Update on Technology Transfer

of high rate µ-RWELL

Matteo Giovannetti [LNF-INFN]

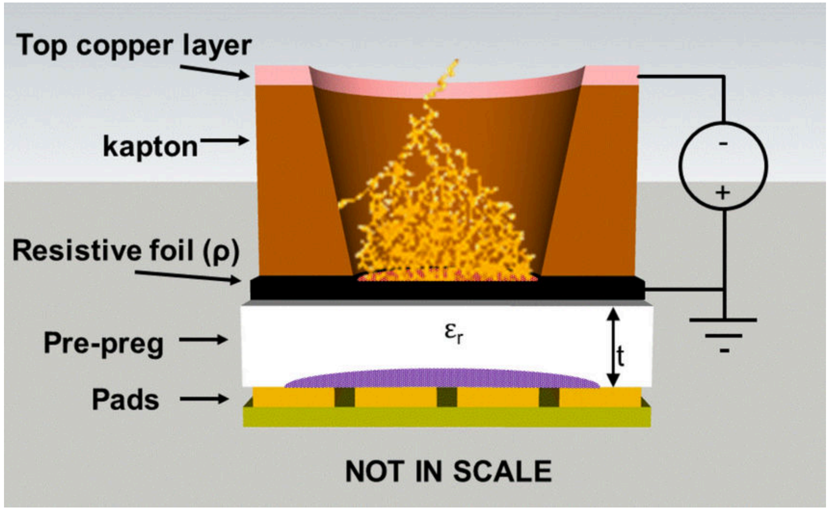
on behalf of
LNF-INFN (leading group)
Bologna-Ferrara INFN teams
R. De Oliveira – CERN-EP-DT-MPT Workshop
R. Pinamonti, M. Pinamonti – ELTOS S.p.A.

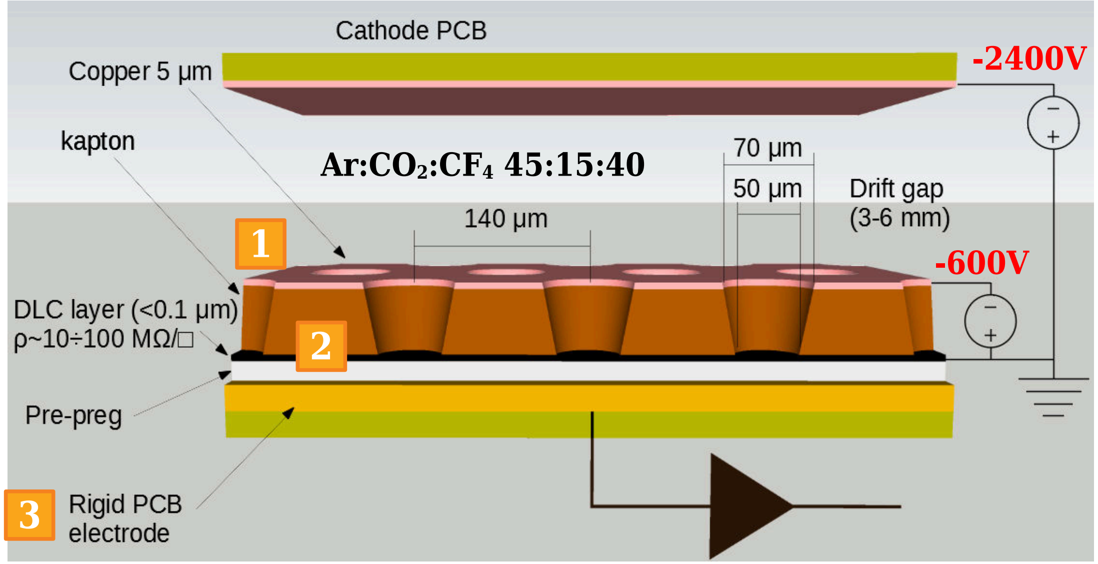
RD51 - WG6, CERN, Dec. 6th 2023

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)

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:





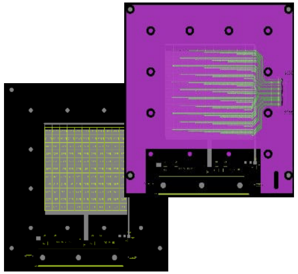
Applying a suitable voltage between the **top Cu-layer and the DLC** the WELL acts as a **multiplication channel for the ionization** produced in the conversion/drift gas gap.

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

µ-RWELL Technology Transfer [flow chart]

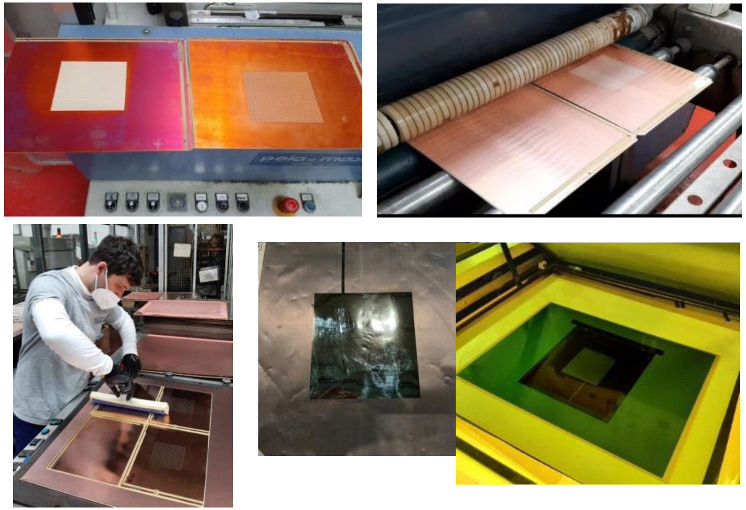
Feedback from tests

LAYOUT design

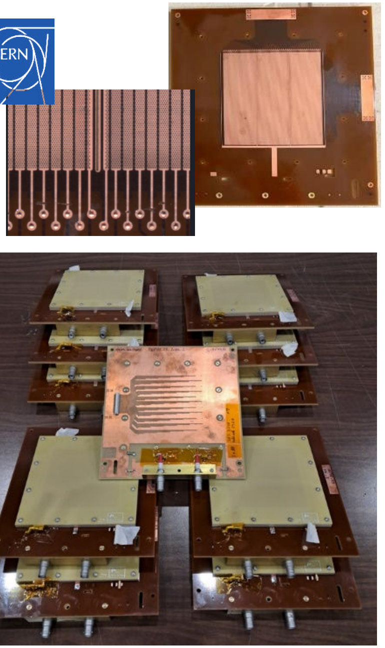


DLC foil production[*]

PCB production



Final detector manufacturing



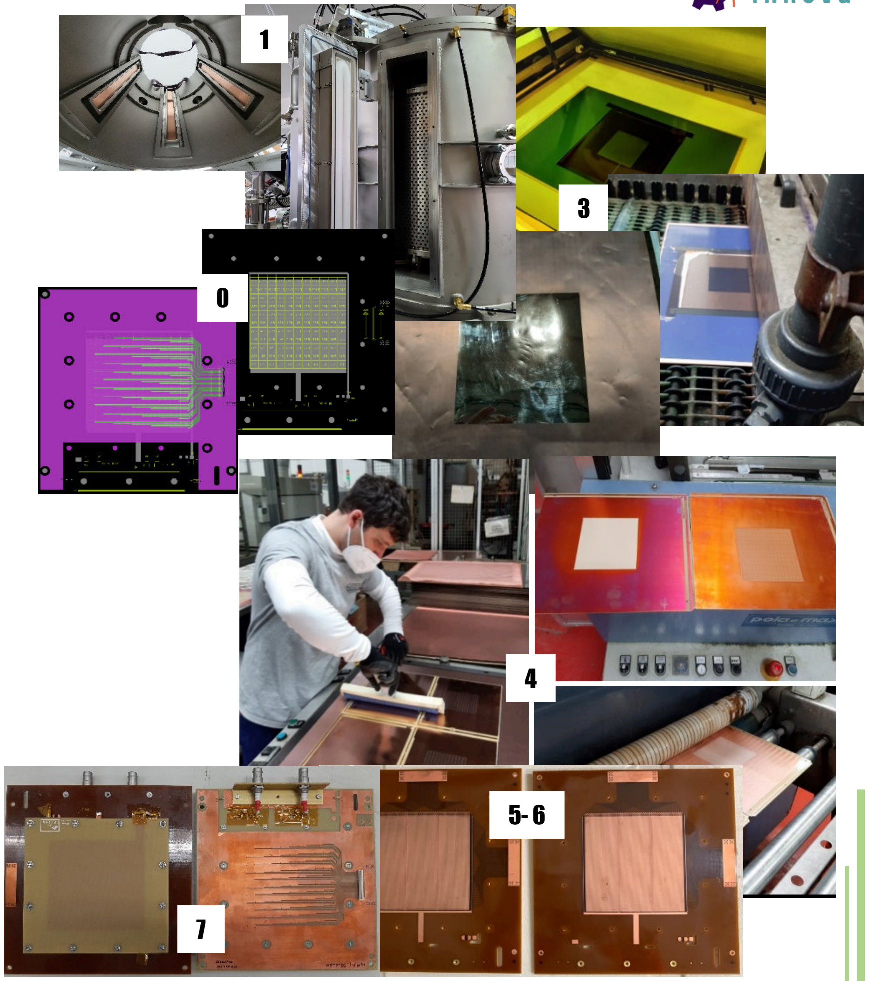
[*] DLC Magnetron Sputtering machine co-funded by INFN- CSN1

µ-RWELL 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
- Production by LNF-INFN crew



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- pad/strip readout

Step 3 – **DLC patterning** by ELTOS
- photo-resist → patterning with BRUSHING-machine

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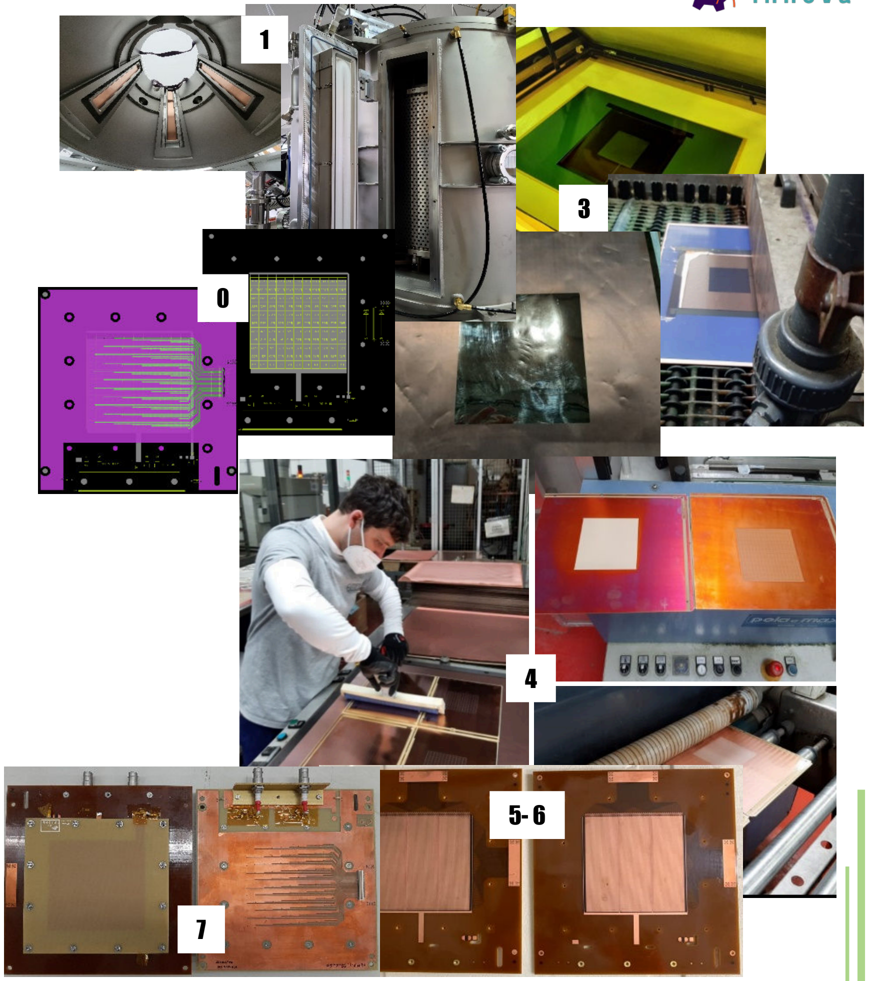
- Large press available, up to 16 PCBs workable at the same time



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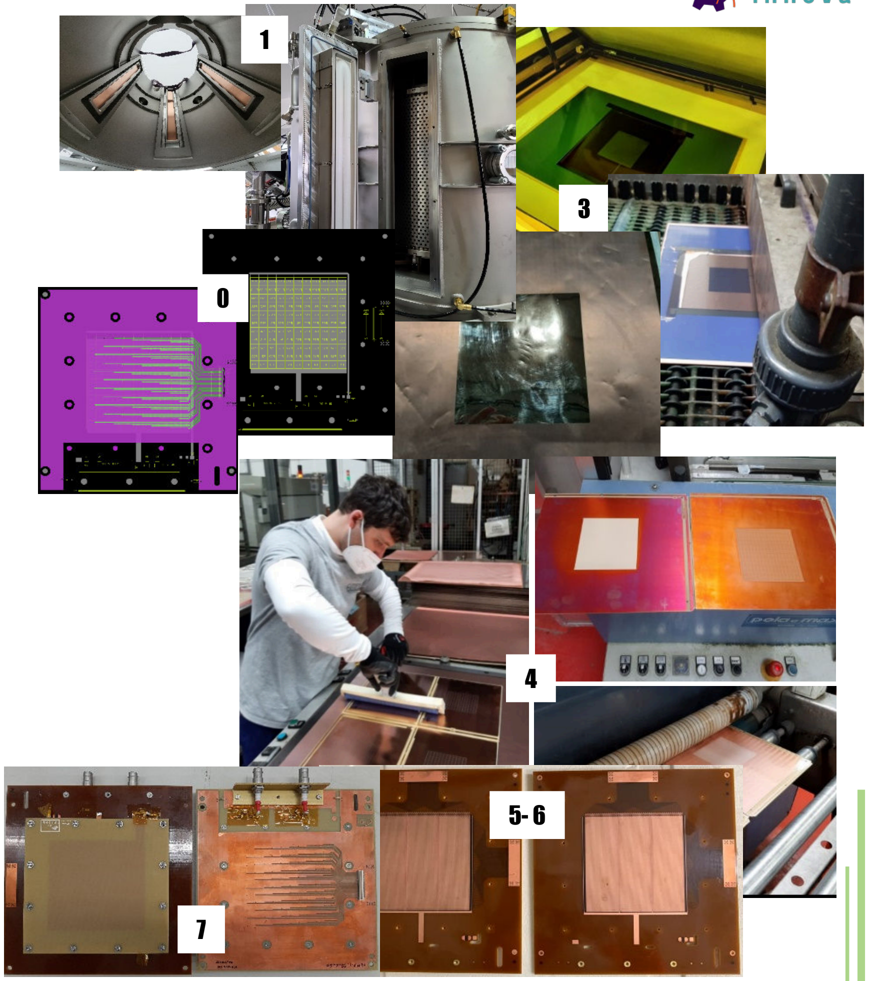
Step 5 – **Ground network connections** creation by CERN
- **PEP** layout: Cu **P**atterning → PI **E**tching → Cu **P**lating

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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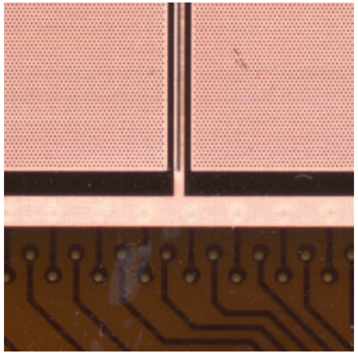
High-rate layout optimisation

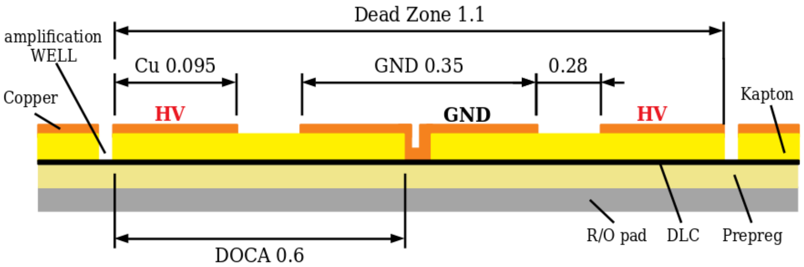
The GOAL: **minimizing** the average **path towards the ground** connection by introducing a **high-density grounding network** on the DLC layer. In **PEP** (Patterning-Etching-Plating) layouts the top Cu layer is connected to the DLC, plating through the APICAL foil.

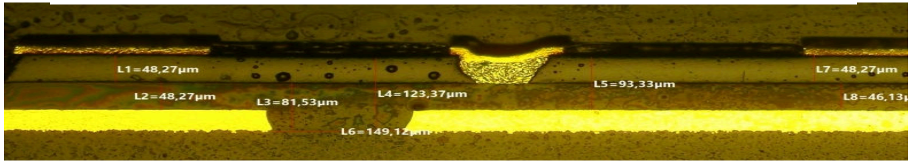
2022 – PEP-groove

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



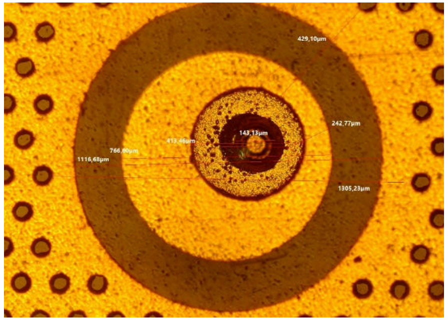
→ **84% geometric** acceptance



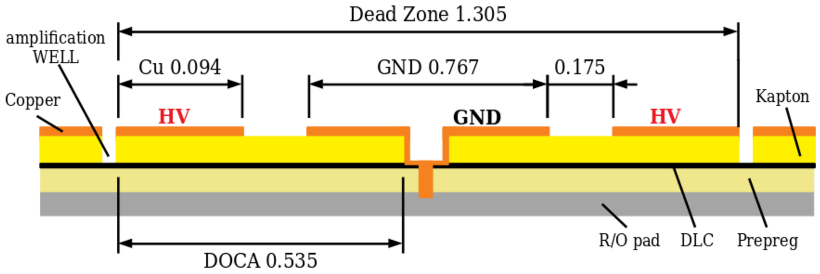


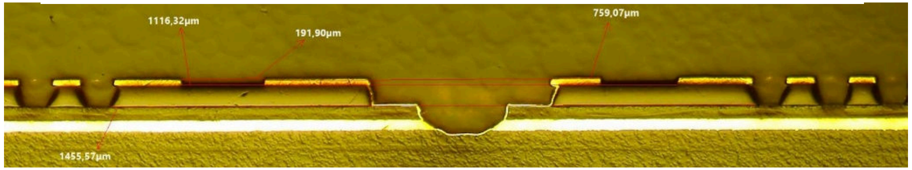
2023 – PEP-dot

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



→ **97% geometric** acceptance





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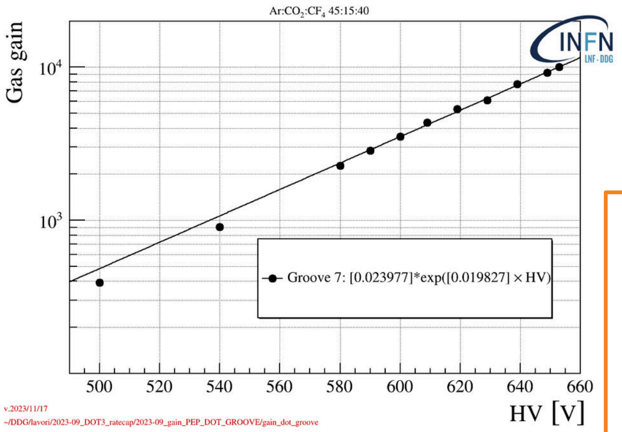
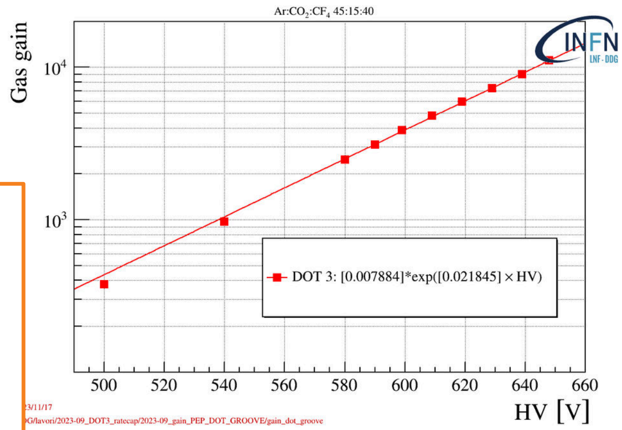
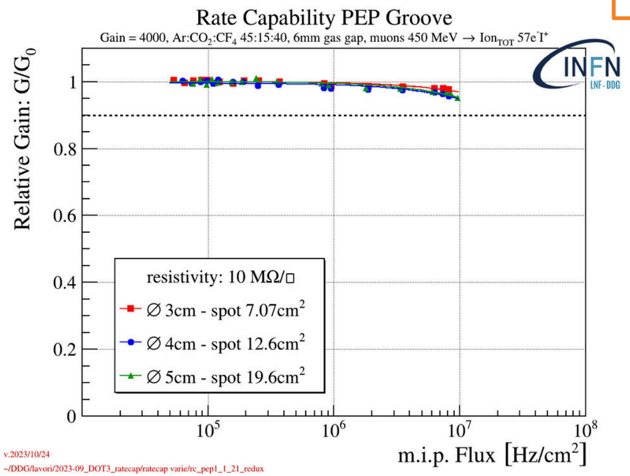


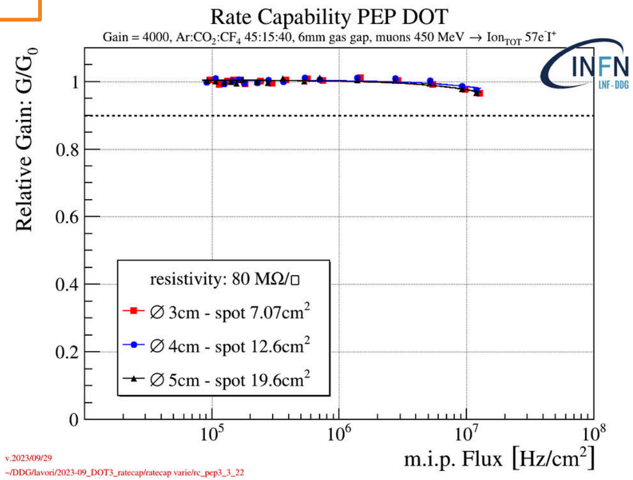
2023 PEP-dot



Both layouts exhibit **satisfactory performance:**

- **gas gain** of up to **10^4**
- **rate capability** (@ 90% drop) **> 10 MHz/cm^2**

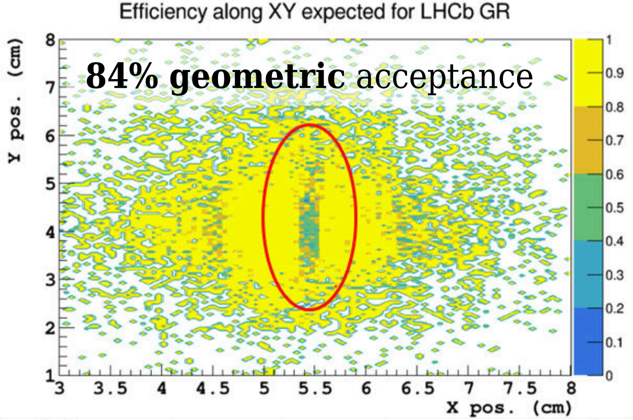


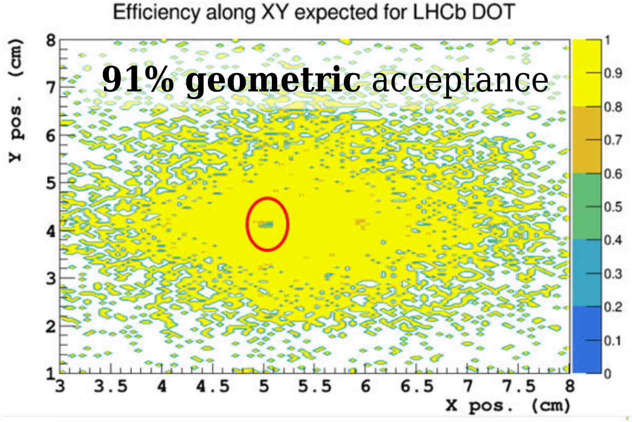


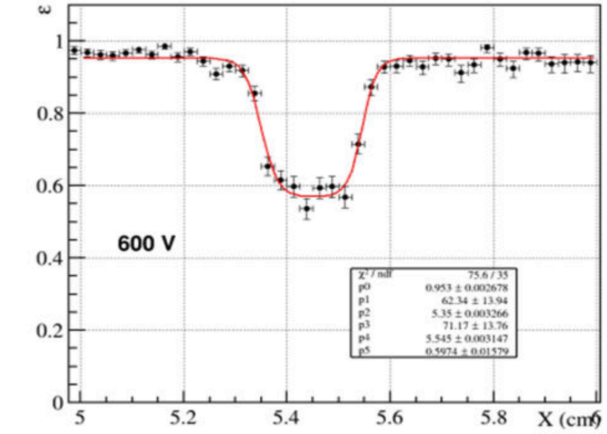
BT'23 [APV25]: Groove-DOT layouts comparison

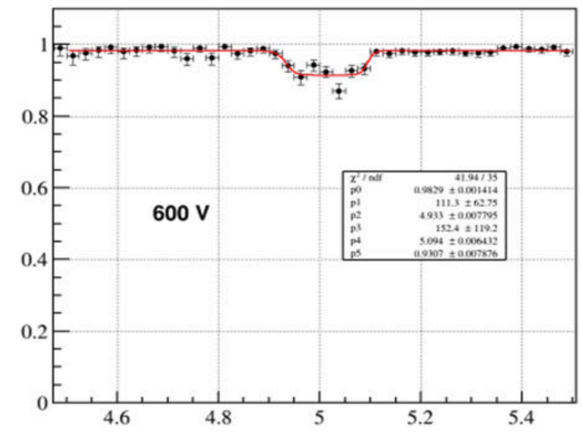
2022 PEP-groove

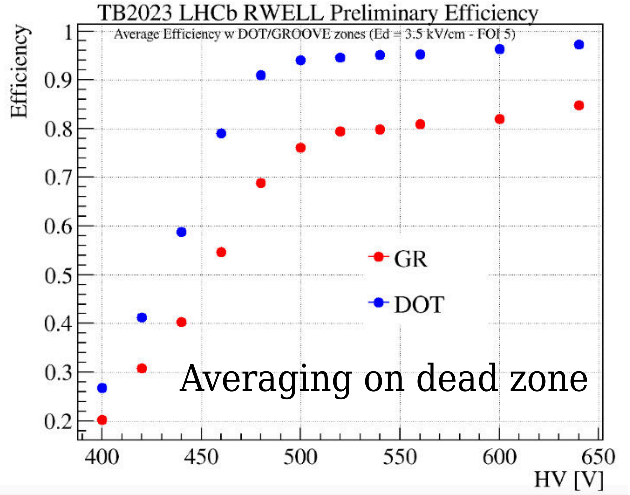
2023 PEP-dot

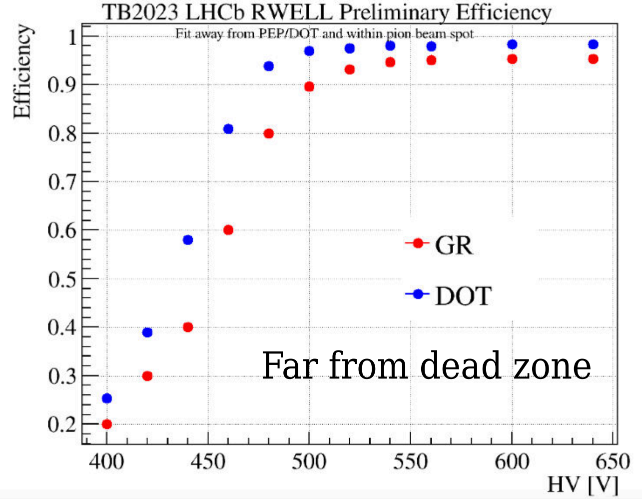












The CERN-INFN DLC machine

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)

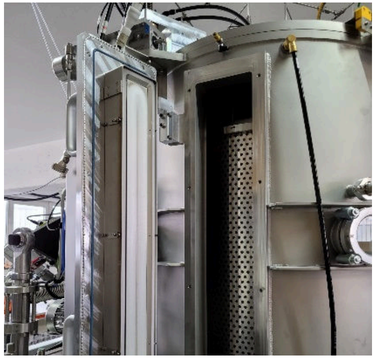
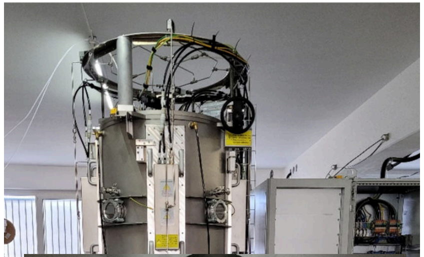
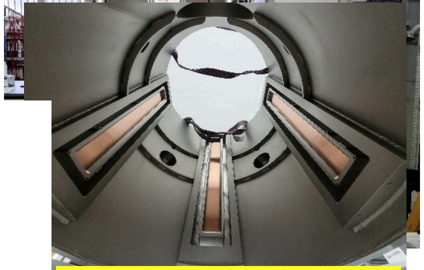
25th - 29th Sep. 2023 – 3rd DLC sputtering test
- Ar + C_2H_2 doping

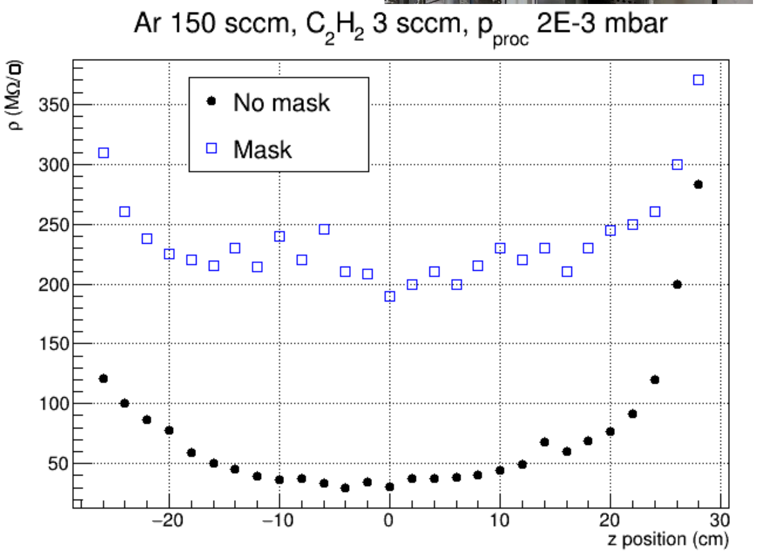
6th - 10th Nov. 2023 – 4th DLC sputtering test
- Ar + C_2H_2 doping (uniformity test)

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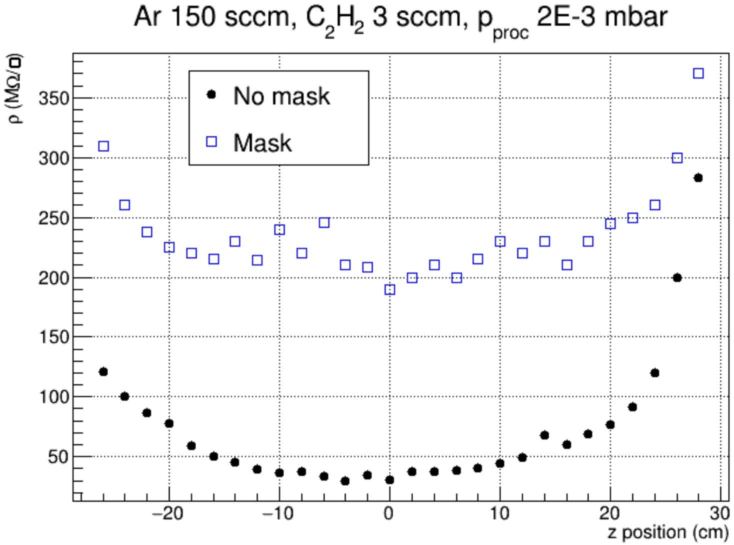
2023 → Stable and uniform DLC resistivity w/ Ar+C_2H_2



2024 → Sputtering large foils!!

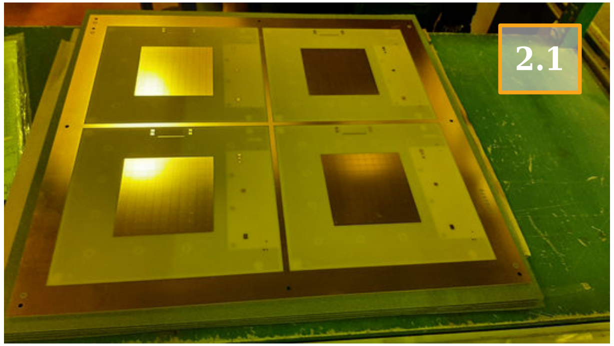
WP7.3.2: Mar.'23 ELTOS production – DLC patterning

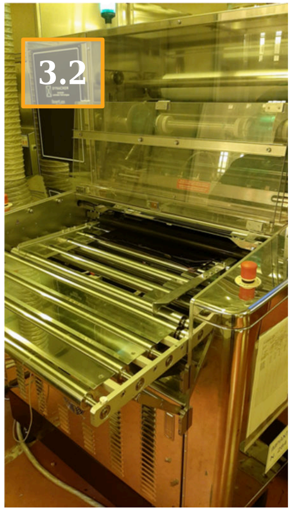
Step 2:

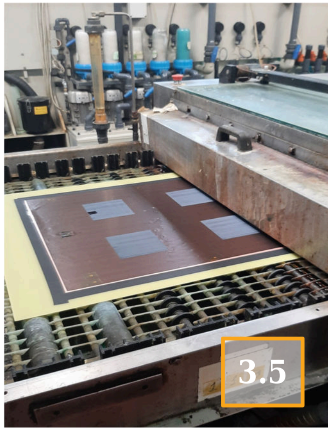
1) R/O **PCB** production

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)





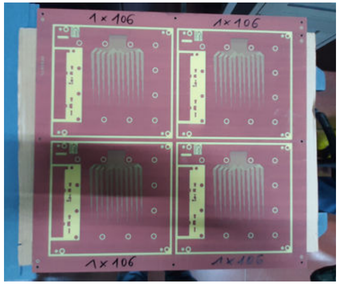


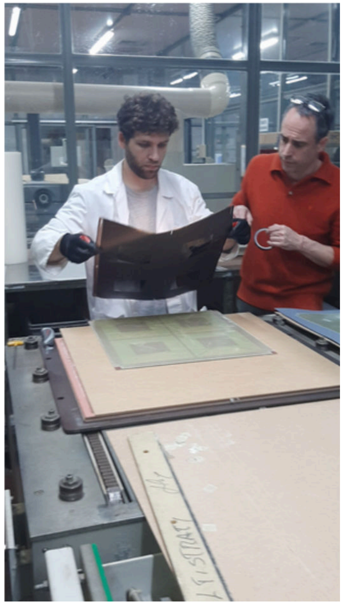
WP7.3.2: Mar.’23 ELTOS production – DLC-foil gluing

Step 4: Cu-Kapton-DLC gluing on PCB

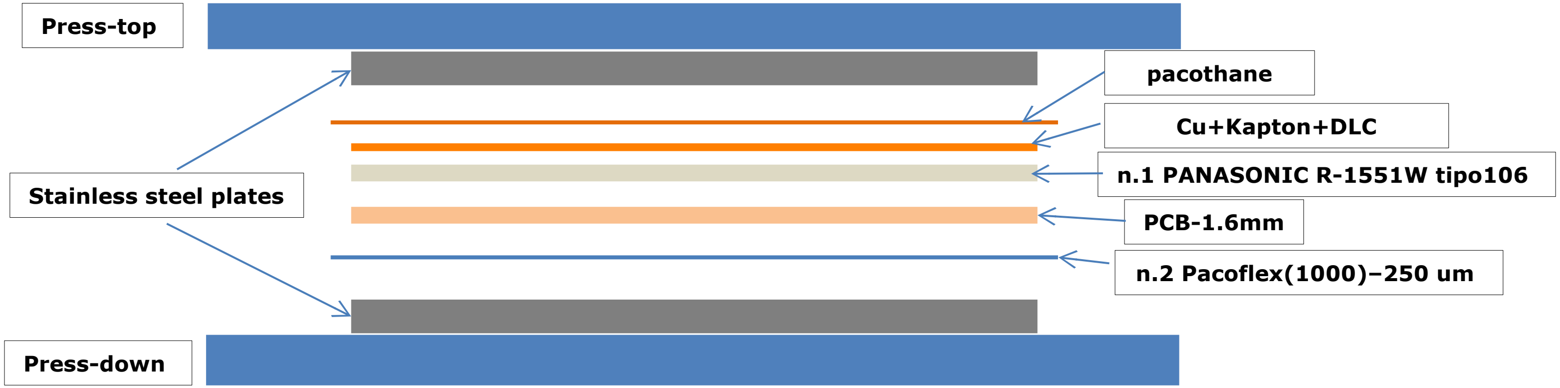
- 16 PEP-dot detectors (9×9mm^2 pad R/O), with **different pre-preg thickness**
- **11/16** detector **delivered/tested** up to now
- Study of signal **pulse amplitude vs coupling capacitance** between DLC and R/O pad.

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

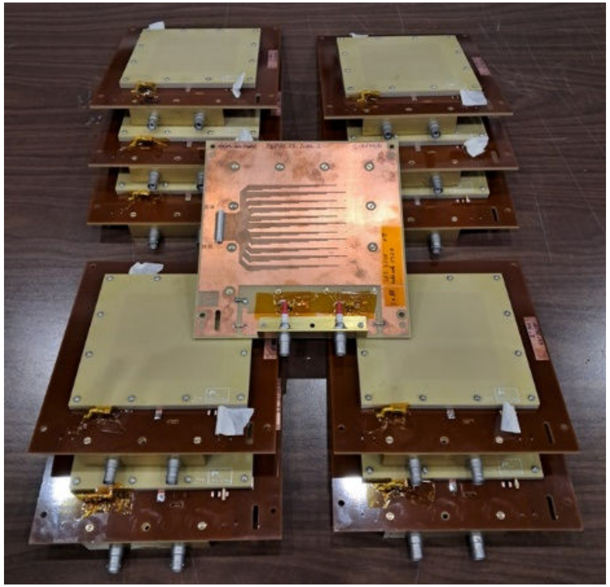


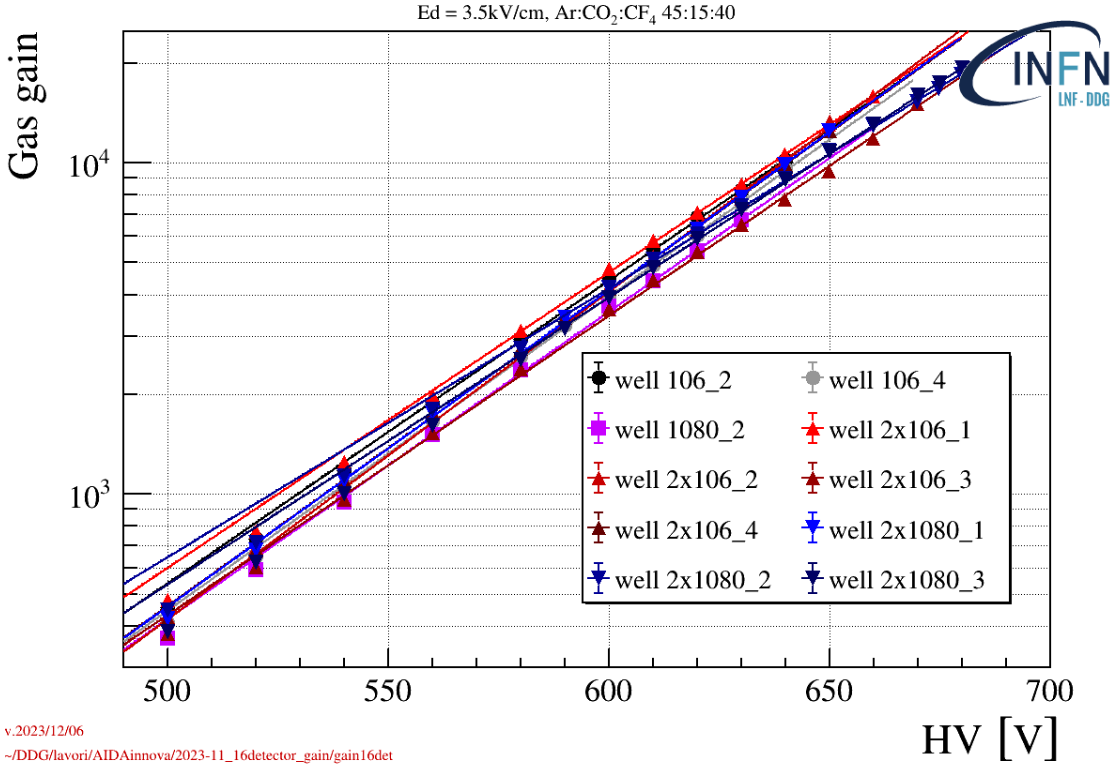


Main parameters:
Pressure 180 N/cm^2
Temperature 210 °C



Co-production pilot test – results



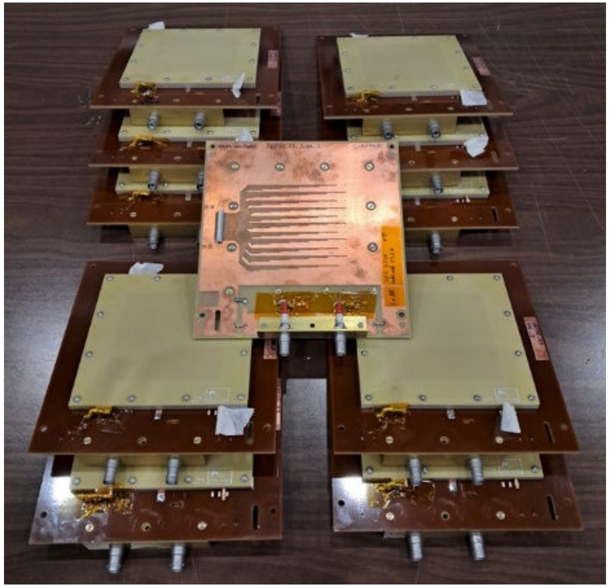


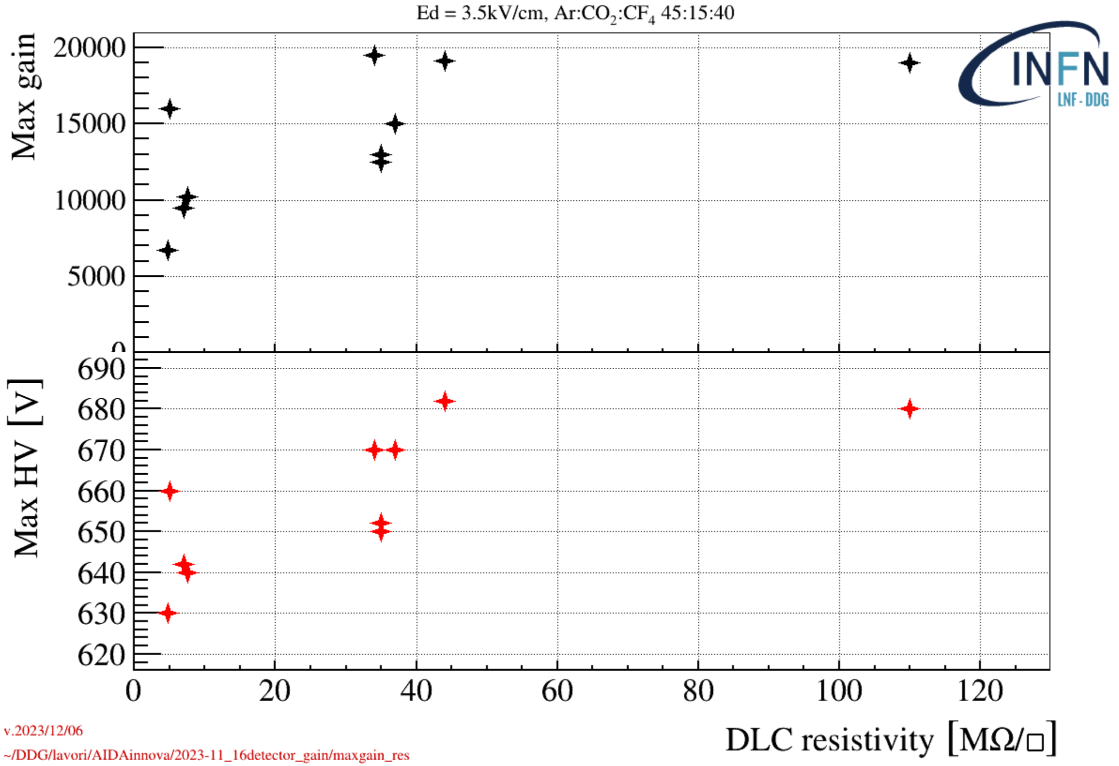
- **11/16** co-produced protos have been **delivered** and **tested**
- **10 are fine → 90% yield**
- 1 should be re-cleaned

Waiting for the delivery of last 5 protos

- Characterized with **X-ray gun → Gas gain** measurement
- **Next** step: measure of the **pulse amplitude** (APV25) vs Gas gain

Co-production pilot test – results





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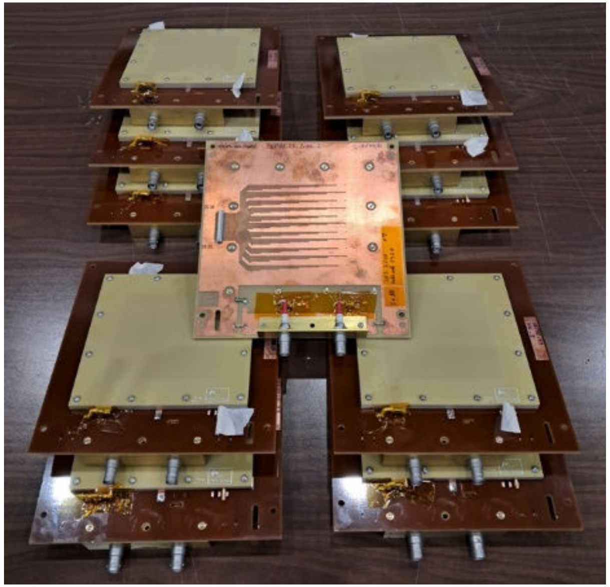

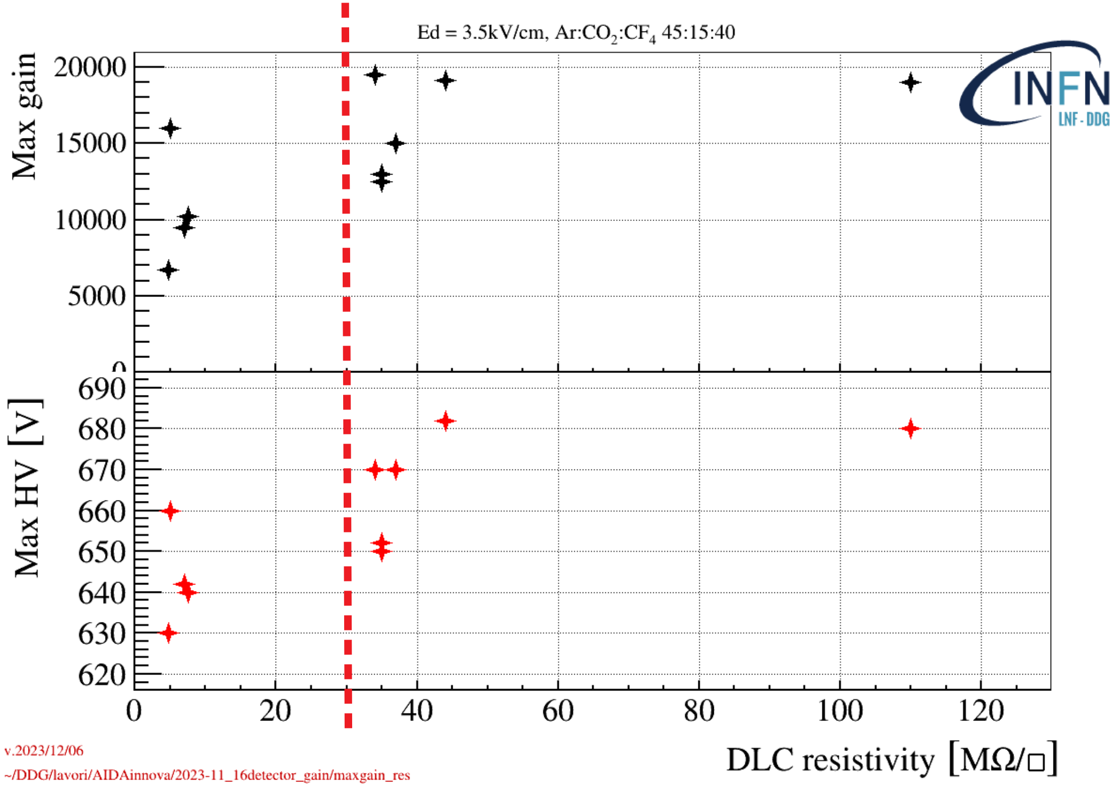

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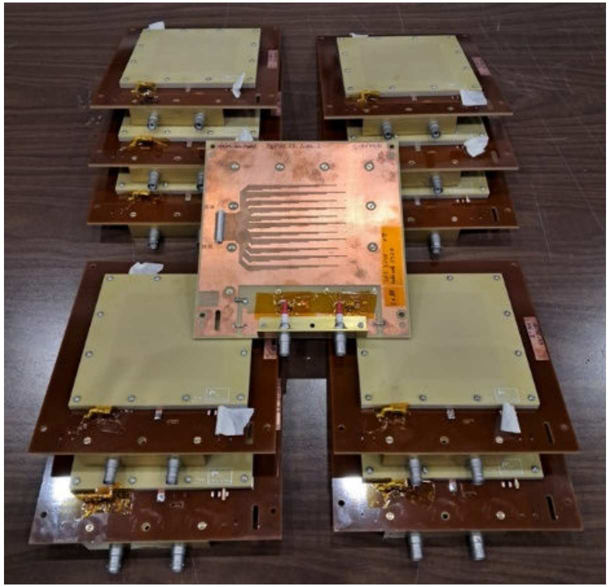

Detector #	Prepreg type	DLC resistivity	Production status	Max HV/Gain	comments
106_1	1x 106		Cleaning		@ CERN
106_2	1x 106	7.5	Delivered	640/10000	
106_3	1x 106		Cleaning		@ CERN
106_4	1x 106	7	Delivered	640/9500	
1080_1	1x1080		Cleaning		@ CERN
1080_2	1x1080	4.8	Delivered	630/6700	
1080_3	1x1080	5	Delivered	n.a.	To be re-cleaned
1080_4	1x1080		Cleaning		@ 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		Cleaning		@ CERN

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Status and plans – '23

2023

- **Optimization** of high-rate µ-RWELL layout – **10x10cm²** active area, 9x9mm² pad, **DOT DLC connection**
- **Beam test** (NA – H8C, June, 2023) – Groove – DOT comparison (developed and tested in 2022) w/ APV25
- Tests of **co-production ELTOS/CERN** and **DLC sputtering machine** @ CERN (tests will continue also in 2024)

Status and plans – '23, '24

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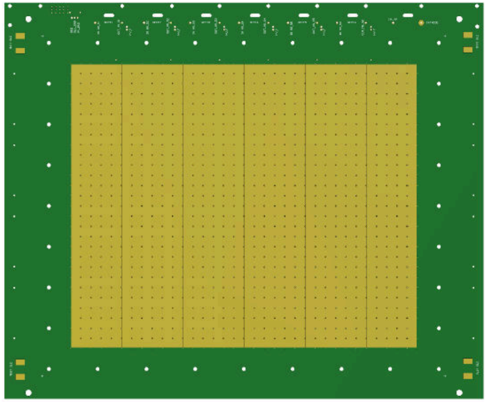
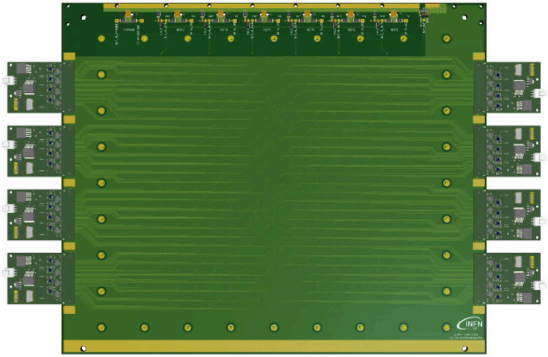
2024

- **Irradiation test** with X-ray @ LNF of the 100x100mm² DOT-layout prototypes
- **GIF++** irradiation test with µ-beam in collaboration with **CERN gas group**
- **Integration of electronics based on the FATIC3 chip**
  (n.100 chip 32chs with multi-project run Jan. 2024).

M2R1 proto-0 (active area 250x300 mm²)

- Designed & discussed w/Rui (Oct./Nov. 2023)
- Delivery (March 2024)
- Characterization w/X-rays (April/May 2024)
- Cosmic rays stand w/APV25 (June – Sept 2024)
- Test beam H8C w/FATIC3 (Oct.2024)





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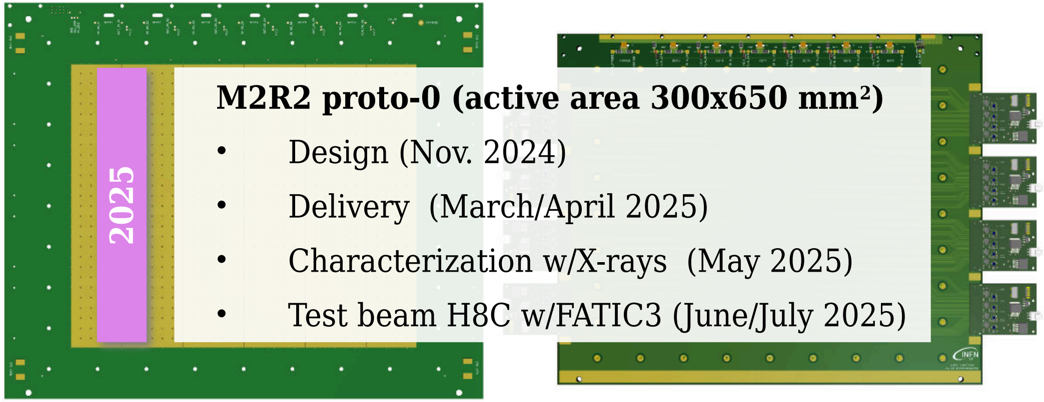
- Tests of **co-production ELTOS/CERN** and **DLC sputtering machine** @ CERN (tests will continue also in 2024)

2024

- **Irradiation test** with X-ray @ LNF of the 100x100mm² DOT-layout prototypes
- **GIF++** irradiation test with µ-beam in collaboration with **CERN gas group**
- **Integration of electronics based on the FATIC3 chip**
  (n.100 chip 32chs with multi-project run Jan. 2024).

M2R1 proto-0 (active area 250x300 mm²)

- Designed & discussed w/Rui (Oct./Nov. 2023)
- Delivery (March 2024)
- Characterization w/X-rays (April/May 2024)
- Cosmic rays stand w/APV25 (June – Sept 2024)
- Test beam H8C w/FATIC3 (Oct.2024)

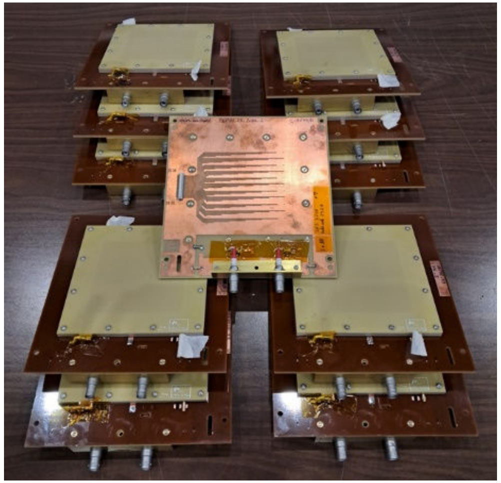


2025

M2R2 proto-0 (active area 300x650 mm²)

- Design (Nov. 2024)
- Delivery (March/April 2025)
- Characterization w/X-rays (May 2025)
- Test beam H8C w/FATIC3 (June/July 2025)

Summary



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- **Several construction steps** performed by ELTOS
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The **R&D with CERN** on **high-rate layouts** will be **finalized within 2024**:

- **Design/optimization** of the high-rate layout → **PEP-Dot**, 97% geom. acceptance **(DONE)**
- **Optimizing main detector parameters:**
  - **$\rho_S \geq$ 30-40 MΩ/□ → maximizing the gas gain (almost DONE)**
  - **Optimization of prepreg thickness**
→ **maximizing collected signal** (within 2023)
  - **Optimization of the amplification stage geometry**
→ maximizing the gas gain (**2024**)
- **Large size high-rate layout** (M2R1 …) construction/test **(April – Oct. 2024)**

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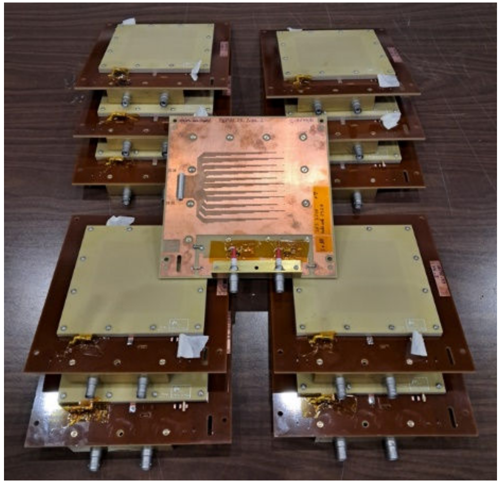

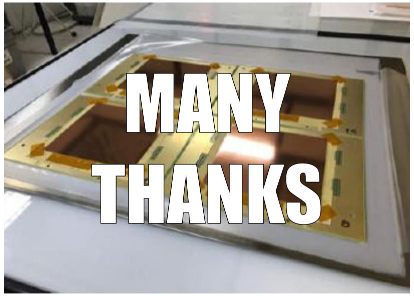

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Spare

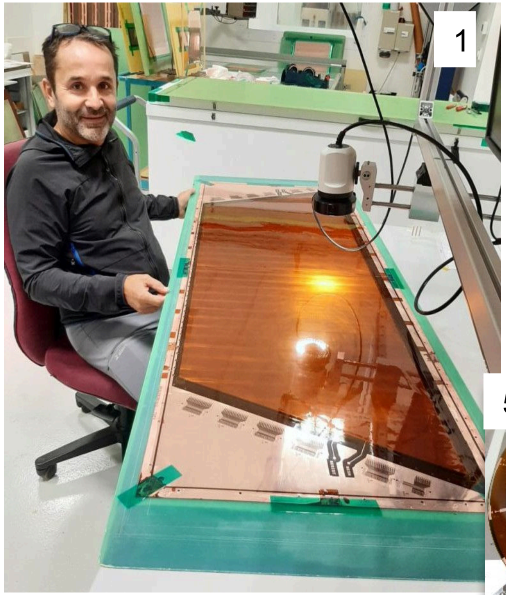
G. Bencivenni et al., *The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD*, 2015 *JINST* **10** P02008
G. Bencivenni et al., *The μ-RWEL detector*, 2017 *JINST* **12** C06027
G. Bencivenni et al., *Performance of μ-RWELL detector vs resistivity of the resistive stage*, *Nucl. Instrum. Meth.* **A 886** (2018) 36.
G. Bencivenni et al., *The μ-RWELL layouts for high particle rate*, 2019 *JINST* **14** P05014
G. Bencivenni et al., *On the space resolution of the μ-RWELL*, 2020 *JINST* **16** P08036
A. Ochi et al., *Carbon sputtering Technology for MPDG detectors*, PoS(TIPP2014)351 (2014).

µ-RWELL technology spread

The µ-RWELLs are 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



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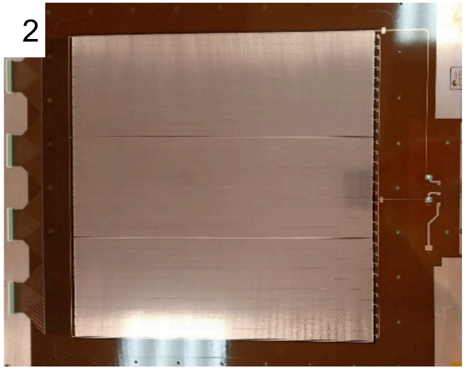

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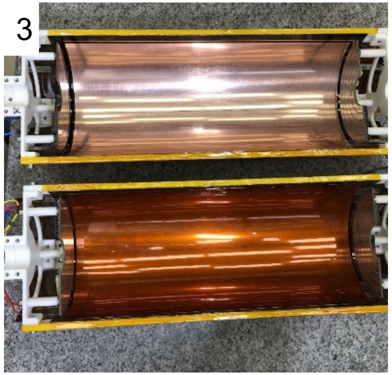

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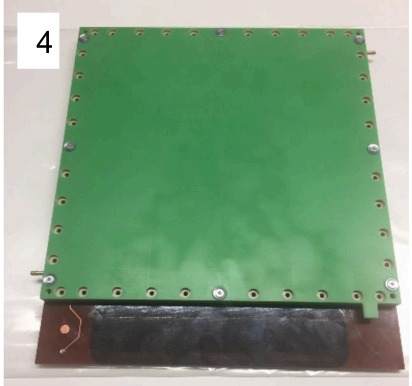

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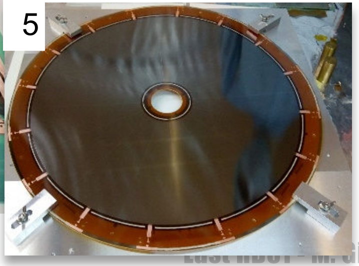

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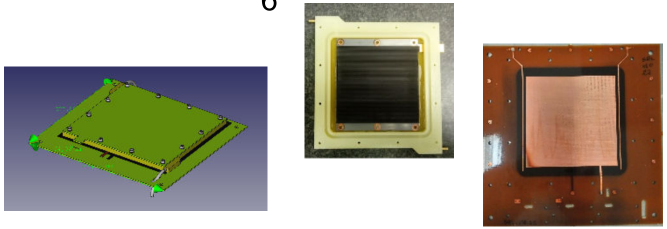

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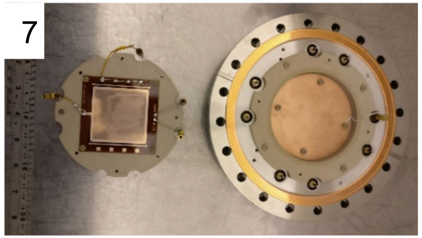
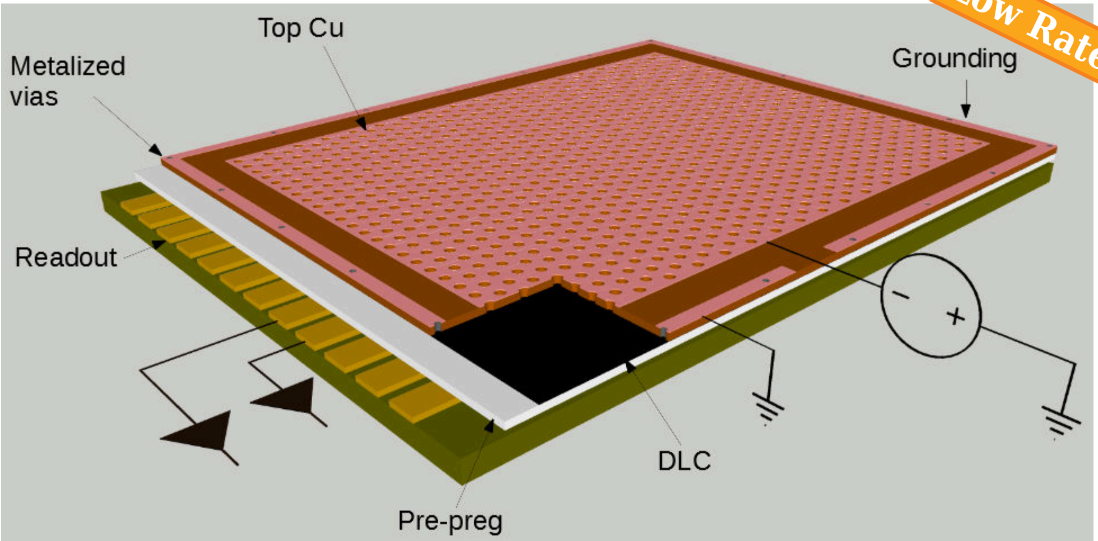


The High Rate layouts

To overcome **the intrinsic limitation** of the Single Resistive layout with edge grounding the solution is to reduce as much as possible the paths towards the ground connection introducing a **high density "grounding network"** on the resistive stage of the detector.

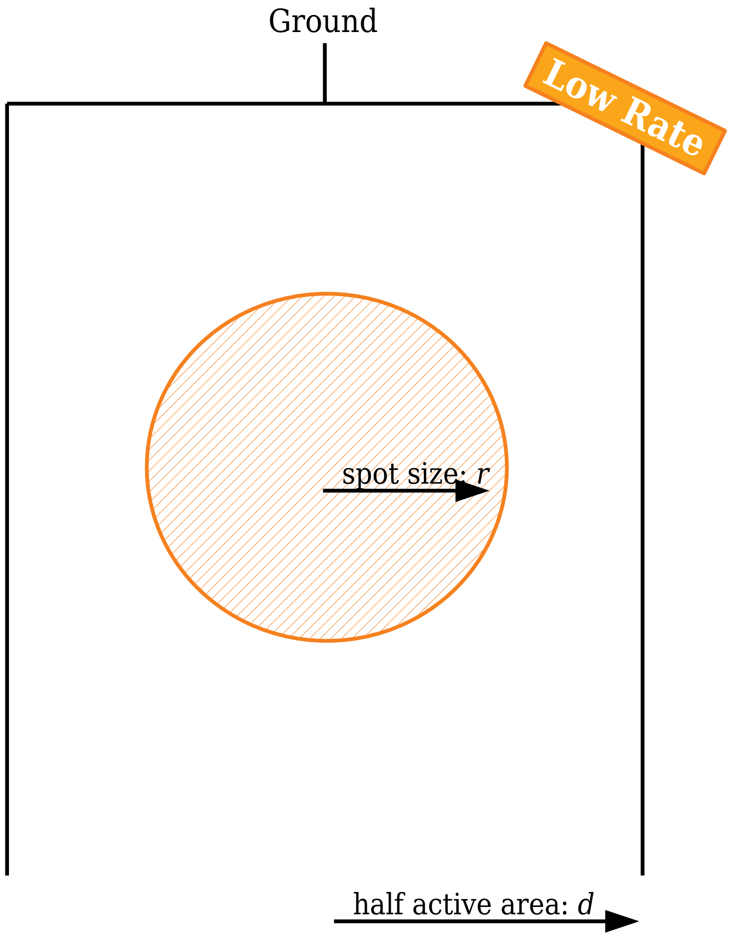
Single Resistive Layout (SRL)

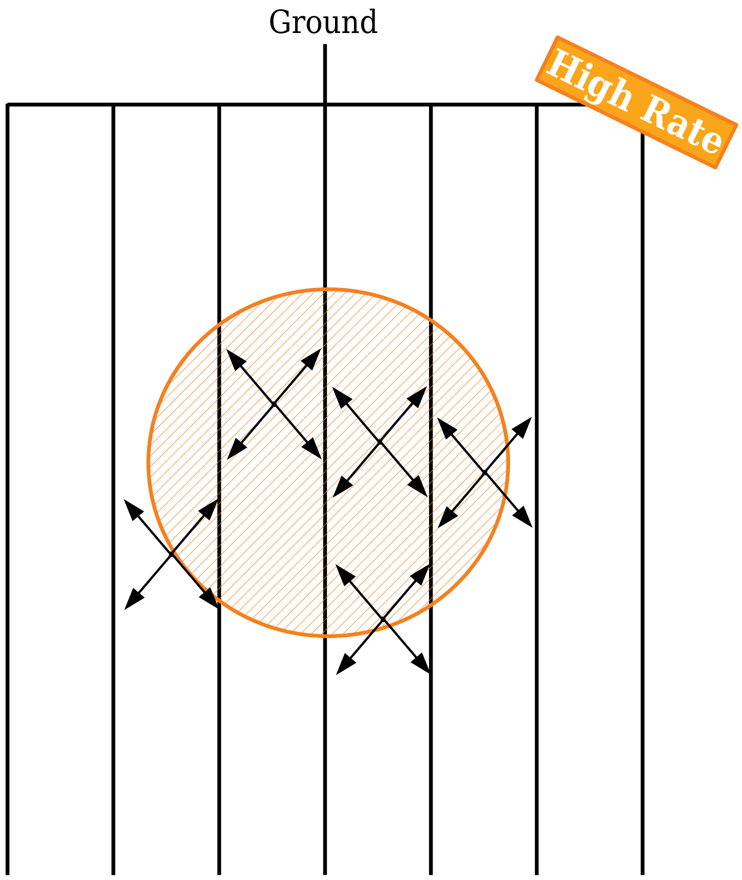
Low Rate



Different layouts with a **"dense grounding network scheme"** have been designed and implemented.

The High Rate layouts

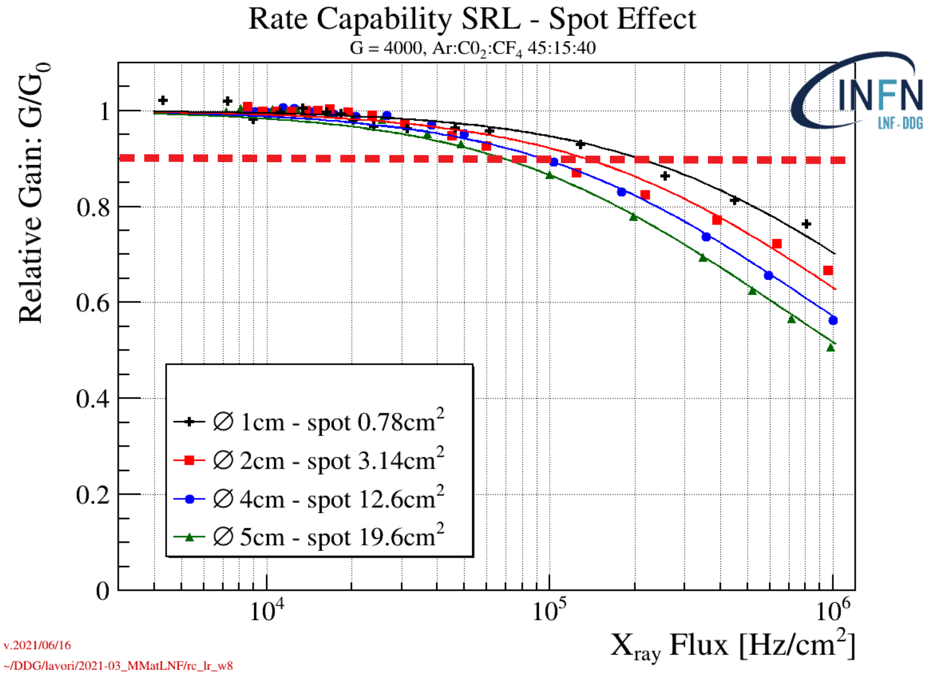




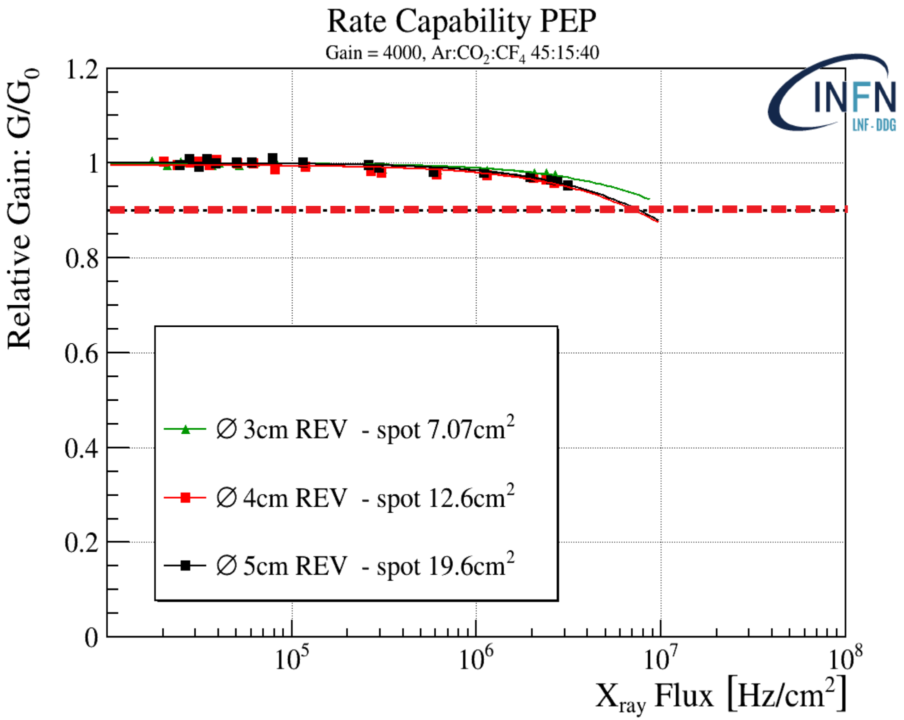
A sort of tiling with smaller low rate schemes.

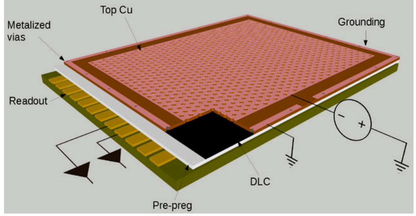
Rate capability – X-Ray measurements

Low Rate



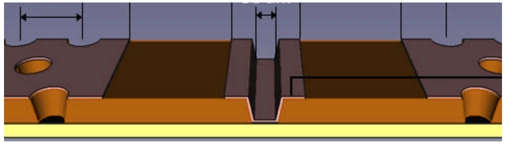
High Rate





Rate capability compatible with m.i.p. as measured @PSI O(10MHz).

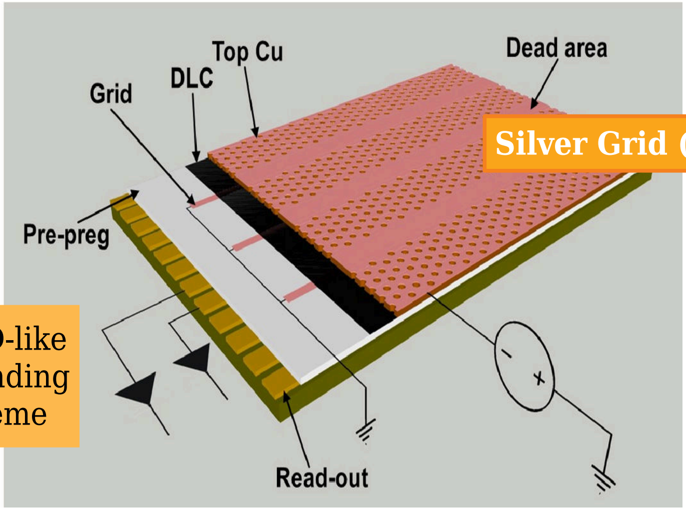
Different primary ionization ⇒ Rate Cap $_{\text{m.i.p.}}$ = 3×Rate Cap $_{\text{X-ray}}$



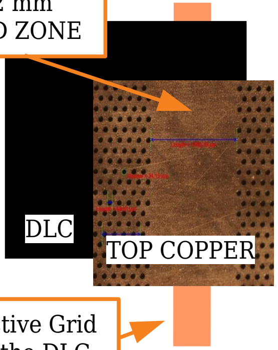
The High Rate layouts

2017

Silver Grid (SG)



GRID-like Grounding scheme



A **conductive grid** is patterned on the back of special DLC foils **(DLC + Cu technology: delicate manufacturing process)**.

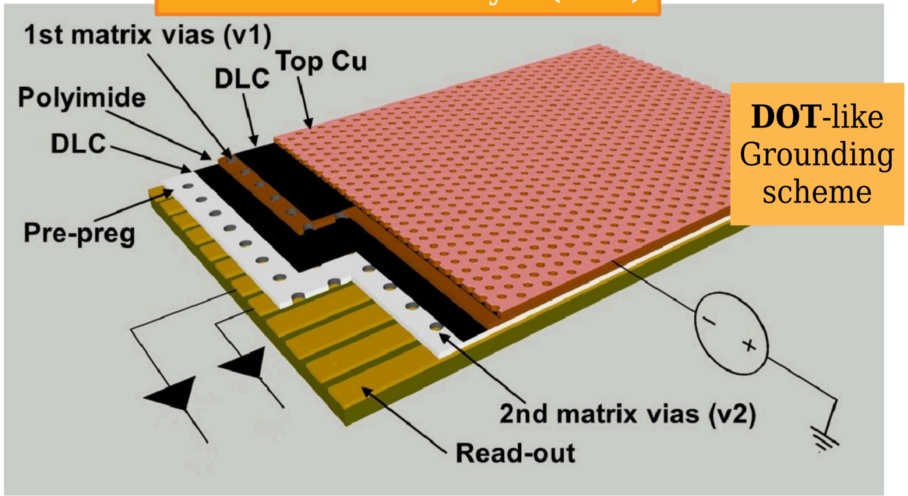
Necessity to introduce a **small DEAD AREA** above the grid, to avoid discharges (tuned to be 5% of the total area).

NOT SCALABLE to large size: distortions and alignment problems **during manufacturing.**

IS POSSIBLE to **check the resistance** of the layer after the detector is built

2018

Double Resistive Layer (DRL)

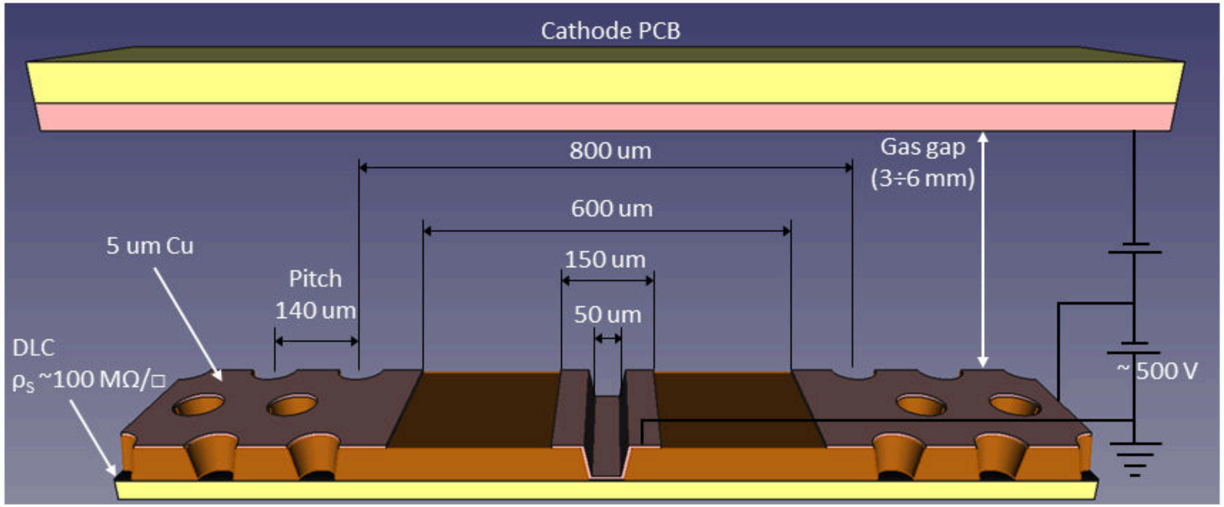


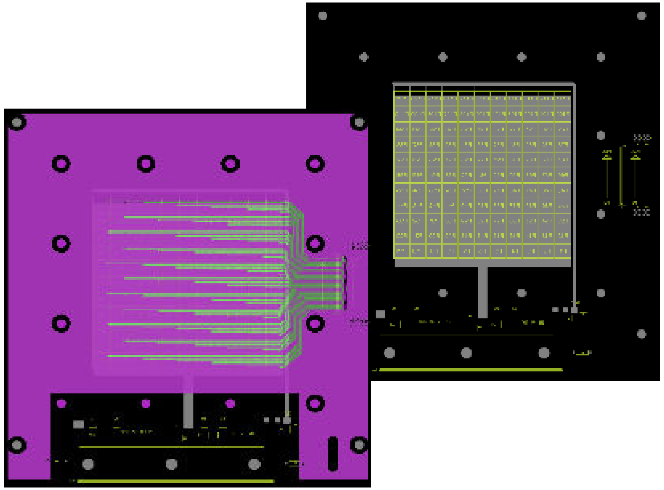
DOT-like Grounding scheme

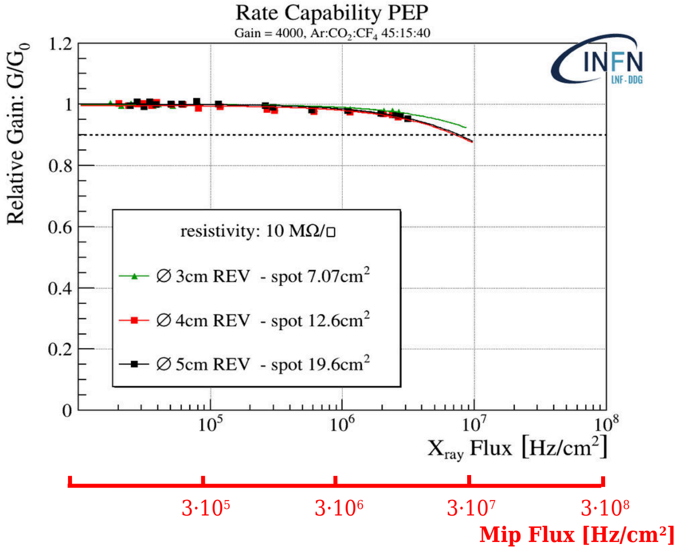
Based on a **3-D** current evacuation scheme:
Two stacked resistive layer connected through a **matrix of conductive vias,** grounded through a further matrix of vias to the underlying readout electrodes.

MORE COMPLEX to buid **than SG** but reliable (for now only 10x10 prototypes).
NOT POSSIBLE to check the resistance of the two layers after the manifacture.

The HR layout – PEP Groove



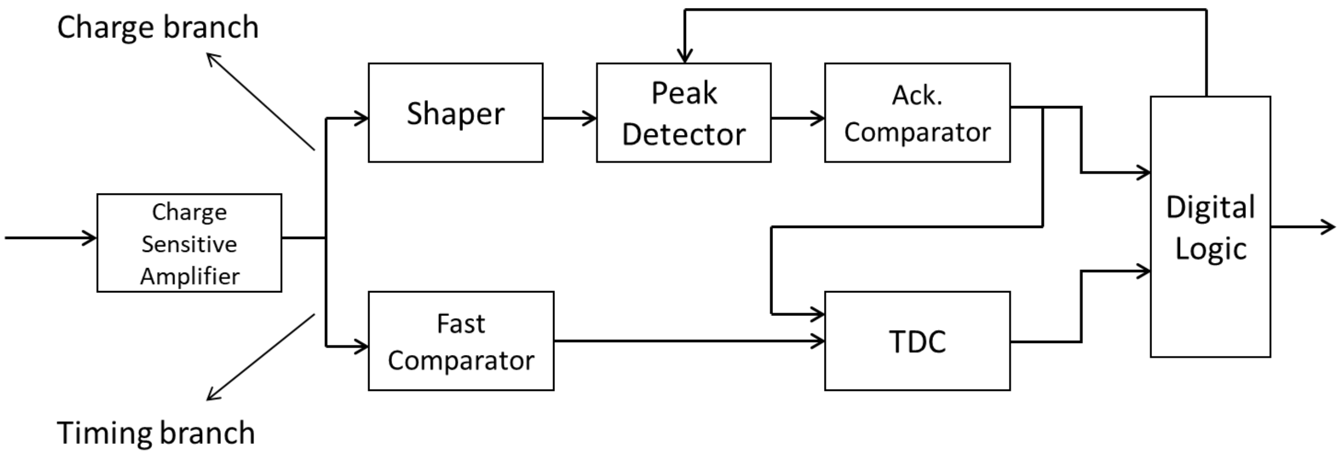




The **PEP** layout (Patterning – Etching – Plating) is the **state of art** of the **high rate** layout of the µ-RWELL developed **for LHCb**

- **Single DLC** layer
- **Grounding line from top** by kapton etching and plating (pitch down to 1/cm)
- **No alignment** problems
- **High rate** capability
- **Scalable to large size** (up to 1.2x0.5 m for the upgrade of CLAS12)

FATIC2 block diagram



Preamplifier features:
- CSA operation mode
- Input signal polarity: positive & negative
- Recovery time: adjustable

CSA mode:
- Programmable Gain: 10 mV/fC ÷ 50 mV/fC
- Peaking time: 25 ns, 50 ns, 75 ns, 100 ns

Timing branch:
- ✓ Measures the arrival time of the input signal
- ✓ Time jitter: 400 ps @ 1 fC & 15 pF (Fast Timing MPGD)

Charge branch:
- ✓ Acknowledgment of the input signal
- ✓ Charge measurement: dynamic range > 50 fC, programmable charge resolution