The µ-RWELL

in High Energy Physics and beyond

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LNF – INFN [1]
CERN [2]

16th IPRD, September 26th 2023

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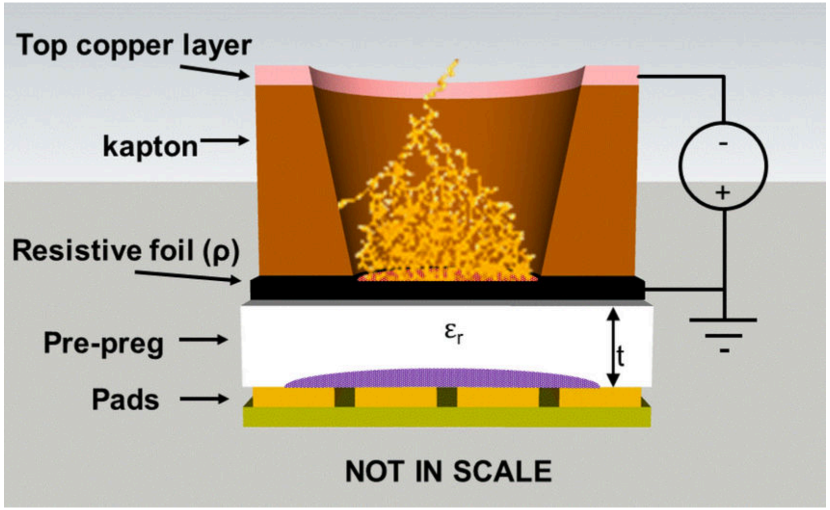
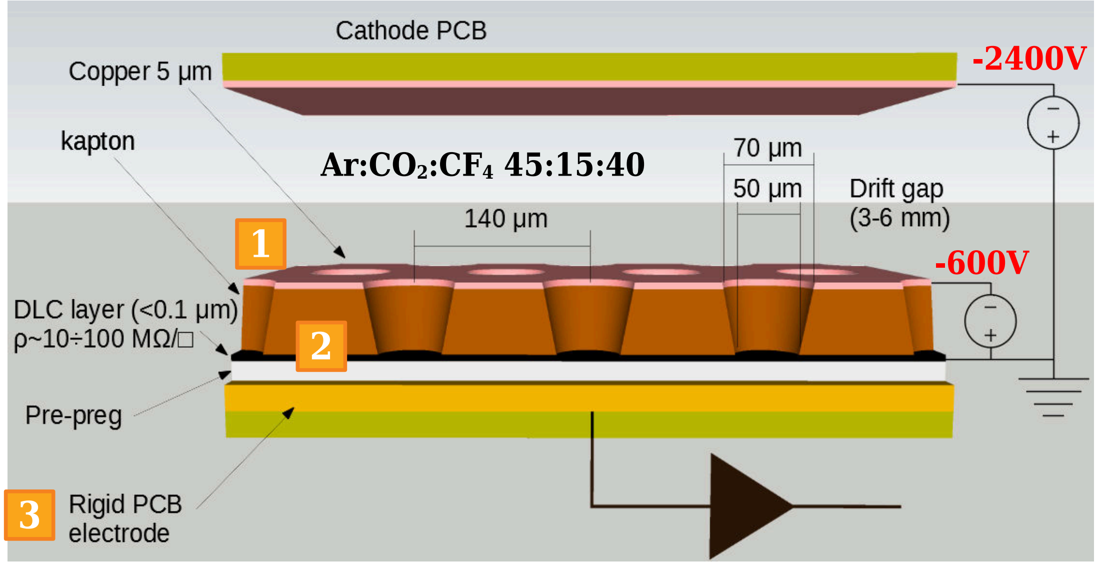
The µ-RWELL detector (reminder)

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 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

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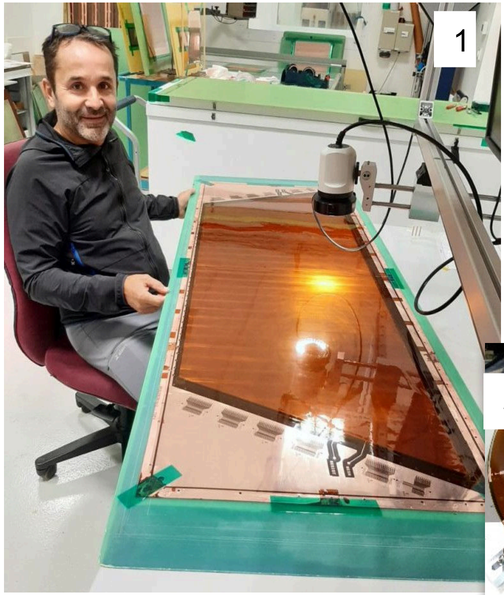

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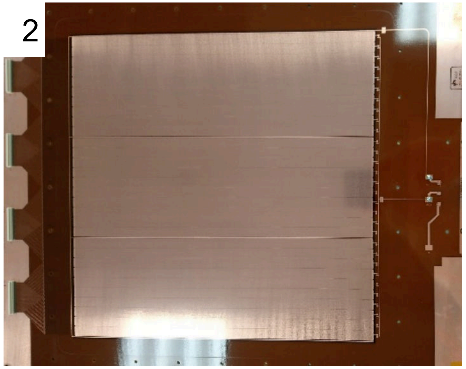

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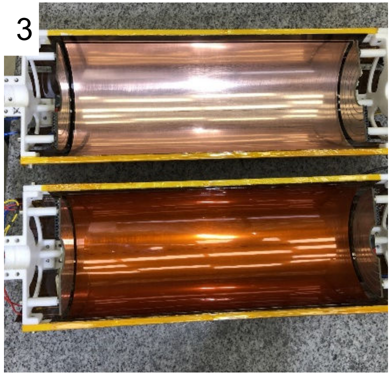

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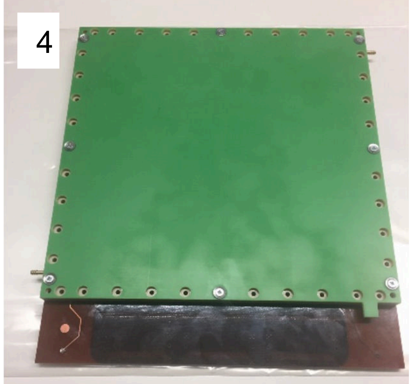

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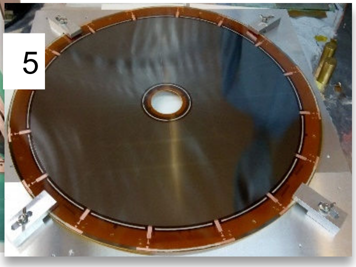

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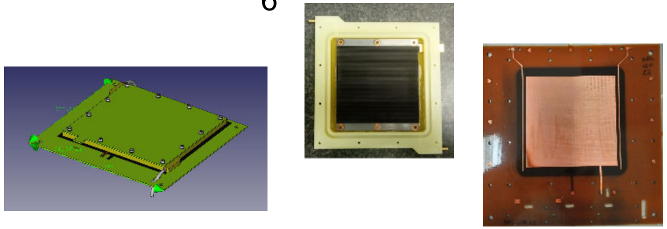

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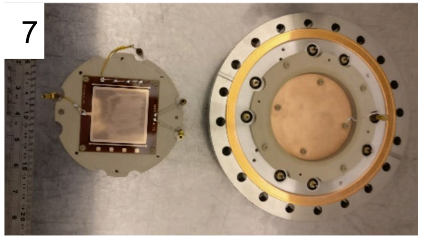
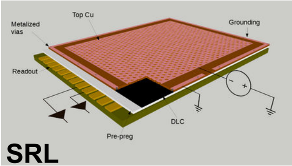
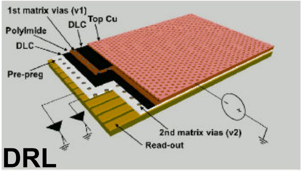


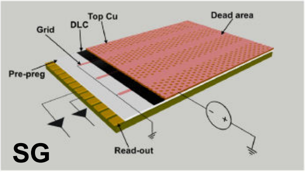
INFN-LNF DDG µ-RWELL R&D – a summary

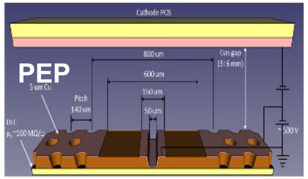
R&D on low-rate layout

R&D on high-rate layout









New MPGD idea in collaboration with GDD

R&D start

TT @ ELTOS

PEP

DOT

2009

2014

2015

2016

2017

2018

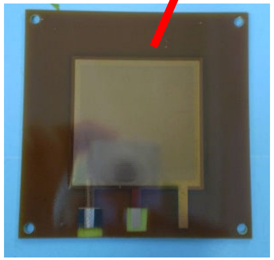
2019

2020

2021

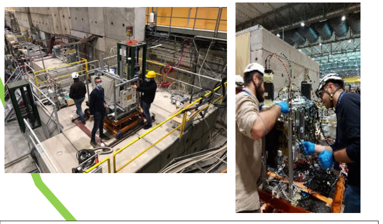
2022

2023

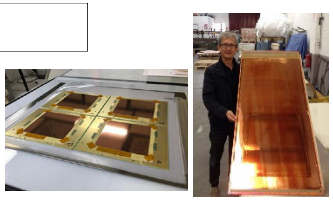


TB @ CERN

TB @ high rate @ PSI

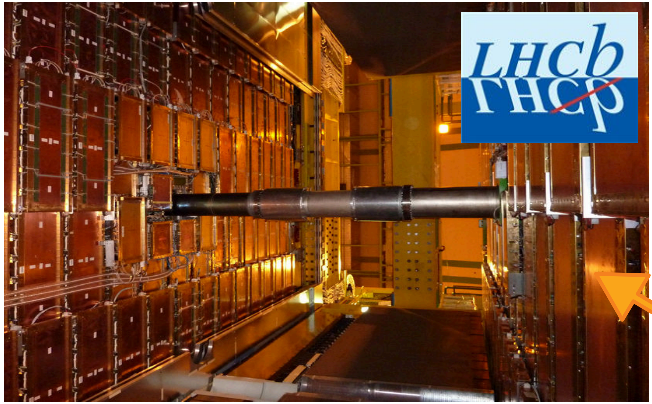


TB @ CERN



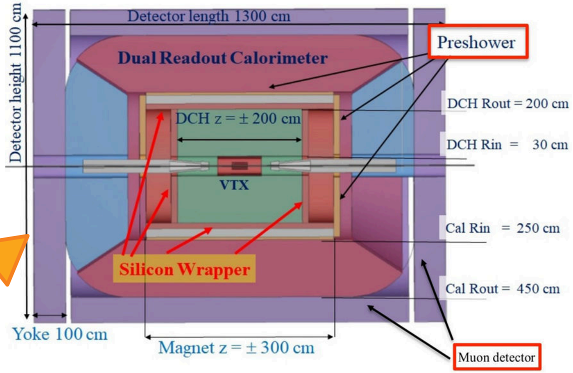
TT @ ELTOS

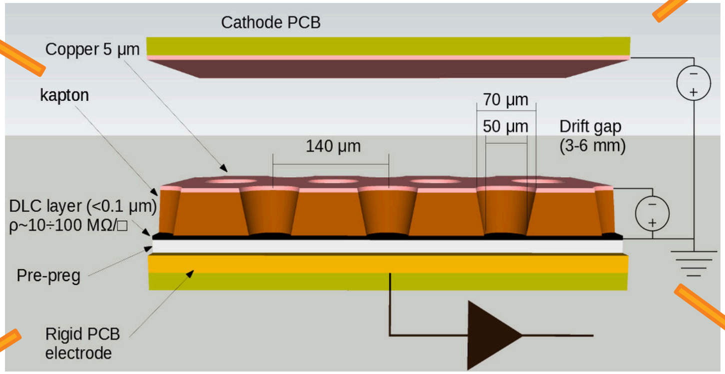
INFN-LNF DDG active projects



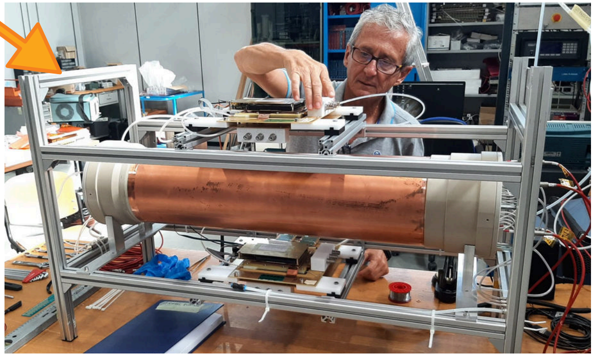
LHCb

IDEA

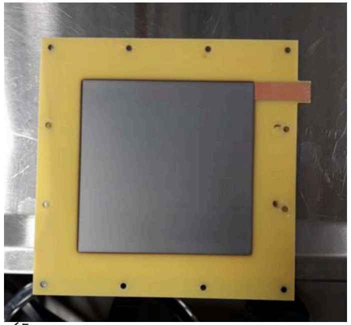




EURIZON

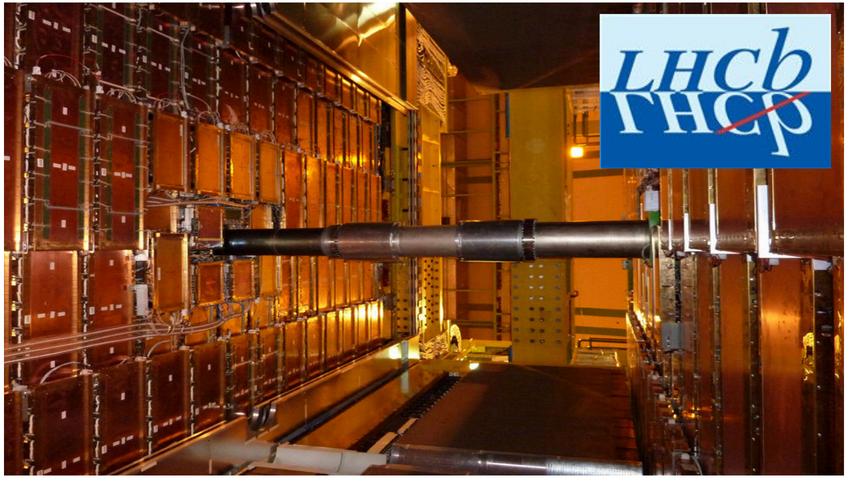


uRANIA



$$\mathrm{n}+{}^{10}_{5}\mathrm{B}\begin{cases}{}^{7}_{3}Li(1.02MeV)+\alpha(1.78MeV) & 6\% \\ {}^{7}_{3}Li(0.84MeV)+\alpha(1.47MeV)+\gamma(0.48MeV) & 94\%\end{cases}$$

μ-RWELL for muon triggering

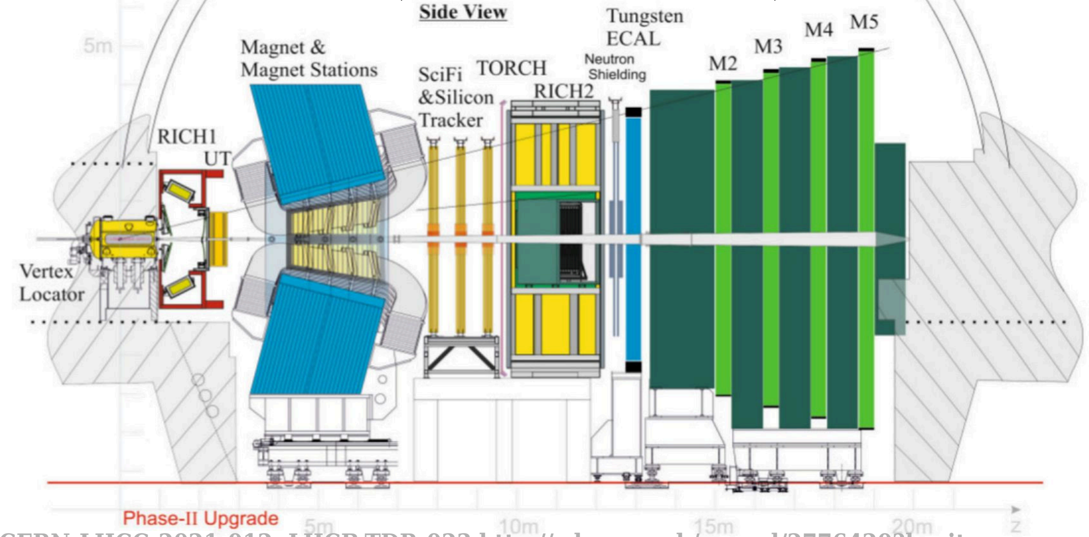


Inner region @ Run5 – Run6 **detector requirements**[1]

- Rate up to **1 MHz/cm²** on detector single gap
- Rate up to **700 kHz** per electronic channel
- Efficiency quadrigap >=99% within a BX (25 ns)
- Stability up to **1C/cm²** accumulated charge in 10y at M2R1

Detector size & quantity (4 gaps/chamber - redundancy)

- R1÷R2: 576 detectors, size 30x25 to 74x31 cm², 90 m² detector – 130 m² DLC



Chamber rates on M2R1-R2 (Hz/cm²)

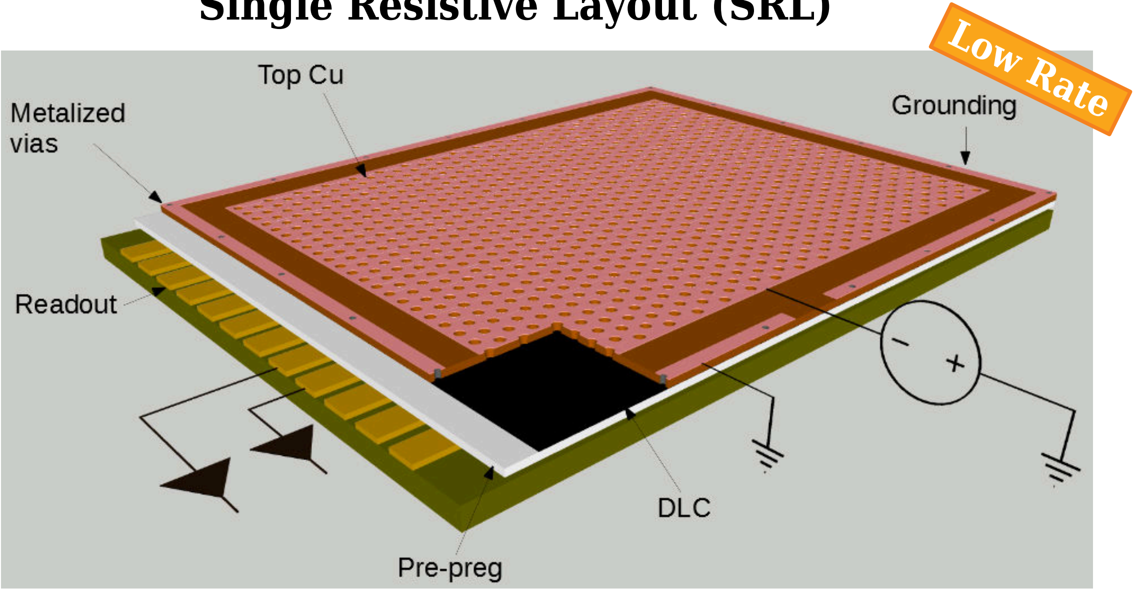
66493	120583		148811		77788
99470	217584		255560		107048
147585	321062	538980	508077	340550	170105
187623	594044			573691	205862
193571	496249			549110	217988
143561	341093	558687	546084	344551	152596
103585	209874		248696		114114
65005	122387		135696		73421

[1] CERN-LHCC-2021-012; LHCB-TDR-023 http://cds.cern.ch/record/2776420?ln=it

The SRL limitation

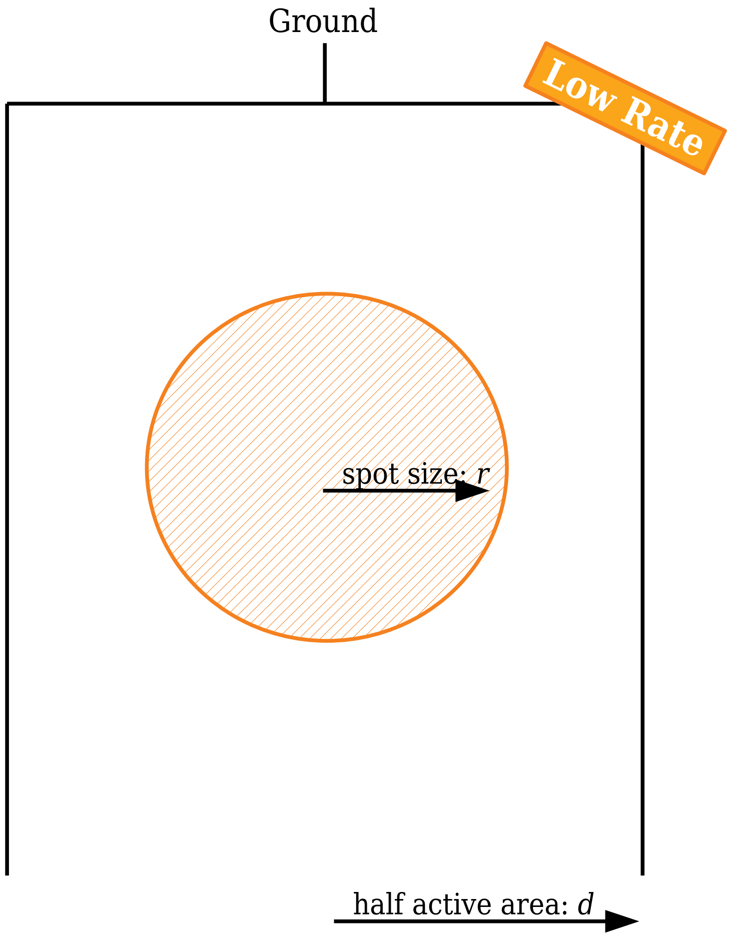
To overcome **the intrinsic limitation** of the Single Resistive layout with edge grounding the solution is to reduce as much as possible the paths towards the ground connection introducing a **high density “grounding network”** on the resistive stage of the detector.

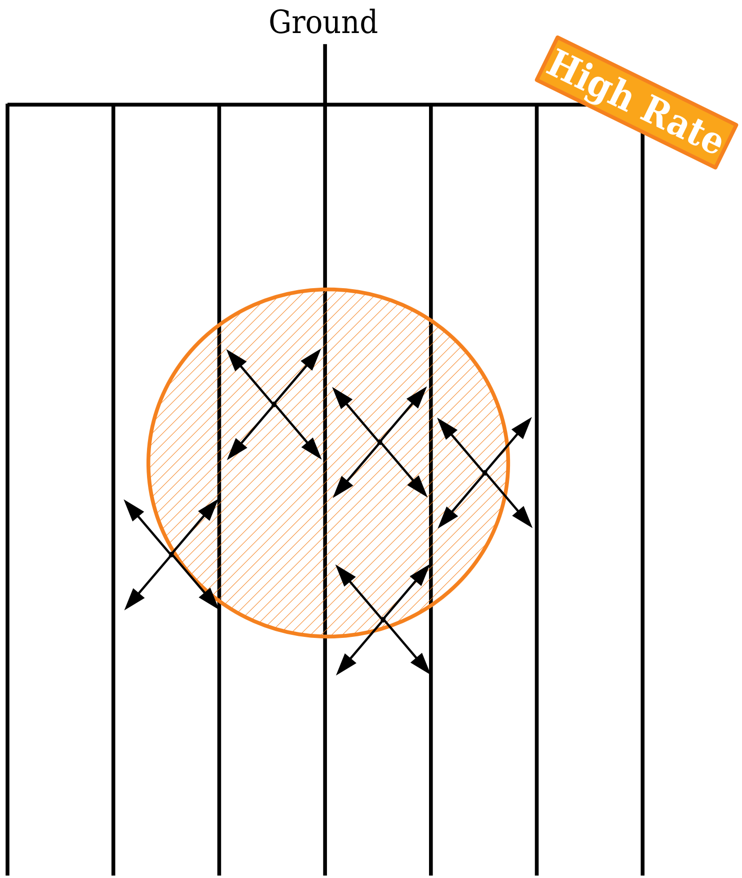
Single Resistive Layout (SRL)



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

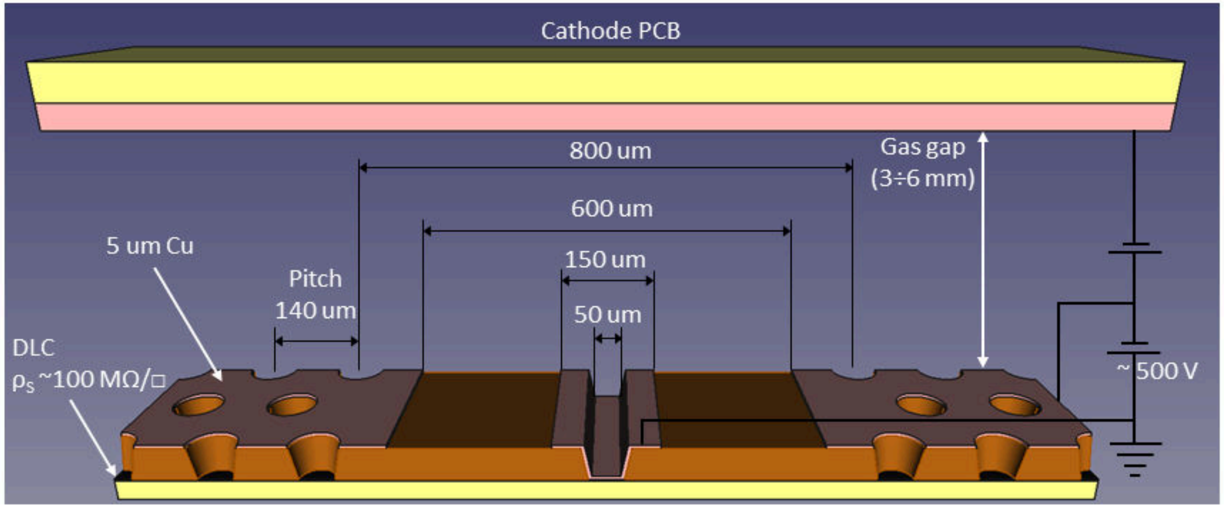
The High Rate layout idea

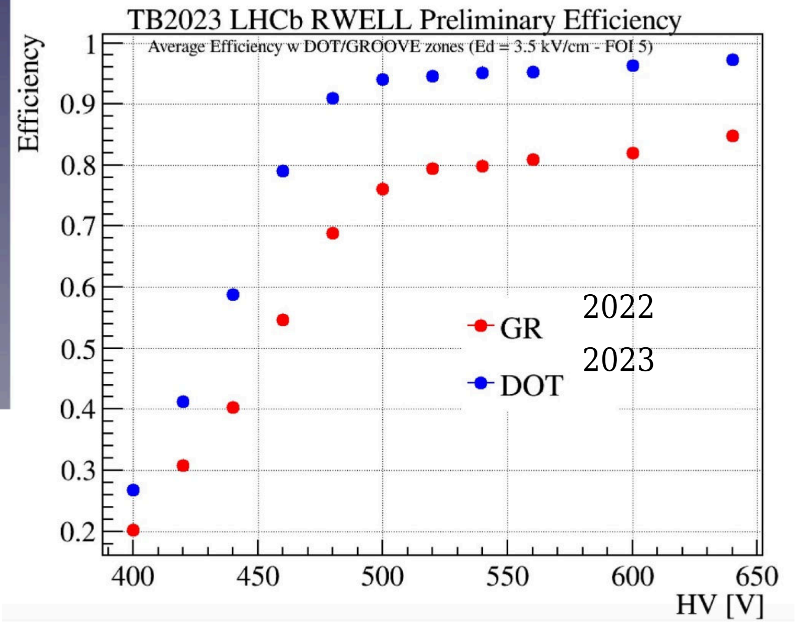




A sort of tiling with smaller low rate schemes.

The High Rate PEP layout

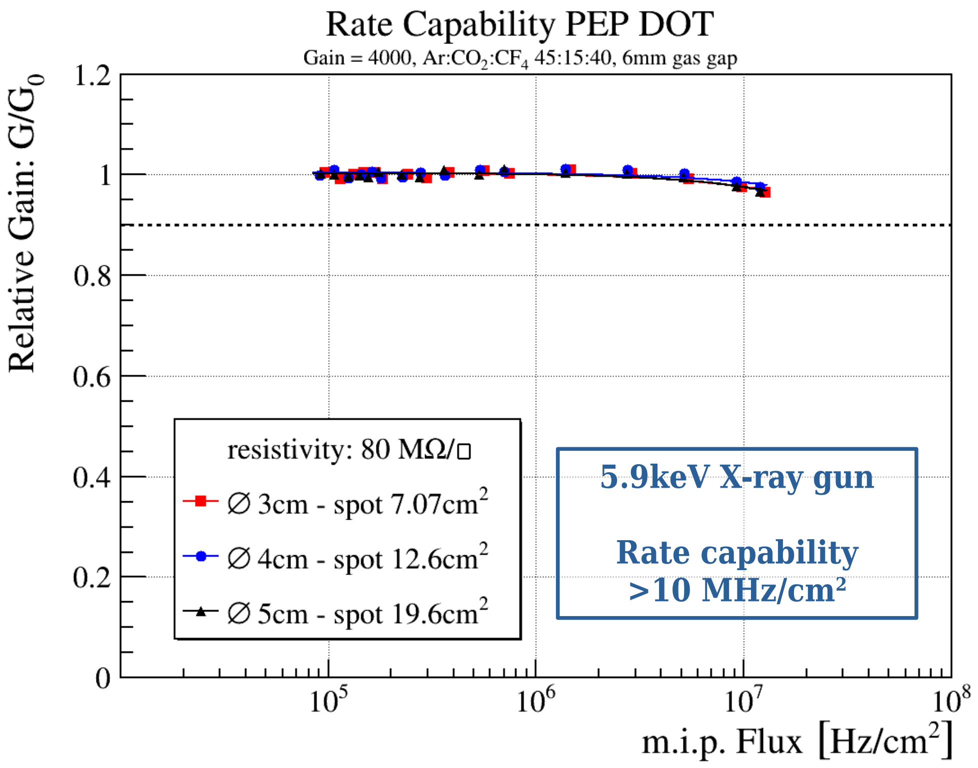




The **PEP** layout (Patterning – Etching – Plating) is the **state of art** of the **high rate** layout of the μ-RWELL developed **for LHCb**

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

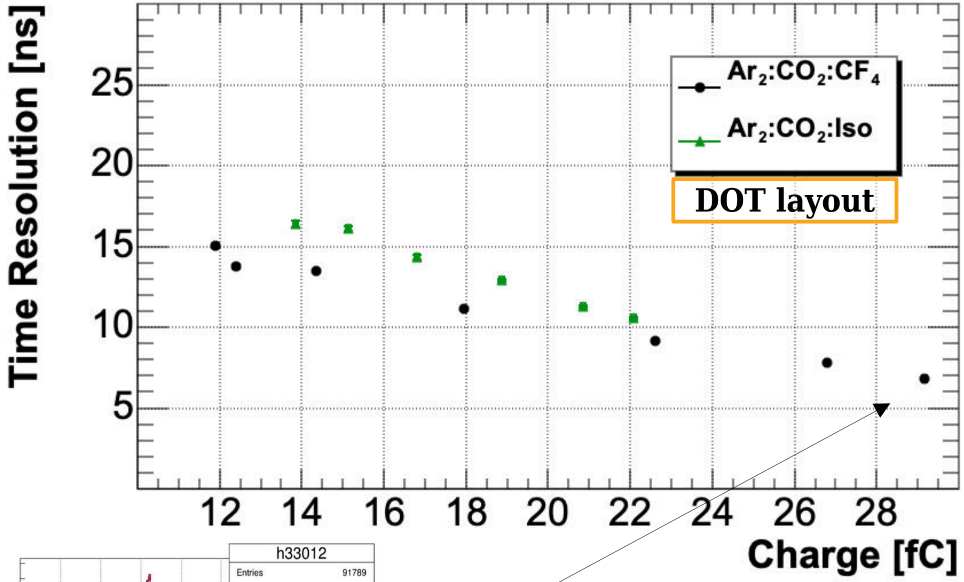
PEP DOT – preliminary results



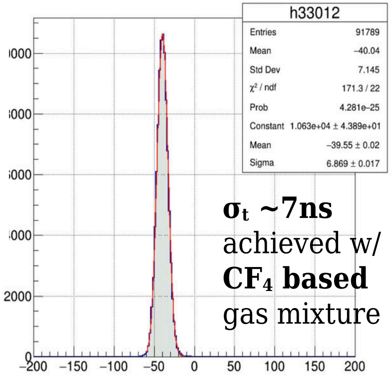
5.9keV X-ray gun

Rate capability >10 MHz/cm²

Gas mixture comparison



DOT layout



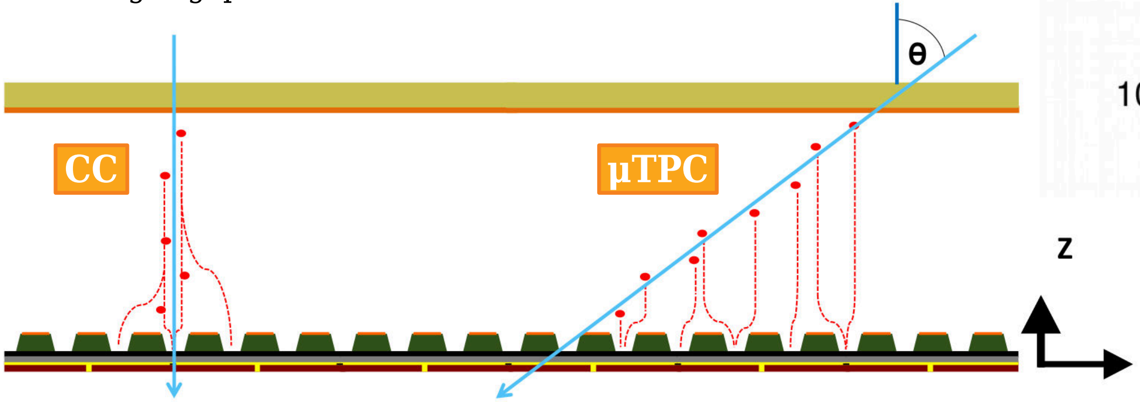
σ_t ~7ns achieved w/ **CF_4 based** gas mixture

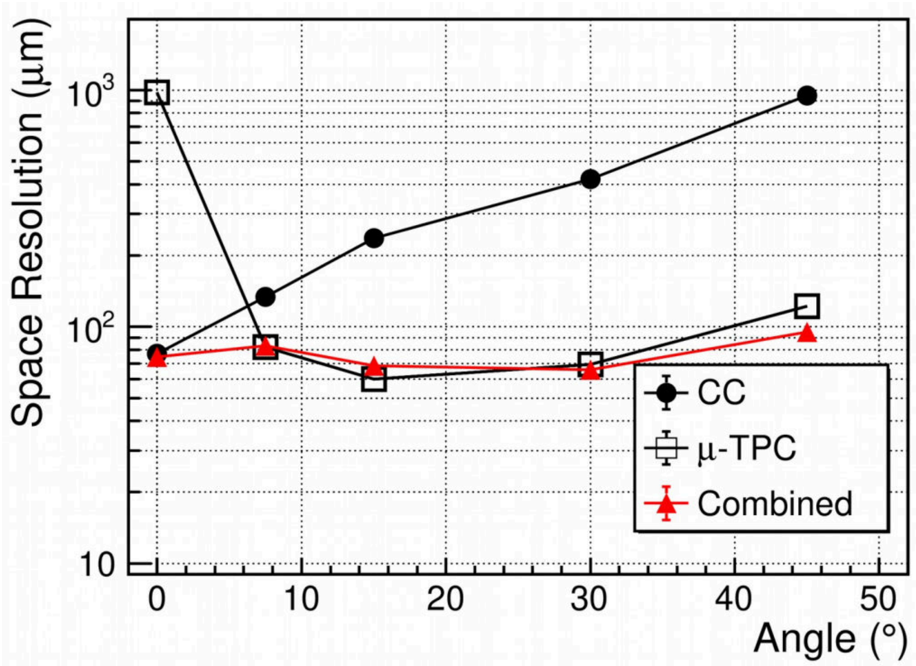
Up to now **CF_4 is fundamental** for the time performance of the detector

µ-RWELL for tracking – 1D

For inclined tracks and/or in presence of high B fields, **the charge centroid (CC) method gives a very broad spatial resolution** on the anode-strip plane.

Implementing the **µTPC mode**[1], using the knowledge of the drift time of the electrons **each ionization cluster is projected inside the conversion gap**, and the track segment in the gas gap is reconstructed.





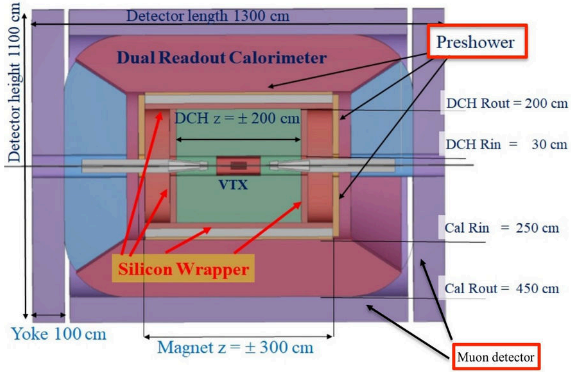
Combinig the CC and µTPC reconstruction (through a wheighted average) **a resolution well below 100 µm** could be reached over a wide incidence angle range.

[1] introduced for ATLAS MMs by T. Alexopoulos

M. Giovannetti et al., *On the space resolution fo the µ-RWELL*, 2020 JINST 16 P08036

µ-RWELL for tracking – IDEA and 2D

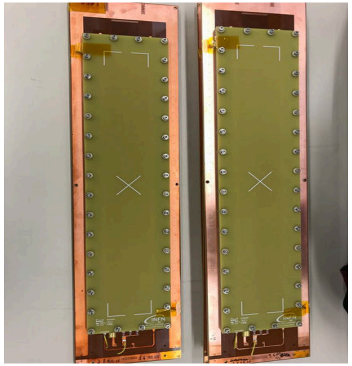
The **IDEA** detector is a **general purpose detector** designed for experiments at **future e^+e^- colliders** (FCCee and CepC). Pre-shower detector and the Muon system are designed to be instrumented with µ-RWELL technology.

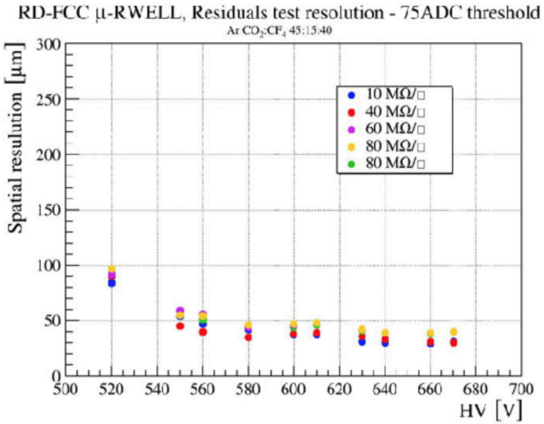


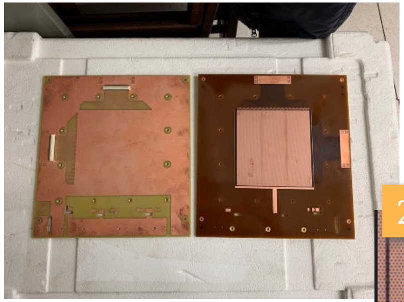
TB 2021 campaign
µ-RWELL prototypes with resistivity varing between 10 and 80 Mohm/sq. (strip pitch=0.4 mm)

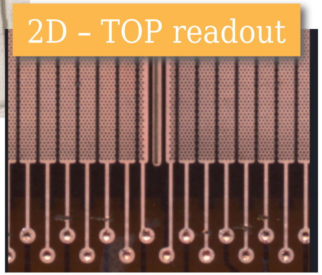
TB 2022 campaign
µ-RWELL prototypes with strip pitch varing between 0.4 to 1.6 mm

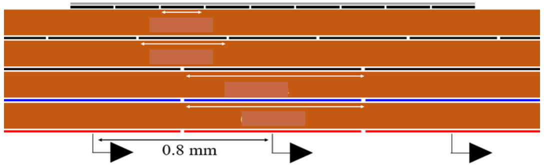
TB 2023 campaign
2D readouts: top R/O and capacitive sharing











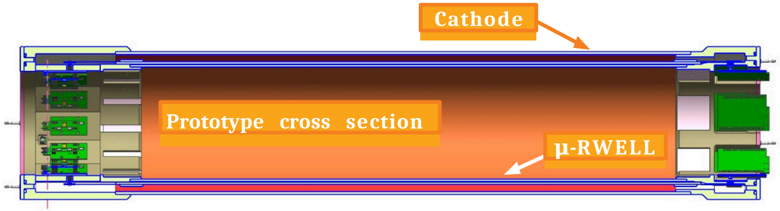
2D – capacitive sharing

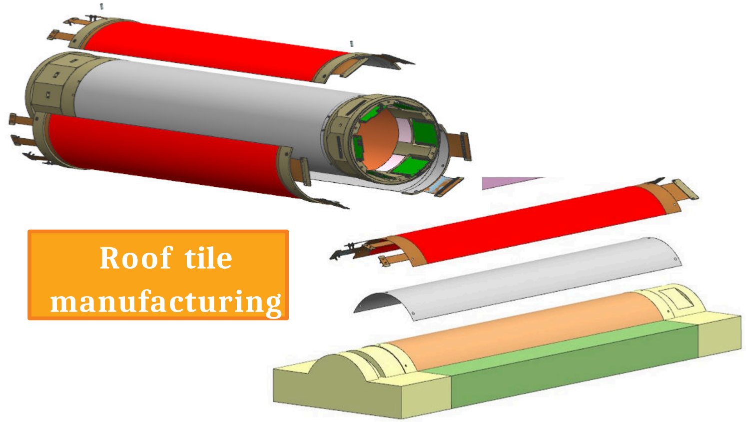
Inspired by another µ-RWELL R&D: K. Gnanvo et al., NIM A 1047 (2023) 167782

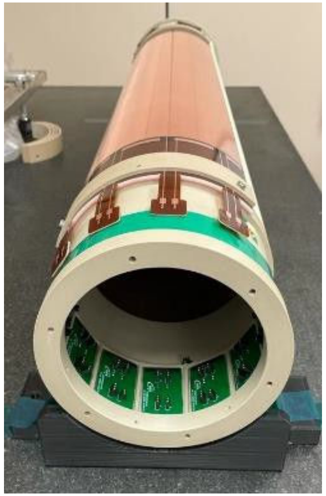
In collaboration with G. Cibinetto, R. Farinelli, L. Lavezzi, M. Gramigna, P. Giacomelli, E. De Lucia, D. Domenci, A. D'angelo, M. Bondi, M. Scodeggio, I. Garzia, M. Melindi

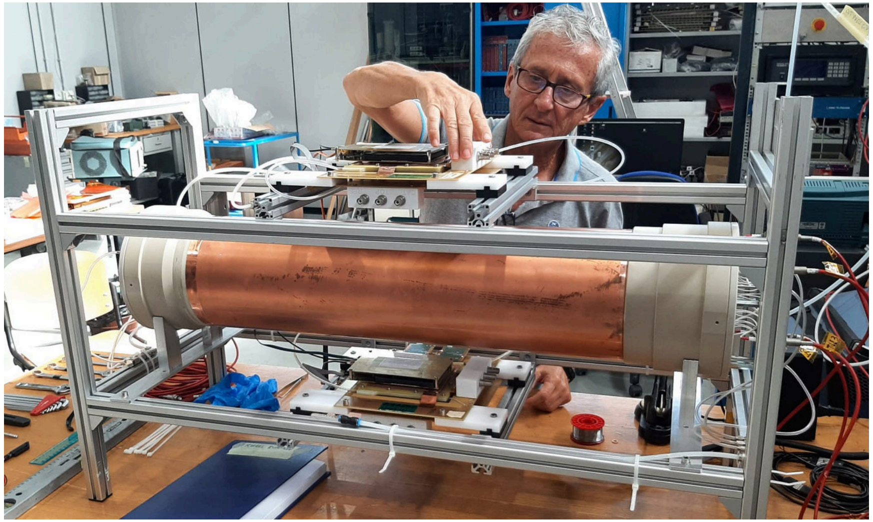
µ-RWELL for tracking – low X_0 & cylindrical

Development of an ultra-light modular **cylindrical µ-RWELL** as **inner tracker** for the Super Charm Tau factory (EURIZON project).
The B2B layout (a double radial TPC) is designed to have a **very low material budget** (0.86÷0.96% X_0) and **modular roof-tile shaped components**: in case of failure/damage of the part, the structure could be opened and the damaged module replaced.









The first cylindrical low mass uRWELL

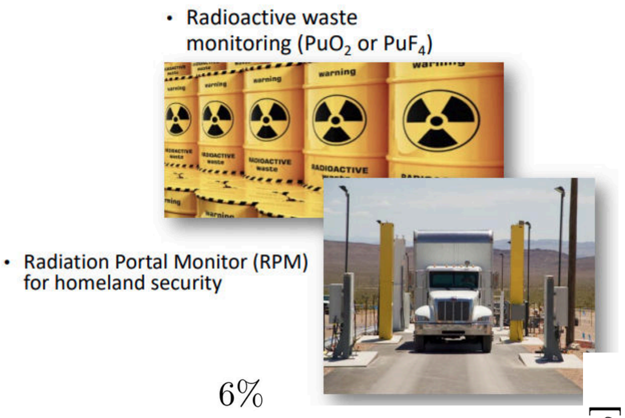
Thanks to the INFN-LNF,Fe Eurizon collaboration.

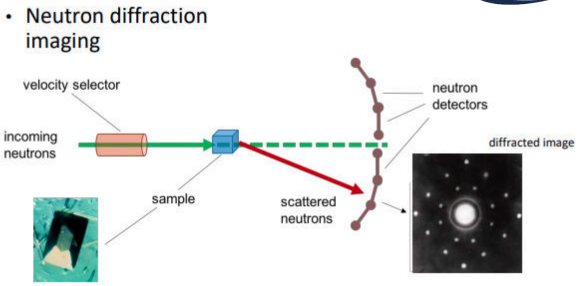
uRANIA-V – μ-RWELL for thermal neutron detection

WHY

- **Probing heavy structure in motion**
- High penetration power

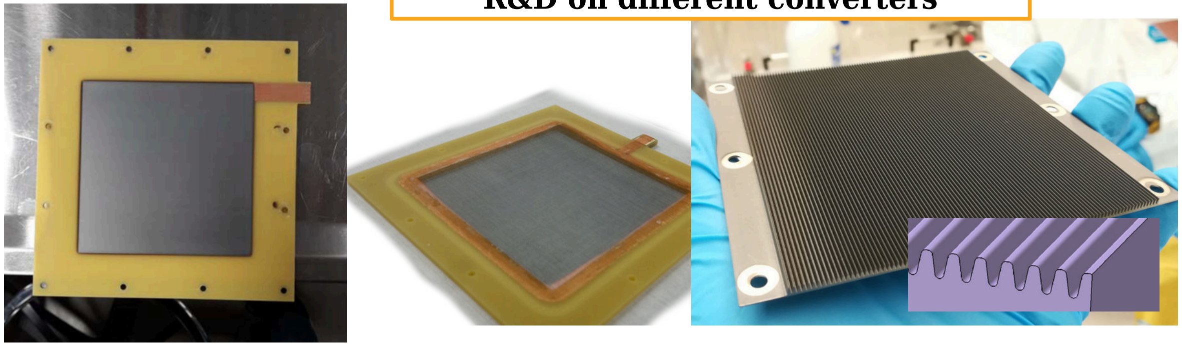
- **Radioactive waste monitoring**
- **Radiation Portal Monitor** (homeland security)
- **Neutron tomography**

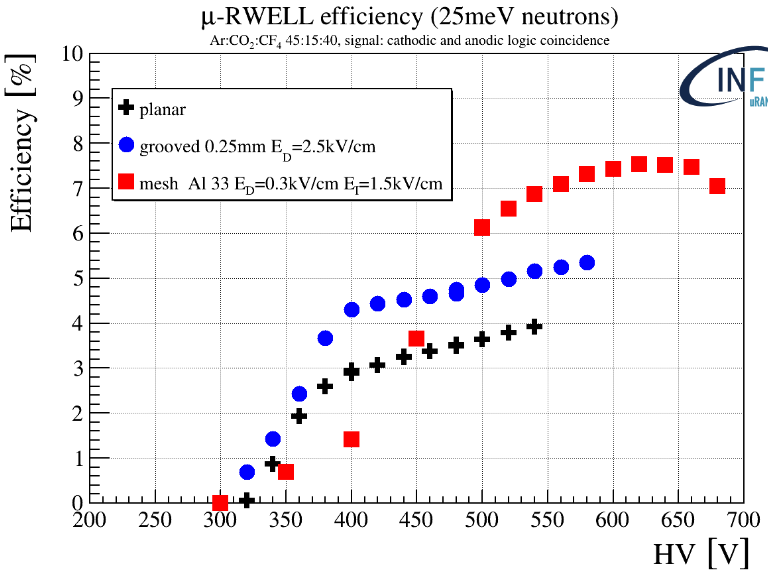




$$\mathrm{n}+{}^{10}_{5}\mathrm{B} \begin{cases} {}^{7}_{3}Li(1.02MeV) + \alpha(1.78MeV) & 6\% \\ {}^{7}_{3}Li(0.84MeV) + \alpha(1.47MeV) + \gamma(0.48MeV) & 94\% \end{cases}$$

R&D on different converters

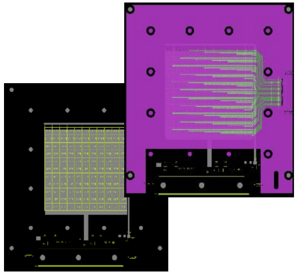




More on poster: *Thermal neutron detection based on resistive gaseous devices*

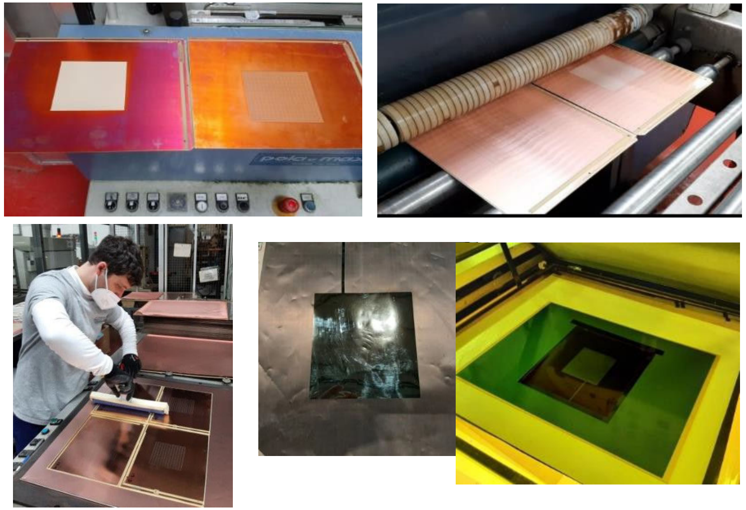
μ-RWELL Technology Transfer [flow chart]

LAYOUT design

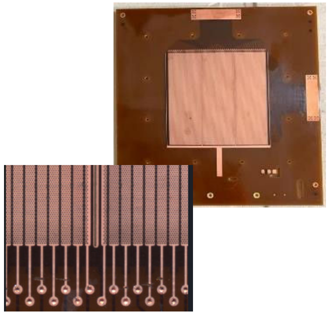


Feedback from tests

PCB production



Final detector manufacturing



DCL foil production[2]

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

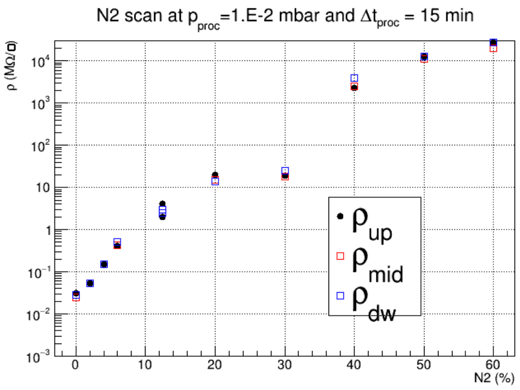
The **TT is fundamental** in order to deliver the **~600 detectors** required for U2.

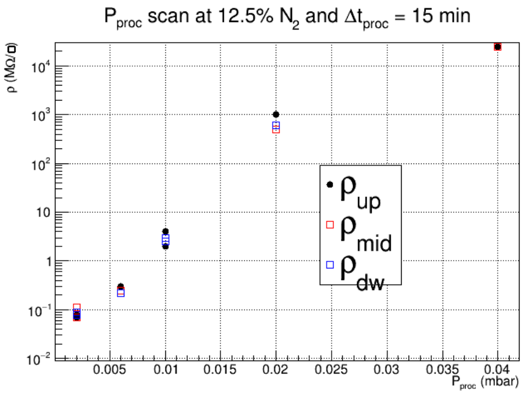
The CERN-INFN DLC machine

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).
  Uniformity around 30% over the vertical axis

25th - 28th Sep. 2023 – 3rd DLC sputtering test
- Ar + C_2H_2 doping





The **resistivity** of the sample is being **monitored** to evaluate the **stability in time**.

- **Flexible** substrates up to 1.7m×0.6m
- **Rigid** substrates up to 0.2m×0.6m
- The machine can **sputter or co-sputter different materials,** creating coating layer by layer.

Conclusions

The µ-RWELL is becoming a mature device, also thanks to the **technology spread** that is giving an important boost to its development.

The advances in the last two years lead to large improvements in terms of stability and production yield.

Fine tuning of the **PEP layout** and **standardization** of the manufacturing is on going.

The challenge is **Techology Transfer** to PCB industry. A key-point has been the acquisition of the **DLC sputtering machine** co-funded by CERN and INFN.

Additional tasks:

→ Eco-gas mixture studies

→ Stability tests (X-ray, gamma/neutron irradiation)

→ Integration with FEE (Fatic, VMM3, etc)

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)

Conclusions

The µ-RWELL is becoming a mature device, also thanks to the **technology spread** that is giving an important boost to its development.

The advances in the last two years lead to large improvements in terms of stability and production yield.

Fine tuning of the **PEP layout** and **standardization** of the manufacturing is on going.

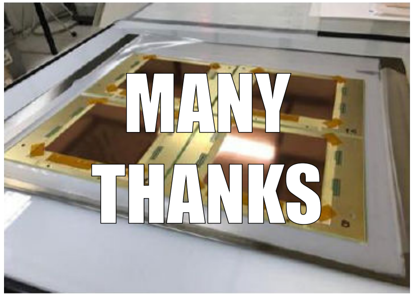
The challenge is **Techology Transfer** to PCB industry. A key-point has been the acquisition of the **DLC sputtering machine** co-funded by CERN and INFN.

Additional tasks:

→ Eco-gas mixture studies

→ Stability tests (X-ray, gamma/neutron irradiation)

→ Integration with FEE (Fatic, VMM3, etc)



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)

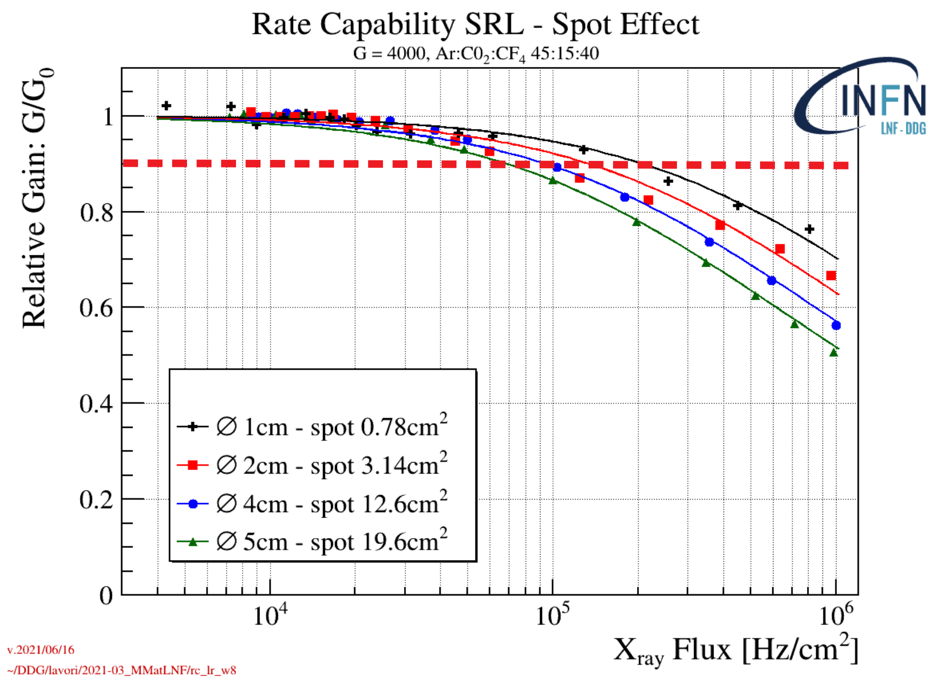
Spare

References

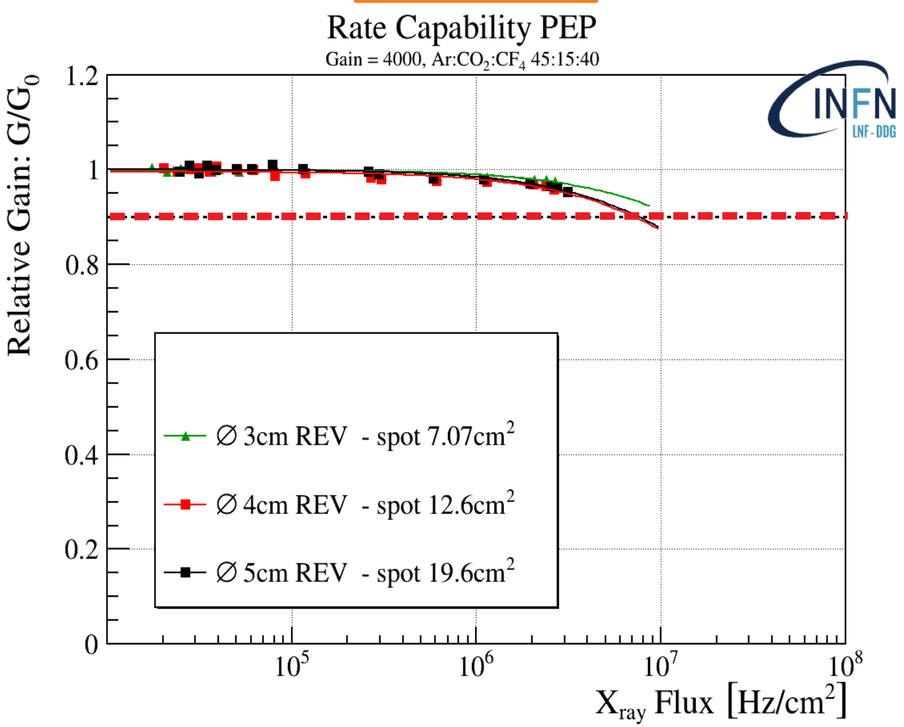
G. Bencivenni et al., *The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD*, 2015 *JINST* **10** P02008
G. Bencivenni et al., *The µ-RWEL detector*, 2017 *JINST* **12** C06027
G. Bencivenni et al., *Performance of µ-RWELL detector vs resistivity of the resistive 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).

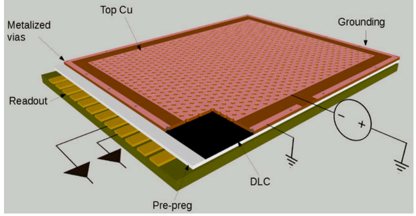
Rate capability – X-Ray measurements

Low Rate



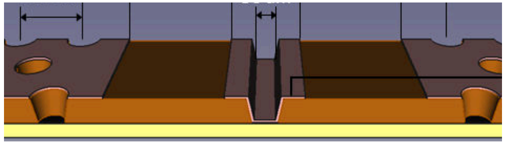
High Rate





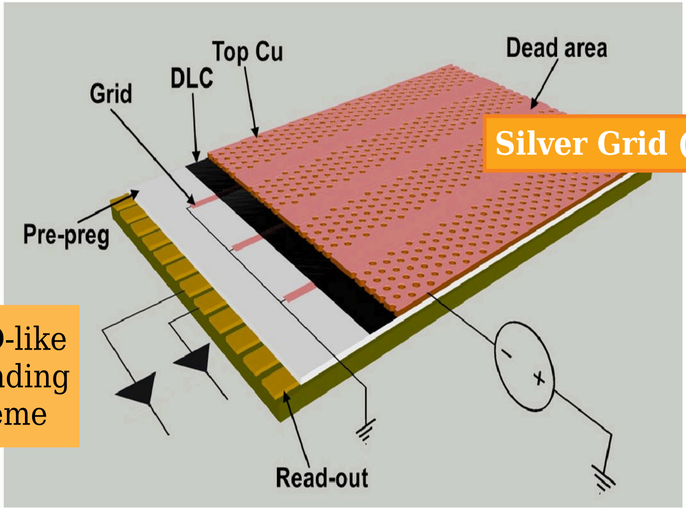
Rate capability compatible with m.i.p. as measured @PSI O(10MHz).

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



The High Rate layouts

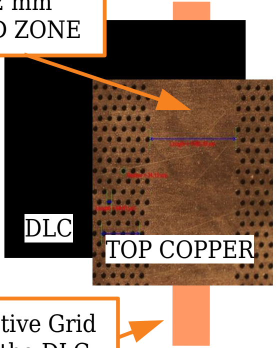
2017



Silver Grid (SG)

GRID-like Grounding scheme

1.2 mm
DEAD ZONE



Conductive Grid
Under the DLC

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

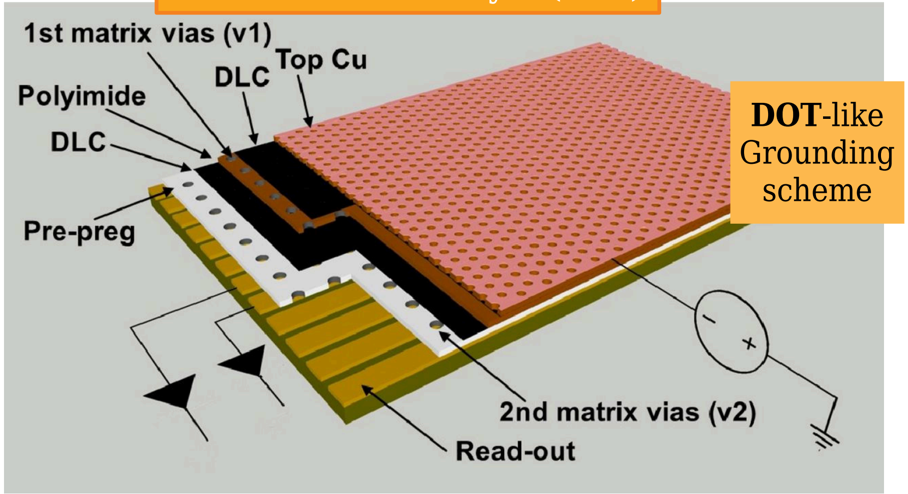
Necessity to introduce a **small DEAD AREA** above the grid, to avoid discharges (tuned to be 5% of the total area).

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.

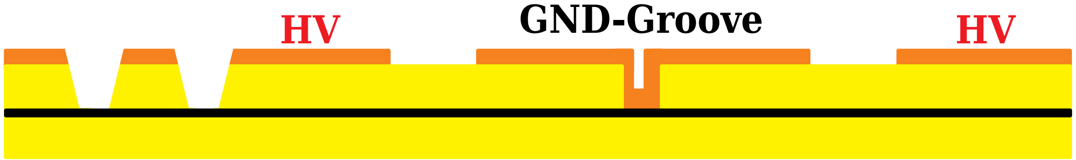
High-rate layout optimisation

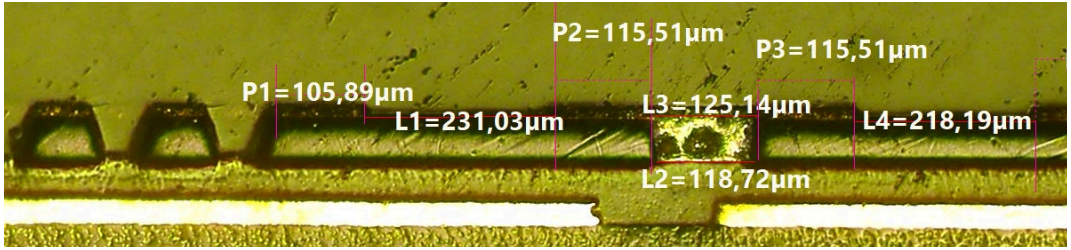
2022 - PEP-groove µ-RWELL

- DLC grounding by conductive GROOVE
  groove pitch = 9mm – groove width = 1.5mm
- PRE-PREG thickness= 50 um
- Geometrical dead zone = 11%
- Pad R/O 9x9mm^2

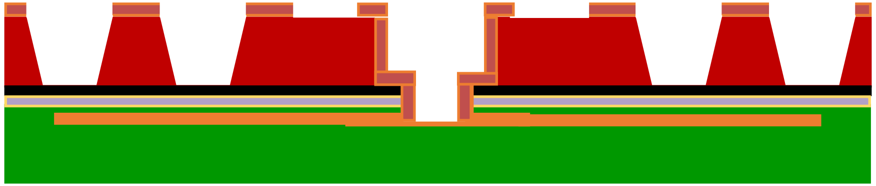
2023 - PEP-dot µ-RWELL

- DLC grounding by conductive DOT
  connected to the readout - Dot rim = 1.6mm
- PRE-PREG thickness= 28 um
- Geometrical dead zone = 2%
- Pad R/O = 9×9mm^2

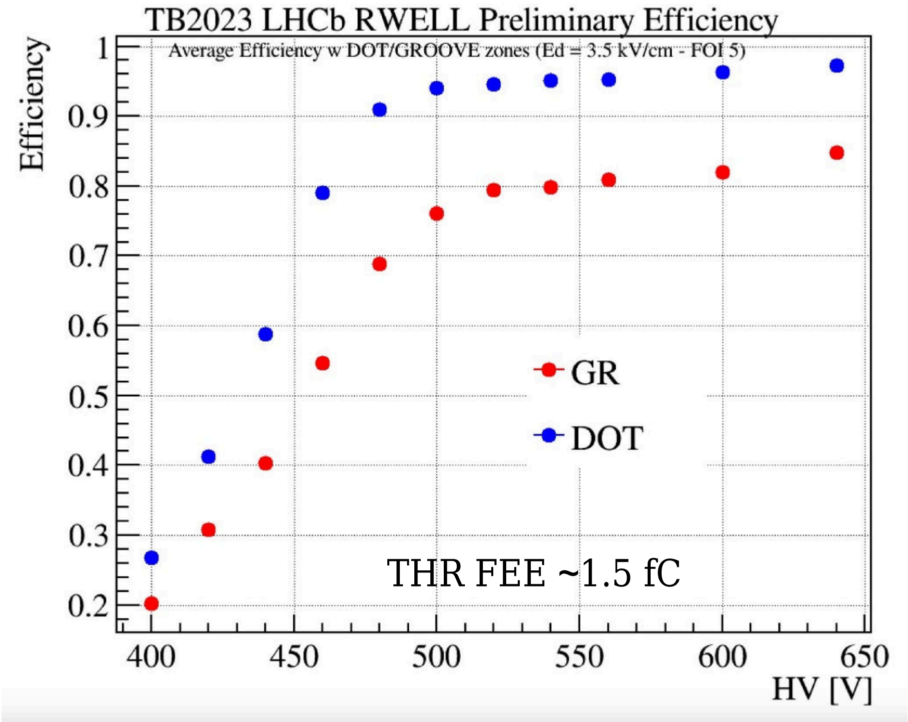




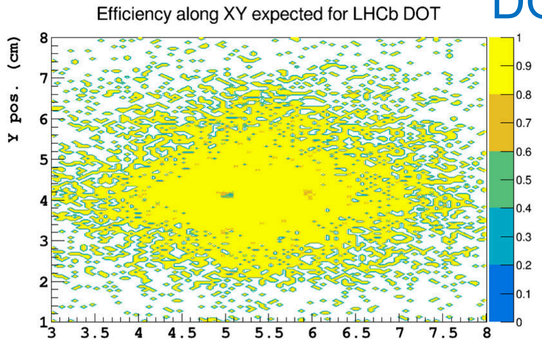
GND-Dot

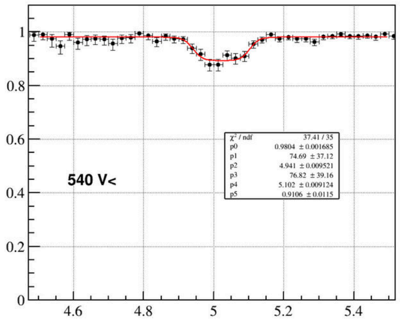


BT’23 [APV25]: Groove-DOT layouts comparison

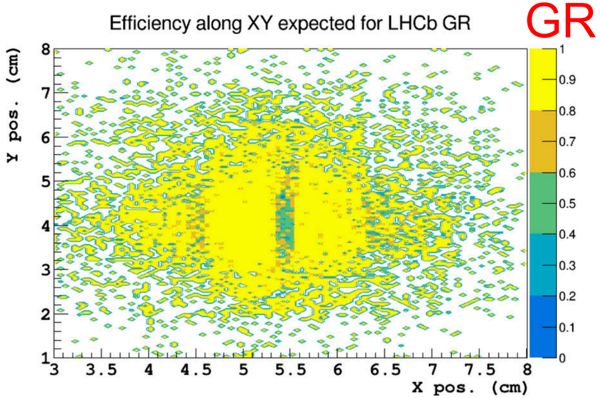


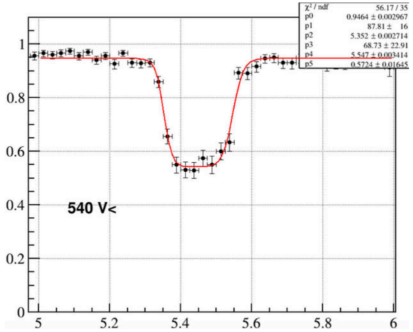
DOT





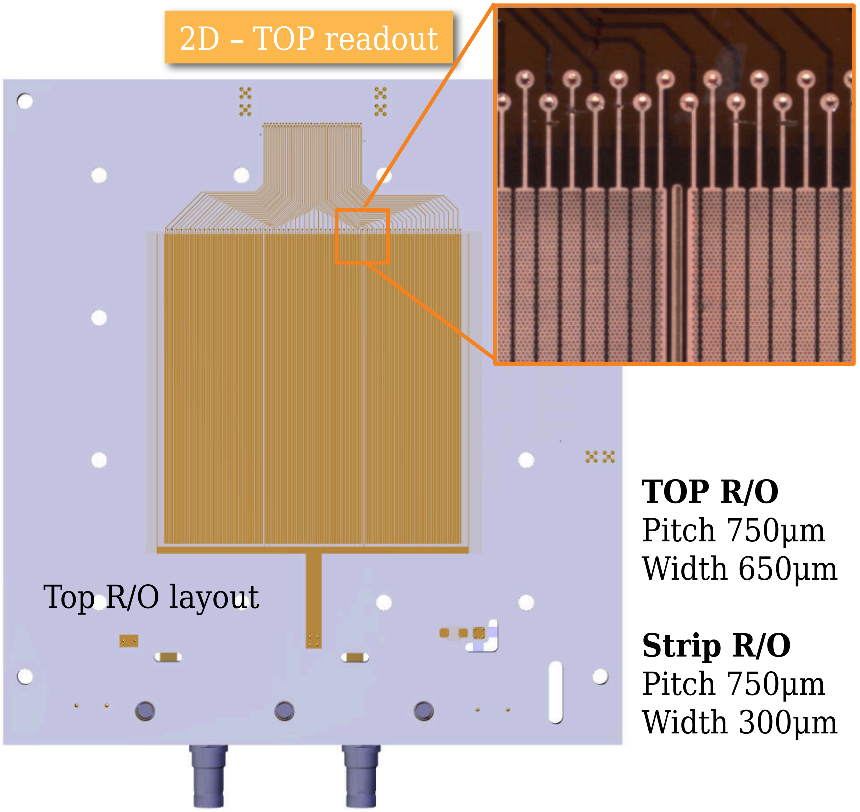
GR





WP7.3.2: (June ’23) 2D Read Out

2D - TOP readout



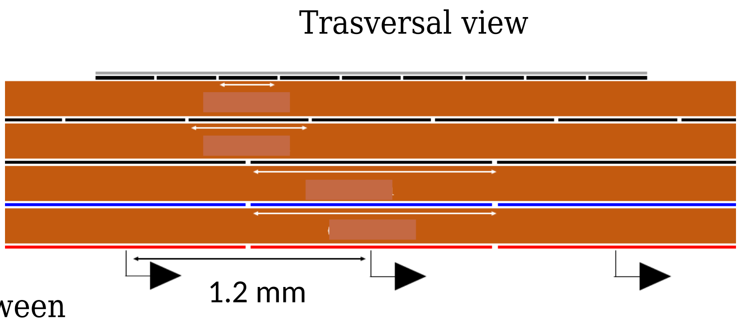
TOP R/O
Pitch 750µm
Width 650µm

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/□

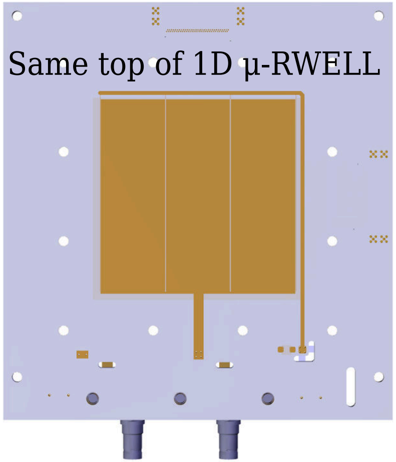
2D – capacitive sharing

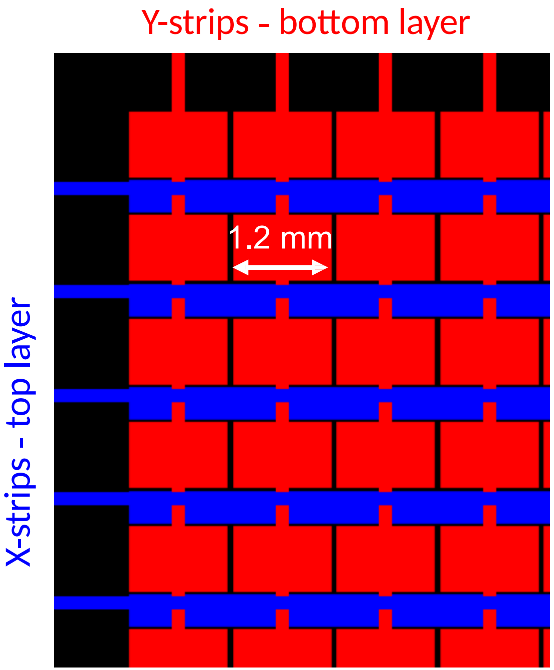
Inspired by another
µ-RWELL R&D:
K. Gnanvo et al., NIM A
1047 (2023) 167782



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/□





TB2023 (APV25) : 2D layouts

preliminary

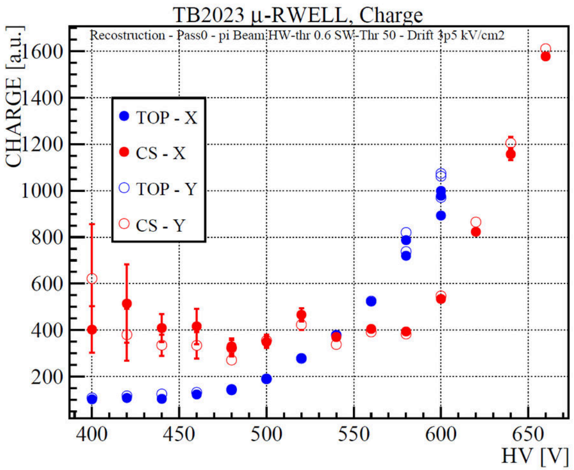
Promising preliminary results for the 2Dlayouts.
Equal sharing between the X-Y views.

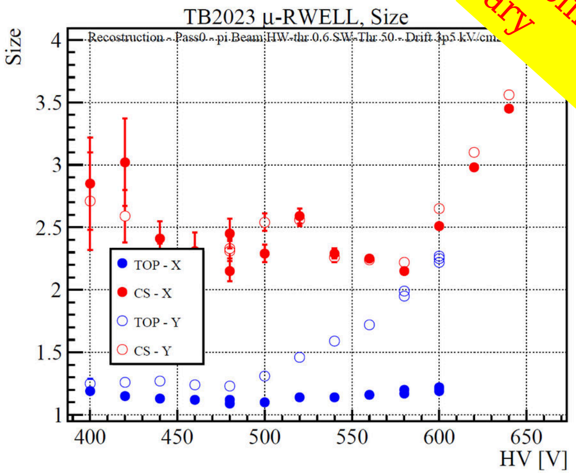
TOP r/o:

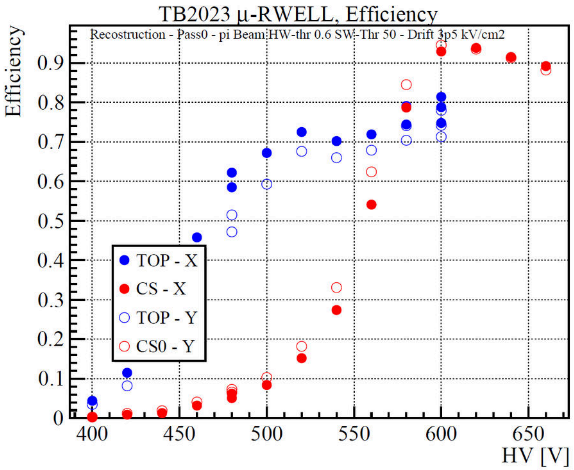
- Higher pulse height mean charge (the signal is not split between the two views)
- X (TOP) with flat cluster size, Y (DLC) increase in cluster size
- X (TOP) flat (digital) space resolution (stirp size x 1.5),
  Y (DLC) better space resolution increasing HV
- Lower HV requiremets for efficiency plateau
  - Lower efficiency plateau (under investigation)

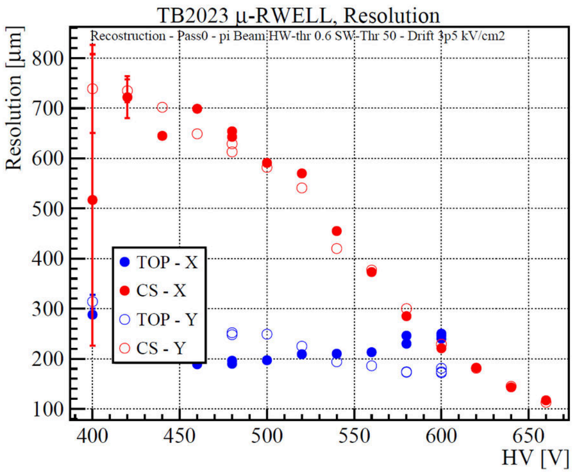
CS r/o:

- Lower pulse height mean charge (the signal is split between the two views)
- Large cluster size due to charge sharing
- Good space resolution, < 150um
- Higher HV requiremets for efficiency plateau
  - efficiency > 95%;









µ-RWELL Technology Transfer 2023

Step 0 - Detector PCB design @ **LNF**

Step 1 - CERN_INFN DLC sputtering machine @ **CERN (+INFN)**
- delivered at the end of Oct. 2022
- **INFN** crew tbd & trained

Step 2- Producing readout PCB by **ELTOS**
- pad/strip readout

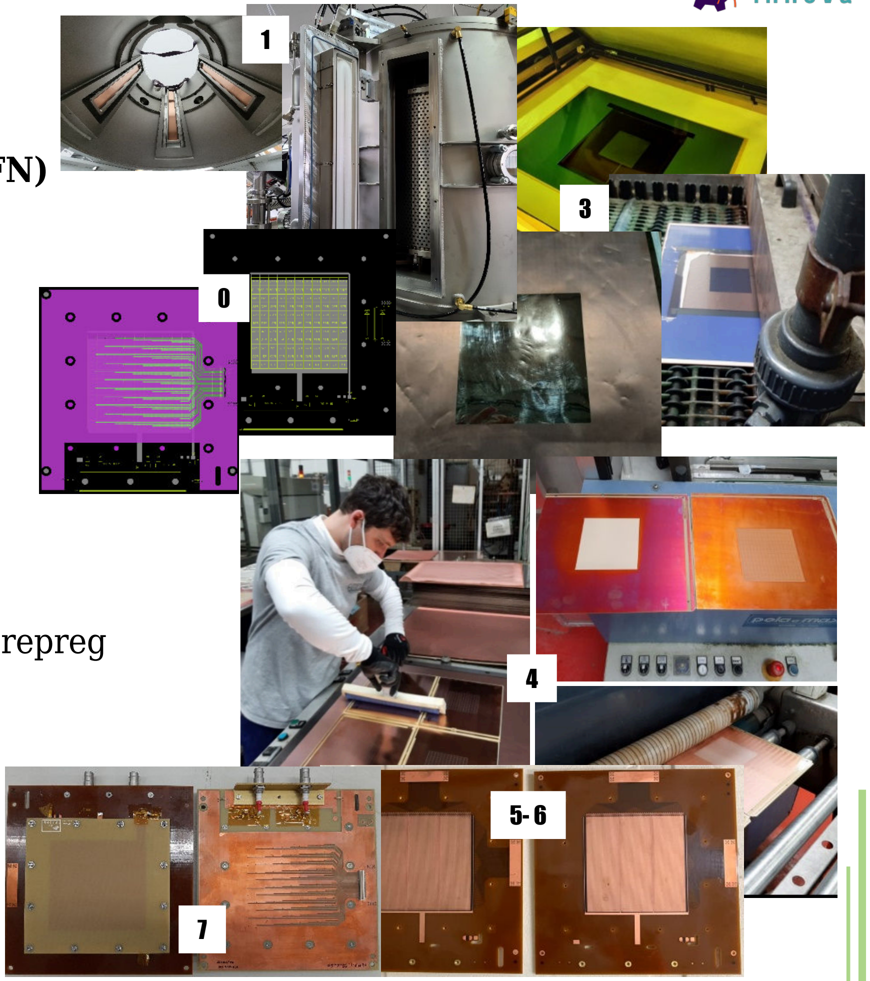
Step 3 - DLC patterning by **ELTOS**
- photo-resist → patterning with BRUSHING-machine

Step 4 - DLC foil gluing on PCB by **ELTOS**
- double 106-prepreg → 2x50µm thick
- PCB planarizing w/ screen printed epoxy → single 106-prepreg

Step 5 - Top copper patterning by **CERN** (in future by **ELTOS)**
- Holes image and HV connections by Cu etching

Step 6 - Amplification stage patterning by **CERN**
- PI etching → plating → ampl-holes

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



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