# The micro-RWELL technology for application in future facilities

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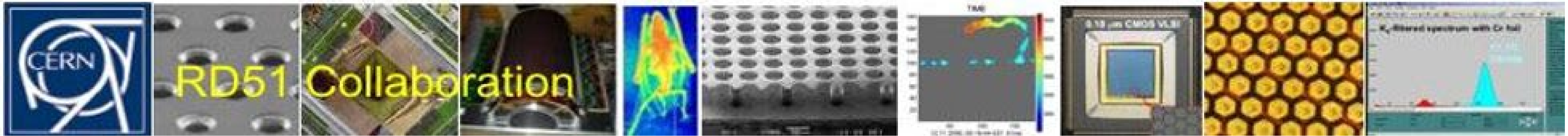
on behalf of
LNF-INFN (leading group)
Bologna-Ferrara INFN teams
R. De Oliveira – CERN-EP-DT-MPT Workshop

The 2023 International Workshop on Circular Electron Positron Collider, Edinburgh, July 3rd 2023

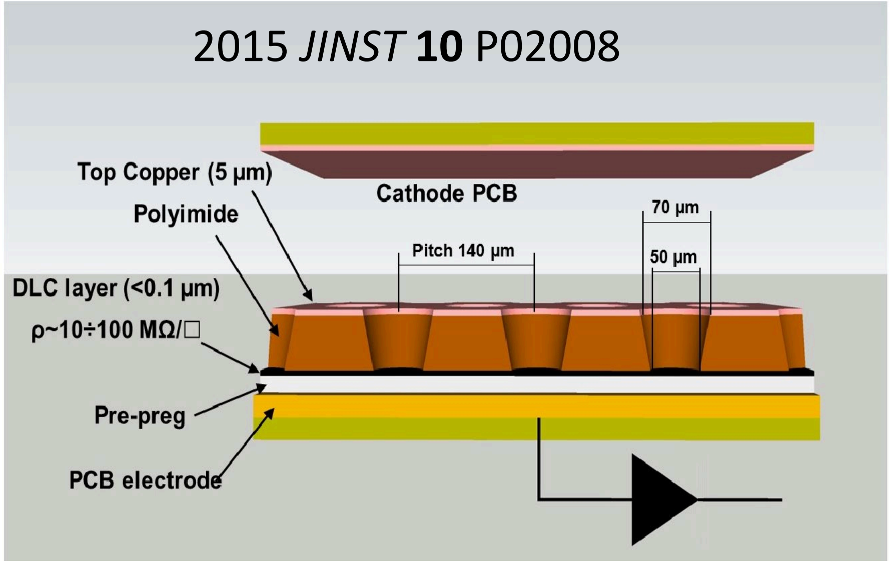


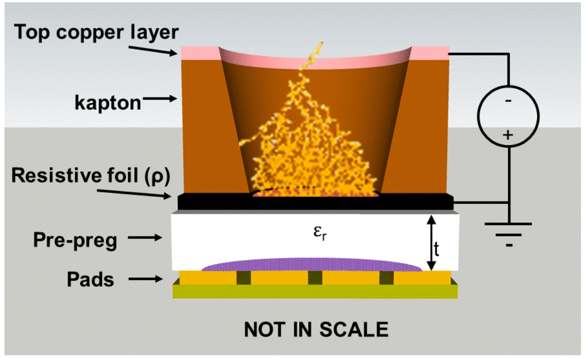
# The μ-RWELL technology at a glance

Developed in collaboration with CERN-EP-DT-MPT workshop
The features can be summarized:

- **Spark suppression**: presence of a resistive layer (Diamond-like Carbon) to quench sparks amplitude (like MM)
- **Compactness**: amplification stage (geometry like WELL and GEM) embedded in the PCB readout → multi-layer PCB std. industrial technology →mass production

But the resistive layer introduces a local gain drop as the rate increases




The "WELL" acts as a multiplication channel for the ionization produced in the gas of the drift gap

The charge induced on the resistive layer is spread with a time constant, $\tau \sim \rho \times C$

*[M.S. Dixit et al., NIMA 566 (2006) 281]:*

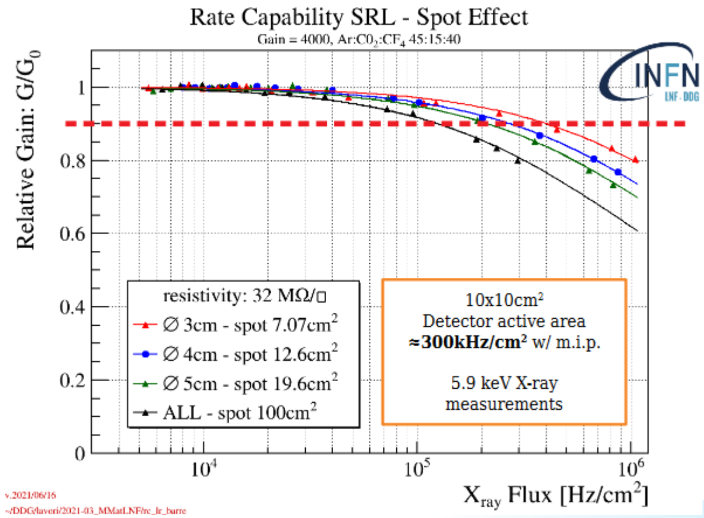
- $\rho$ → the DLC surface resistivity
- $C$ → the capacitance per unit area, depending on the distance between the DLC and the readout plane

$$\frac{G}{G_0} = \frac{-1 \pm \sqrt{1 + 4p_0\varphi}}{2p_0\varphi}$$

Naïf model for the **average resistance Ω** between the charge point collection and the perimetrical grounding line

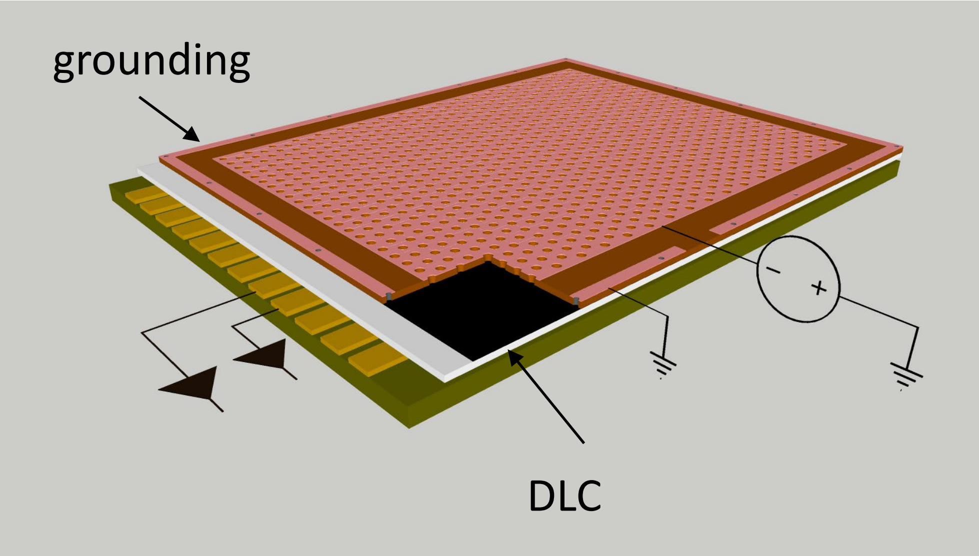
$$\Omega(r) = \frac{p_0(r)}{\alpha e N_0 G \pi r^2} = \rho_S \frac{d - \frac{r}{2}}{\pi r}$$

***α*** from the fit to the gain vs. applied ΔV
***N₀*** from GARFIELD++ simulation
***r*** radius of the X-rays spot
***d*** average distance to the ground



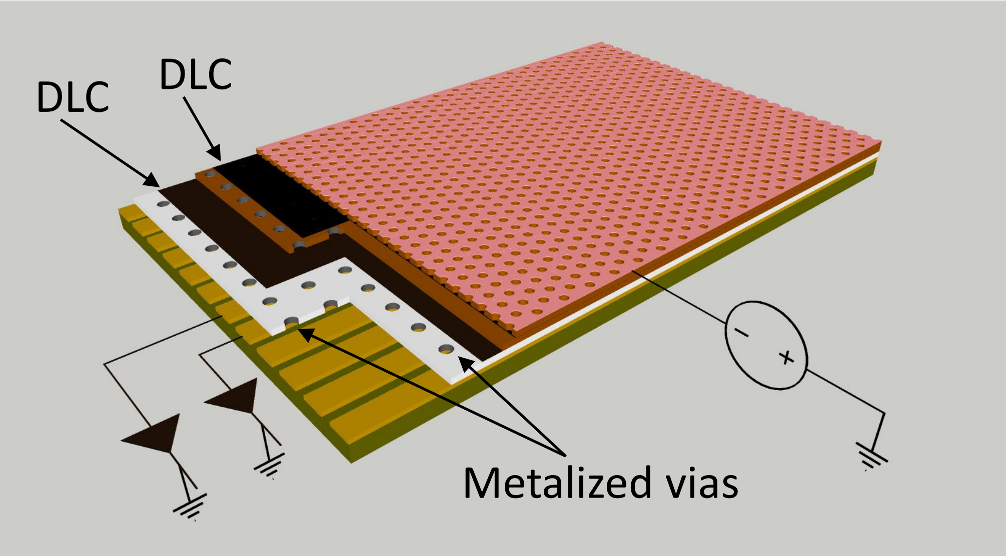
# The μ-RWELL technology: the evolution

The **parameter *d*** becomes foundamental to produce detector for high rates purposes
An extensive R&D has been conducted to optimize the DLC grounding to make the detector stand up to several MHz/cm$^2$




**S**ingle **L**ayer

- Single DLC layer
- Large *d* (~active area size)
- Low rate purposes (up to 100 kHz/cm$^2$)
- Easy for industry




**D**ouble **L**ayer

- Stack of DLC foils inteconnected by a matrix of conductive vias
- *d* ~1 cm
- High rate purposes (>10MHz/cm$^2$)
- Complex manufacturing

...

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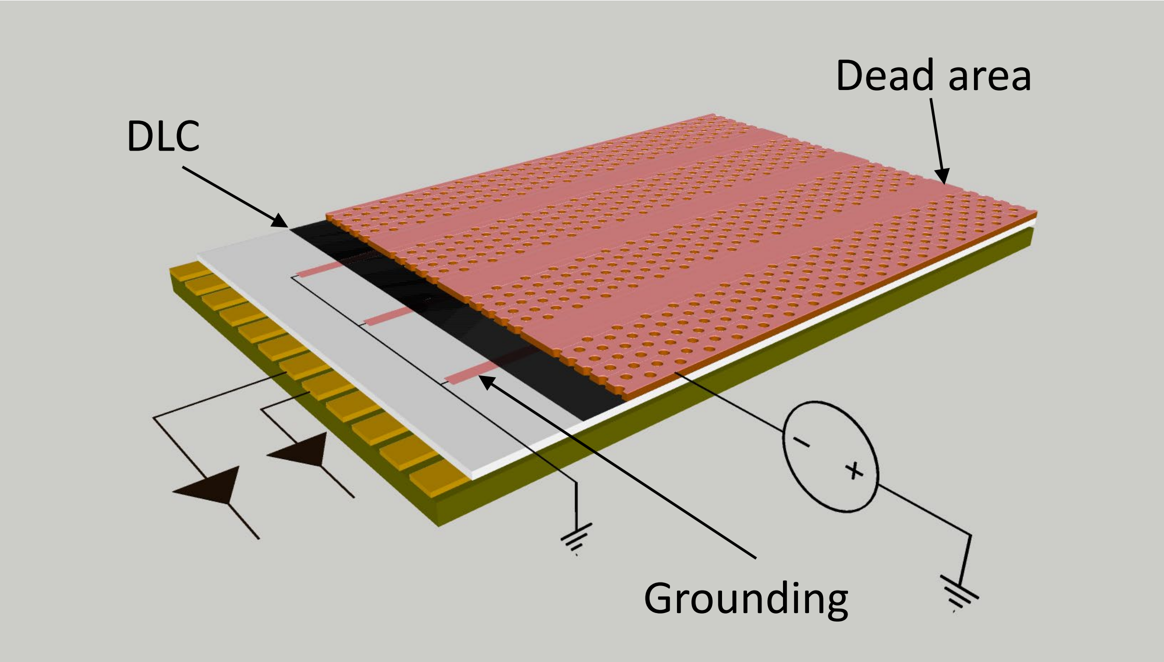
… 

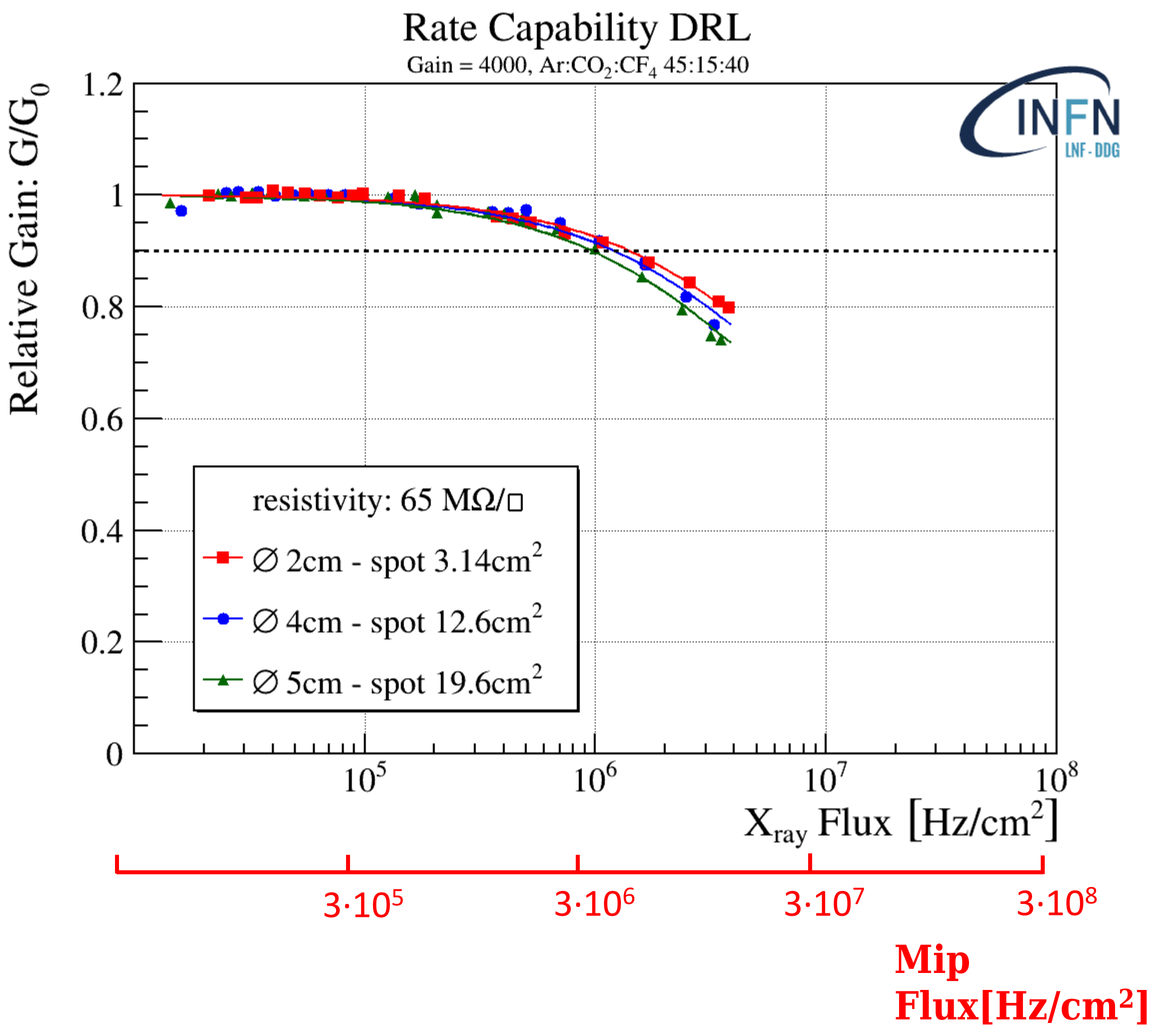
…

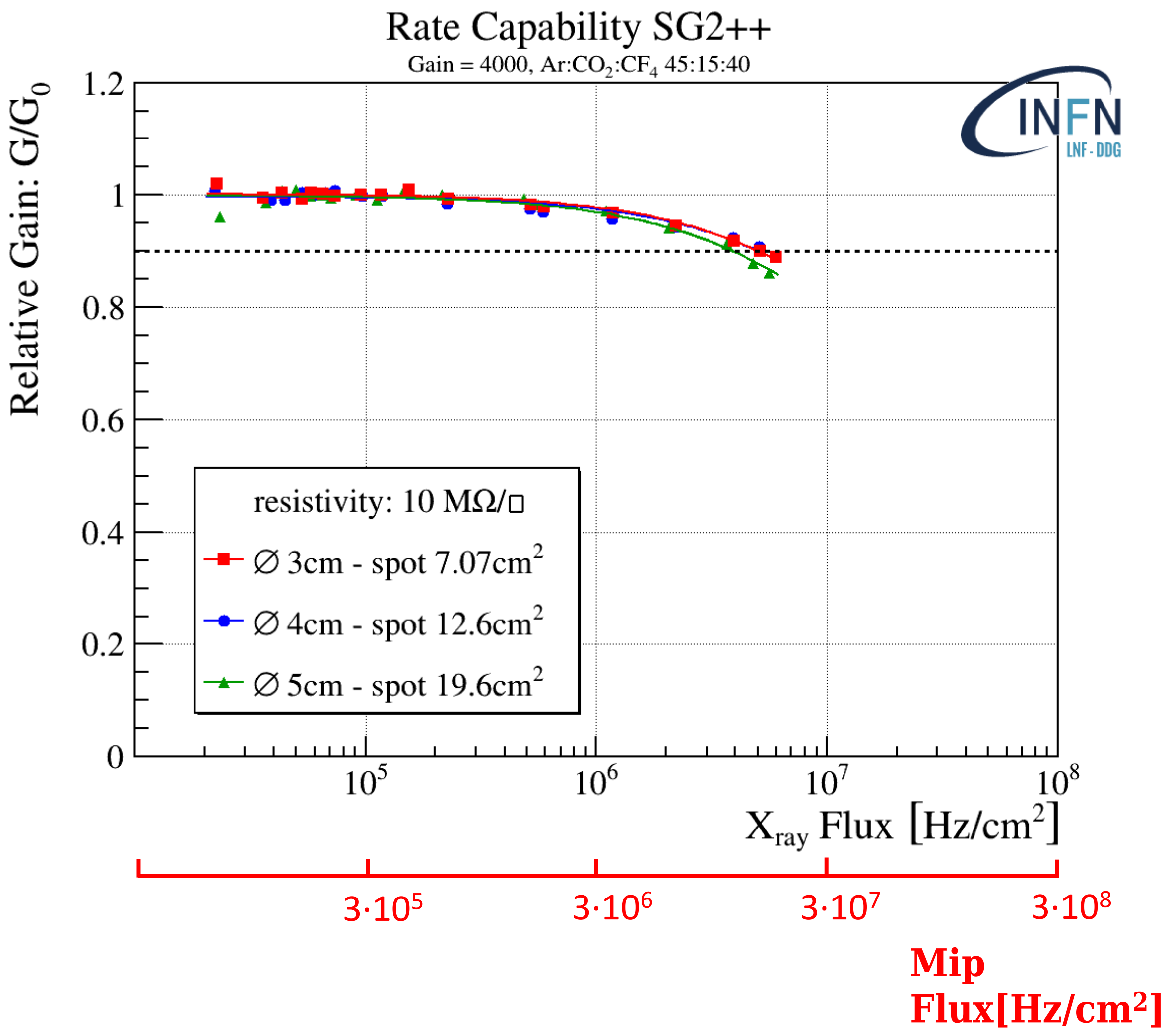
**S**ilver **G**rid

- DLC grounded by coated Cu strips below
- d ~1 cm
- High rate purposes (>10MHz/$cm^2$)
- Complex Cu+DLC sputtering; difficult alignment of the grounding lines with the dead areas on the top of the amplification stage (expecially for large size detector)

# High-rate layouts: performance with X-rays

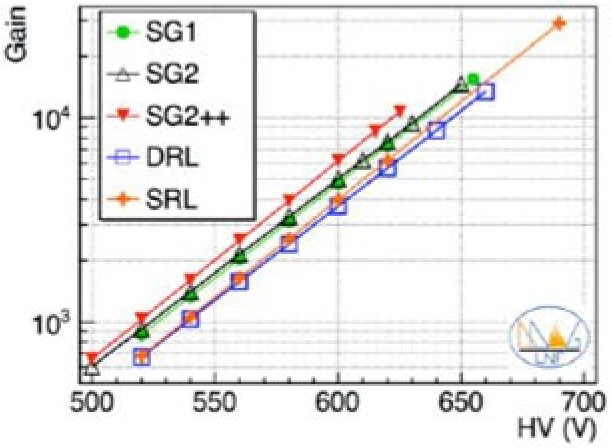
Energy of X-rays: 5.9 keV; ionization three times larger than a Mip in 6 mm gas gap



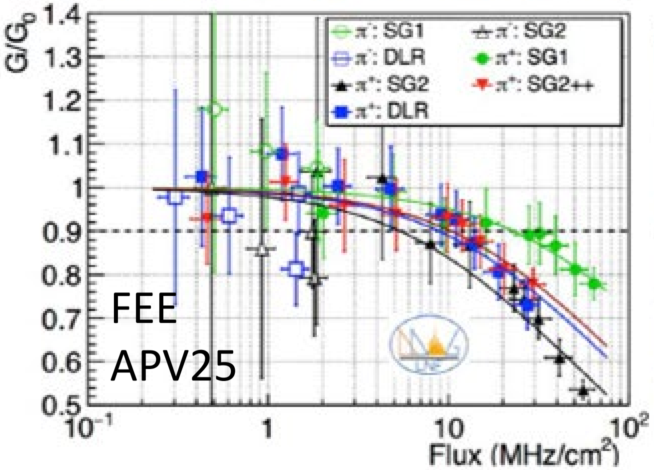



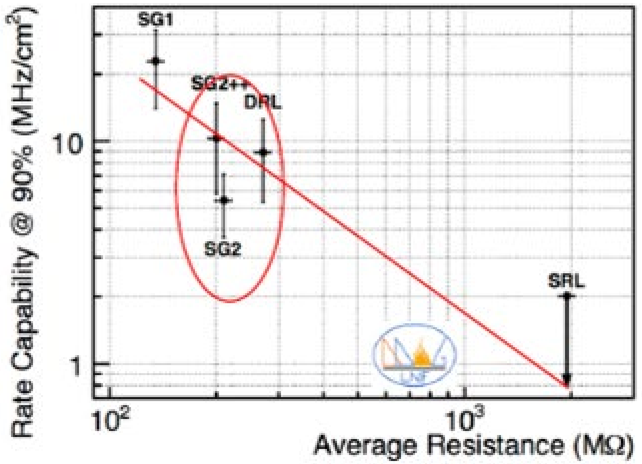
# The µ-RWELL techology: measurements

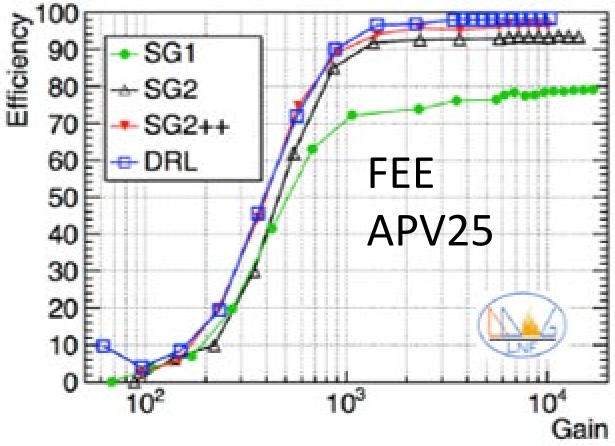
Gain up to ~ $10^4$

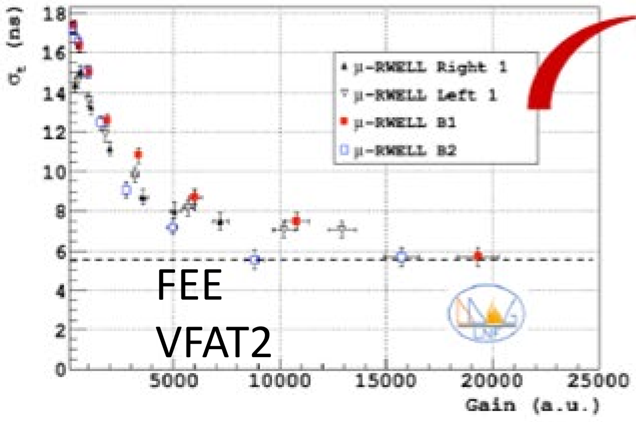


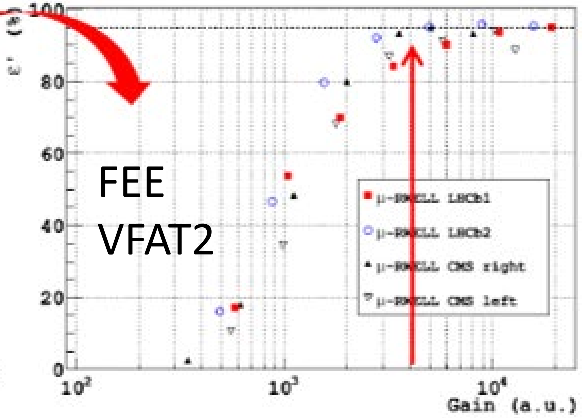

Rate capability (@ G = 5000) ~ 5-10 MHz/cm$^2$



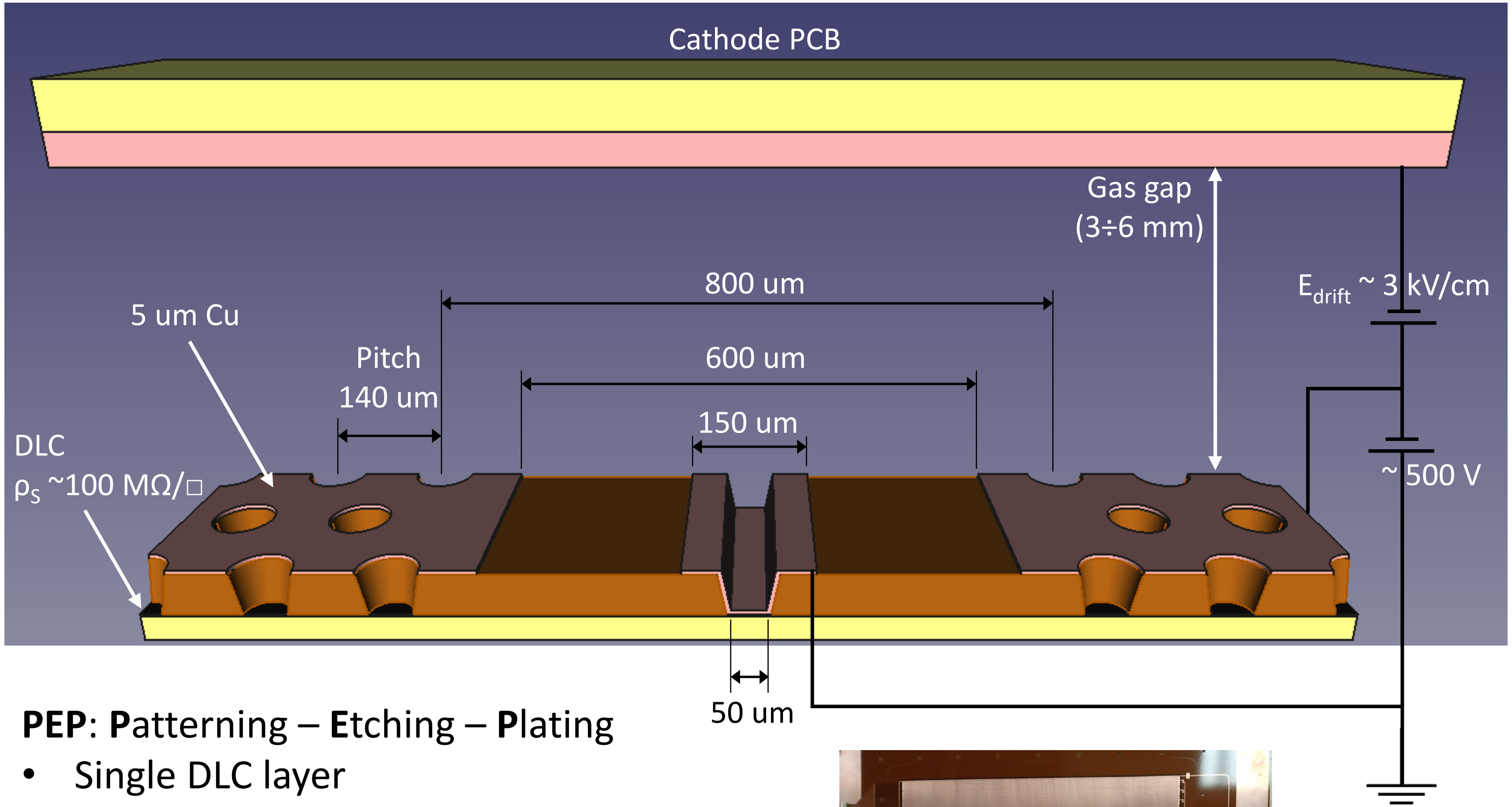

Efficiency ~ 98%

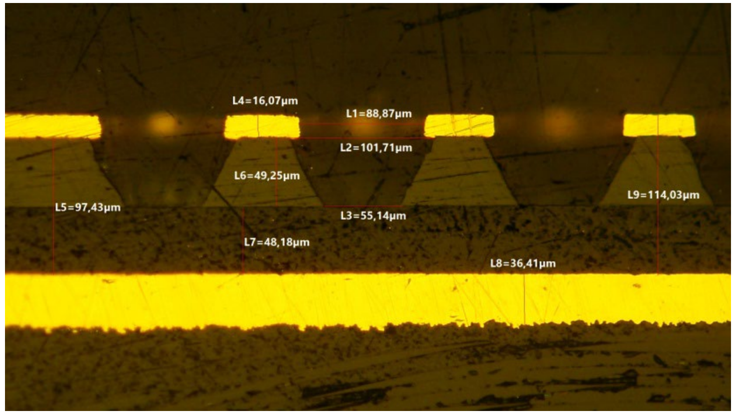
$\sigma_t$ ~ 5-6 ns

Efficiency in 25 ns

2020 *JINST* **15** C09034

# The µ-RWELL technology: the evolution




Geometrical PARAMETERS

| Layout | GND pitch [mm] | Dead Area [mm] | DOCA [mm] | Geom. Acceptance |
|---|---|---|---|---|
| PEP1 | 6 // 8 | 1 | 0.475 | 66% |
| PEP2.1 | 8.9 | 0.8 | 0.375 | 91% |
| PEP2.2 | 17.8 | 0.8 | 0.375 | 95.5% |

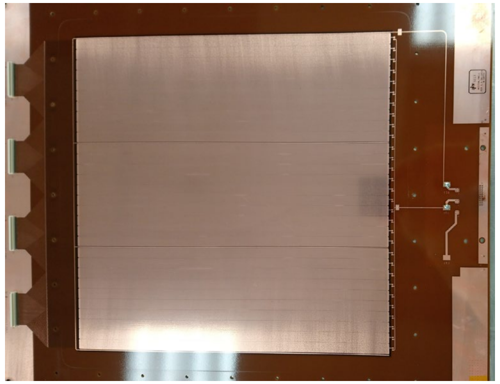
DOCA (Distance of Closest Approach): the minimum distance between a grounding line and an amplification channel.

**PEP**: **P**atterning – **E**tching – **P**lating

- Single DLC layer
- Grounding from top by Cu and kapton etching and plating
- No alignment problems
- Scalable to larger sizes

**Present prototype: 30 x 30 cm²**

**In construction 50 x 50 and 150 x 50 cm²**

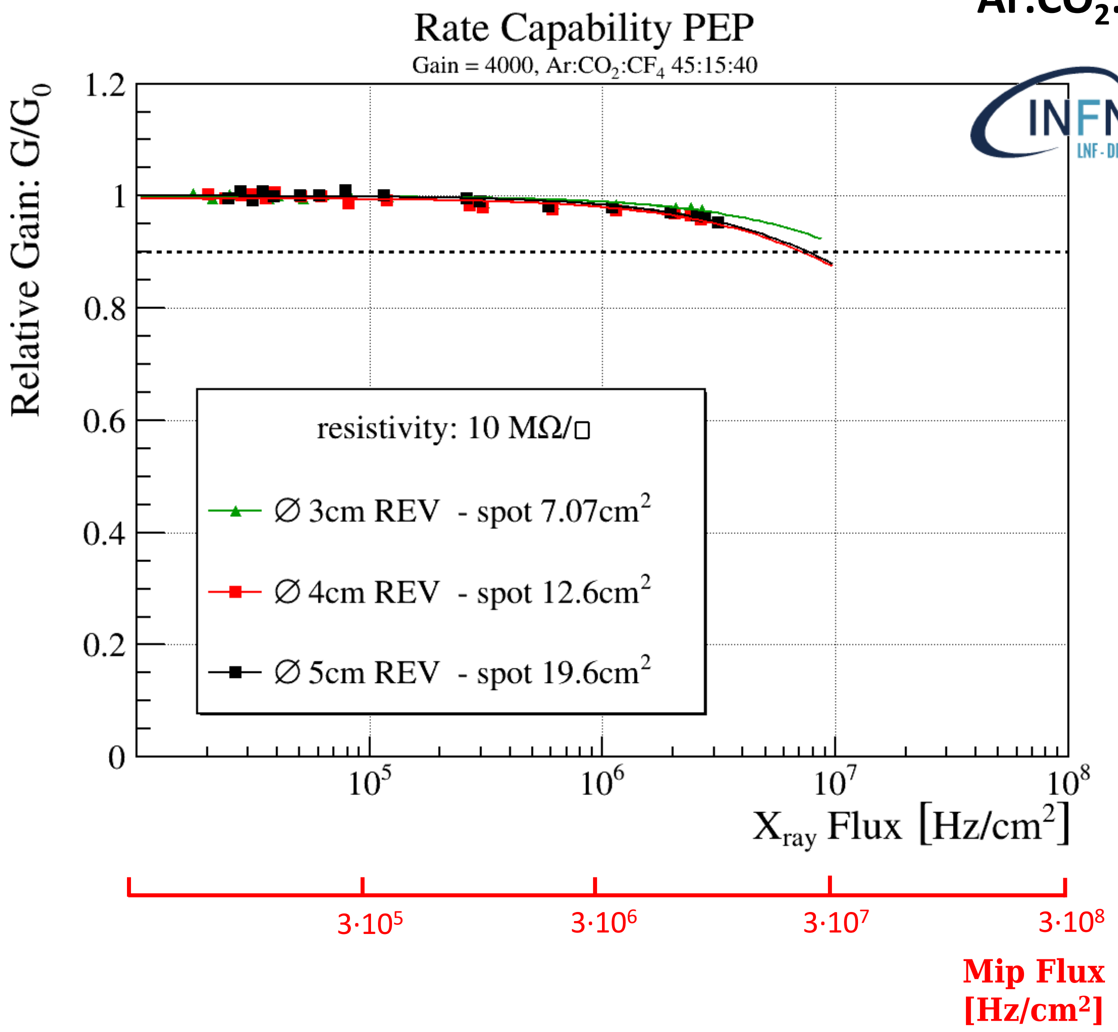


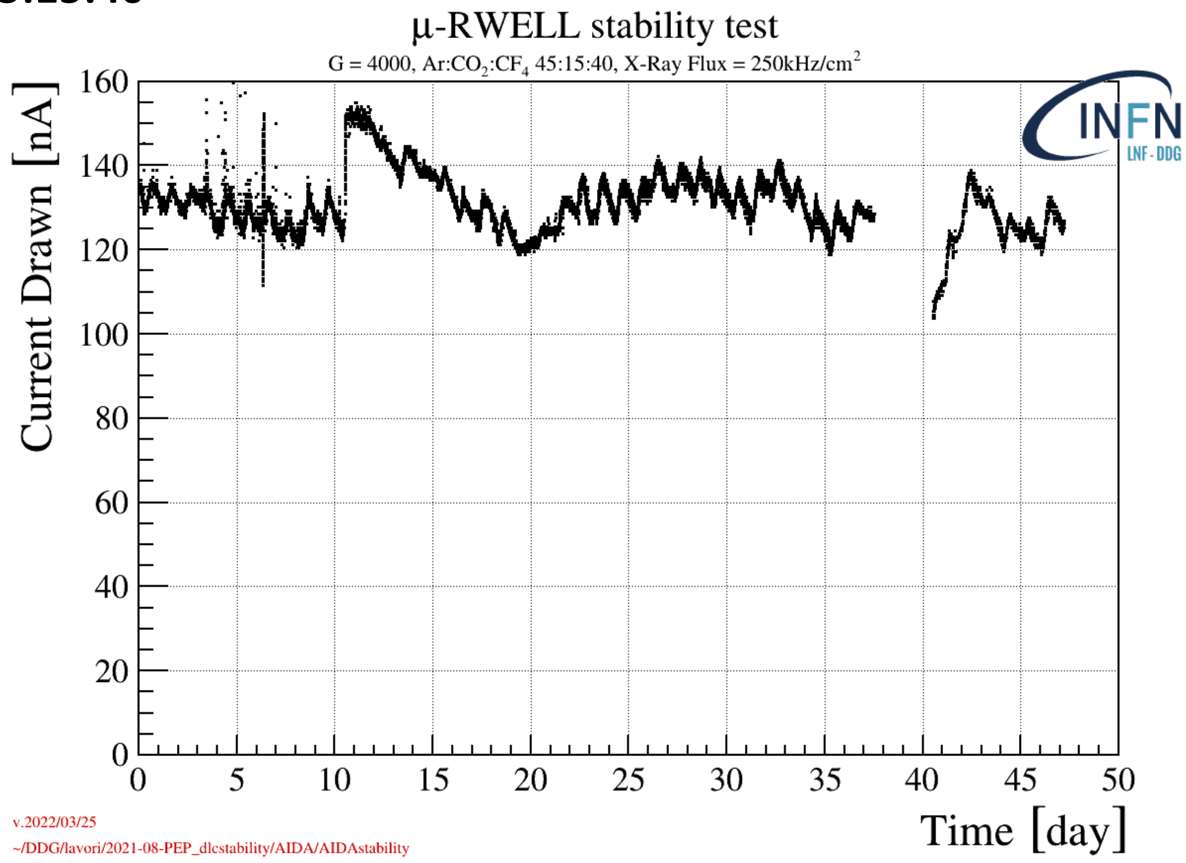
ACTIVE AREA
30 x 30 cm²

**Suitable for large size apparatuses**

# The µ-RWELL technology: X- rays measurements

**Ar:$CO_2$:$CF_4$ 45:15:40**

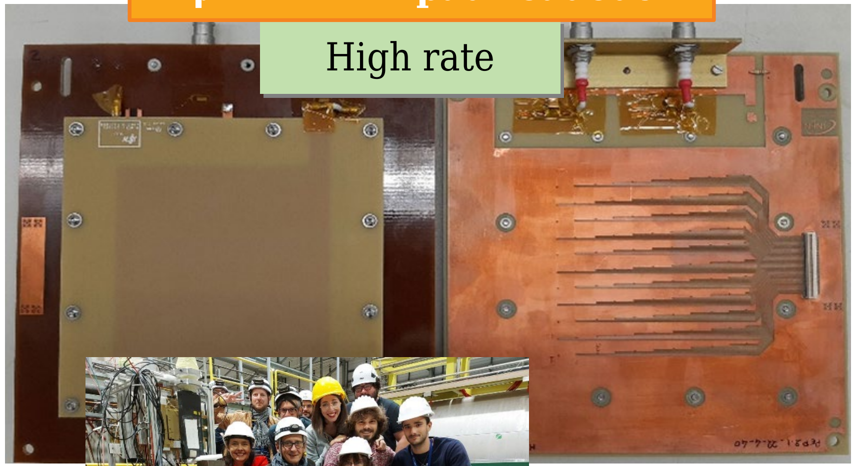


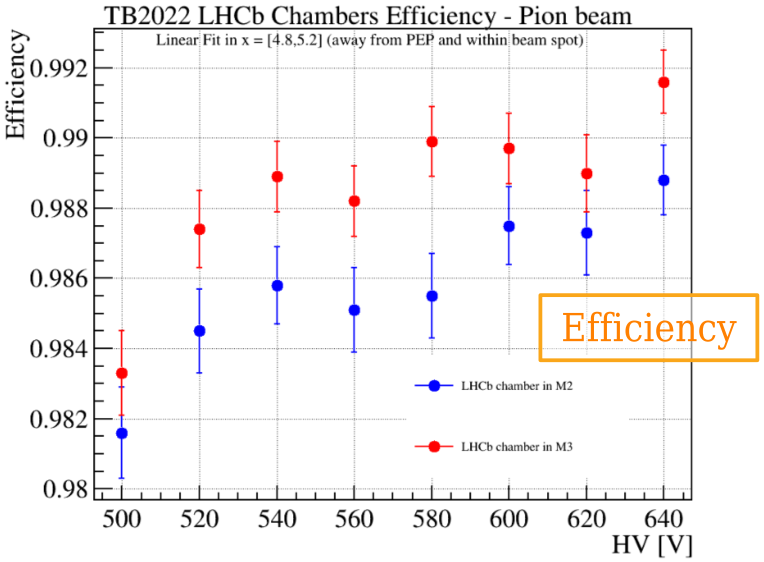



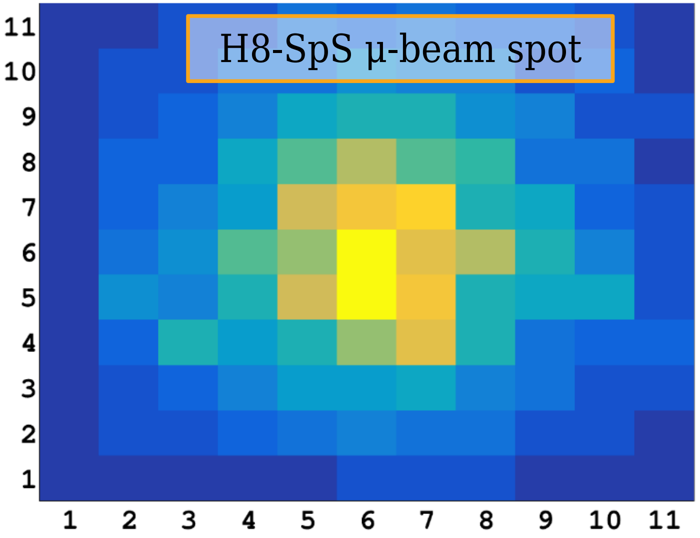
# The μ-RWELL technology: beam tests measurements

**μ-RWELL - pad readout**

High rate

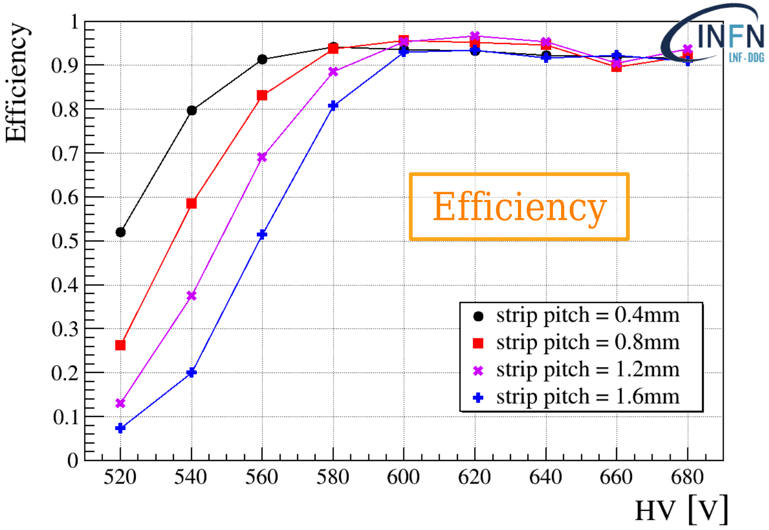


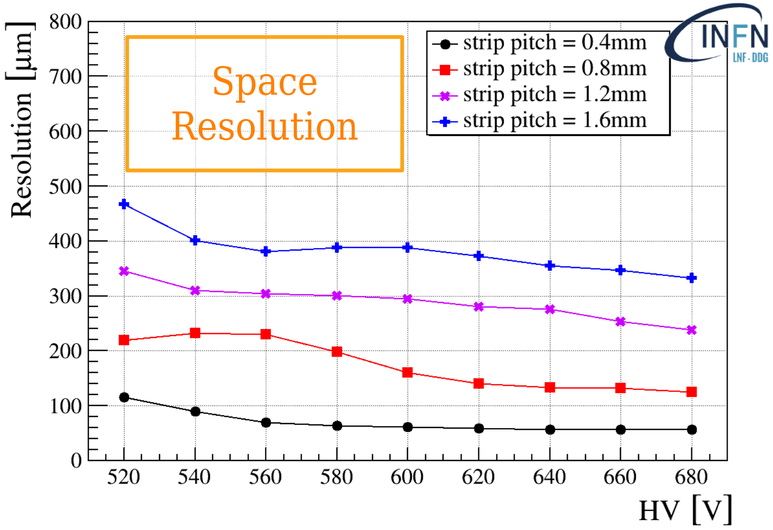



**μ-RWELL - 1D readout**

Tracking

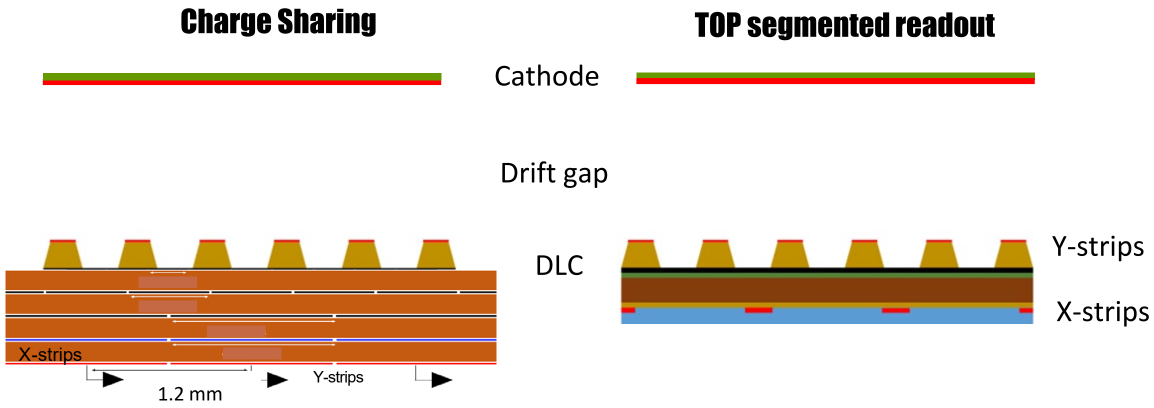


# The µ-RWELL technology: beam tests measurements

In view of experiments at future colliders, 2D readout have been implemented
Two layouts are under study:

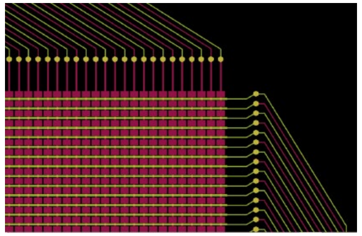
## 2 layouts for 2D readout

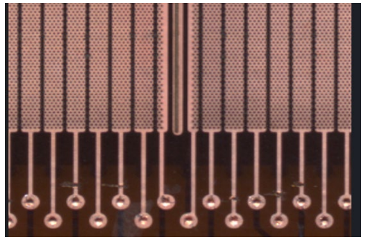


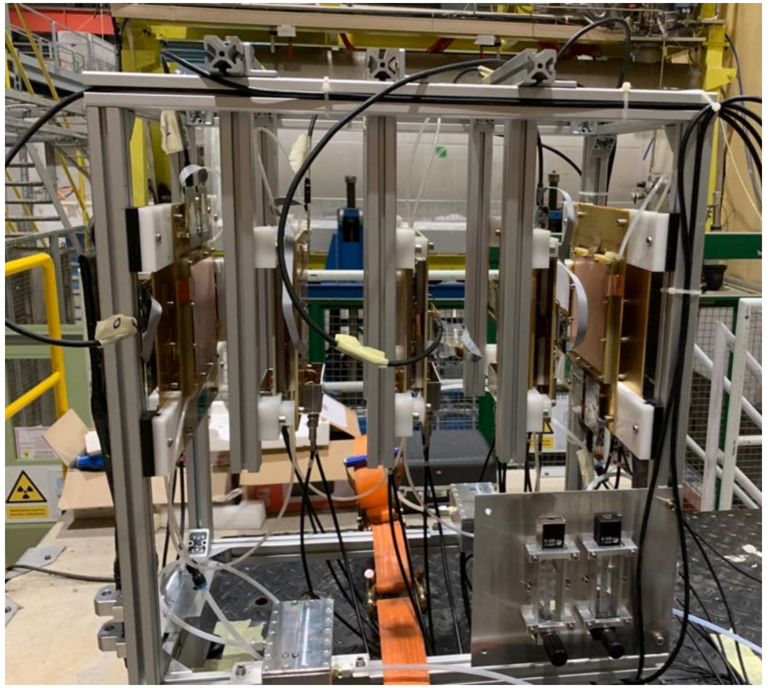

The signal propagates by capacitively couplings to the planes each containing one set of strips

The copper layer of the amplification stage is segmented and connected to the FEE: the signal induced by ions is then recorded

Readout board

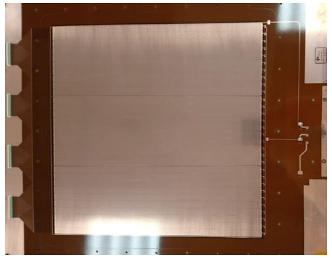
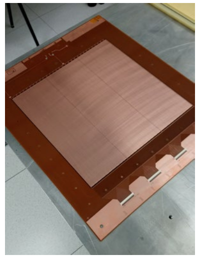






Beam test done in June 2023, the analysis is ongoing

# The µ-RWELL technology: TT

**Need for industry!!!**

The three stages are embedded in a single PCB, produced by **standard ridig-flex PCB manufacturing (even involving mixed multi-layer).**

MEMENTO:
Amplification stage +
Resistive stage +
Readout plane =
**µ-RWELL_PCB**

**Start!**

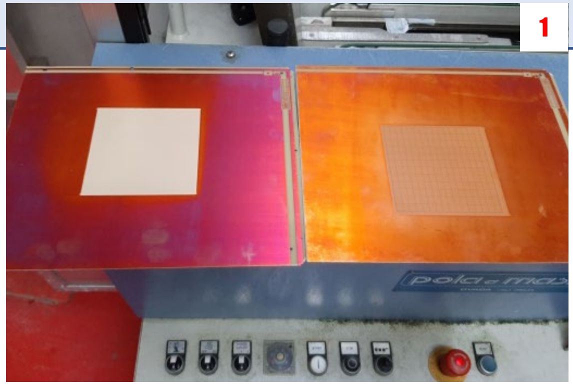
INFN LNF Istituto Nazionale di Fisica Nucleare

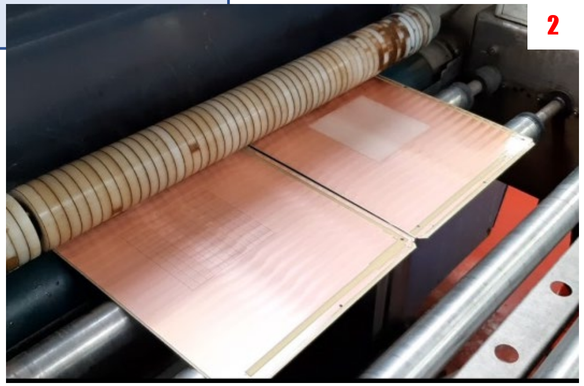
AIDA innova EU-project;

µ-RWELL techn. transf.

ELTOS

PCB production






DLC sputtering know-how

DCL foil prod.*

CERN

INFN Istituto Nazionale di Fisica Nucleare

**Completed µ-RWELL_PCB shipping**

CERN

Detector manufacturing

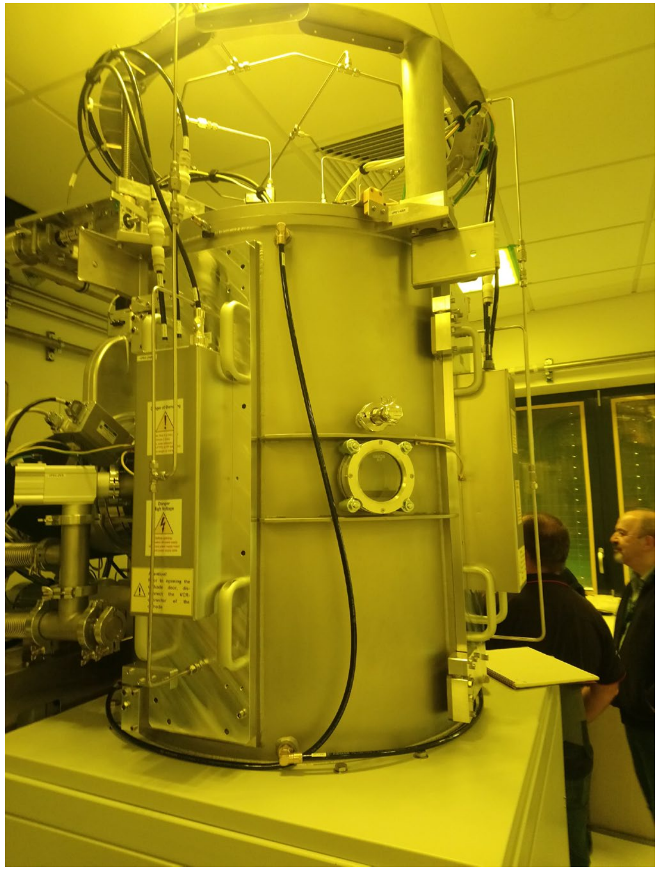
PCB shipping

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

# The Magnetron Sputtering Machine at CERN

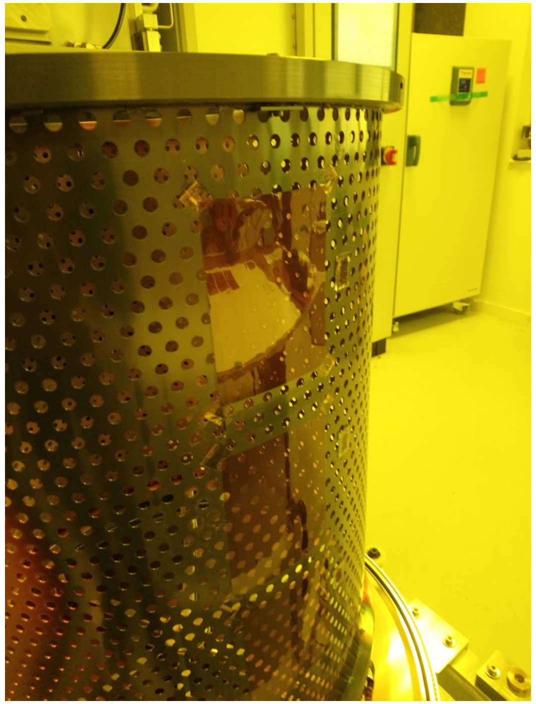
A Magnetron Sputtering Machine has been co-funded by CERN and INFN

An extensive test campaign has just started in June 2023 to understand the parameters of the operation of the machine (plasma pressure, deposition time, percentage of doping component in the plasma, etc.)



Vacuum chamber

The drum is installed on a trolley and once the substrate is fixed it is lifted inside the vacuum chamber



Each test has been performed on three kapton samples sticked on the supporting drum

This will allow to speed up the production of the detectors

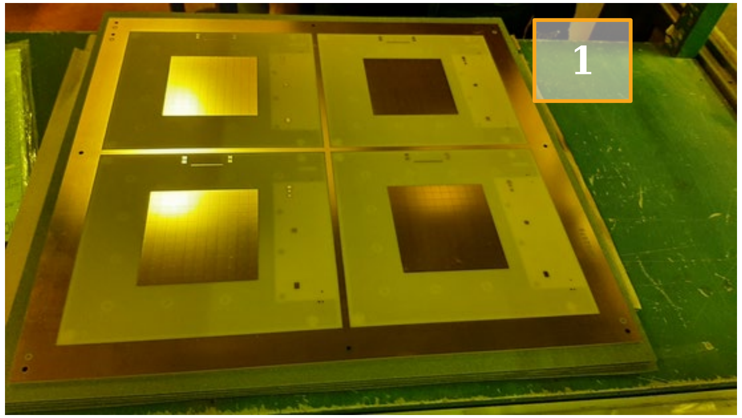
# Mar. ‘23: ELTOS production

**PCB** production

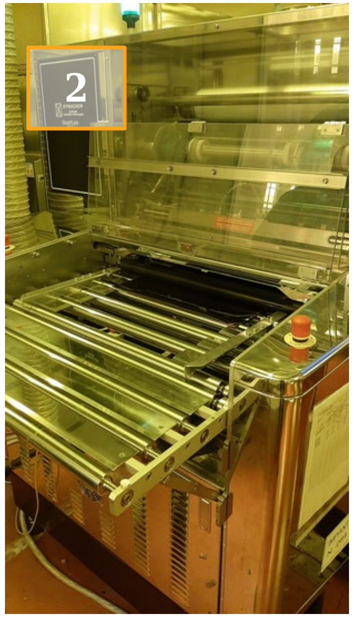
Photoresist **lamination** for DLC protection

Photoresist **development**

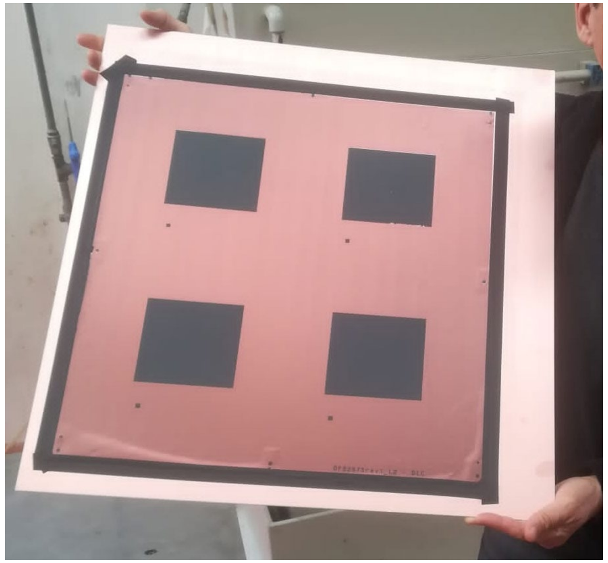
**DLC patterning** with brushing machine
(@CERN different approach: JET-SCRUBBING)





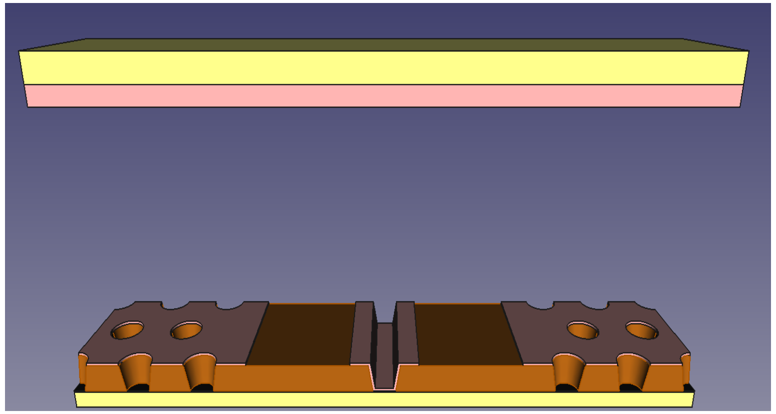


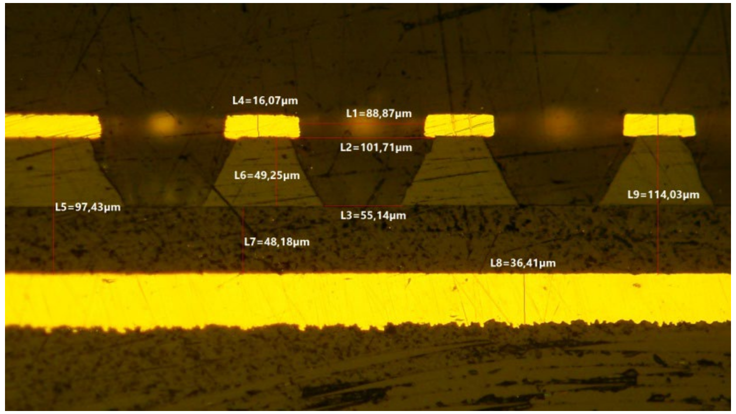


# Summary & outlook

- The **micro-Resistive WELL** is a recent MPGD suitable for **large area applications** (i.e. experiments at future accelerators)
- The most recent version of **the detector fulfills the requirement** on the rate capability
- Due to the relative simplicity of the technology, **the technology is being trasferred to the industry** for the mass production



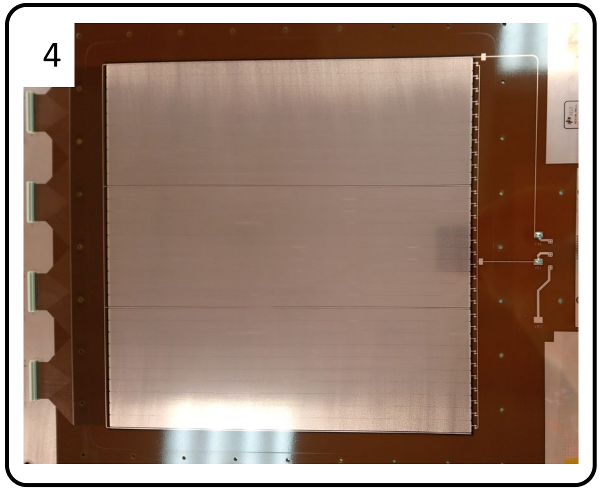


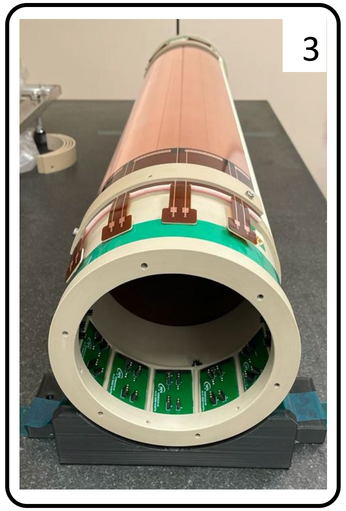

- Stability tests (X-ray, gamma/neutron irradiation)
- Mechanical improvement of some detector components (i.e. replacing FR4 with PEEK)
- TT to be continued with ELTOS company
- Extensive tests on the Magnetron Sputtering Machine

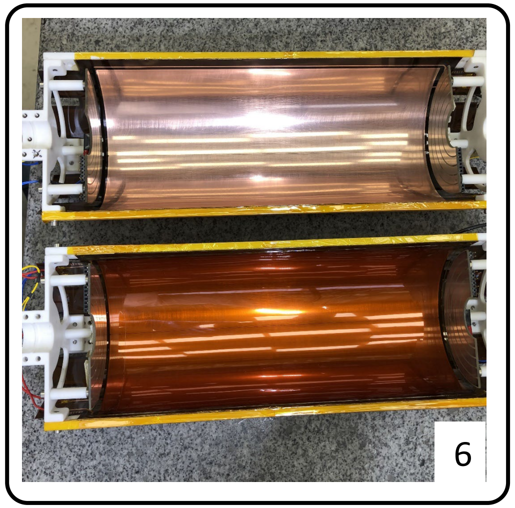
# Addendum

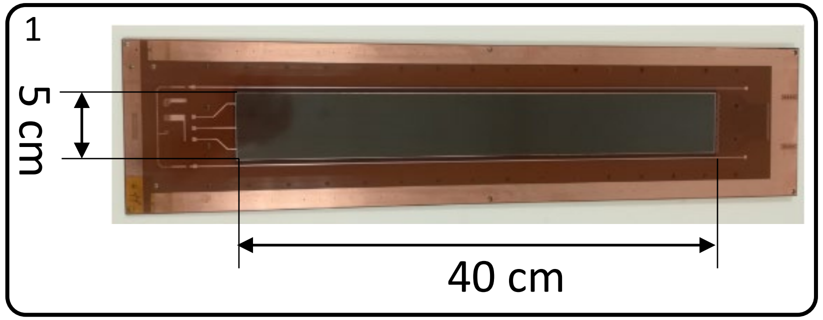
The micro-Resistive WELL is involved also in

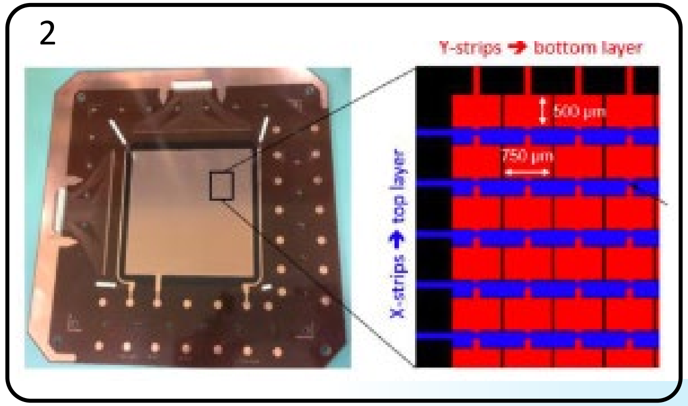
1. **LHCb**: replacing the MWPC that cannot stand with high particle rates foreseen in run 5 and 6
2. **CLASS12** @ JLAB: the upgrade of the muon spectrometer
3. **EURIZON (under EU approval)**: the Inner Tracker based on cylindrical micro-RWELL for a super Charm-Tau factory (coll. with LOSON S.r.l)
4. **X17 @ n_TOF EAR2**: for the amplification stage of a TPC dedicated to the detection of the X17 boson
5. **UKRI:** neutron detection with pressurized $^3$He-based gas mixtures
6. **TACTIC @ YORK Univ.:** radial TPC for detection of nuclear reactions with astrophysical significnace
7. **URANIA-V**: a project funded by CSN5 for neutron detection, an ideal spin-off of the EU-founded ATTRACT-URANIA
8. **Muon collider:** hadron calorimeter

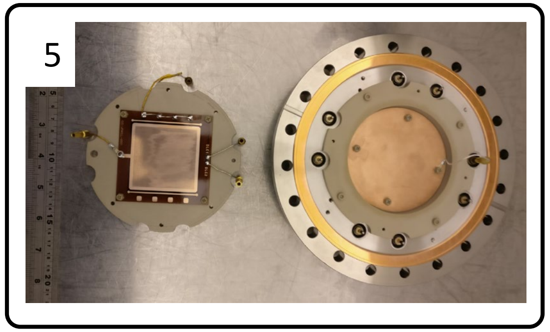


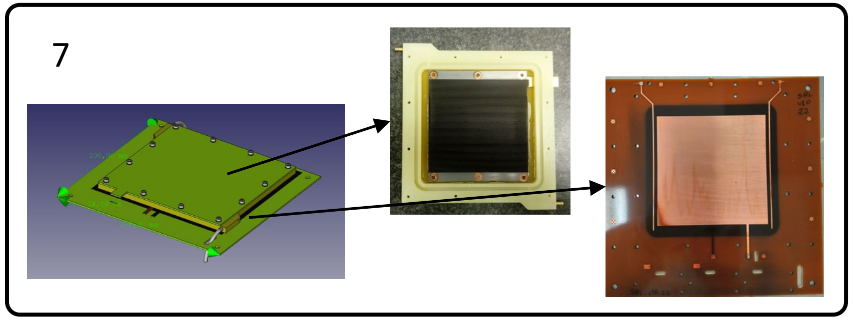



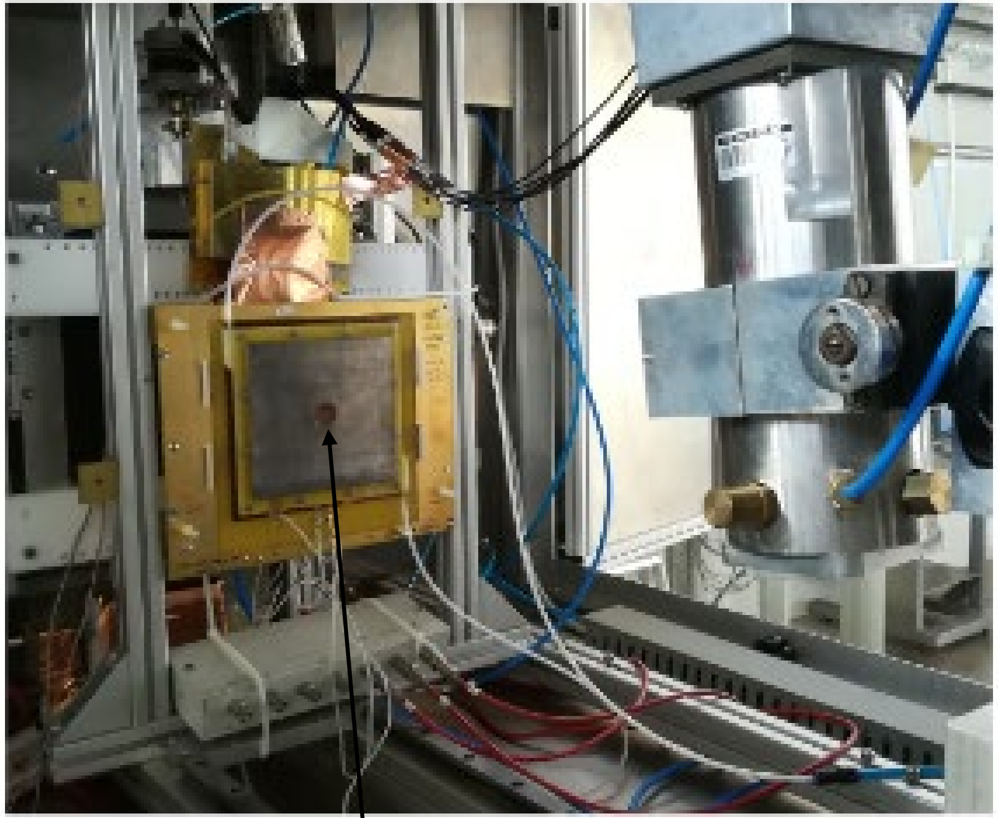



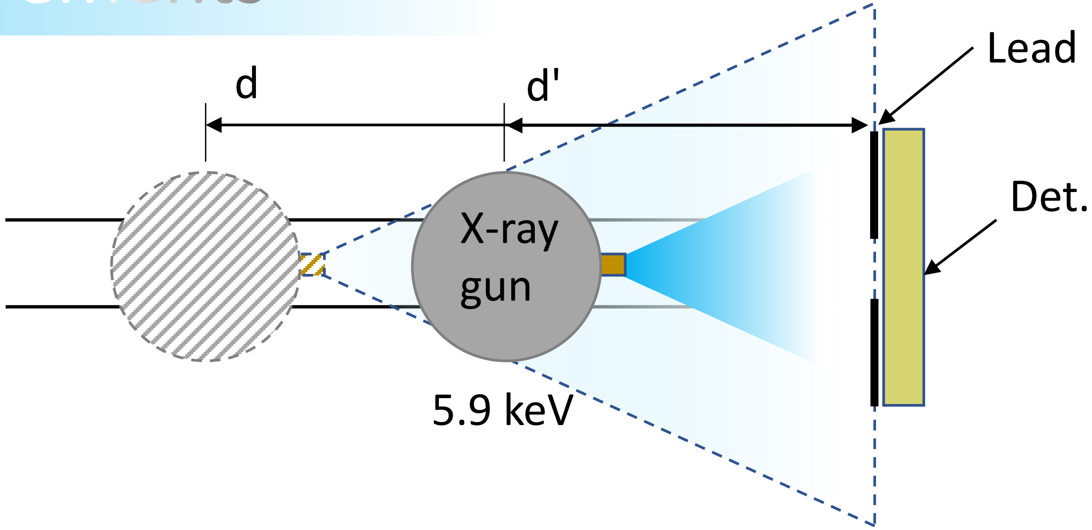



SPARE

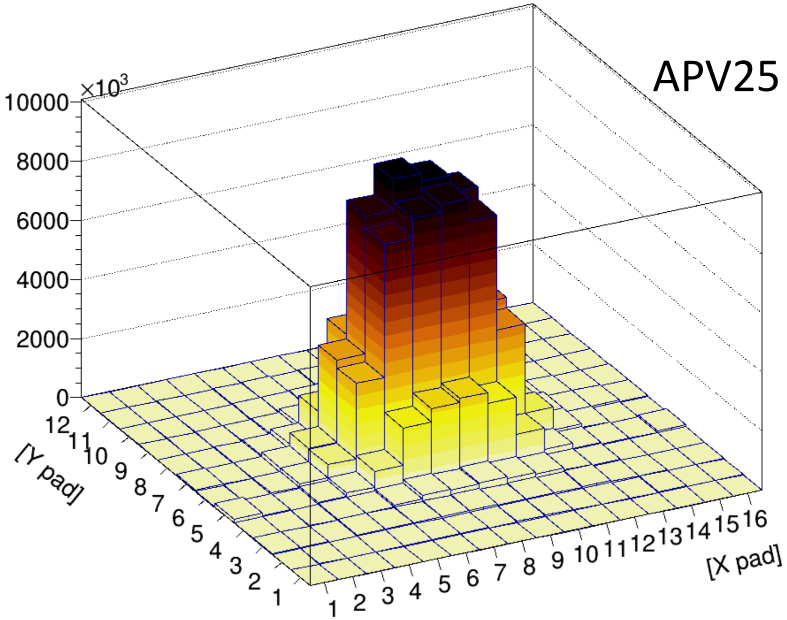
# The µ-RWELL technology: X- rays measurements

Setup





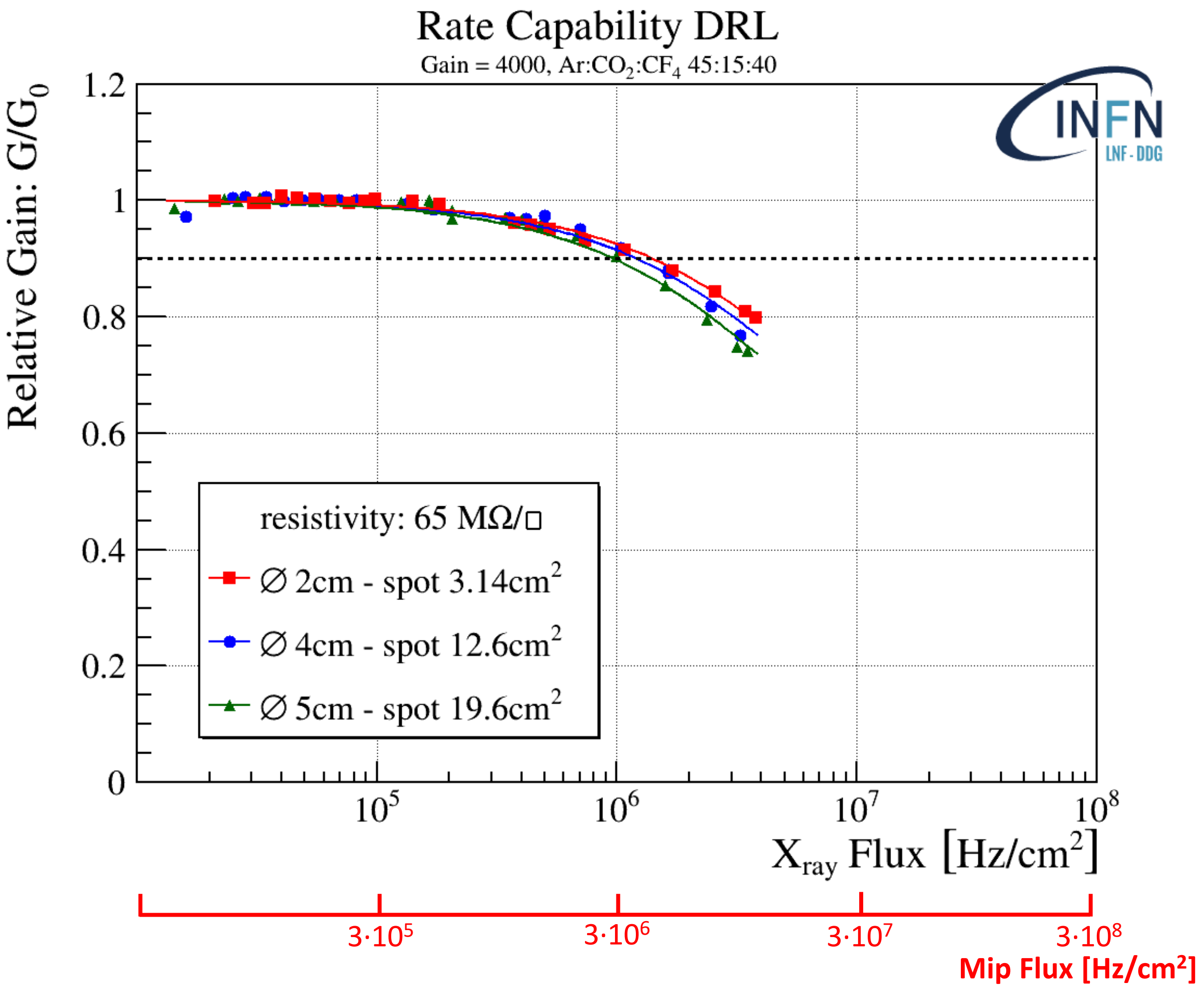

Gun installed on rail to **change the distance** from the detector → to **change the X-rays rate**

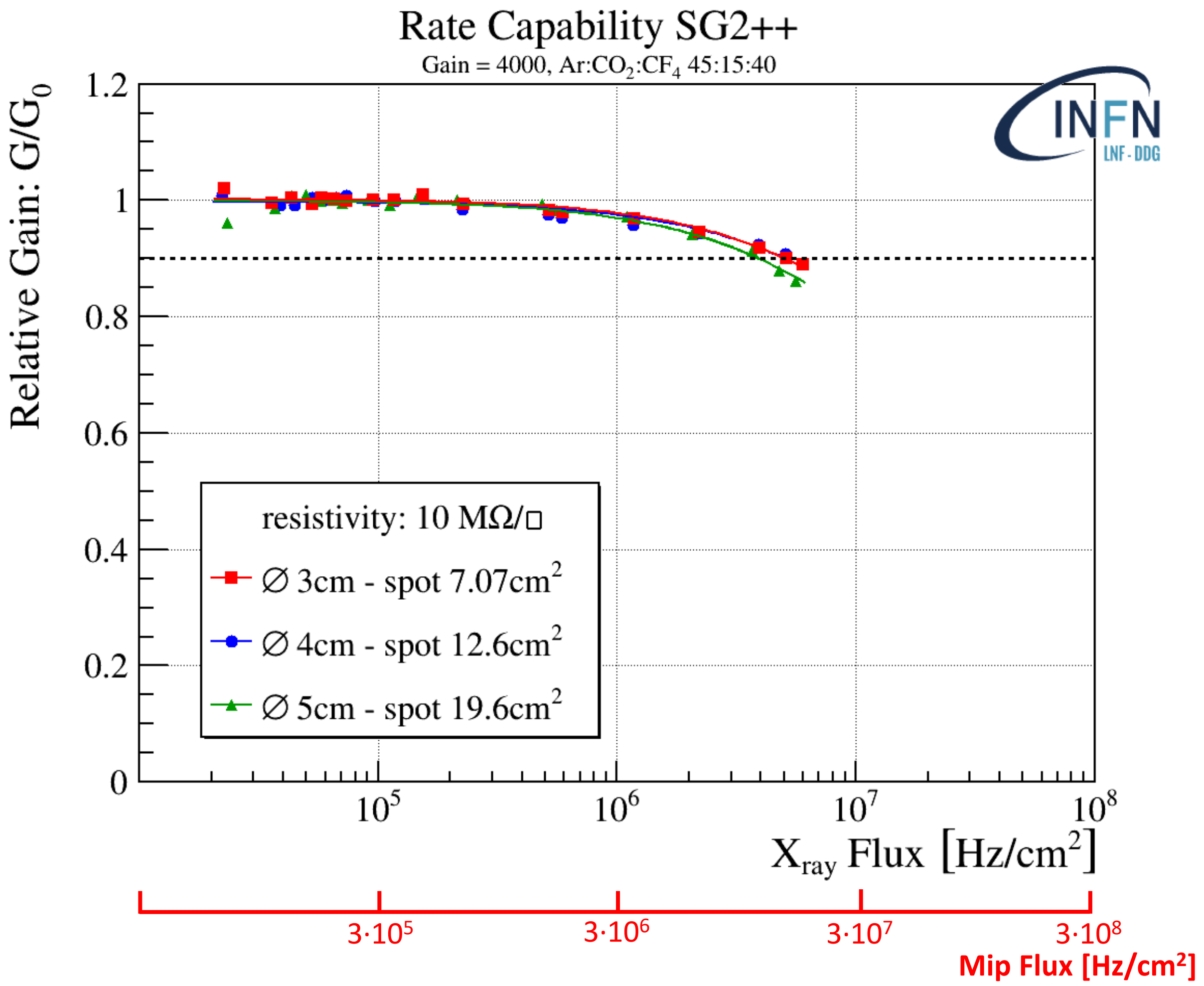



Spot nearly uniform on the irradiated area

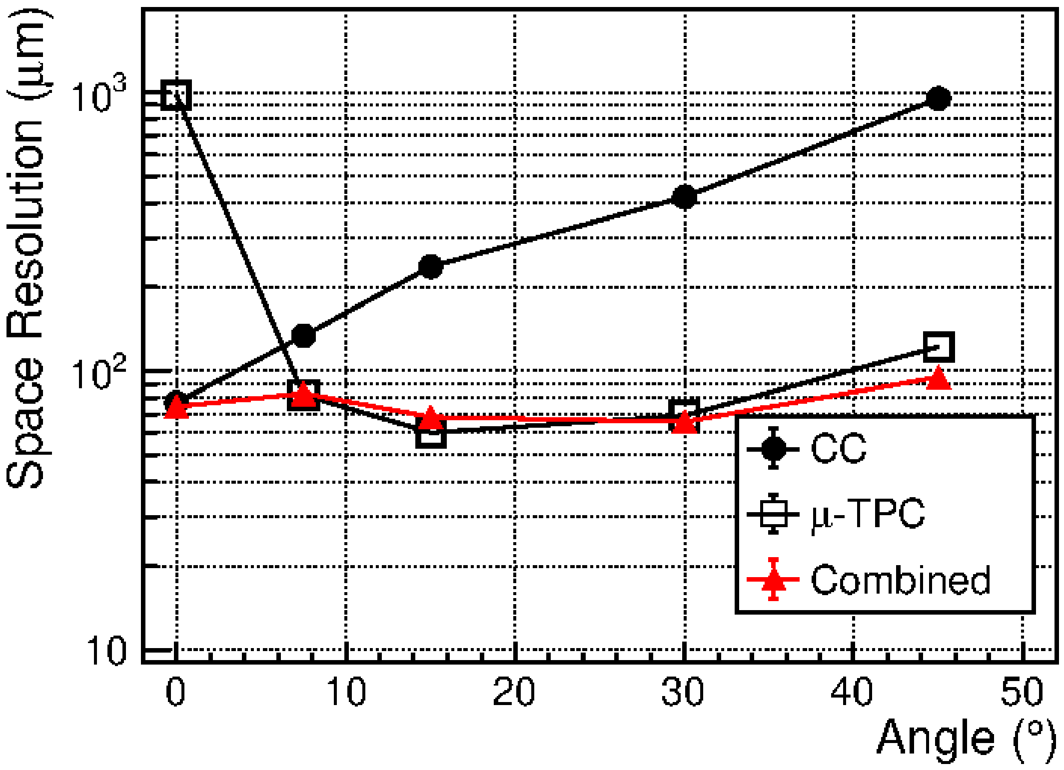
A lead square shielding, with length **L larger than the active area** and a circular window (*r*) is plugged on the cathode where ***r*** is **larger than the grounding pitch**.
The thickness of the lead is 1 mm (~ 500 $X_0$)

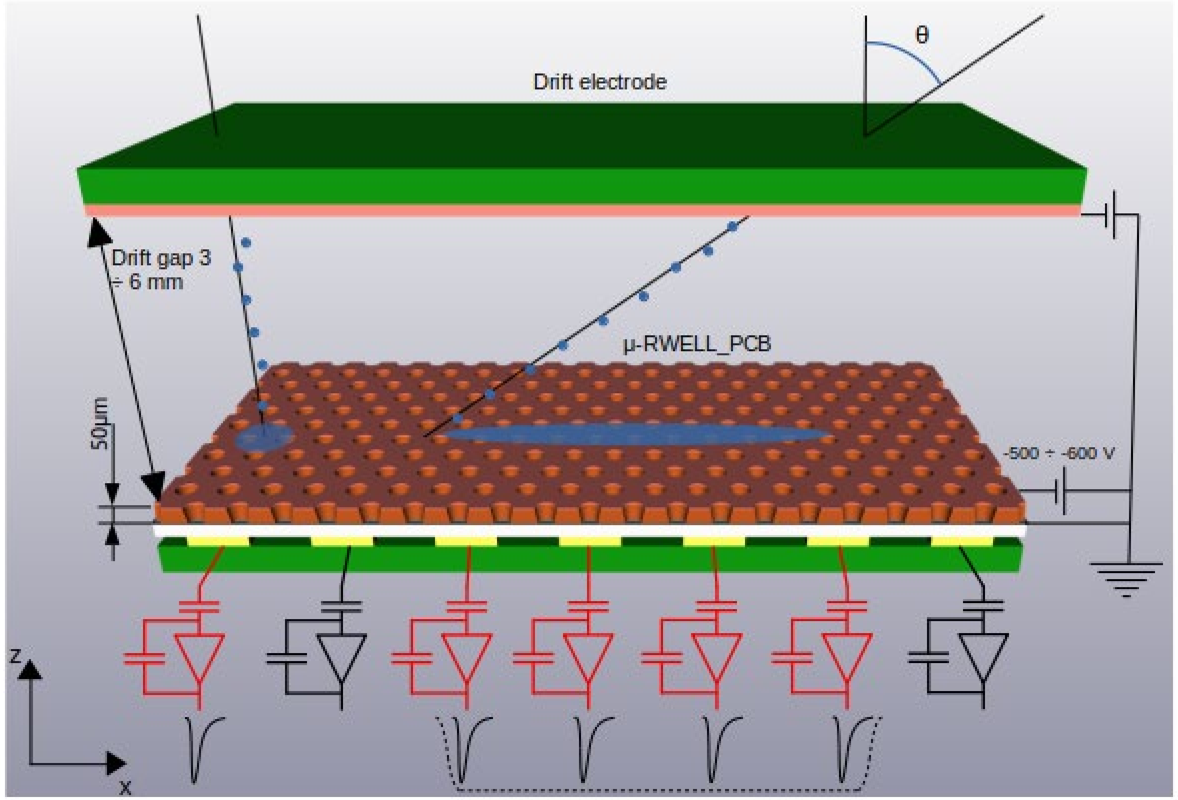
# The μ-RWELL technology: X- rays measurements



# The µ-RWELL techology: measurements

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# µ-RWELL operation in $^3$He based gas mixtures

## Aim

- Neutron scattering applications
- Small area (100x100mm$^2$)
- High Efficiency(>70% at 25meV)
- High Position resolution (<0.5mm FWHM)

- Stopping gas to stop the range of the proton and triton of the reaction

$$n + {}^3He \rightarrow {}^1H + {}^3H + 770\ keV$$

- Measurements of the gain with a gas mixture containing 1 bar of $^3$He and 1 to 6 bar of $CF_4$
- To date only MWPC and MSGC could operate at those gas pressures


Science and Technology Facilities Council

ISIS Neutron and Muon Source

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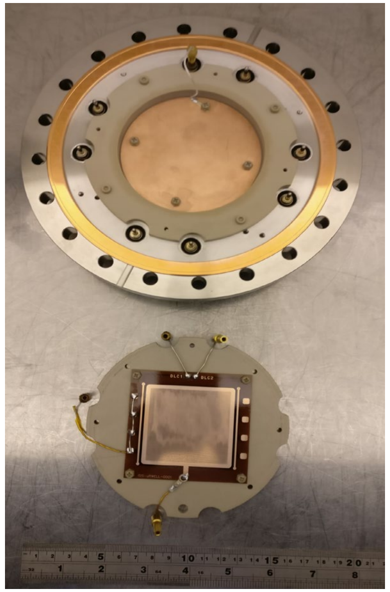
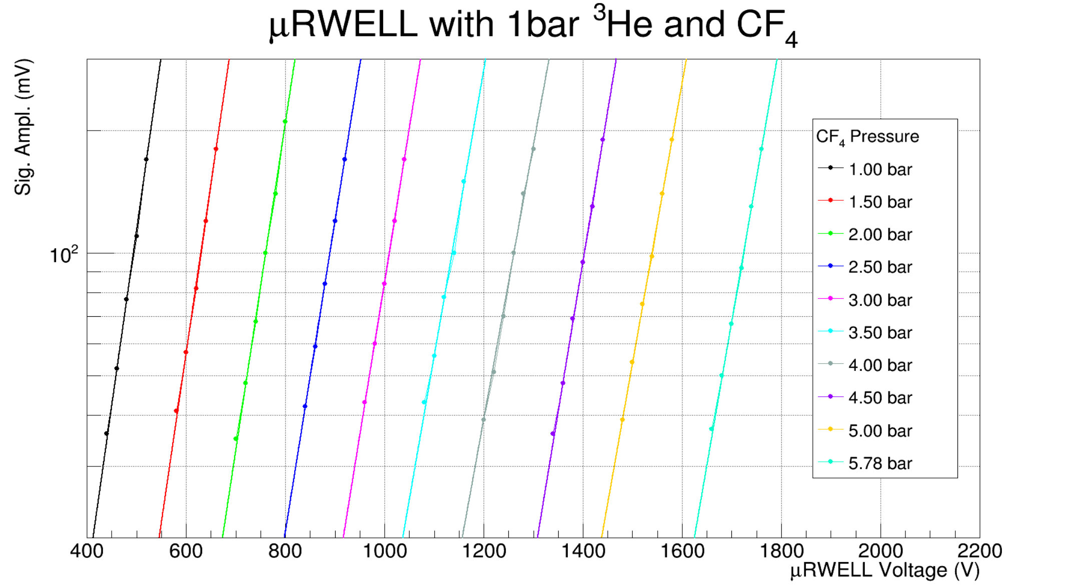
## Setup

- 50x50 active area
- Active volume 16mm thick
- Sealed vessel

  (up to 7bar pressure)
- Neutrons from AmBe Source

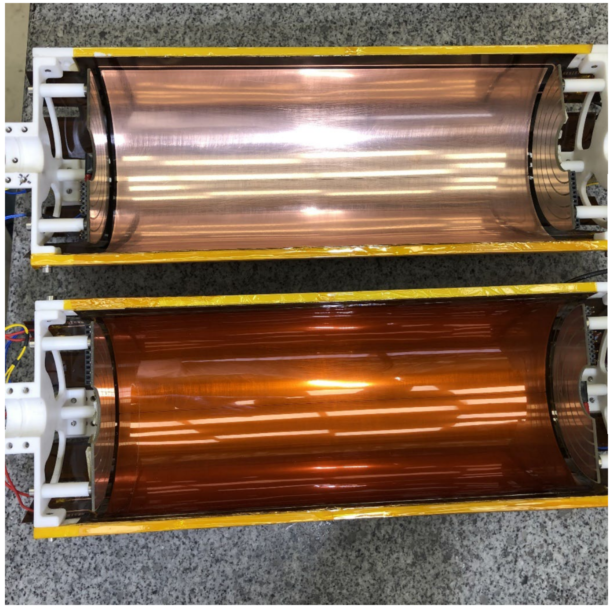


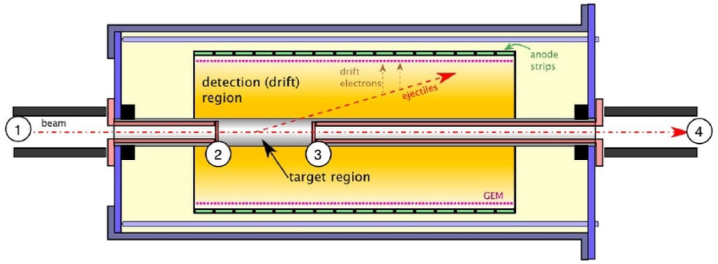


# μ-RWELL for TACTIC

**T**RIUMF **A**nular **C**hamber for **T**racking and **I**dentification of **C**harged particles

- Active-target detector with cylindrical geometry designed to study nuclear reactions with astrophysical significance
- Aims at efficient small reaction cross-section measurements at low energies
- Will use μ-RWELLs in a **curved cylindrical geometry** for detection of various reactions products of interest with a range of energies (tens of keV to few MeV)
- Total length of detection region (shaded yellow): 251.9 mm and radius: 53 mm
- μ-RWELLs are currently installed inside and first alpha signals were seen. Future tests with reference sources and with a stable beam are planned.






**TEST**

- Time projection chamber with planar geometry
- Test chamber dimensions: 150 mm x 480 mm x 120 mm
- Distance between cathode and μRWELL surface (drift gap): 30 mm
- μ-RWELL active area dimensions: 35 mm x 251.85 mm; μ-RWELL overall dimensions: 336 mm x 80 mm; Foil thickness: 0.2 mm
- Anode is segmented into 60 pads of width 4.2 mm
- Designed to test MPGDs and electronics for TACTIC