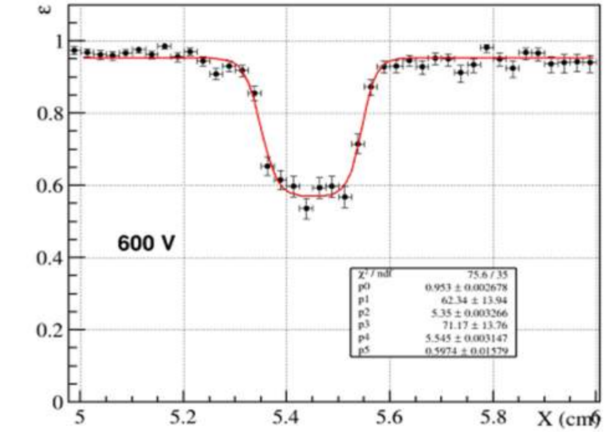
Both layouts exhibit **satisfactory performance:**

- **gas gain** of up to **10^4**
- **rate capability** (@ 90% drop) **> 10 MHz/cm²**

WP7.3.2: High-rate layout optimization

2022 PEP-groove





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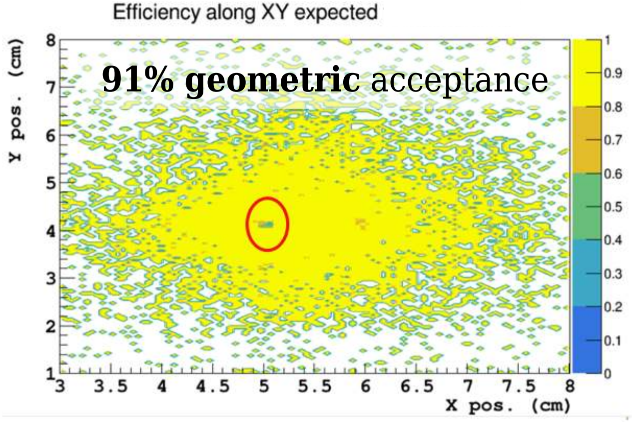

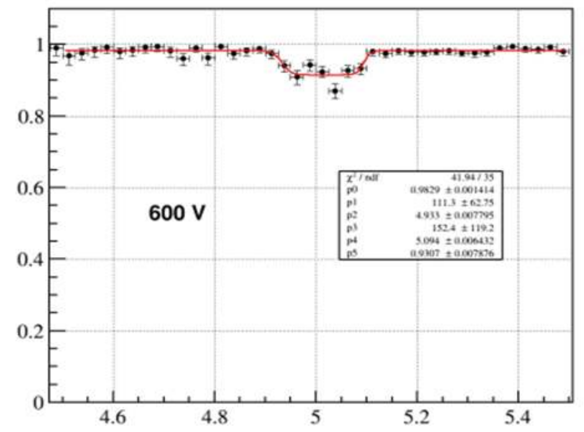

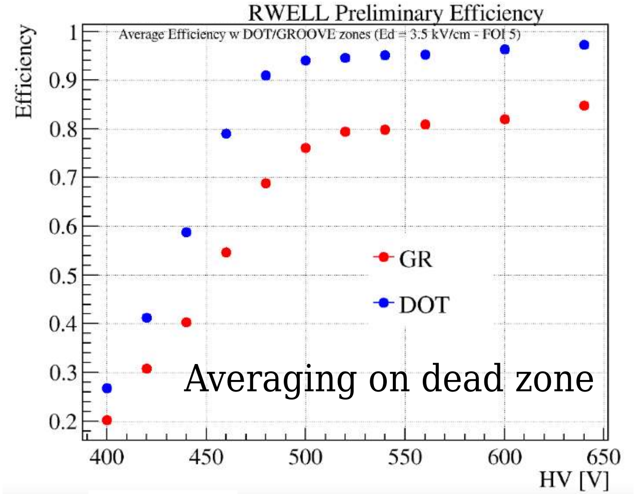

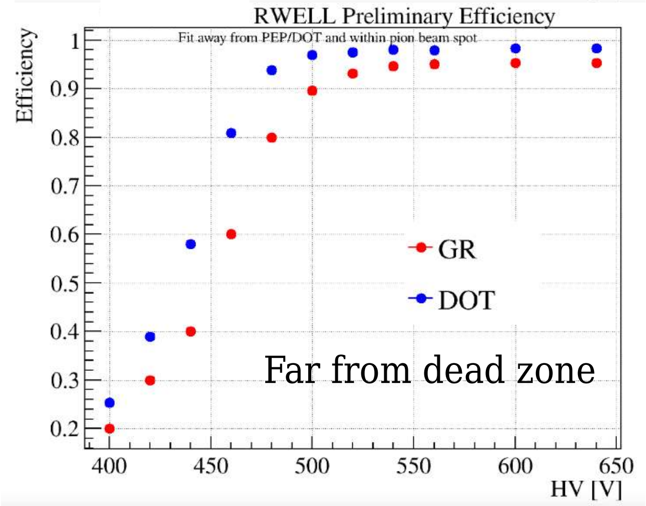

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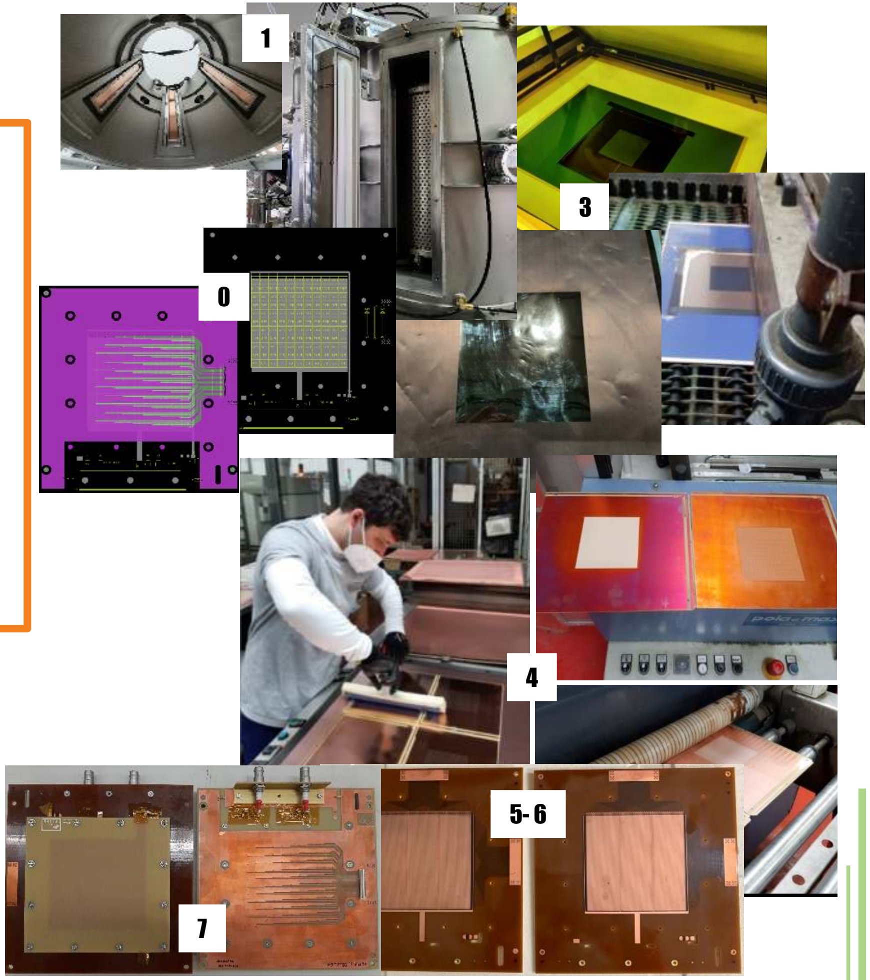


This research has been supported by the E.U. Project AIDAInnova Task 7.3 (European Union's Horizon 2020 Research and Innovation programme, grant agreement N.101004761)

C.I.D. - The CERN-INFN DLC machine

31st Oct. 2022 – Delivered
31st Oct. - 4th Nov. 2022 – Commissioning & test training
21st - 23rd Nov. 2022 – 1st DLC sputtering test
- Ar + N_2 doping

19th - 28th Jun. 2023 – 2nd DLC sputtering test
- Ar + N_2 doping (% and P scan)

25th - 29th Sep. 2023 – 3rd DLC sputtering test
- Ar + C_2H_2 doping

6th - 10th Nov. 2023 – 4th DLC sputtering test
- Ar + C_2H_2 doping (uniformity test)

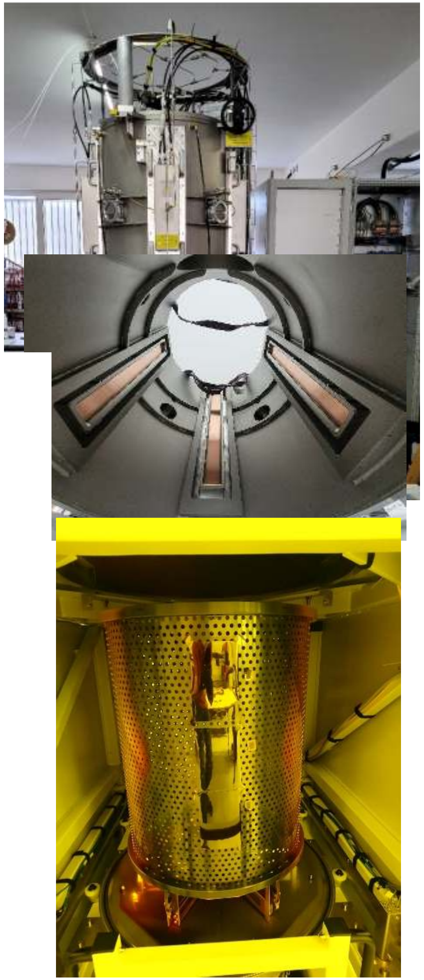
19th - 23th Feb. 2024 – 5th DLC sputtering test
- Tuning large foil sputtering process

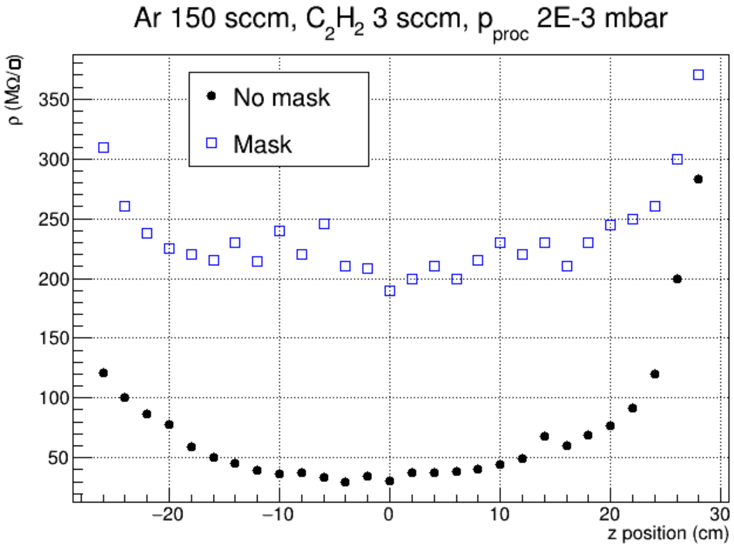
Technical features:
- **Flexible** substrates up to 1.7m×0.6m
- **Rigid** substrates up to 0.2m×0.6m

Five cooled target holders, arranged as two pairs face to face and one on the front, equipped with five shutters.

CID allows to **sputter** or **co-sputter different materials**, to create a coating layer by layer or an adjustable **gradient** in the coating.

Thanks to Rui, Serge, Givi and Gianfranco – more details in this talk





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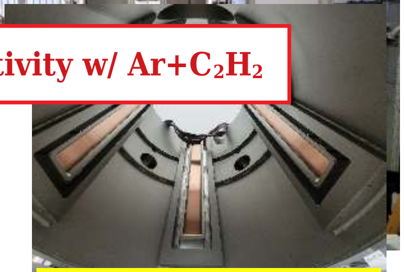
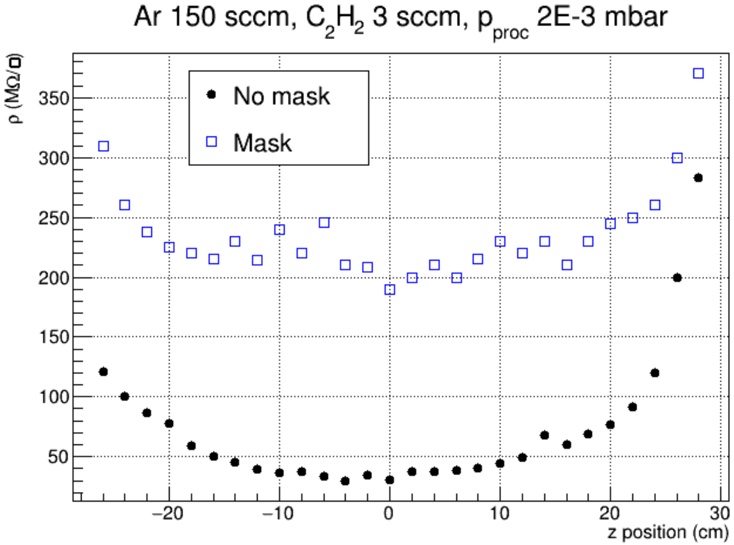


2023 → Stable and uniform DLC resistivity w/ Ar+C_2H_2



2024 → Sputtering large foils!!

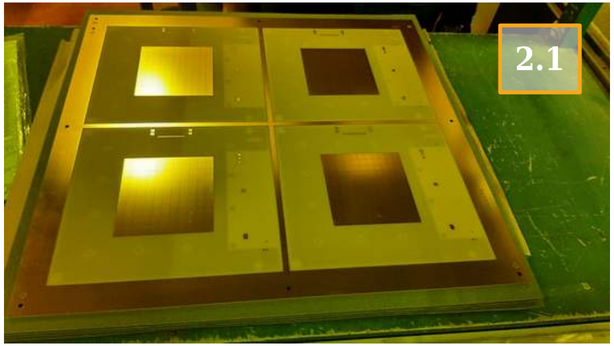
WP7.3.2: co-production pilot test – DLC patterning

Step 2:

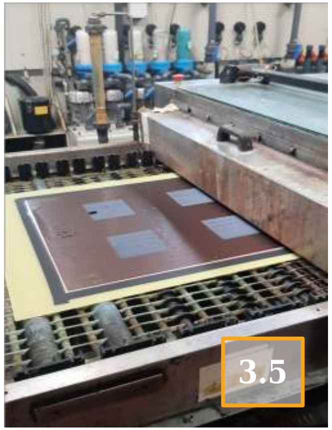
1) R/O **PCB** production

Step 3:

2) Photoresist **lamination** for DLC protection
3) Photoresist UV-**exposure**
4) Photoresist **development**
5) **DLC patterning** with brushing machine
(@CERN different approach: JET-SCRUBBING)



DLC
Kapton
Cu

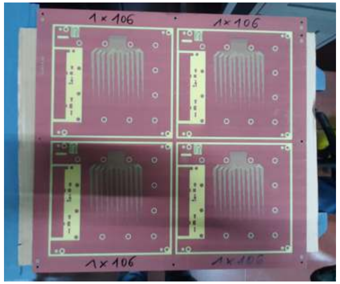


WP7.3.2: co-production pilot test – DLC-foil gluing

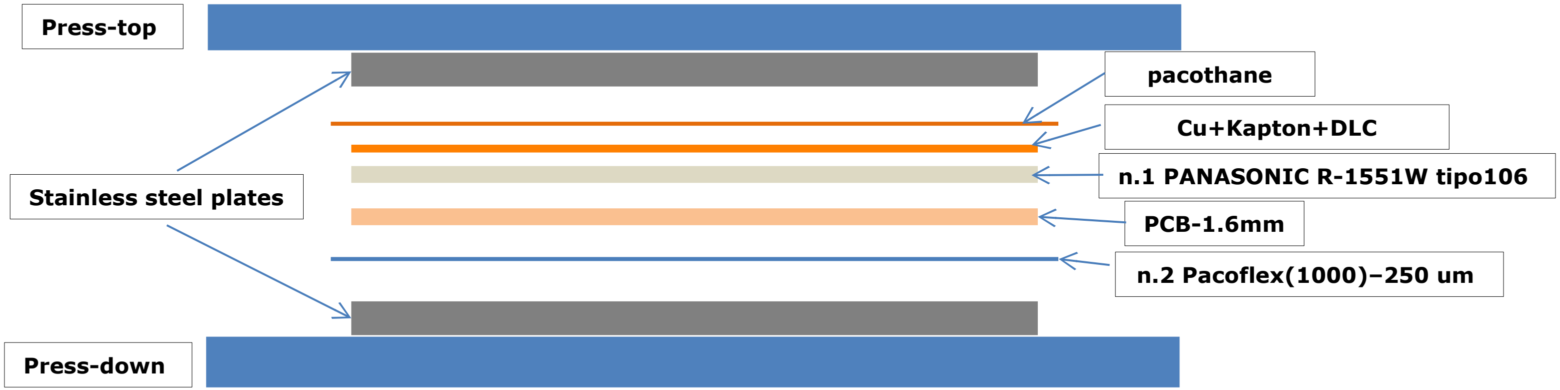
Step 4: Cu-Kapton-DLC gluing on PCB

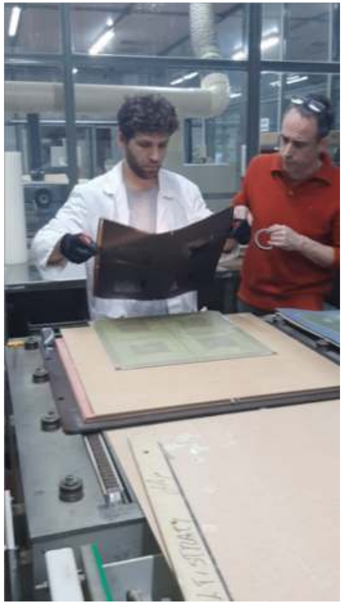
- 16 PEP-dot detectors (9×9mm^2 pad R/O), with **different pre-preg thickness**
- **11/16** detector **delivered/tested** up to now
- Study of signal **pulse amplitude vs coupling capacitance** between DLC and R/O pad.

Pre-preg	Δx [μm]
106	50
1080	75
x2 106	100
x2 1080	150

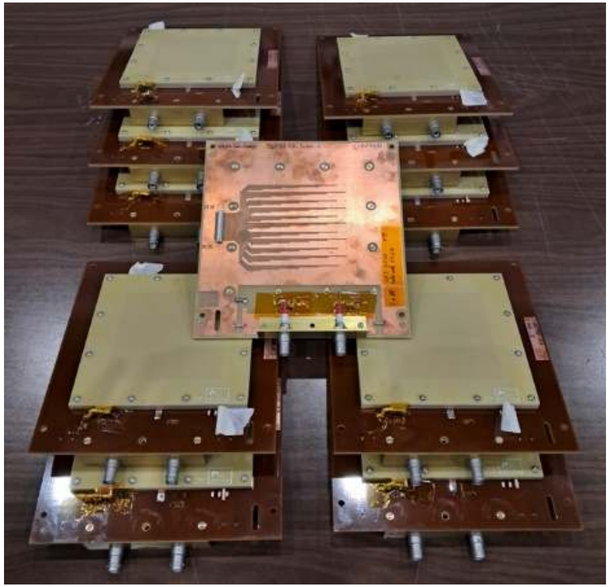


Main parameters:
Pressure 180 N/cm^2
Temperature 210 °C





WP7.3.2: co-production pilot test – results

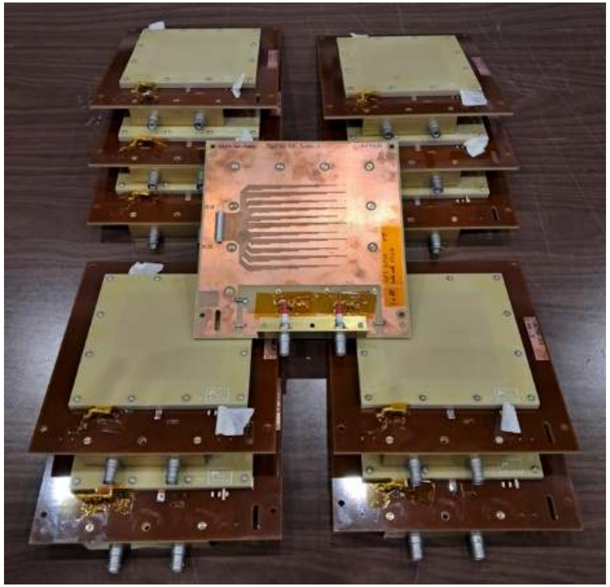


Detector #	Prepreg type	DLC resistivity	Production status	Max HV/Gain	comments
106_1	1x 106		Ready to be delivered		@ CERN
106_2	1x 106	7.5	Delivered	640/10000	
106_3	1x 106		Ready to be delivered		@ CERN
106_4	1x 106	7	Delivered	640/9500	
1080_1	1x1080		Ready to be delivered		@ CERN
1080_2	1x1080	4.8	Delivered	630/6700	
1080_3	1x1080	5	Ready to be delivered	Re-cleaned	@ CERN
1080_4	1x1080		Ready to be delivered		@ CERN
2x106_1	2x106	35	Delivered	660/16000	
2x106_2	2x106	37	Delivered	650/13000	
2x106_3	2x106	35	Delivered	670/15000	
2x106_4	2x106	34	Delivered	650/12500	
2x1080_1	2x1080	33	Delivered	670/19500	
2x1080_2	2x1080	110	Delivered	680/19000	
2x1080_3	2x1080	44	Delivered	680/19000	
2x1080_4	2x1080		Ready to be delivered		@ CERN

- **11/16** co-produced protos have been **delivered** and **tested**
- **10 are fine → 90% yield**
- 1 has been re-cleaned

Waiting for the delivery of last 5 protos

WP7.3.2: co-production pilot test – results



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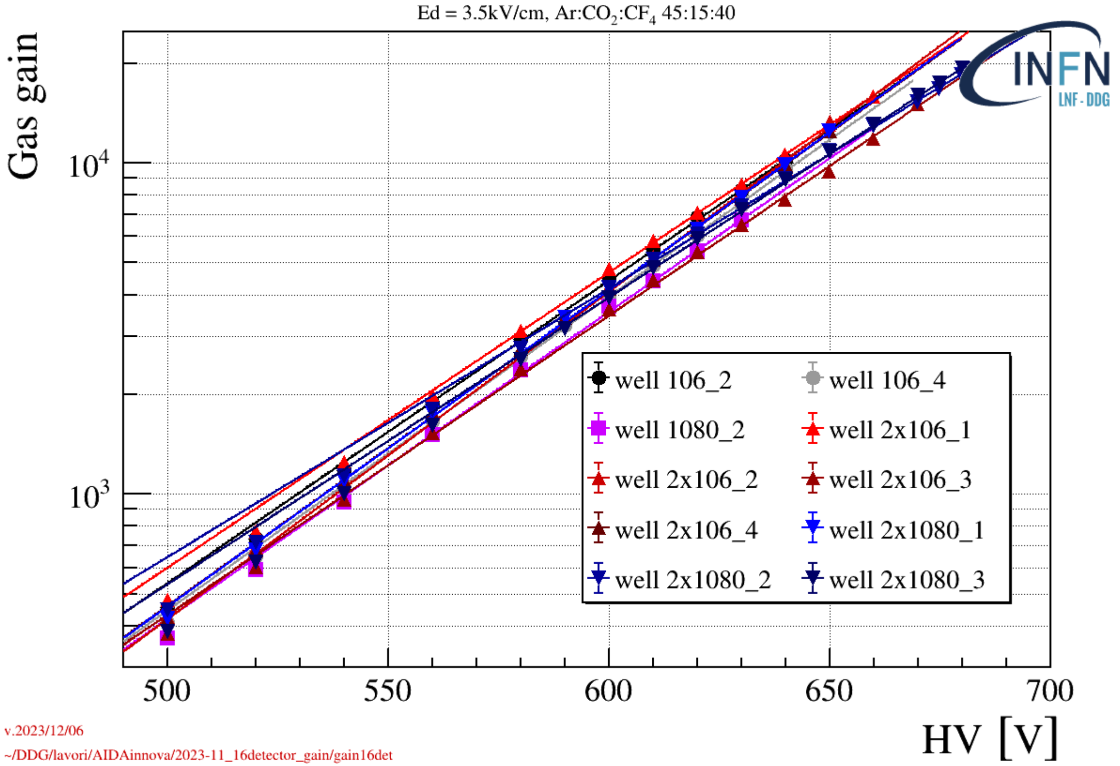
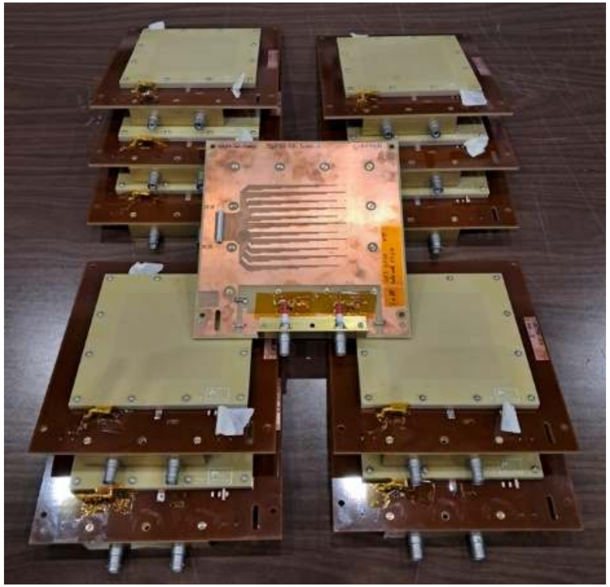
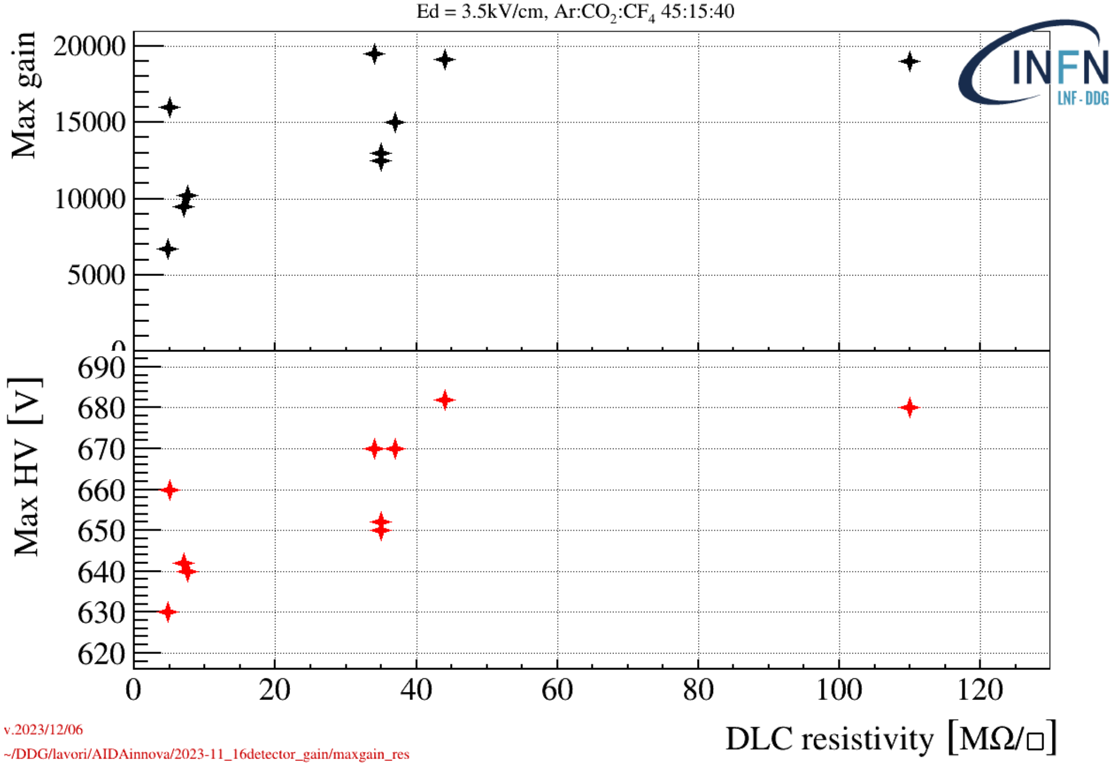


Characterized with **X-ray gun → Gas gain** measurement

WP7.3.2: co-production pilot test – results





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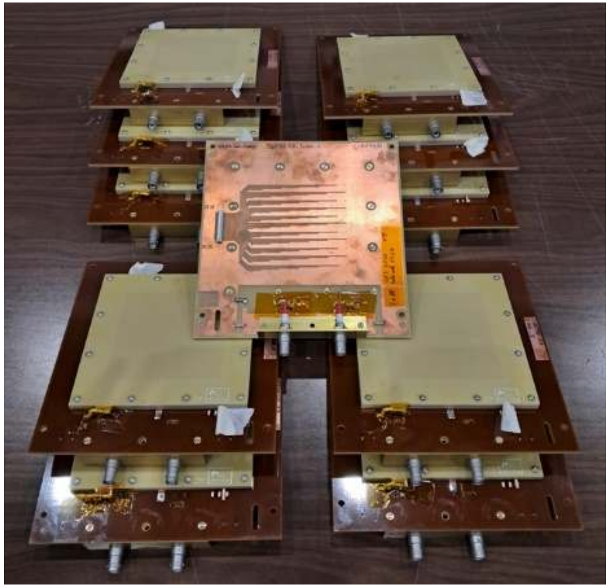

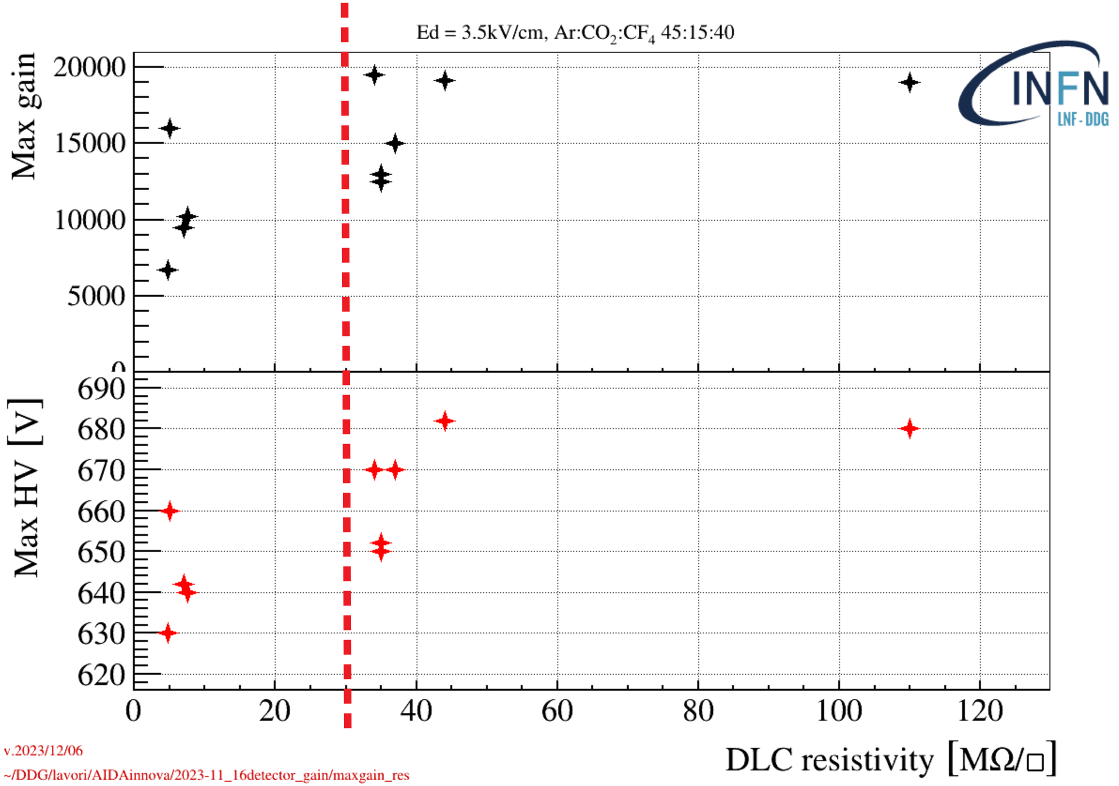

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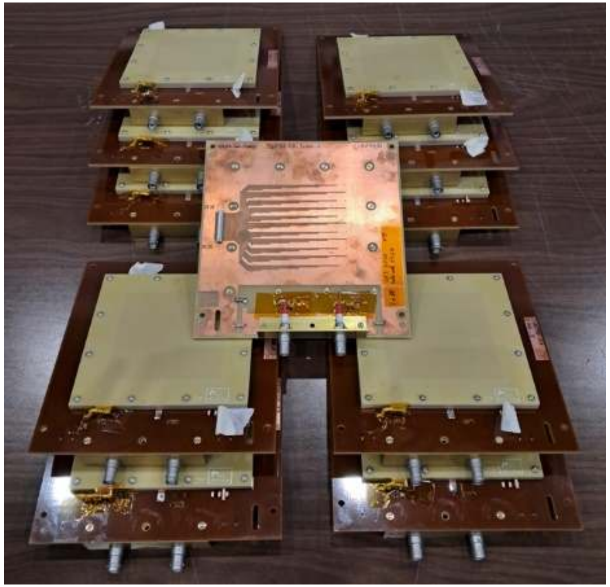
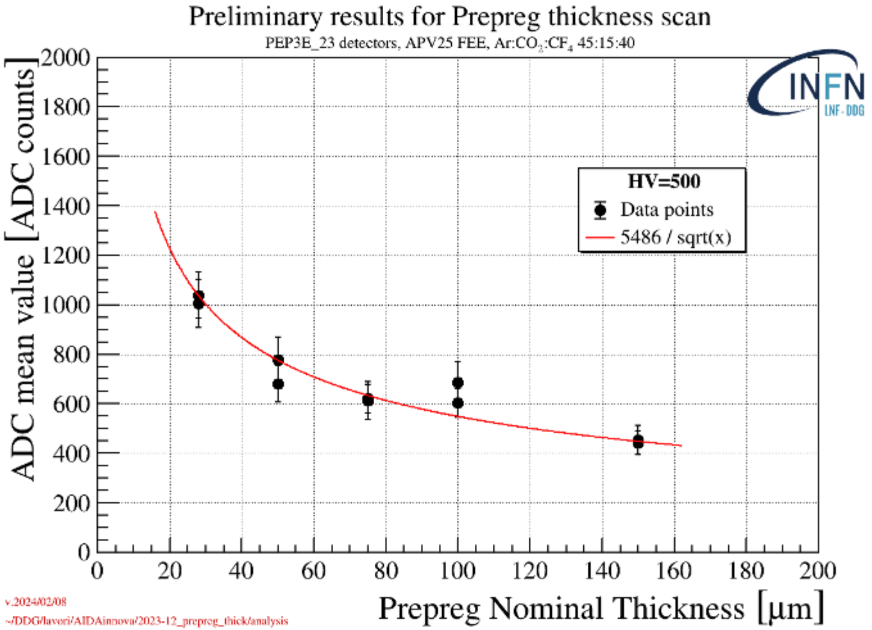
Characterized with **X-ray gun → Gas gain** measurement

WP7.3.2: co-production pilot test – results





- **11/16** co-produced protos have been **delivered** and **tested**
- **10 are fine → 90% yield**
- 1 should be re-cleaned

Waiting for the delivery of last 5 protos

Measure of the **pulse amplitude** (APV25) vs prepreg thickness. The thinner the prepreg, the larger the capacitance between the R/O and the DLC, the larger the induced signal.

While the **S/N** depends also on the type of FEE used (the larger the capacitance, the larger the Noise), the increase in signal for thinner prepreg can be considered a general result.

WP7.3.2: next steps

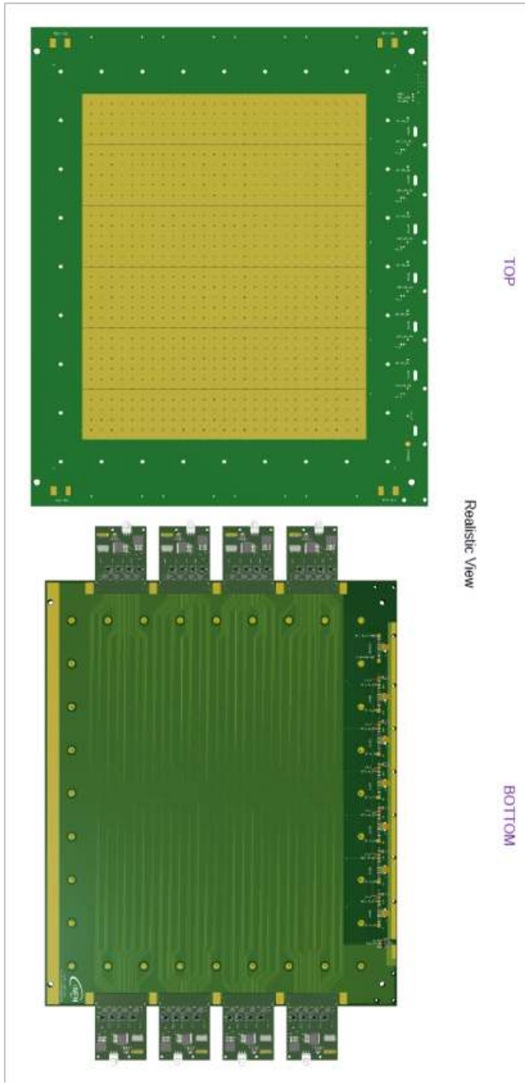
PEP layout with an active area 250x300 mm²

- Designed & discussed w/Rui (**Oct./Nov. 2023 - done**)
- Delivery (**April/May 2024**)
- Characterization w/X-rays (**June/July 2024**)

MILESTONE - June/July 2024)

MS28: build a 0.3×0.3 m^2 prototype and the readout plane, with the new structure

Preparation of a synthetic **addendum to the report** (design, construction, presentation of the X-rays characterization results …)



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    - Design/optimization of the high-rate layout → **PEP-dot** (97% geom. Acceptance) (DONE)
    - Optimizing main detector parameters:
        - $\rho_S \geq 50M\Omega/\square$ → maximizing the gas gain
        - Optimization of the prepreg thickness → maximizing the collected signal
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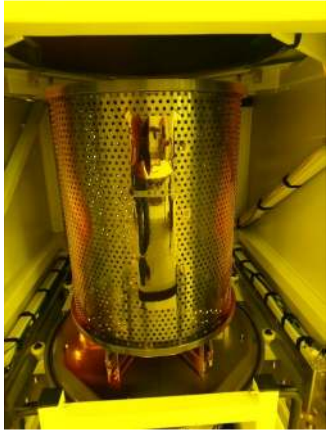
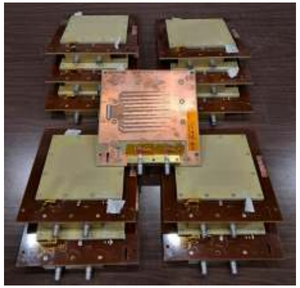
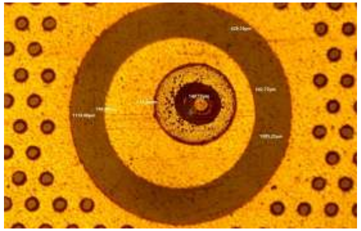
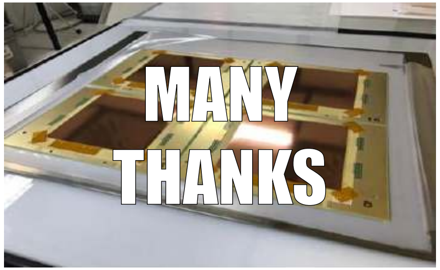
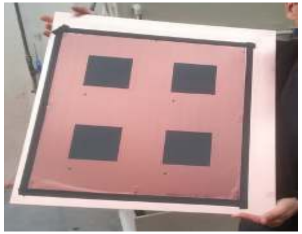










Spare

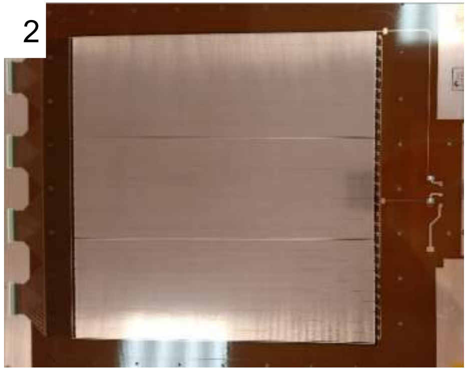
μ-RWELL technology spread

The μ-Resistive WELL is proposed in

1. **CLAS12 @ JLAB:** the upgrade of the muon spectrometer
2. **X17 @ n_TOF EAR2**: for the amplification stage of a TPC dedicated to the detection of the X17 boson
3. **TACTIC @ YORK Univ.:** radial TPC for detection of nuclear reactions with astrophysical significnace
4. **Muon collider:** hadron calorimeter
5. **CMD3:** uRWELL Disk for the upgrade of the tracking system
6. **URANIA-V**: a project funded by INFN-CSN5 for neutron detection,
7. **UKRI:** neutron detection with pressurized ^{3}He-based gas mixtures

1

2



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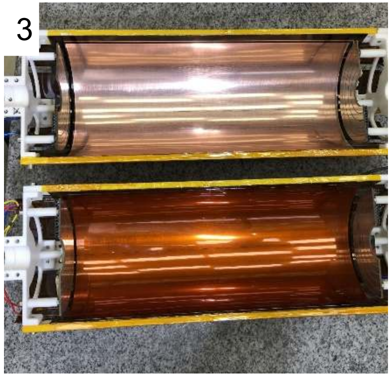

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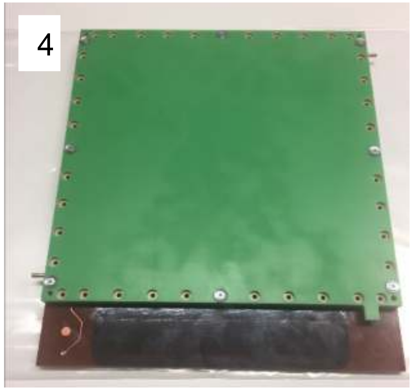

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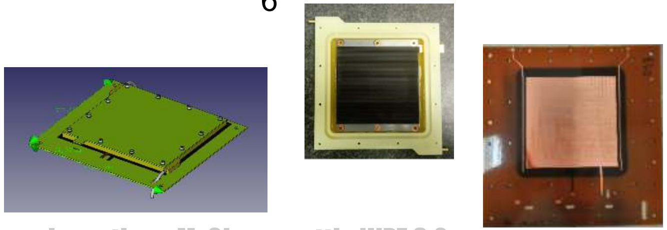

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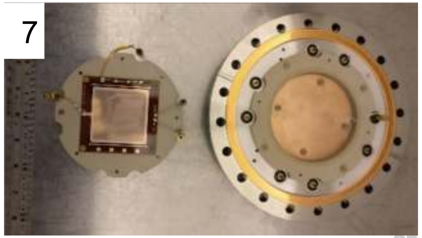

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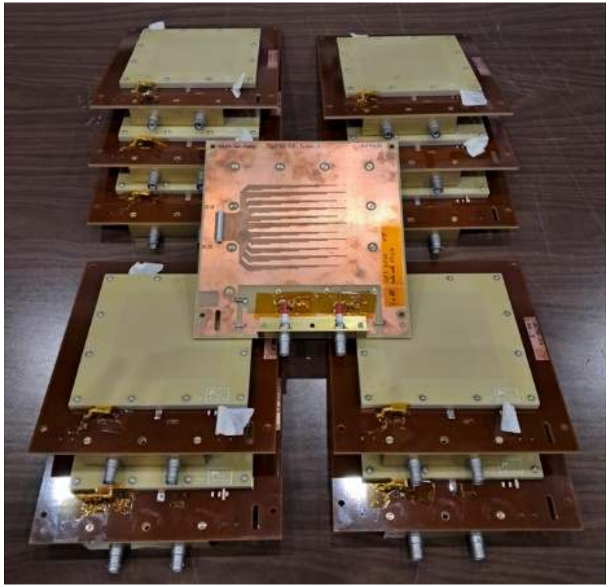

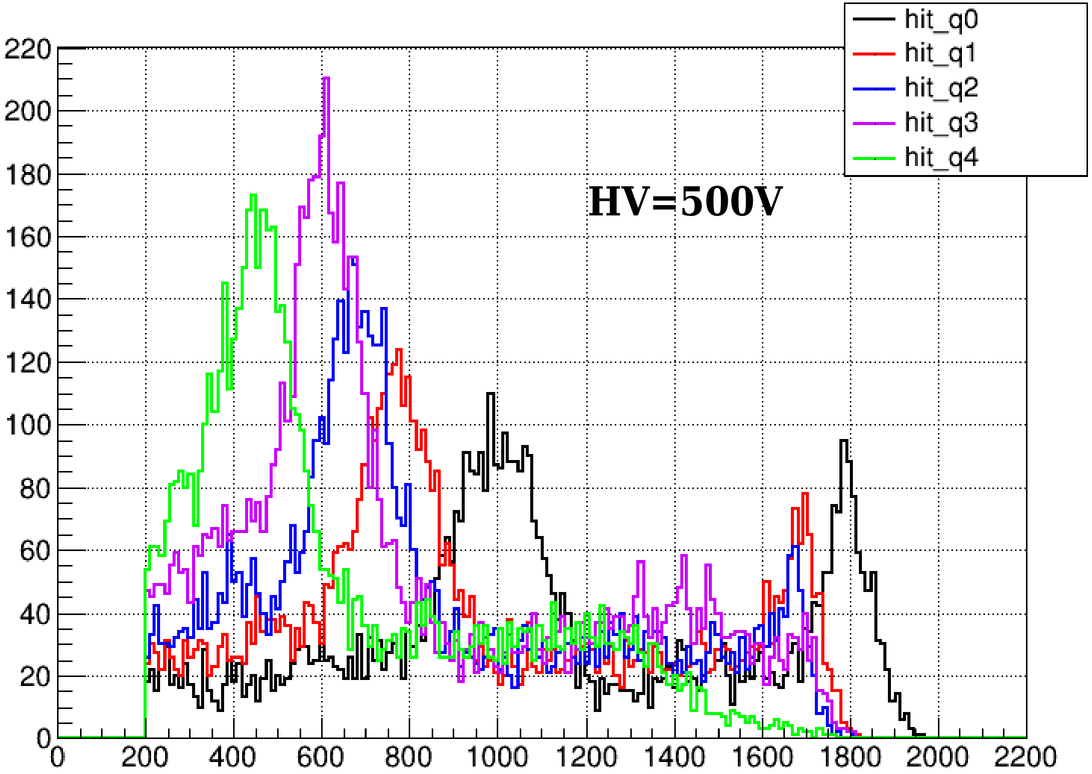

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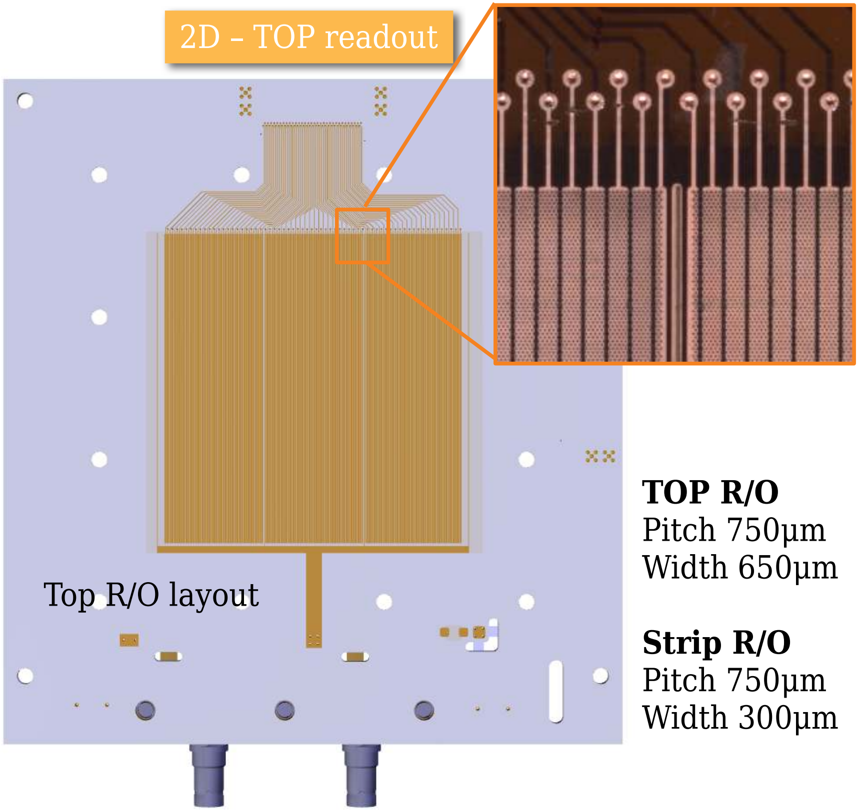
Measure of the **pulse amplitude** (APV25) vs prepreg thickness

WP7.3.2: (June ’23) 2D Read Out

2D – TOP readout



TOP R/O
Pitch 750μm
Width 650μm

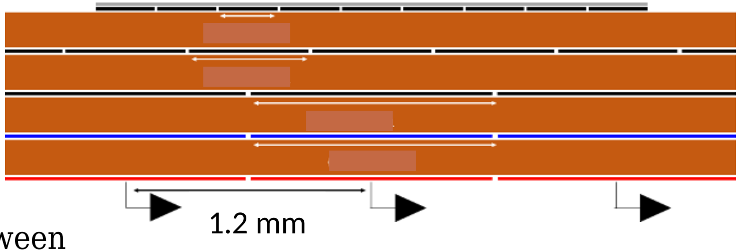
Strip R/O
Pitch 750μm
Width 300μm

No PEP in the active area
Kapton foil between DLC and strip R/O:
stacking 25+12+25μm (pre-preg/kapton/pre-preg)
ρ_S= 20 MΩ/□

2D – capacitive sharing

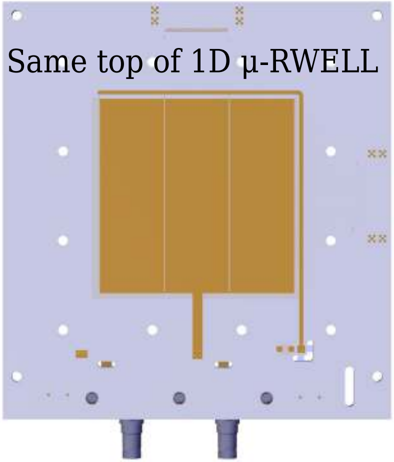
Inspired by another
μ-RWELL R&D:
K. Gnanvo et al., NIM A
1047 (2023) 167782

Trasversal view

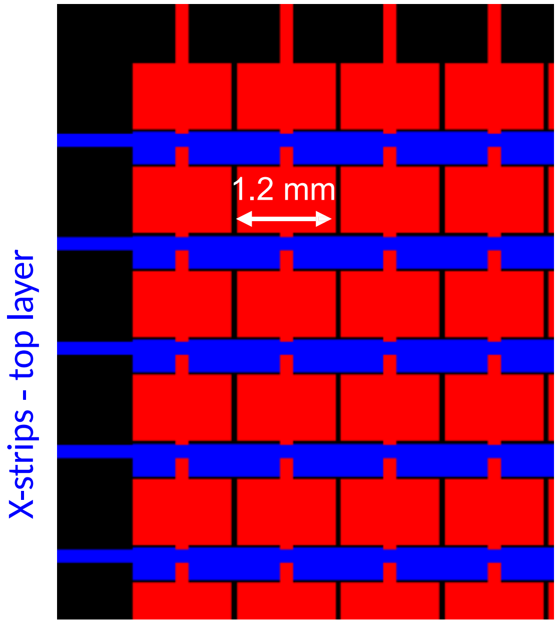


Capacitive coupling between
TOP and R/O:
3 layers of pads (L=0.3/0.6/1.2mm)

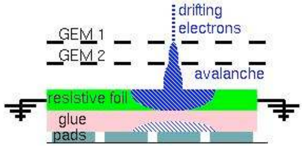
No PEP in the active area
ρ_S= 60 MΩ/□

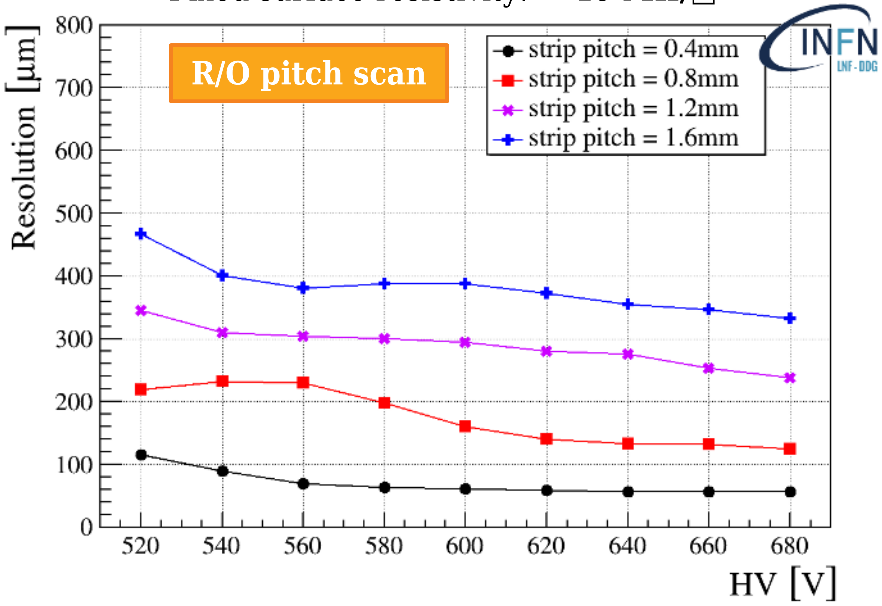


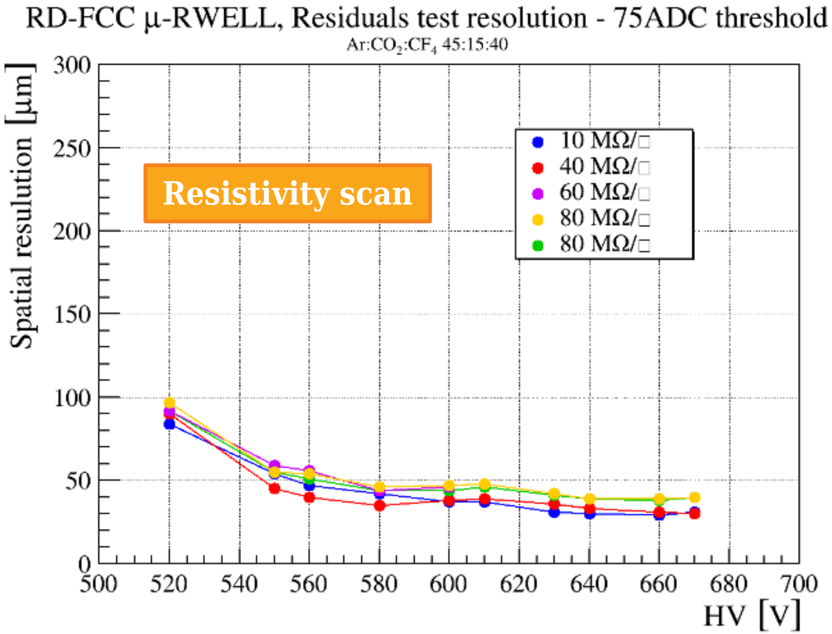
Y-strips - bottom layer



µ-RWELL: DLC charge spread







Fixed strip pitch (0.4 mm) and width (0.15 mm)

Need to **reduce** # FEE **channels**

=

Increase the R/O **pitch**

As expected: reduction of the space resolution.

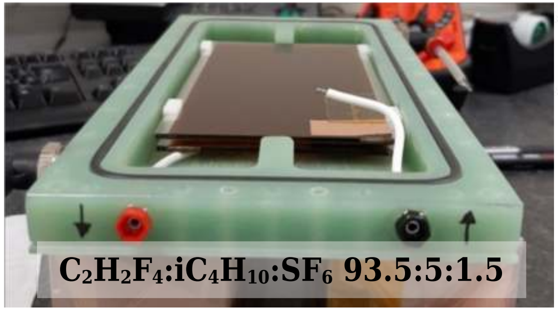
No effects in **this resistivity range**.
→ DLC resistivity uniformity is not a crucial parameter
Near future: charge dispersion through different R/O architecture → capacitive sharing R/O

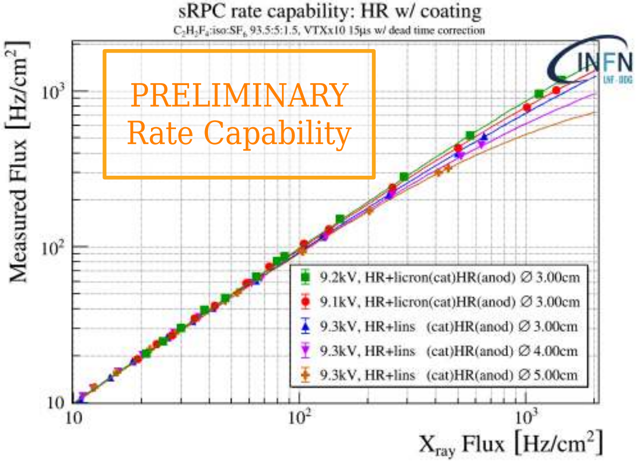
sRPC – an MPGD-tech based RPC

Glass 140×78 mm^2
DLC 120×64 mm^2

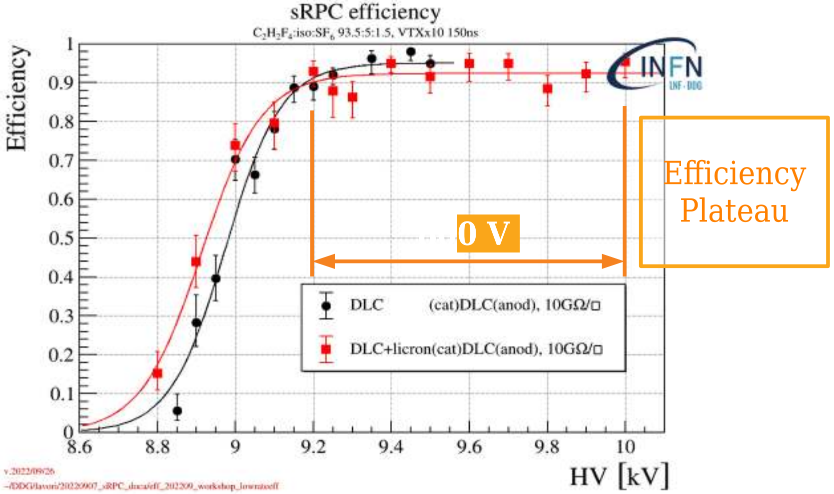
DLC-based RPC:

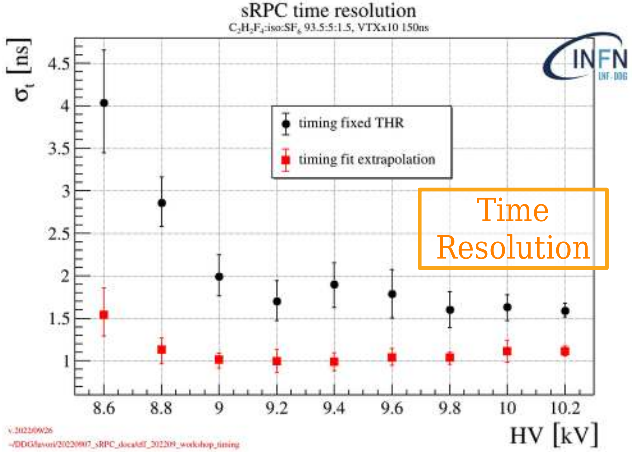
- **From bulk resistivity to surface resistivity**: easy tunable resistivity w.r.t. bakelite or glass
- µ-RWELL inspired **High Rate schemes**
- Flexible substrate



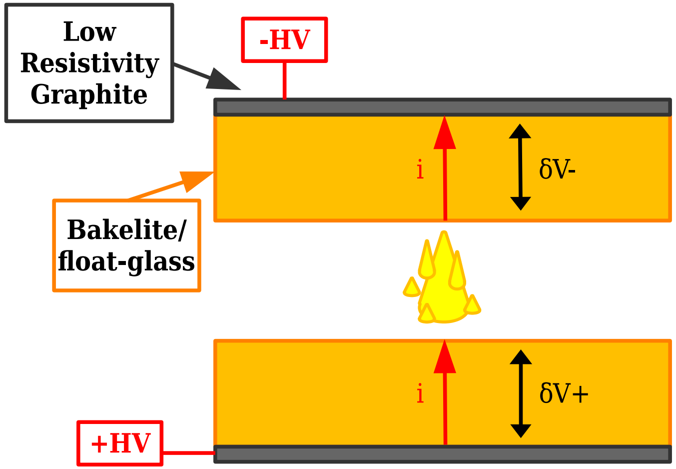


A promising novel technology, from MPGD material and technology experience.



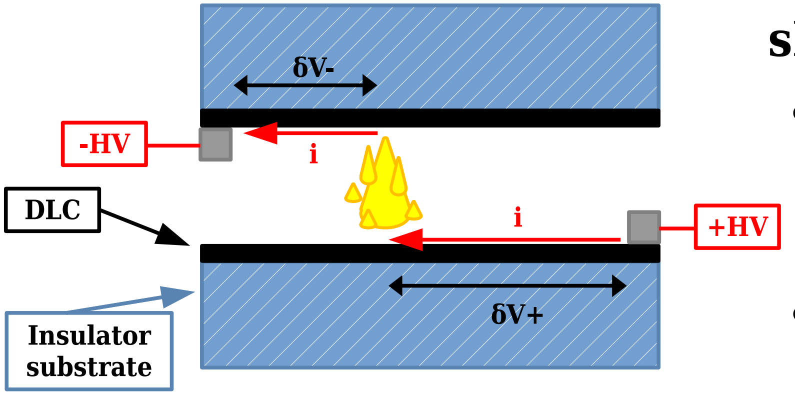


Bulk RPC vs Surface RPC



Classical RPCs

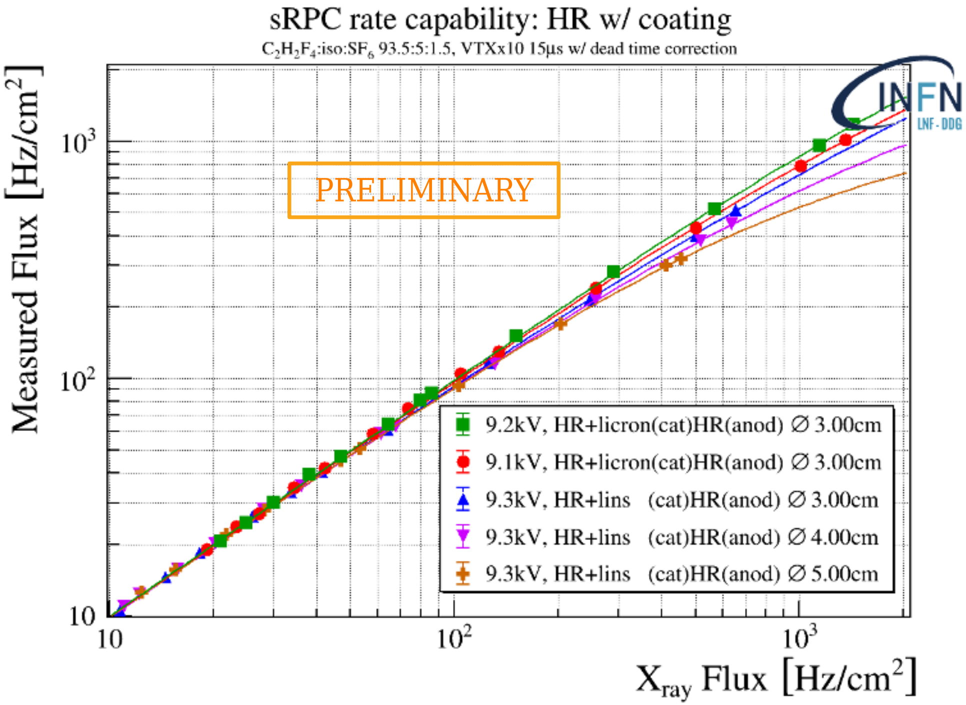
- Bulk resistivity electrodes (bakelite, float-glass, ...)
- Recovery time proportional to **volume resistivity, electrode thickness**
  - $\tau=\rho_V\varepsilon_0(\varepsilon_r+2d/g)$
  - Low volume resistivity and thin electrodes, together with the reduction of the gas gain (⊕high gain low noise pre-amp) is the standard recipe to increase the detector rate capability.



sRPCs - surface RPC

- Surface resistivity electrodes manufactured with sputtering techniques of Diamond-like-carbon (DLC) on flexible supports
  - The technology allows to realise large electrodes with a DLC **surface resistivity** in a **very wide range: 10 MΩ/□ ÷ 10 GΩ/□**
- High density current evacuation schemes, similar to those used for resistive MPGD (μ-RWELL and MicroMegas), can be implemented to improve the rate capability of the detector

High Rate layout – preliminary results



A **preliminary** measurement of the **rate capability** (defined as the radiation flux corresponding to an efficiency drop of 20%) of the high-rate layout has been **performed** by irradiating the detector **with a 5.9 keV X-ray gun** with a spot size comparable with the pitch of the conductive grid realized on the DLC (ρ_{DLC}≈1.6 GΩ/□).

Rate capability of ~1 kHz/cm² with X-ray