59th International Winter Meeting on Nuclear Physics

The µ-Resistive WELL in HEP and beyond

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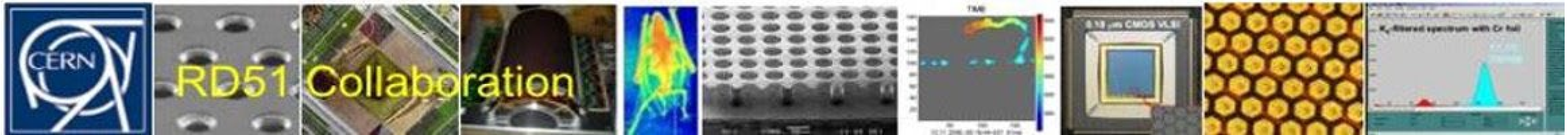
1. LNF
2. CERN

Bormio, January 27th 2023



The µ-RWELL technology at a glance

Developed in collaboration with CERN-EP-DT-MPT workshop

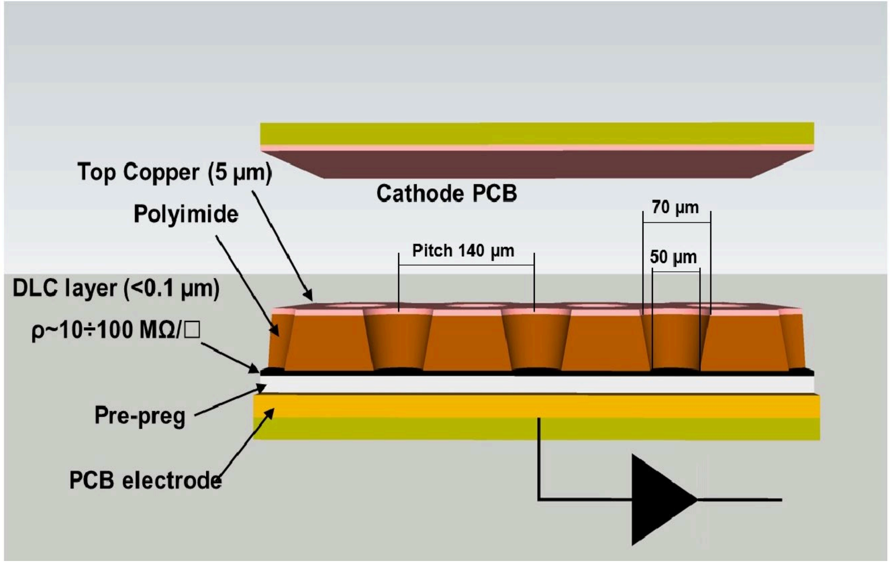
The features can be summarized:

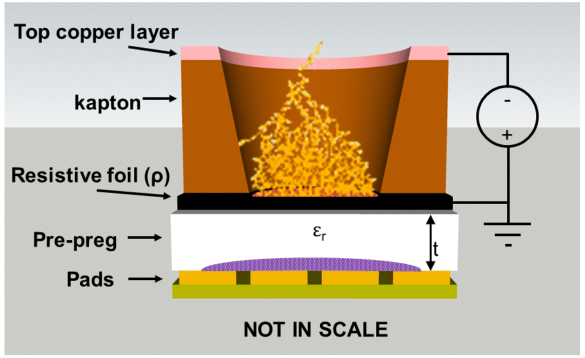
- **Spark suppression**: presence of a resistive layer (Diamond-like Carbon) to quench sparks amplitude (like MM)
- **Compactness**: amplification stage (geometry like WELL and GEM) embedded in the PCB readout → multi-layer PCB std. industrial technology →mass production

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

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

2015 *JINST* **10** P02008





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]:

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

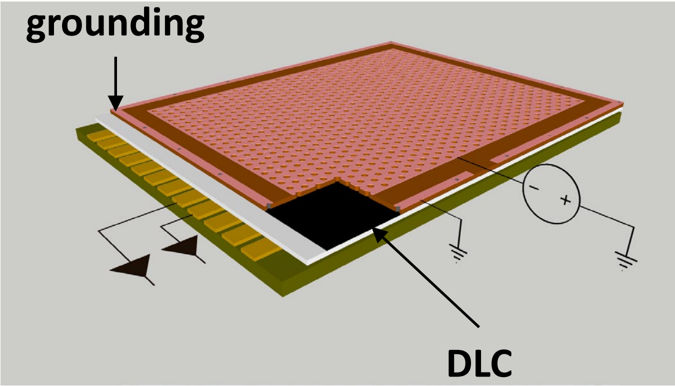
Naïf model for the **average resistance Ω** between the charge point collection and the perimetrical grounding line

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

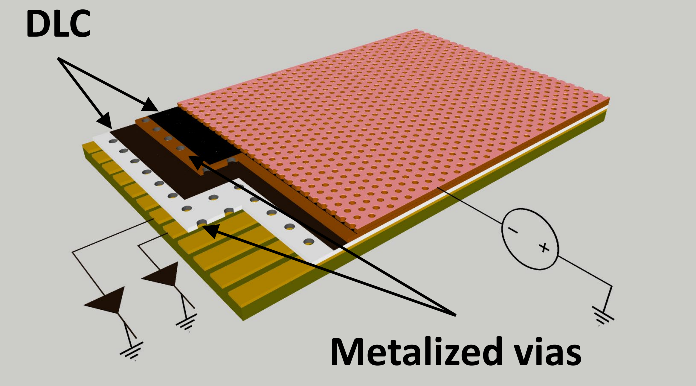
α from the fit to the gain vs. applied ΔV
N₀ from GARFIELD++ simulation
r radius of the X-rays spot
d average distance to the ground

The μ-RWELL technology: the evolution

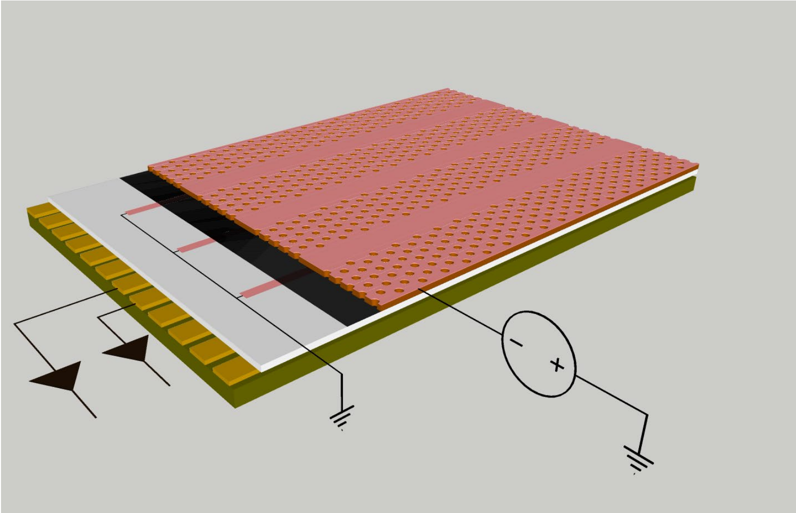
The **parameter *d*** becomes foundamental to produce detector for high rates purposes
An extensive R&D has been conducted to optimize the DLC grounding to make the detector stand up to several MHz/cm^2



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



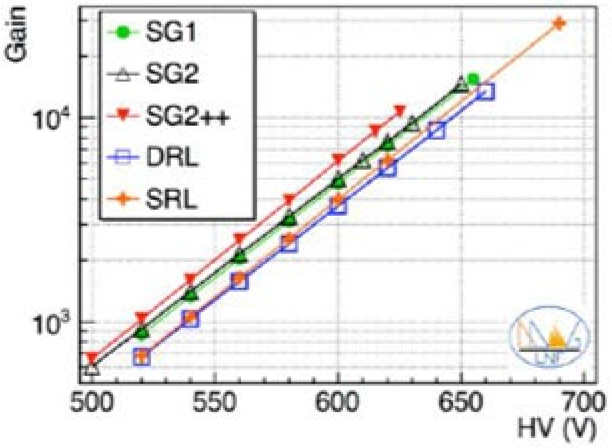
Double Layer
- **Stack of DLC foils inteconnected by a matrix of vias**
- ***d* ~1 cm**
- **High rate purposes (>10MHz/cm^2)**
- **Complex manufacturing**



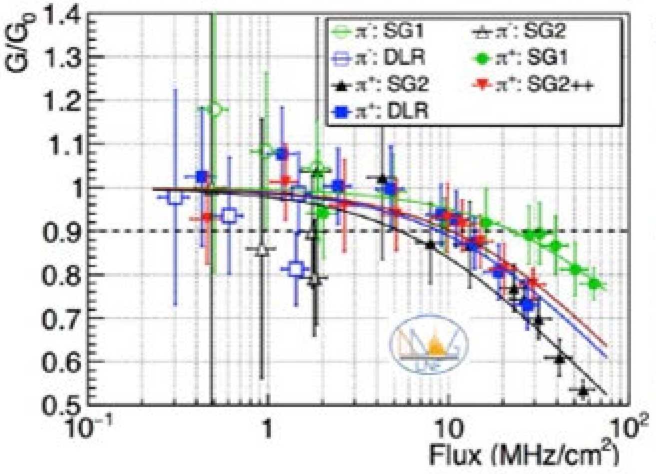
Silver Grid
- **DLC grounded by coated Cu strips below**
- **d ~1 cm**
- **High rate purposes (>10MHz/cm^2)**
- **Complex Cu+DLC sputtering; difficult alignment of the grounding lines with the dead areas on the top of the amplification stage (expecially for large size detector)**

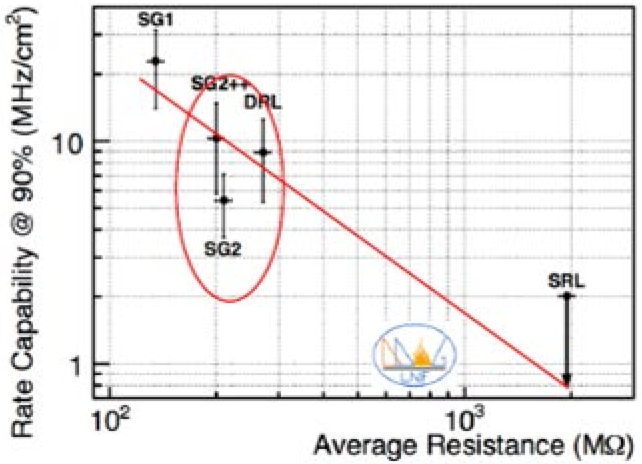
The µ-RWELL techology: measurements

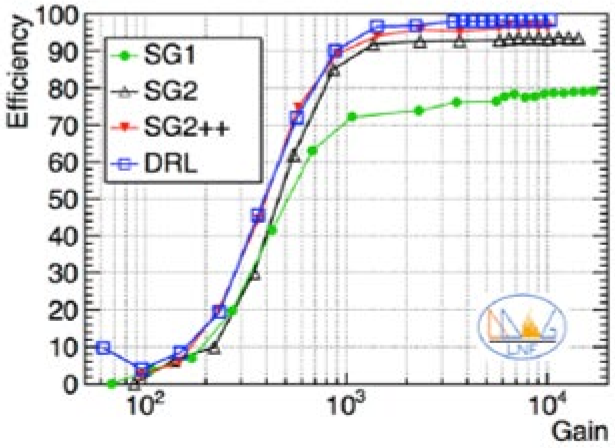
Gain up to ~ 10^4



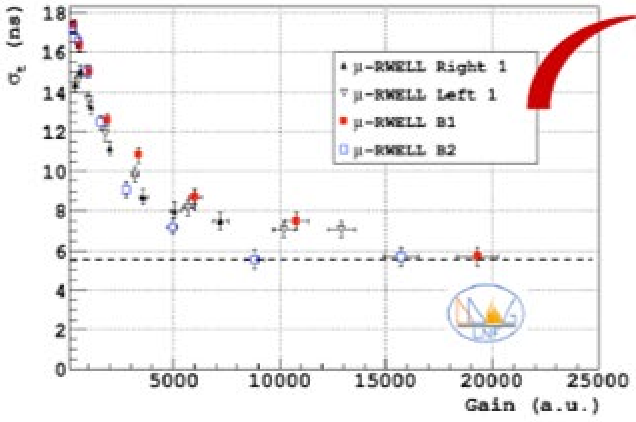
Rate capability (@ G = 5000) ~ 5-10 MHz/cm^2



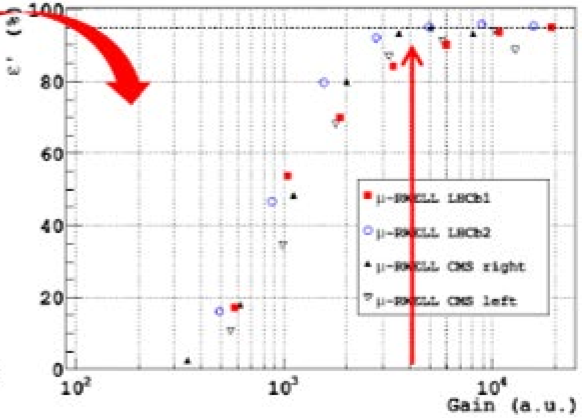




Efficiency ~ 98%



σ_t ~ 5-6 ns

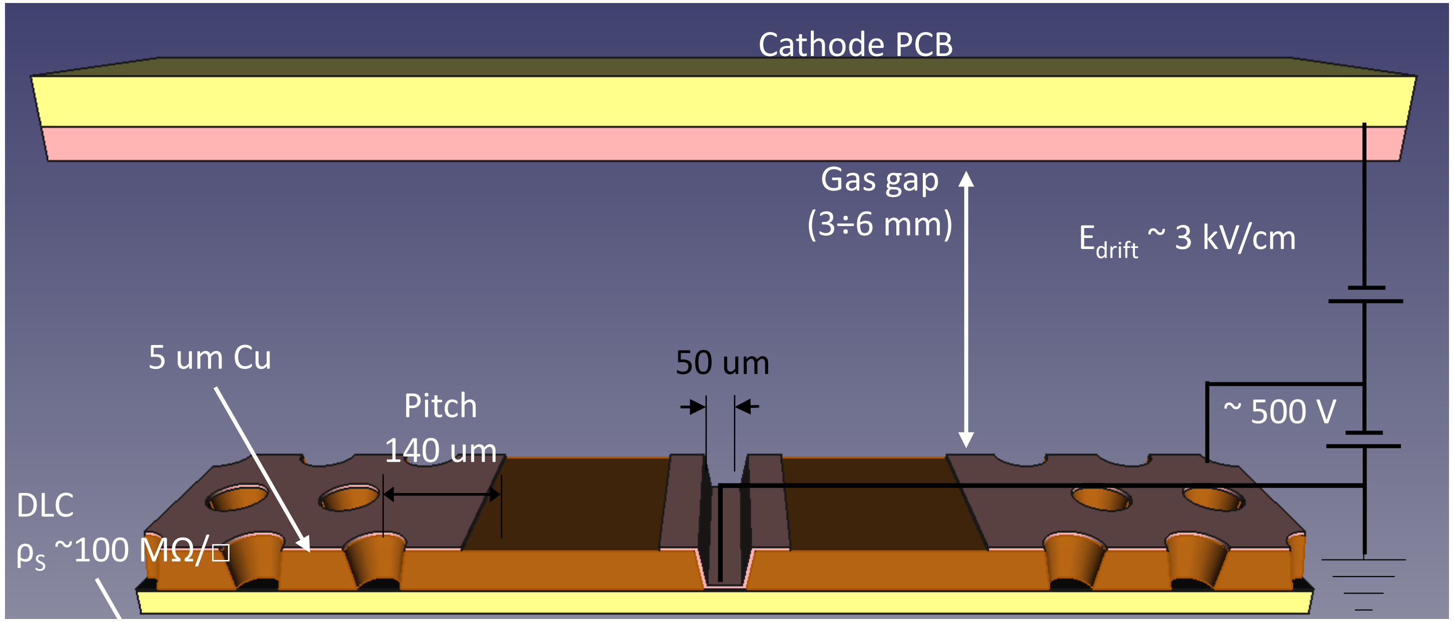


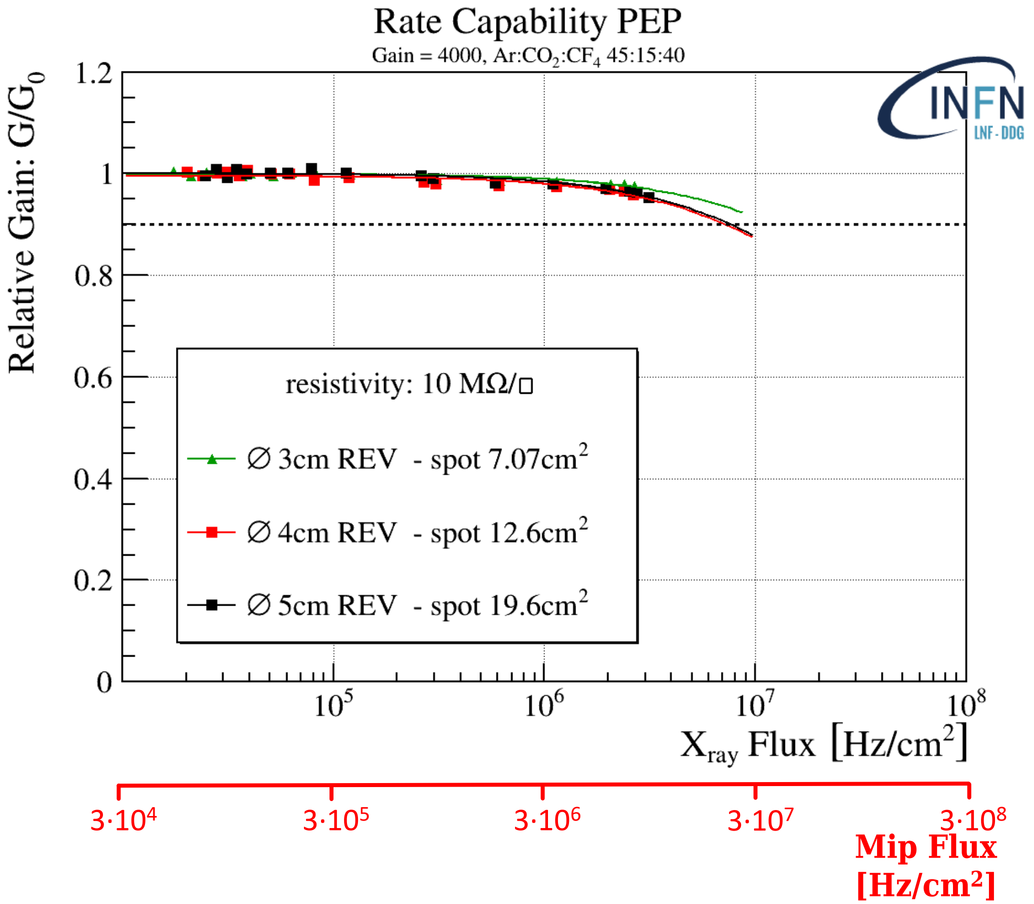
Efficiency in 25 ns

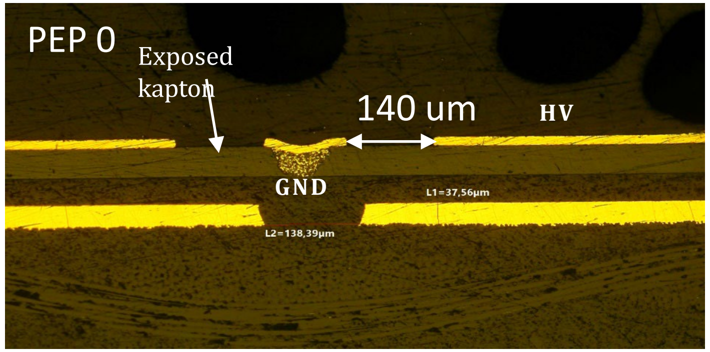
…

2020 *JINST* **15** C09034

The µ-RWELL technology: the evolution







PEP0 layout:

- distance between GND and HV too short → MSGC-like effect (current instabilities)
- good copper plating of the PEP

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

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

The μ-Resistive WELL evolution in few words…

The winning version is the one with the best rate capability

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MONEY, MONEY, MONEY!

The μ-Resistive WELL evolution in few words…

The winning version is the one with the best rate capability

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MONEY, MONEY, MONEY!

=

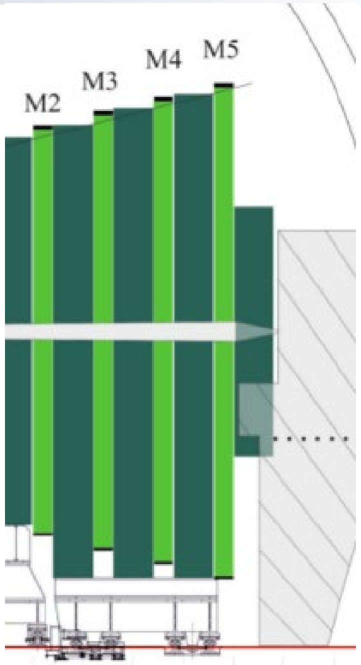
The winning version is the *cheapest* and the one with the best rate capability

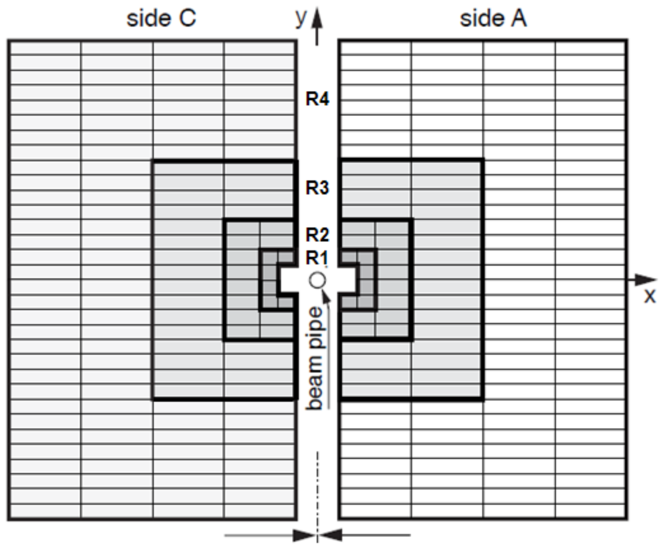
Applications in HEP: muon triggering

The MWPC (4 of them compose a station) cannot stand the expected peak (and average) rate capability

Requirements for Run 5-6 (2035-2042):

- Rate up to 1 MHz/cm^2 per single detector gap; 600 kHz per pad
- Efficiency (station)>99% within a BX (25 ns)
- **Stability for 10 y of operation (up to 1 C/cm2)**





PROPOSED SOLUTION: micro-RESISTIVE WELL technology

Each MWPC will be replaced with a **stack of 4 gaps** in the region **R1 and R2**

- **R1÷R2: 576 gaps, size 30x25 to 74x31 cm^2, 90 m^2 det., 130 m^2 DLC**
- R3: 768 gaps, size 120x25 to 149x31 cm^2, 290m^2 det.
- R4 : 3072 gaps, size 120x25 to 149x31 cm^2, 1164 m^2 det.

For R3 and R4 region this technology is not a suitable solution due only to the large input capacitance of the detector.

Maximum expected rate

Rates (kHz/cm^2)	M2	M3	M4	M5
R1	749	431	158	134
R2	74	54	23	15
R3	10	6	4	3
R4	8	2	2	2

Area (m^2)	M2	M3	M4	M5
R1	0.9	1.0	1.2	1.4
R2	3.6	4.2	4.9	5.5
R3	14.4	16.8	19.3	22.2
R4	57.6	67.4	77.4	88.7

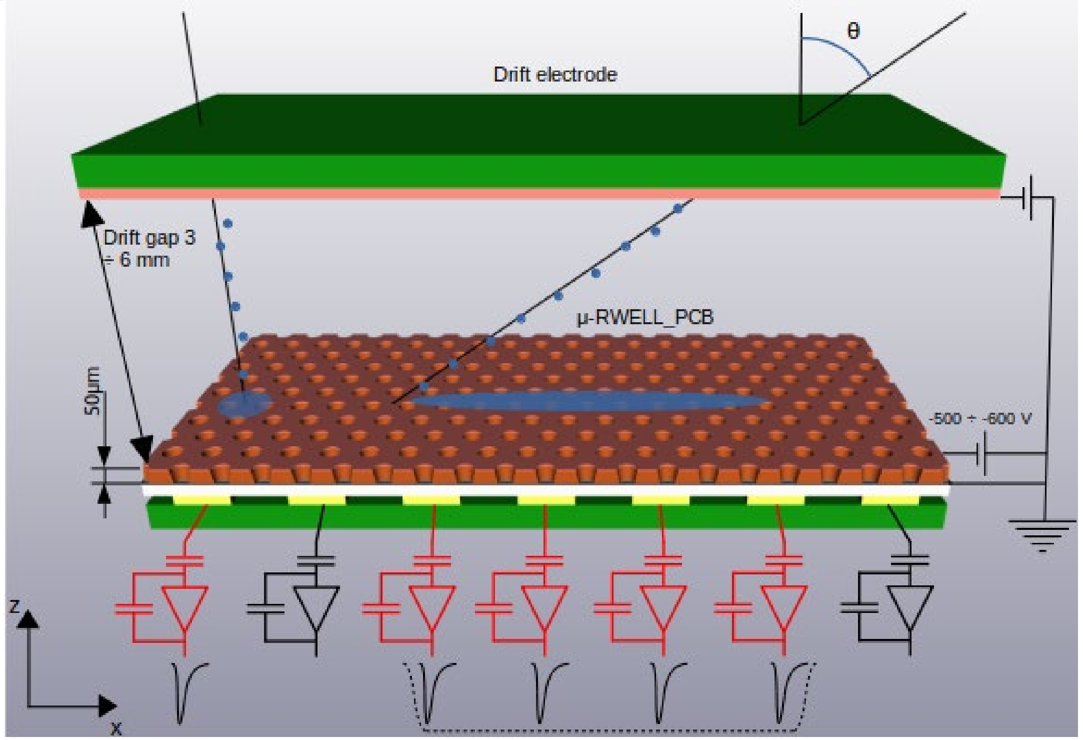
Preliminary

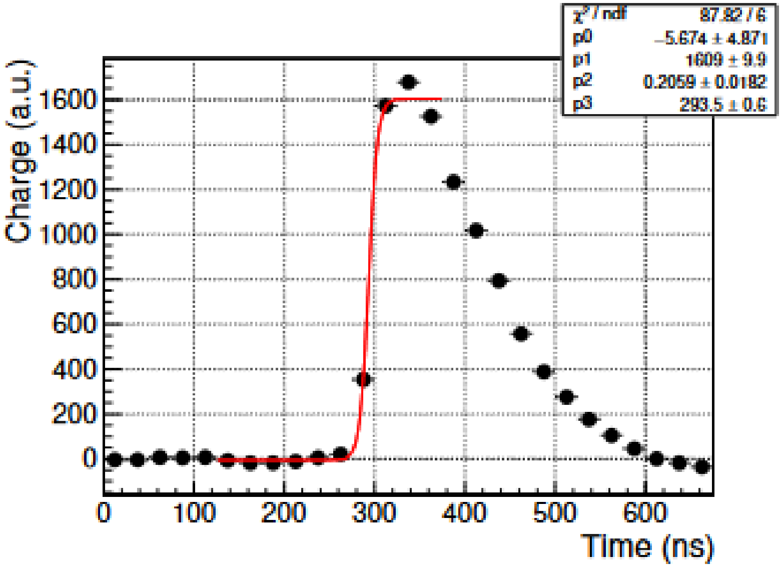
CERN-LHCC-2021-012 ; LHCB-TDR-023 http://cds.cern.ch/record/2776420?ln=it

Applications in HEP: Tracking

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

An improvement of the position reconstruction is given by the µTPC algorithm (*T. Alexopoulos et al., NIM A 617 (2010) 161*):
the three-dimensional reconstruction of the particle track inside the detector drift gap is performed using the arrival time of the induced signals on the readout

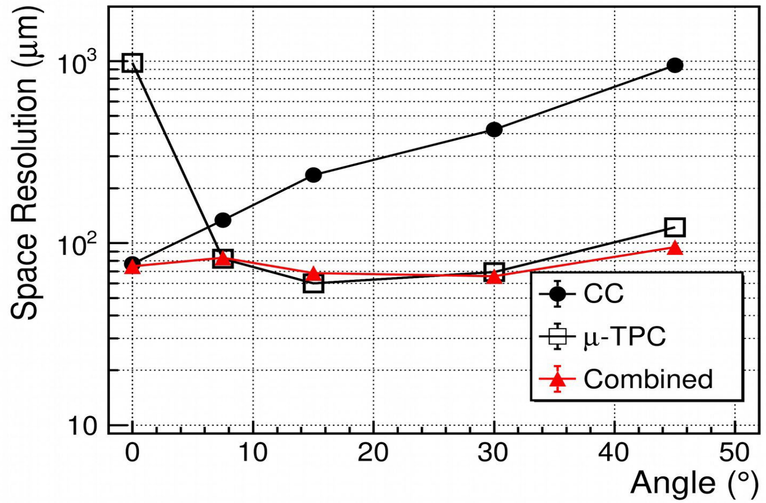




APV25 charge sampling

The combination of the two algorithms is given by

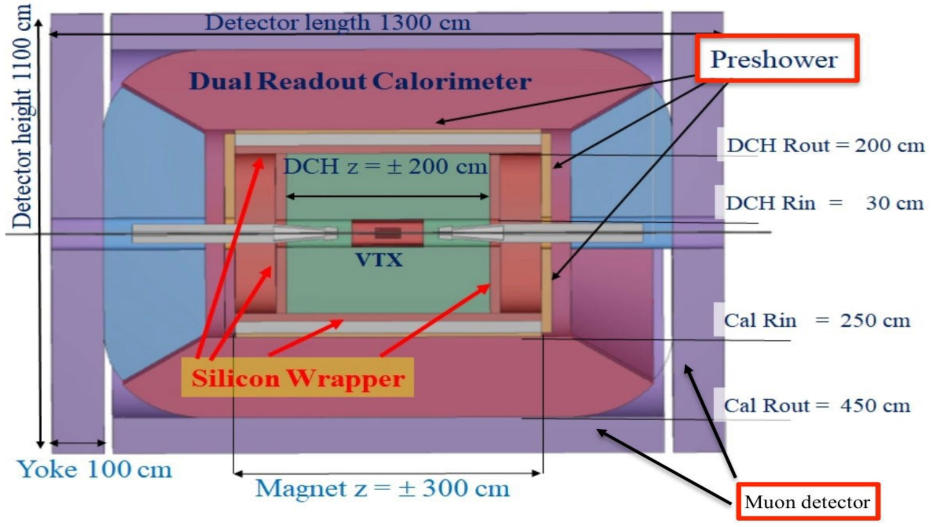
$$x_{\mathrm{comb}} = \frac{x_{\mathrm{CC}}/\sigma^2_{\mathrm{CC}} + x_{\mathrm{TPC}}/\sigma^2_{\mathrm{TPC}}}{1/\sigma^2_{\mathrm{CC}} + 1/\sigma^2_{\mathrm{TPC}}}$$

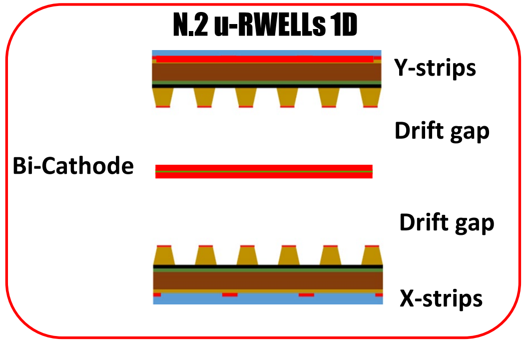


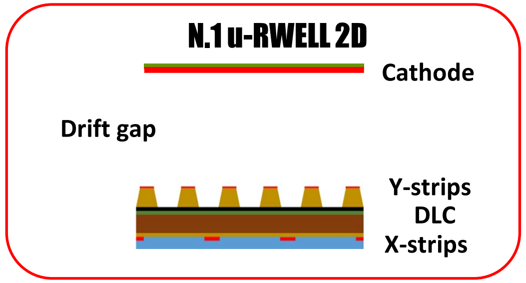
In collaboration with G. Cibinetto, R. Farinelli, L. Lavezzi

Applications in HEP: Tracking

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.

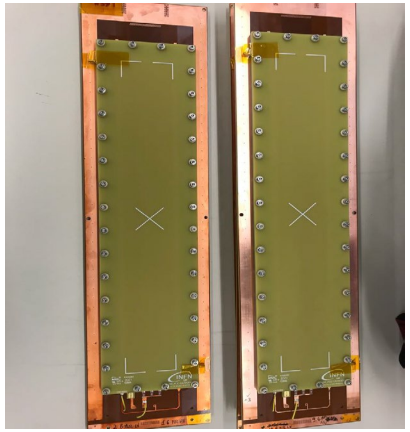


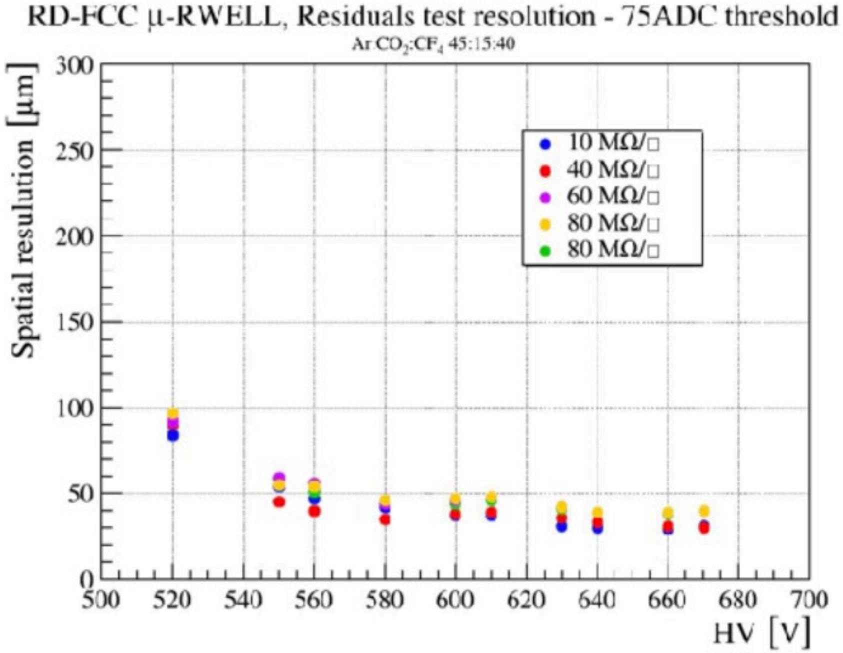




TB 2021 campaign

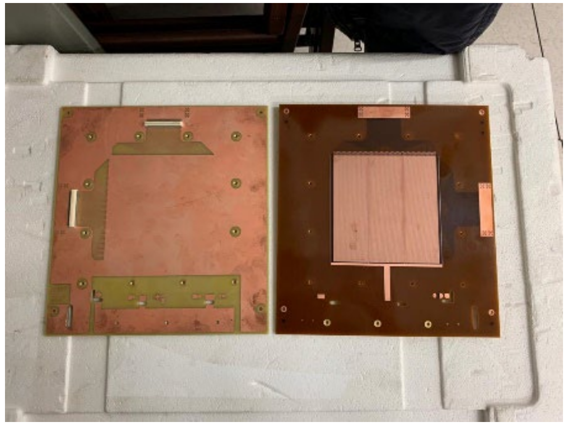
μ-RWELL prototypes with resistivity varing between 10 and 80 Mohm/sq. (strip pitch=0.4 mm)





TB 2022 campaign

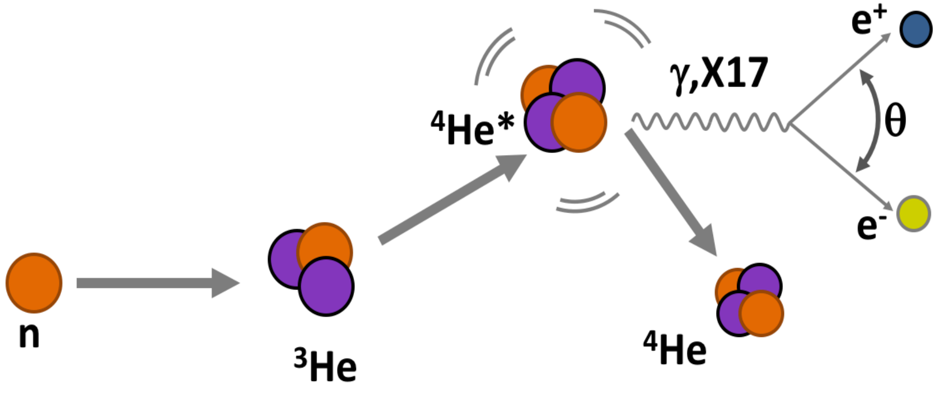
1D and 2D μ-RWELL. For the 1D strip pitch from 0.4 to 1.6 mm



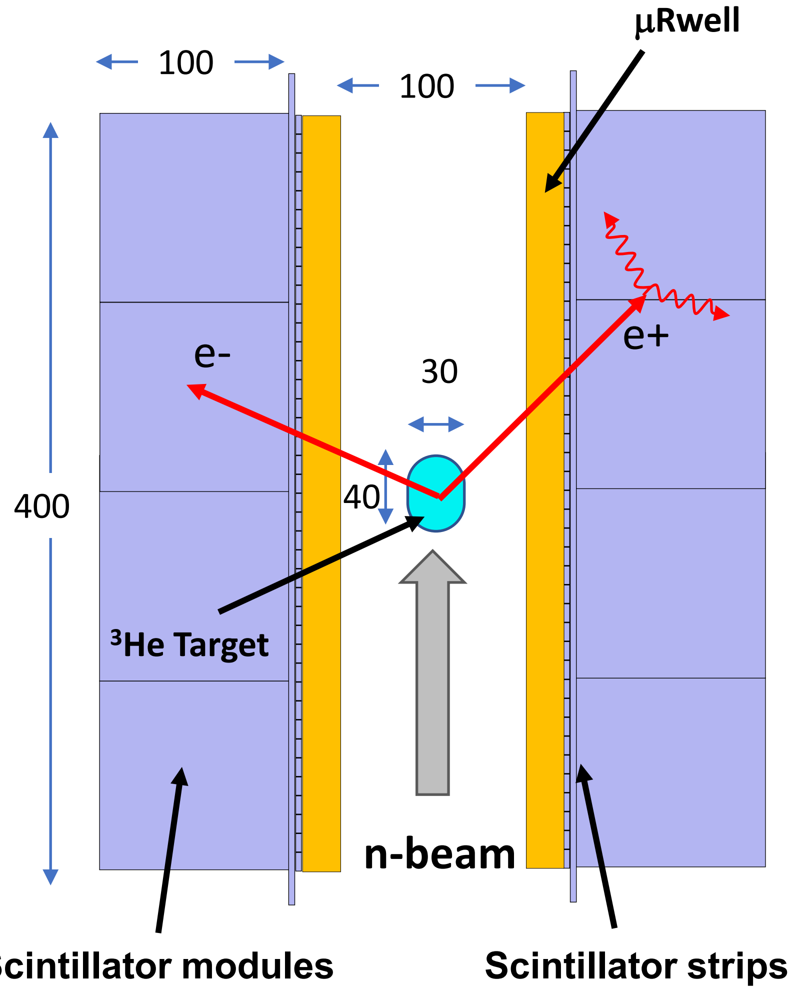
In collaboration with G. Cibinetto, R. Farinelli, L. Lavezzi, M. Gramigna, P. Giacomelli, E. De Lucia, D. Domenici, A. D'angelo, M. Bondi, M. Scodeggio, I. Garzia, M. Melindi

Applications in HEP: X17 at n_TOF

COURTESY OF C. GUSTAVINO



^{3}He(n,e$^+$e$^-$)^{4}He



PHYSICS:

- X17 existence snd properties (mass, J^p..)
- X17 Coupling.

EXPERIMENTAL REQUIREMENT:

Measurement of the e$^+$e$^-$ 4-momenta

SETUP:

Two large area module, each one composed by:

-1 mTPC faced to the target (40x45 cm^2 mRwell).

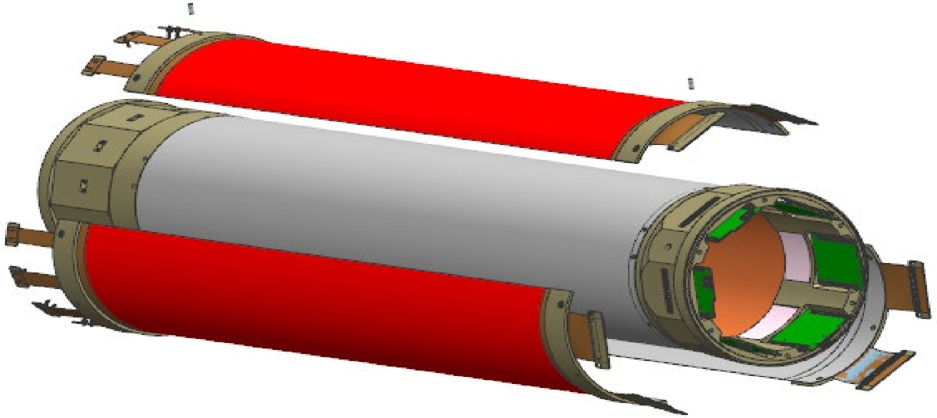
-2 planes of orthogonal scintillator strips.

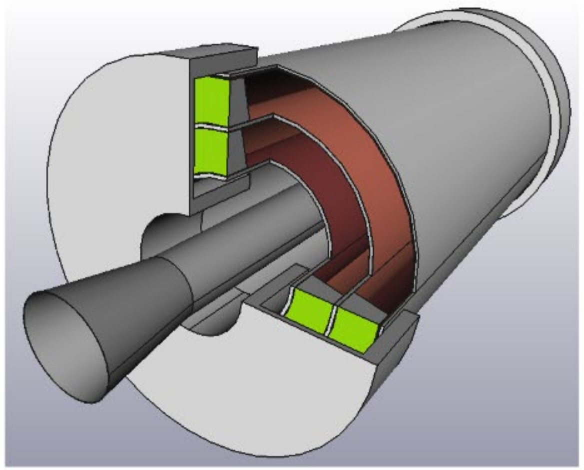
-1 plane composed by scintillator modules

Applications in HEP: Tracking

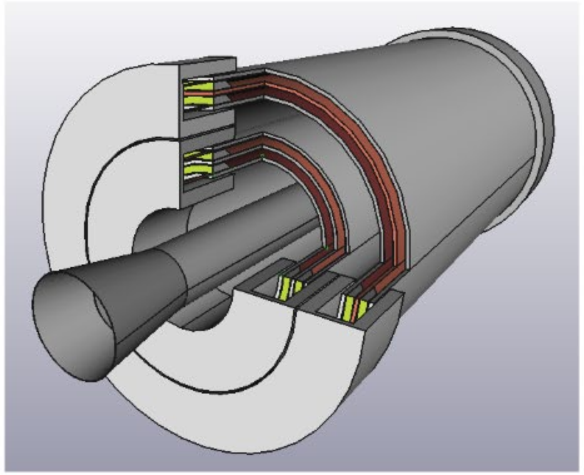
Development of an ultra-light modular **cylindrical μ-RWELL** as **inner tracker** for the Super Charm Tau factory (EURIZON project).

The B2B layout (a double radial TPC) is designed to have a **very low material budget** (0.86÷0.96% X0) and **modular roof-tile shaped components**: in case of failure/damage of the part, the structure could be opened and the damaged module replaced.

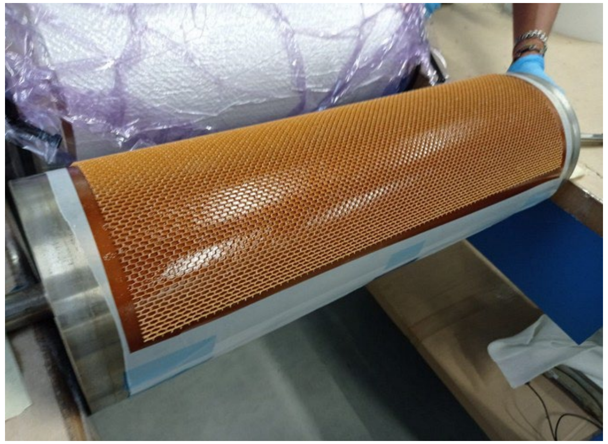




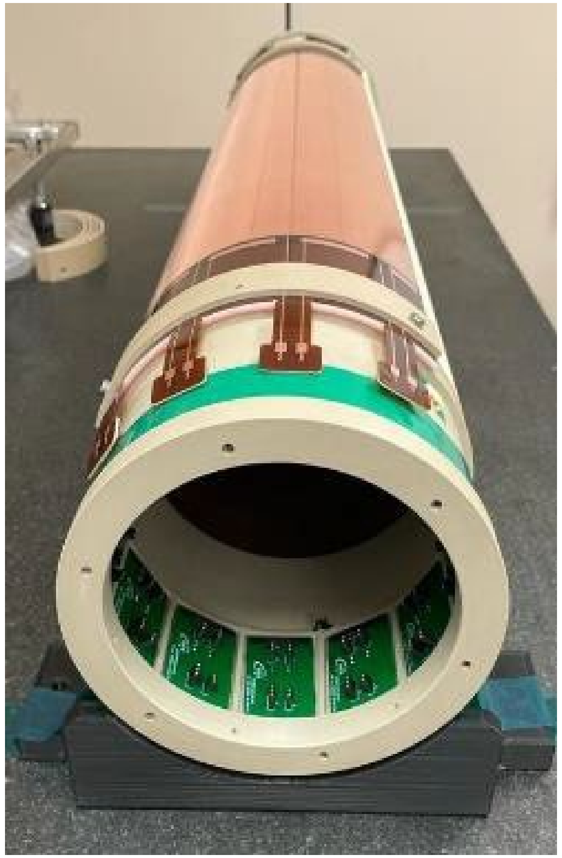
Thick drift gap (2 anodes)



Narrow drift gaps (4 anodes)



Roof tile manufacturing



The first cylindrical low mass uRWELL: ready to be closed and tested

In collaboration with G. Cibinetto, R. Farinelli, M. Gatta, M. Melchiorre, G. Papalino, D. Di Bari

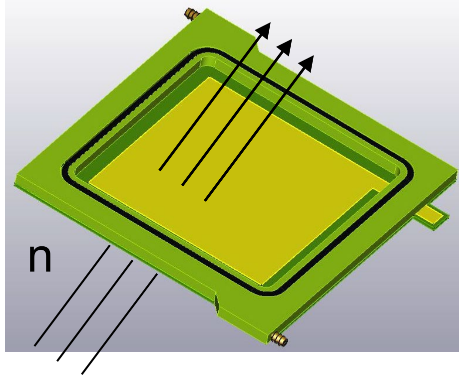
Applications beyond HEP: neutron detection

Beyond high energy physics, particle detectors find room for social life application (ex. homeland security).
In particular neutron detection is:

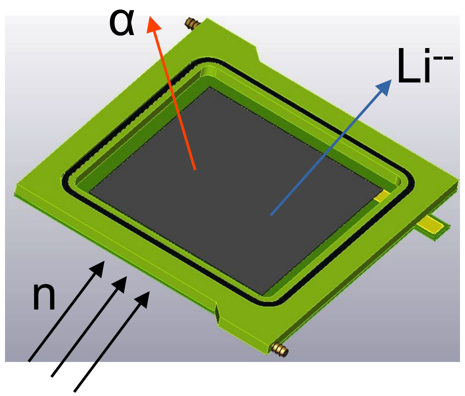
- Basic to fight against radioactive material smuggling
- Strictly necessary for radioactive waste monitoring
- Complementary to X-ray materials radiography

These activities needs detectors *simple* to be scaled up to large areas (low rate, ~1m^2), *flexible* to be adapted to different geometries (cylindrical) and using a *converter* not interfering with the readout (es. $^{10}B_4C$ converter, strip- or pad-segmented readout)

μ-RWELL cathode



+ $^{10}B_4C$ sputtering =



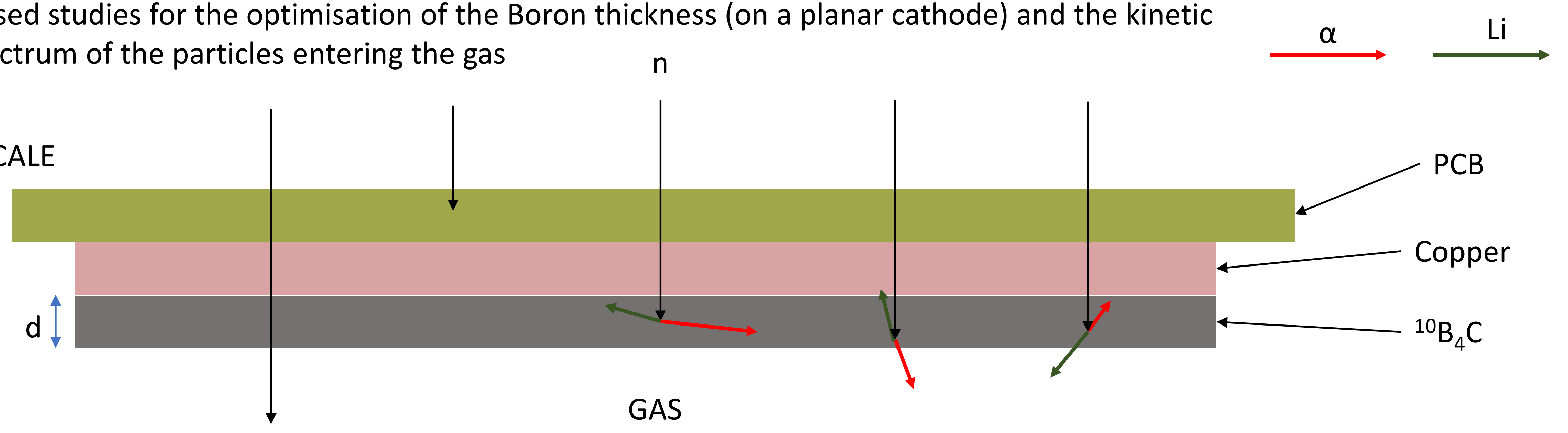
From the reactions:

$$n+{}^{10}B \rightarrow {}^{7}Li^{*}(0.84\ MeV) + \alpha(1.47\ MeV) + \gamma(0.48\ MeV) \qquad 93\%,\ Q=2.3\ MeV$$
$$n+{}^{10}B \rightarrow {}^{7}Li(1.16\ MeV) + \alpha(1.78\ MeV) \qquad 7\%,\ Q=2.79\ MeV$$

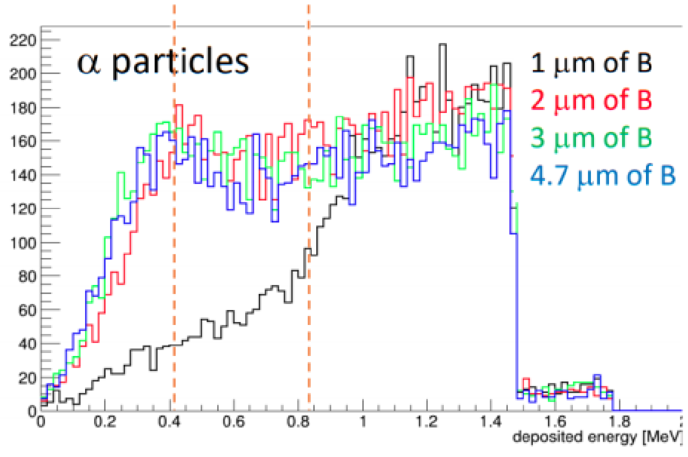
at least one slow charged particle is released inside the gas with a huge amount of primary ionization electrons.

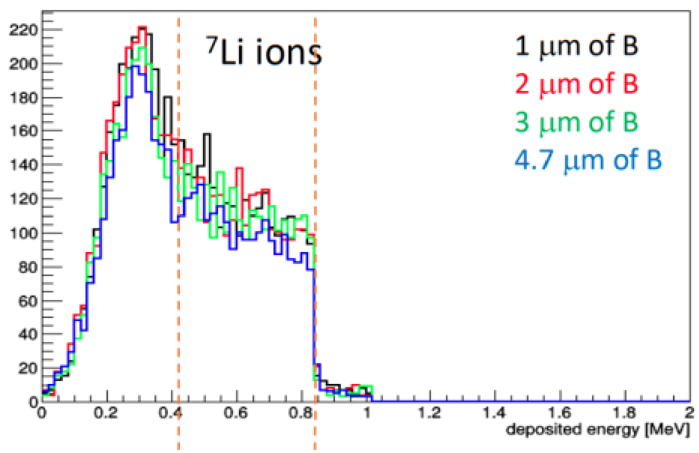
Applications beyond HEP: uRANIA project

Geant4-based studies for the optimisation of the Boron thickness (on a planar cathode) and the kinetic energy spectrum of the particles entering the gas



Energy released by the particles in the gas



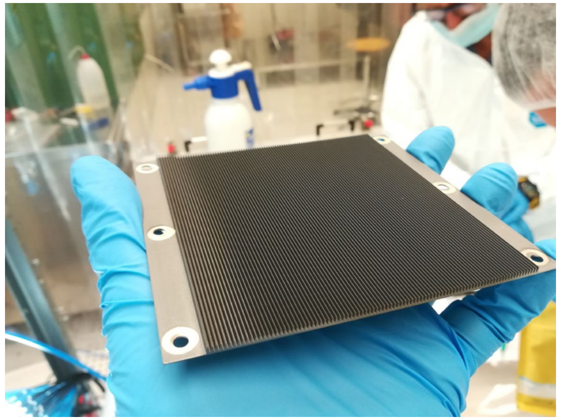


GARFIELD++ simulations to have an estimate of the ionisation created by the slow heavy particles

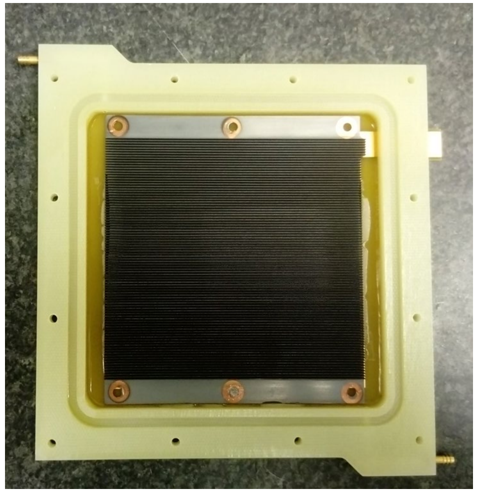
We chose a nominal thickness of 2 microns

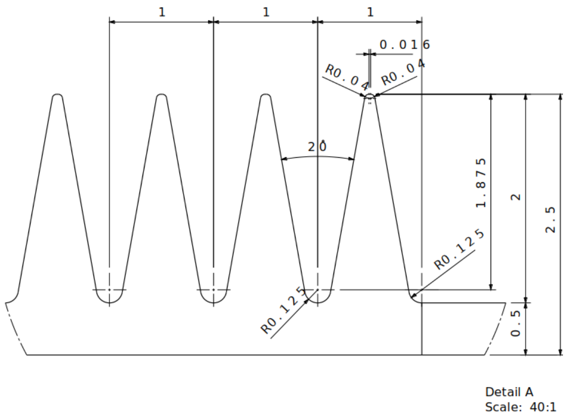
Applications beyond HEP: uRANIA project

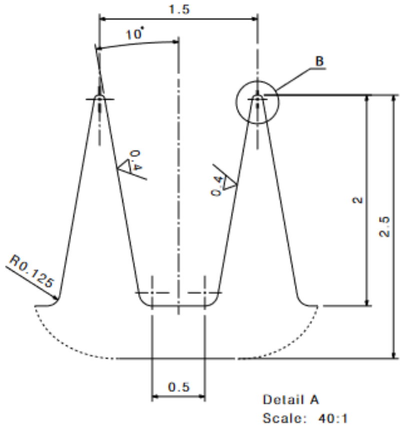
Alternative geometries of the coverter have been studied exploiting the possibility to interchange the cathode and to install further electrodes inside the active volume

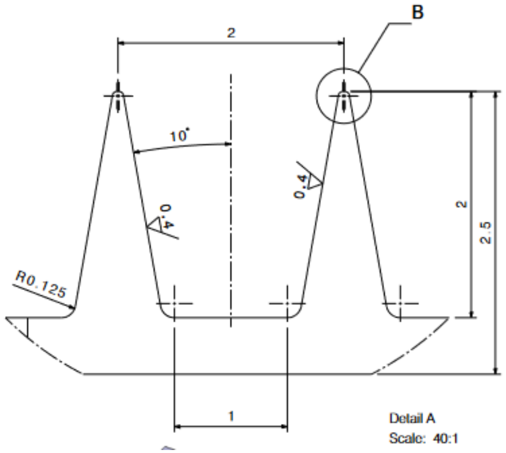


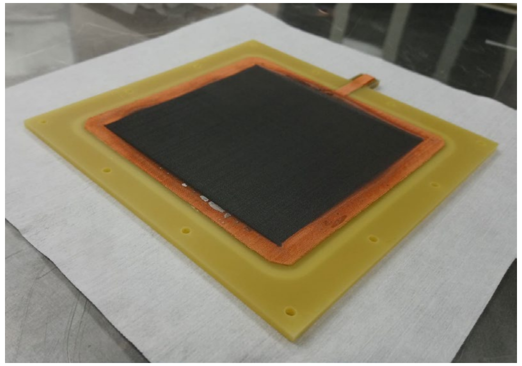
Grooved copper electrode sputtered with $^{10}B_4C$ at the ESS Coating Workshop in Linkopping (SE)



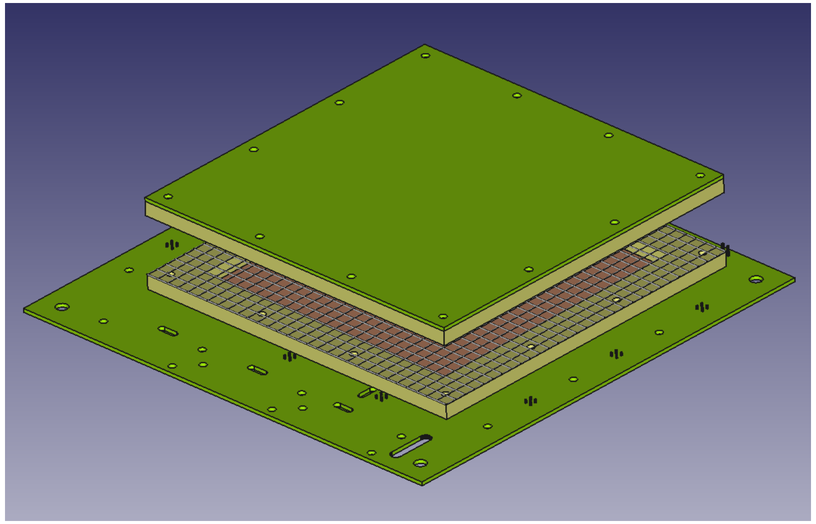






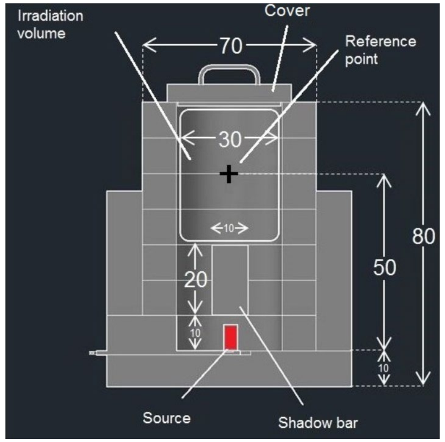


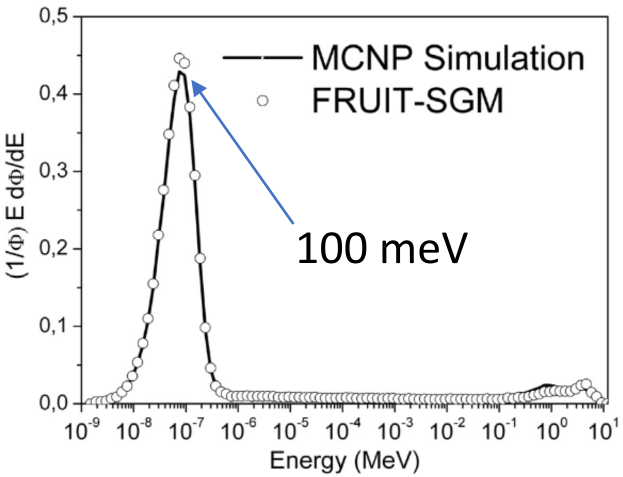
Metallic coated mesh to be inserted between cathode and amplification stage



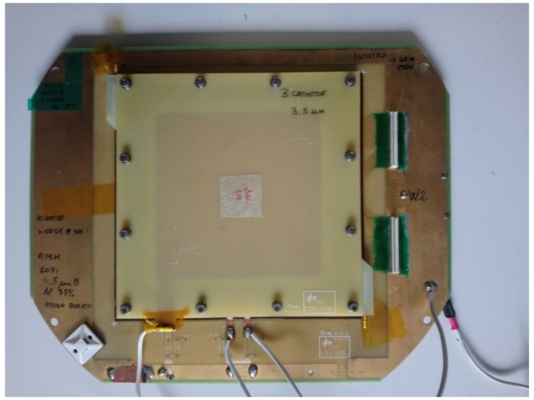
Applications beyond HEP: uRANIA project

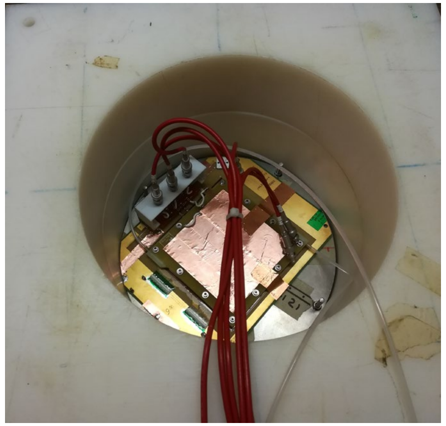
Measurements done at the HOTNES facility at ENEA Frascati



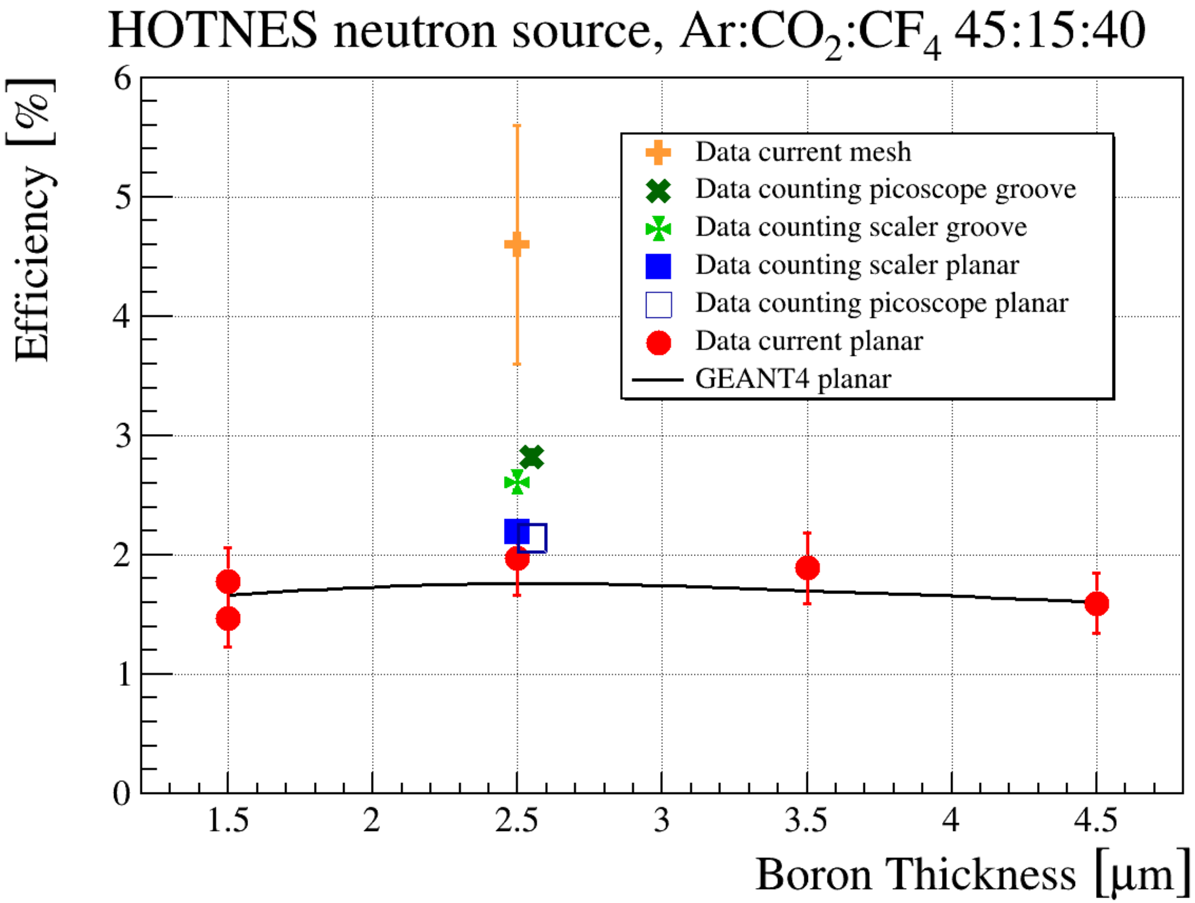


Measurements done in current and in counting mode, equipping the detector with a CREMAT CR-110 amplifier





First data taking campaign: detector shaped to fit the small pit
u-RWELL_PCB re-drawn for the following tests.



An efficiency up to 5% has been achieved for neutrons with average kinetic energy of 100 meV
Simulations suggests a detection increased of a factor 2 for 25 meV kinetic energy neutrons

The µ-RWELL technology: TT

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

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

Start!

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ELTOS

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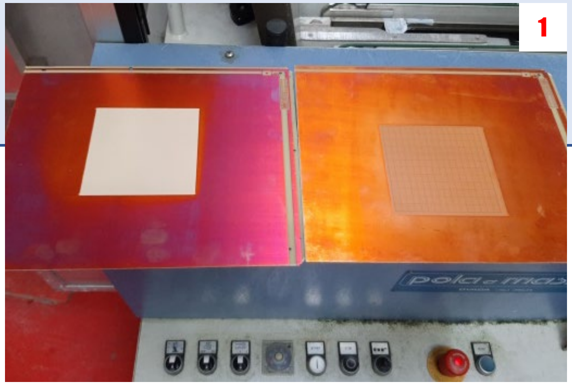
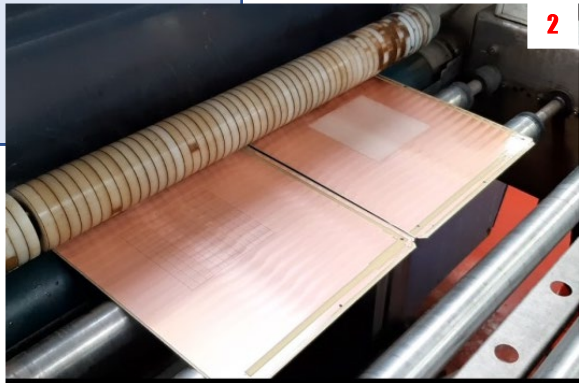
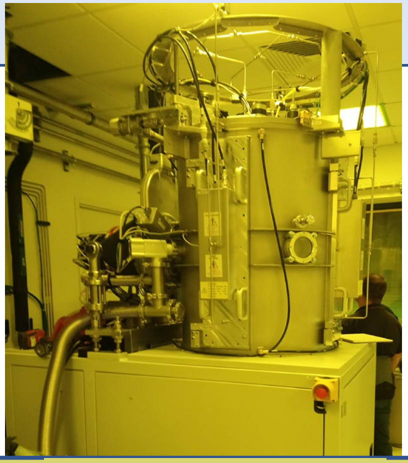
µ-RWELL techn. transf.

PCB production





DLC sputtering know-how



DCL foil prod.*

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PCB shipping

CERN

Detector manufacturing

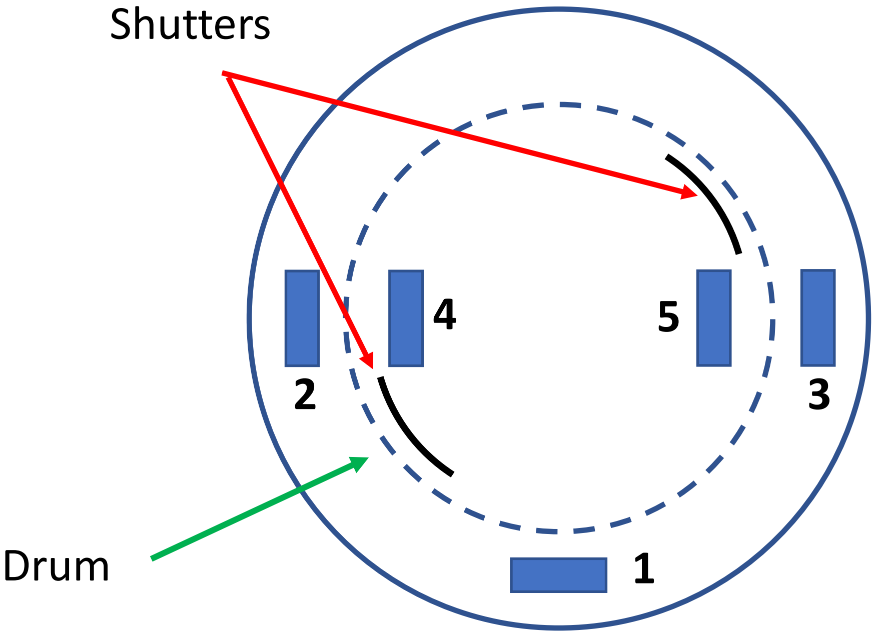
Completed µ-RWELL_PCB shipping

CID: CERN-INFN DLC machine

- **Flexible substrates, coating** areas **up to 1.7 m × 0.6 m**
- **Rigid substrates, coating** areas up to **0.2 m × 0.6 m**
- **Five cooled target holders,** arranged as two pairs face to face and one on the front, equipped with five shutters
- **Sputtering & co-sputtering different materials,** in order to create a coating layer by layer or an adjustable gradient in the coating

- ✓ **Installation**
- ✓ **Commissioning** & **training**
- ✓ **Test-phase**
- CERN-INFN test runs **TBD**

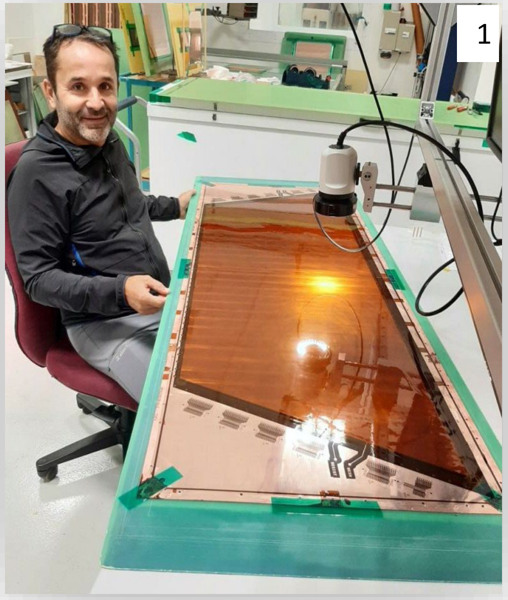
1, 2, 3 Changeable targets
4, 5 Fixed targets

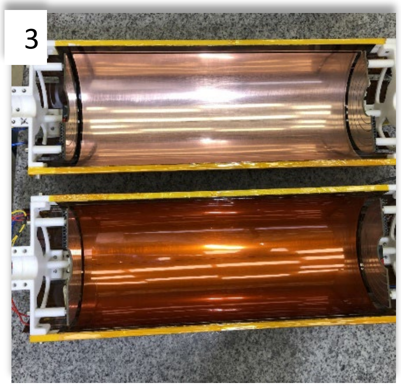


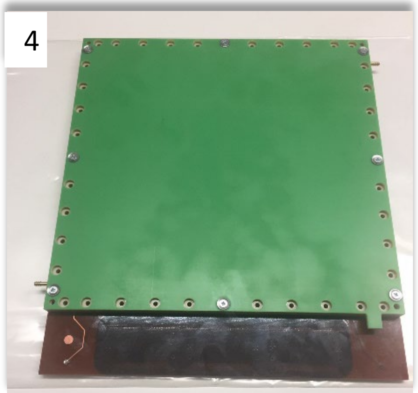
Addendum

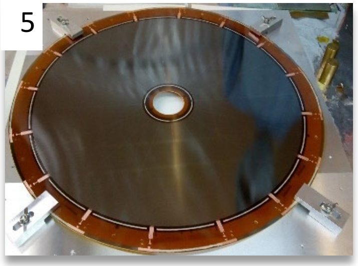
The micro-Resistive WELL is proposed in

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 CSN5 for neutron detection, an ideal spin-off of the EU-founded ATTRACT-URANIA
7. **UKRI:** neutron detection with pressurized ^{3}He-based gas mixtures









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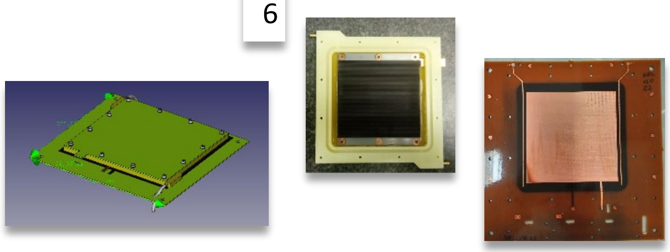
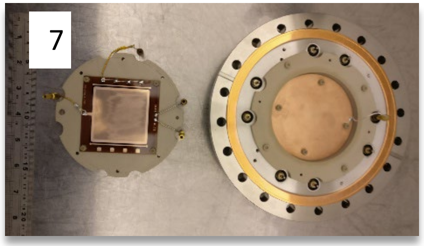
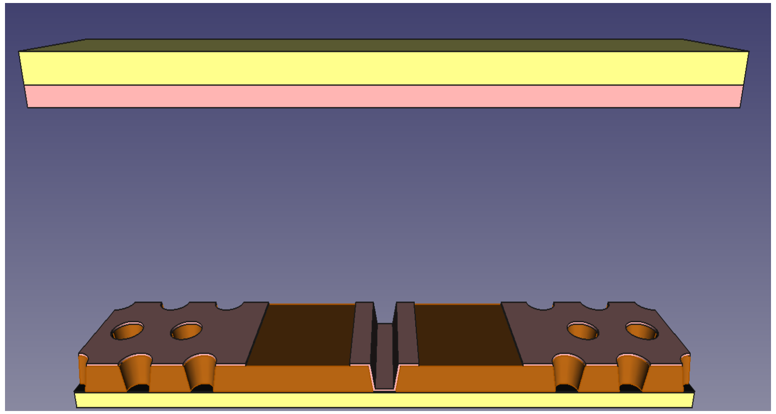
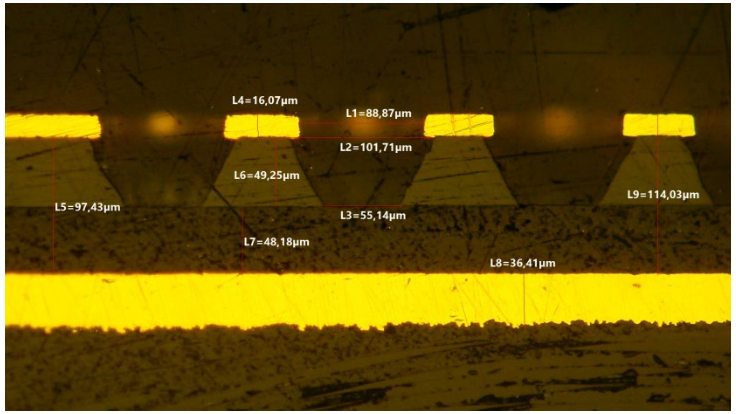




Summary & outlook

- The micro-RWELL detector shows very interesting behaviour both for HEP and non-HEP applications
- The efforts 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 ongoing
- The measurements validated the ideas implemented in the DLC grounding: O(10 MHz/cm^2) rate capability for the PEP version
- Promising results in neutron detection (efficiency projected to 10% for thermal neutron)
- The challenge is TT to PCB industry. A key-point has been the acquisition of the DLC sputtering machine co-funded by CERN and INFN





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- Eco-gas mixture studies to be done
- Stability tests (X-ray, gamma/neutron irradiation)
- Integration with alternative Front-End Electronics (FATIC, VMM3, …)

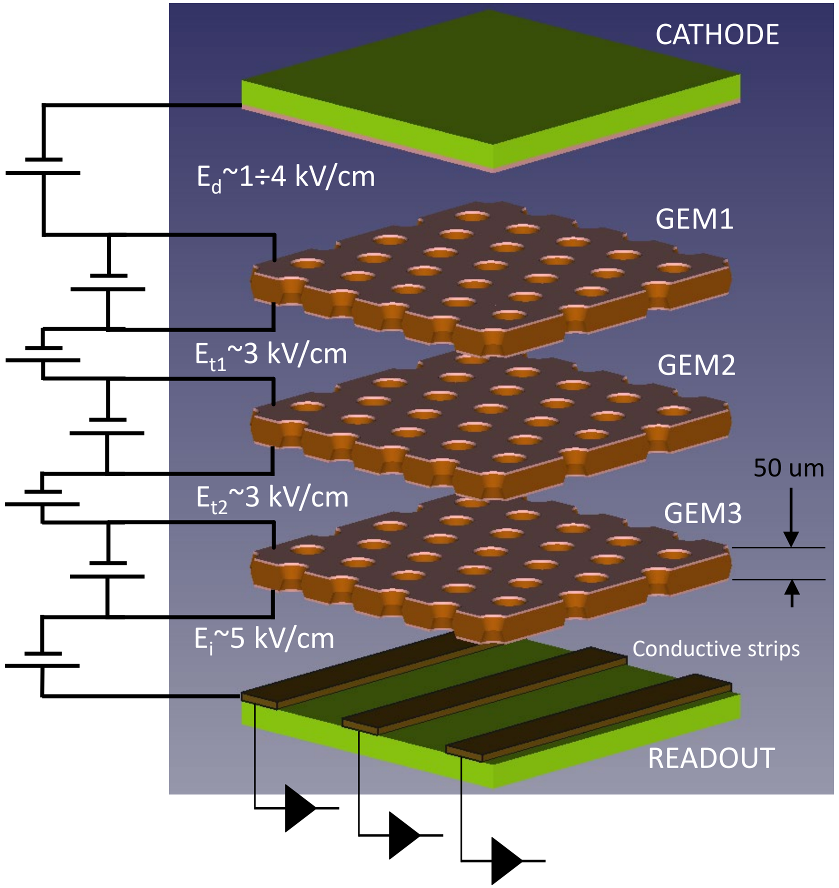
THANK YOU

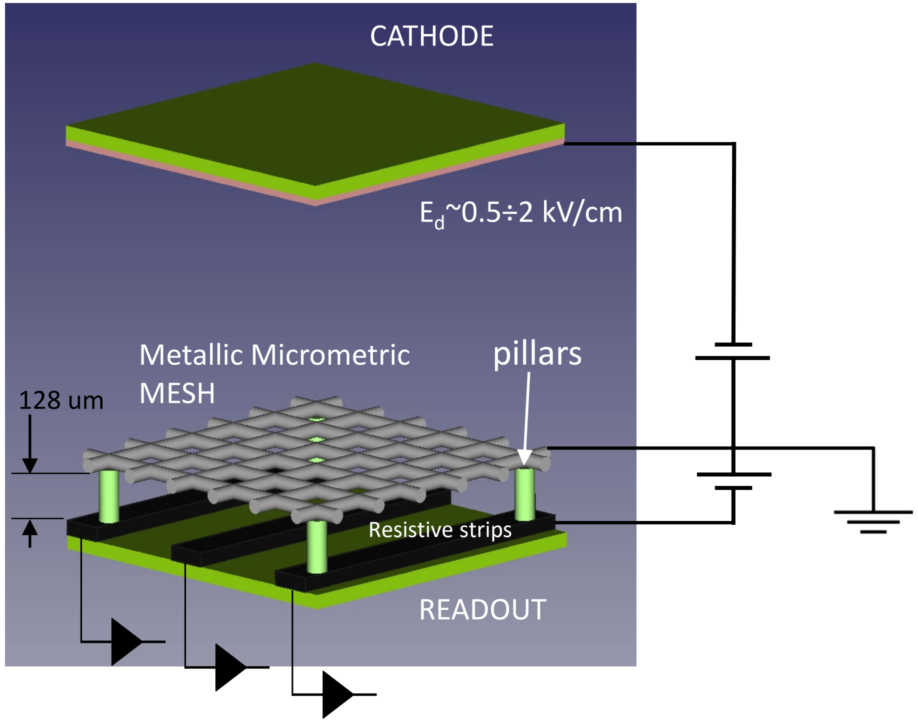
(for your patience)

BACKUP

Micro-Pattern Gaseous Detectors (MPGD)

MicroMegas and GEM have been for long time the main detectors belonging to the class of MPGD
MicroMegas improved the robustness to discharges thanks to the introduction of a resistive layer, while GEMs, with a stack of amplification stages allowing to operate each stage at lower potential, reduced the discharge probability **for a single foil**



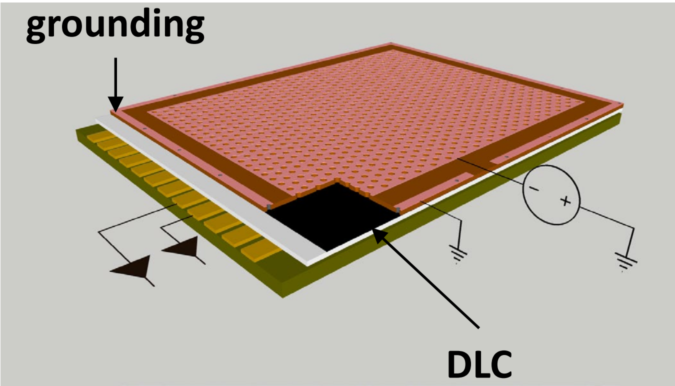


How to merge and improve the most important features of the two detectors (rate capability, compactness and spark robustness with no need to stretch any electrode)?

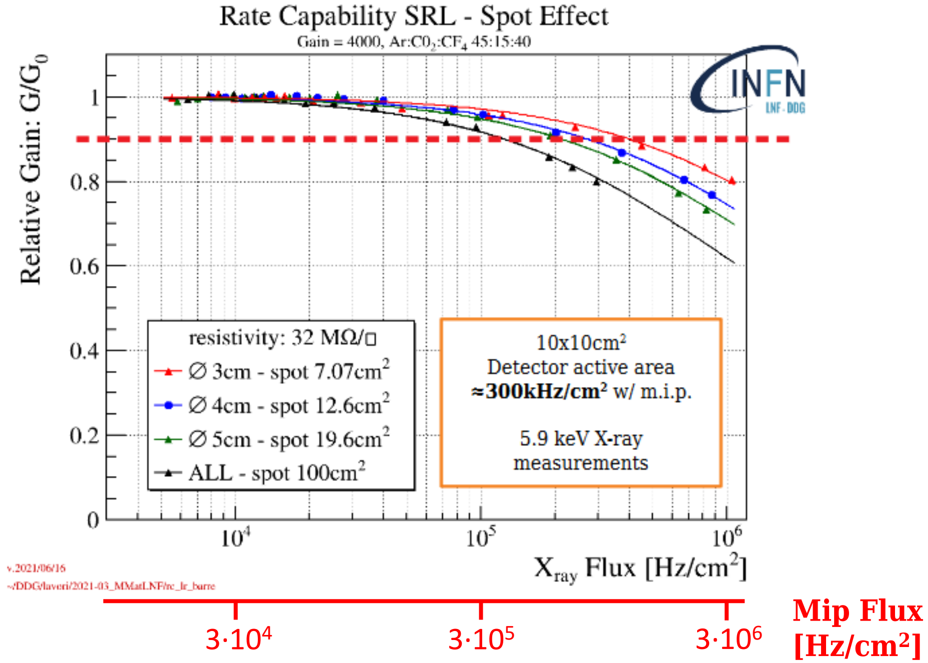
The µ-RWELL technology: the evolution

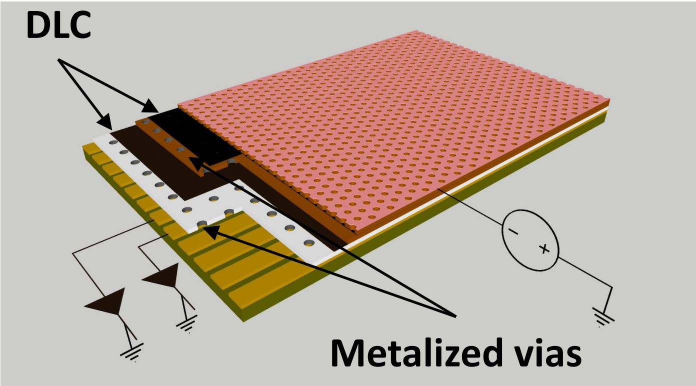
The **parameter *d*** becomes foundamental to produce detector for high rates purposes

An extensive R&D has been conducted to optimize the DLC grounding to make the detector stand up to several MHz/cm^2

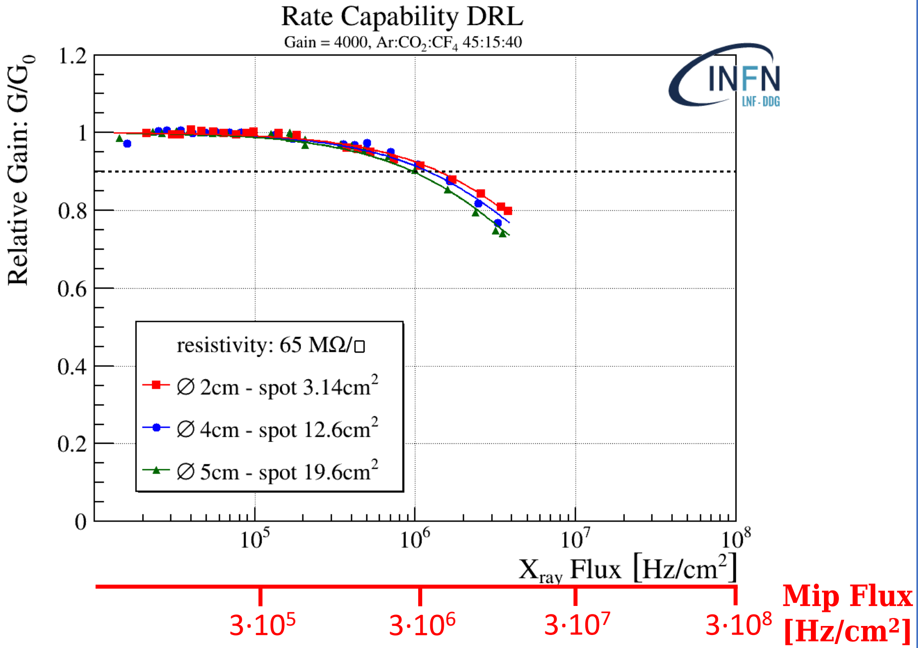


Single Layer
- **Single DLC layer**
- **Large *d* (~active area size)**
- **Low rate purposes (up to 100 kHz/cm^2)**
- **Easy for industry**





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



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The μ-RWELL technology: the evolution

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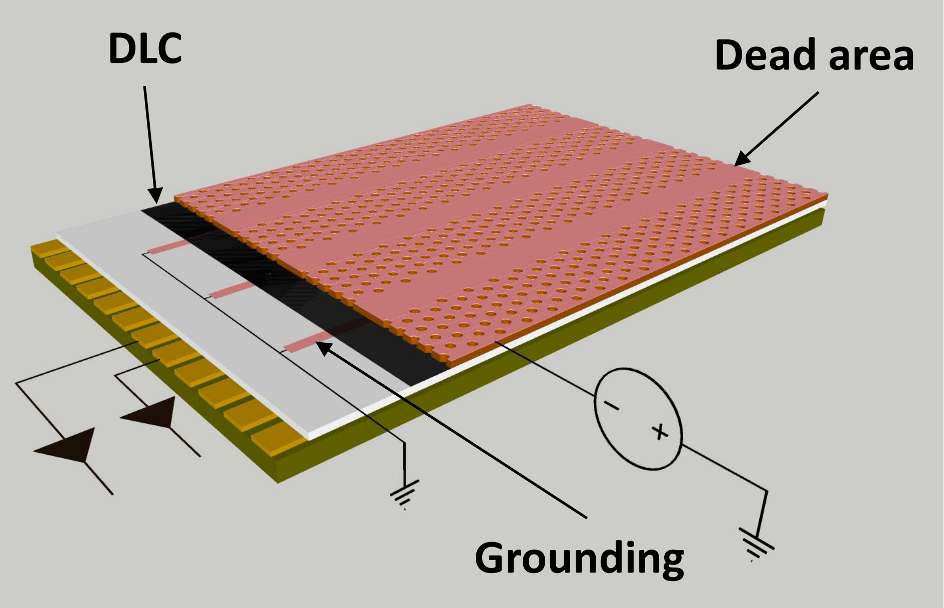
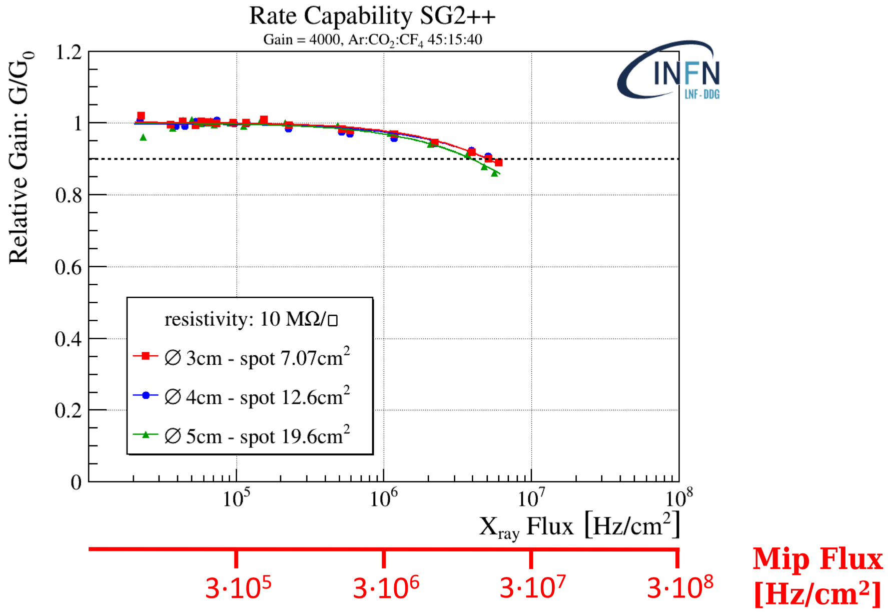
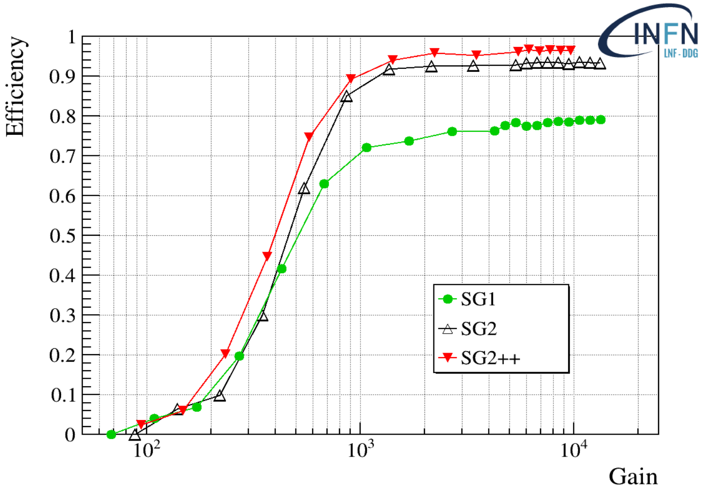
...

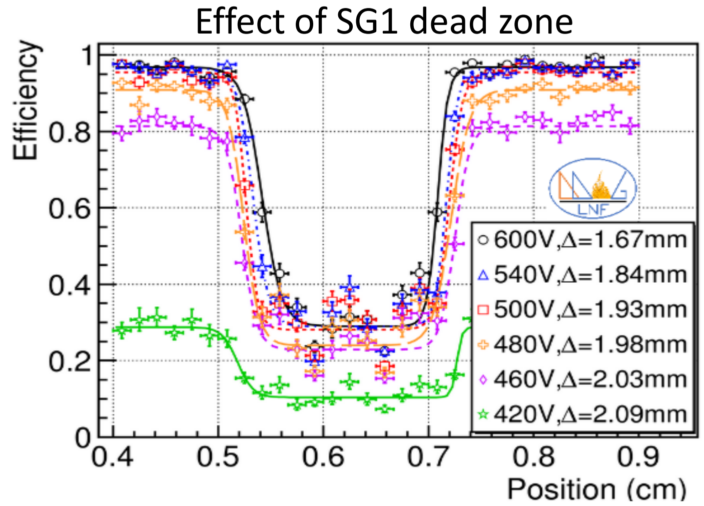




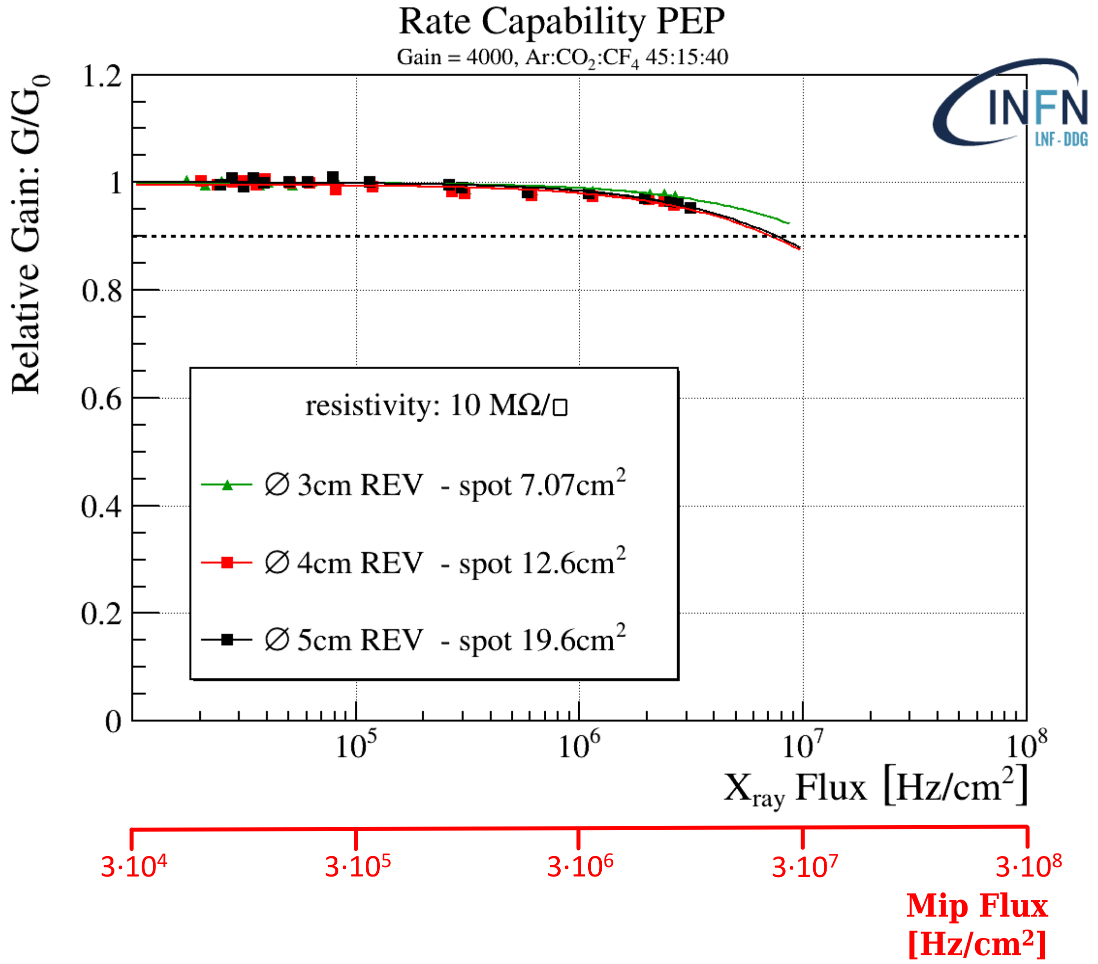
Silver Grid

- **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)**



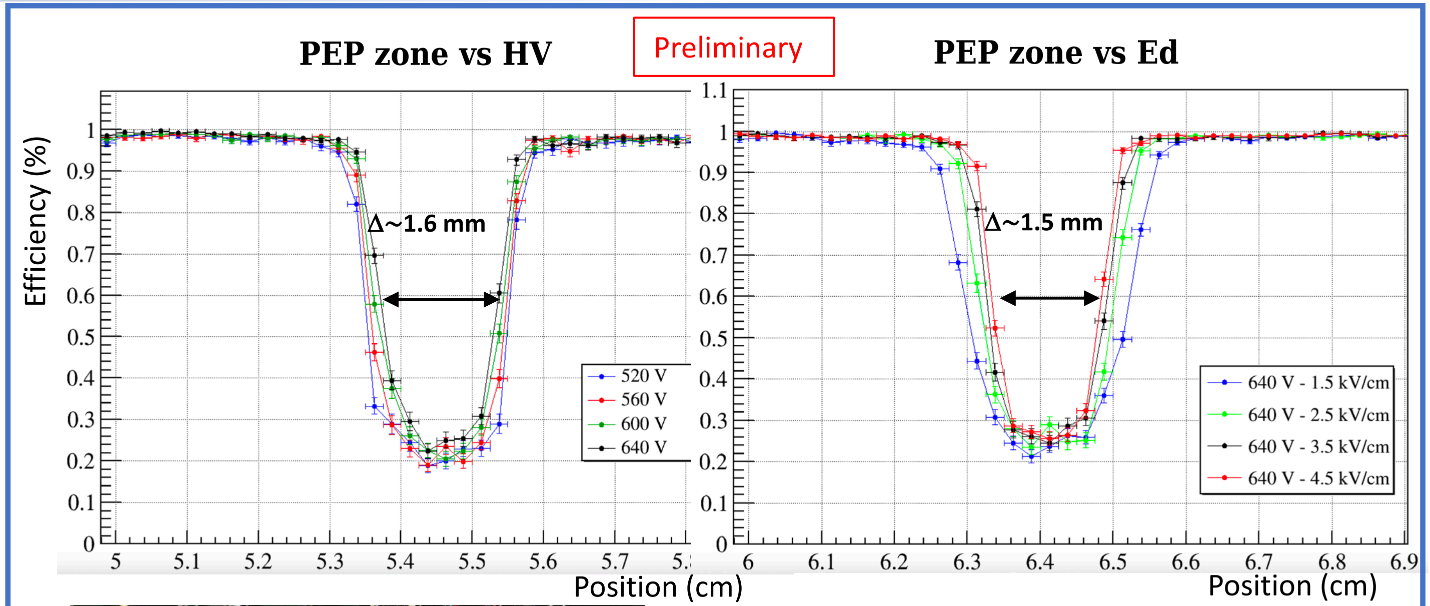


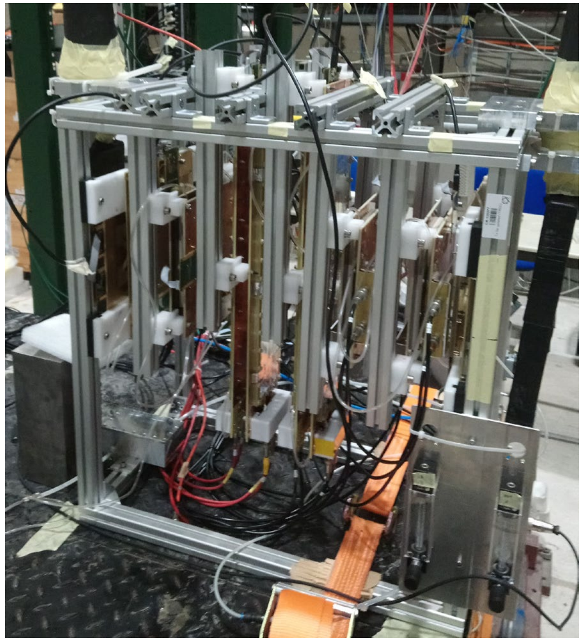
PEP: measurements overview



A rate capability under X-rays irradiation of 10 MHz/cm^2 (to be scaled by three for mip) is **extrapolated.**

The flux is limited by the capability of the X-ray gun





Test beam at H8C SPS Cern North Area

- 4 chambers, PEP, with readout 1D (strips, 600 um pitch). 10 x 10 cm^2 active area
- 4 chambers, LR, with readout 1 D and pitches from 0.4 to 1.6 mm.
  40 x 5 cm^2 active area
- 2 chambers, PEP, with pads (each pad about 1 cm^2). 10 x 10 cm^2 active area

Ar:CO_2:CF_4 45:15:40 gas mixture;

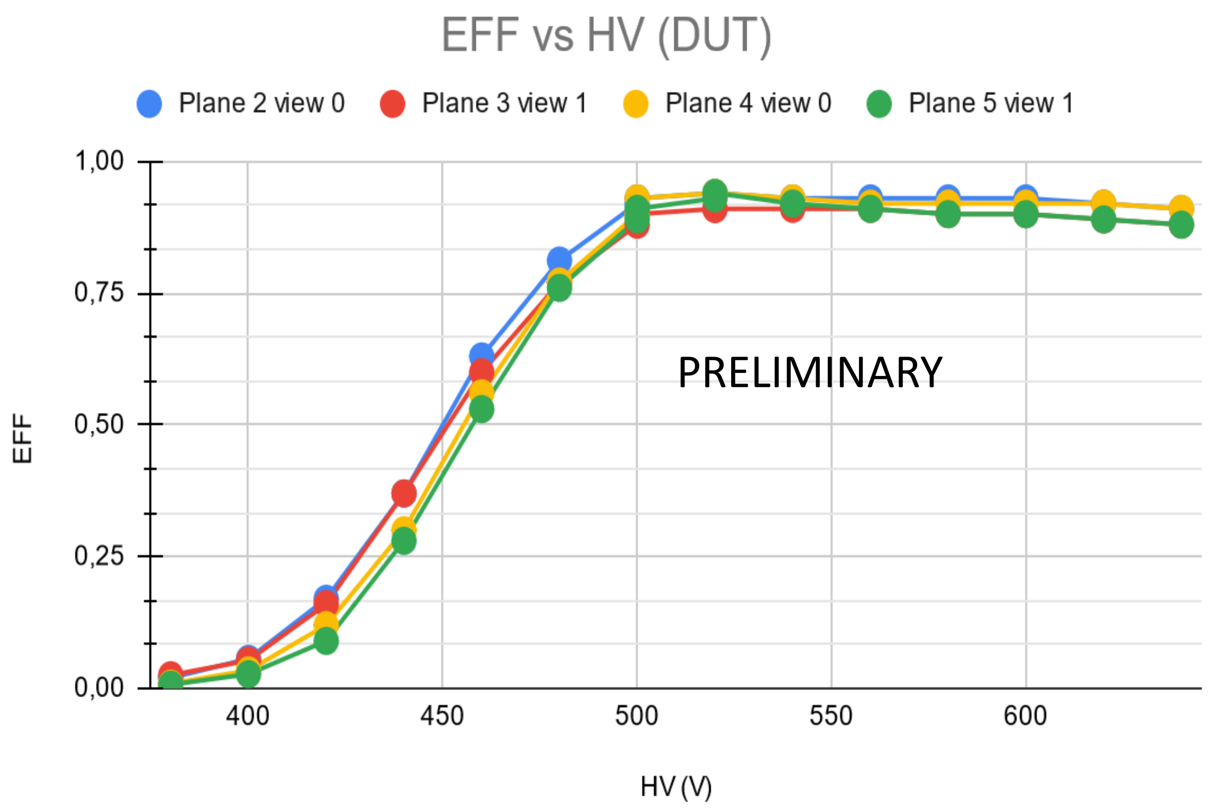
APV25 FEE

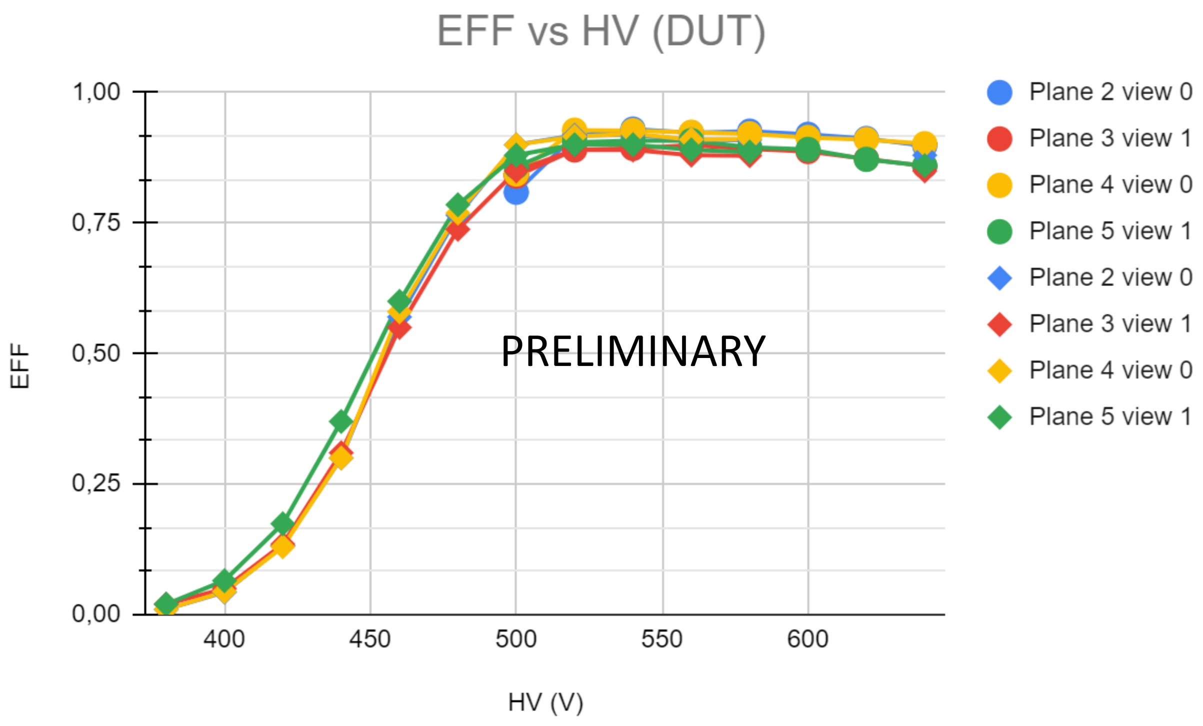
The μ-RWELL technology: the test beam 2022

The plans of the test beam:

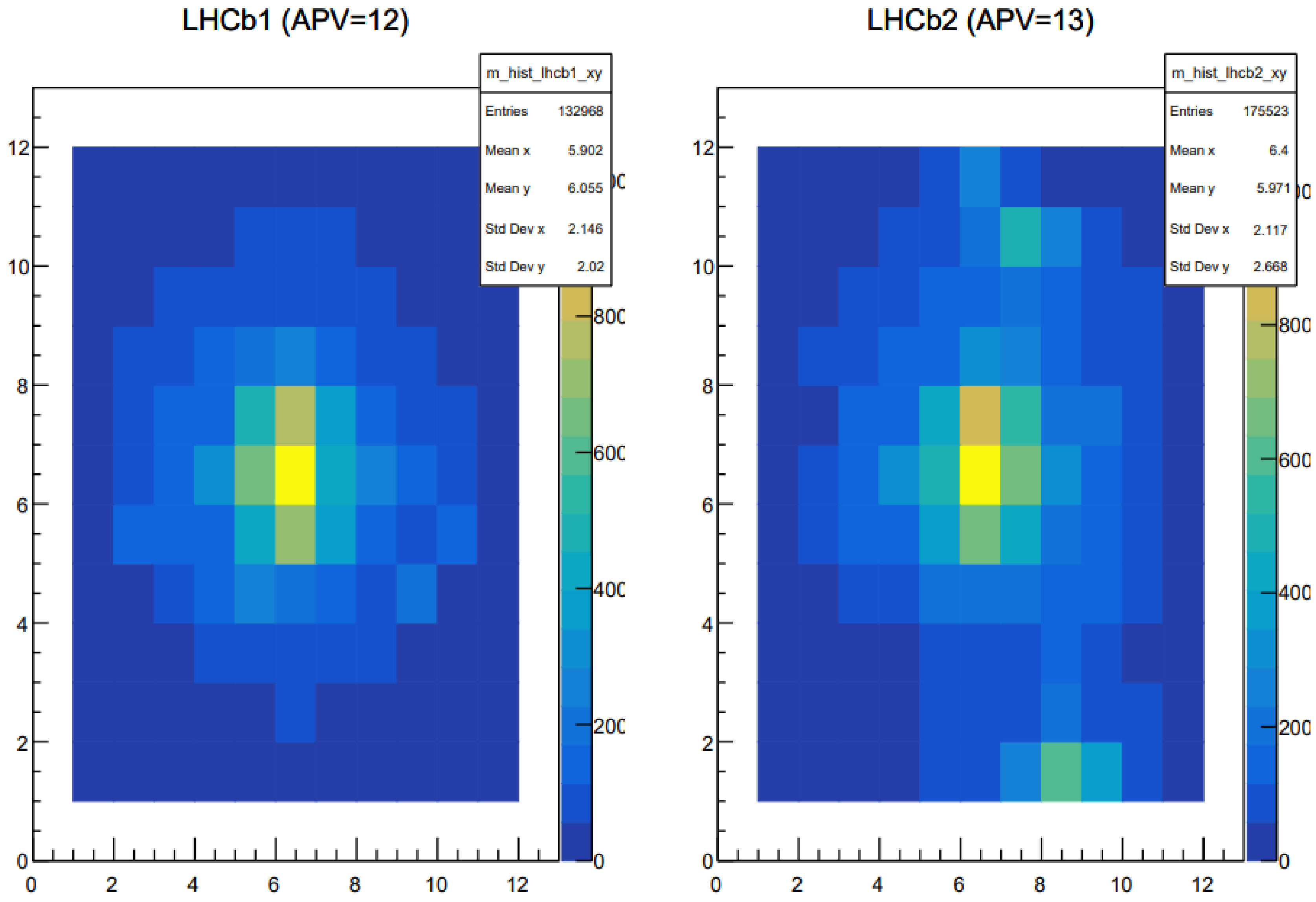
- Study of the spatial resolution
- Efficiency study around the dead area of the PEP
- Cluster size vs. Readout pitch

Plans successfully achieved: analisys in progress





The µ-RWELL technology: the test beam 2022



Beam profile reconstructed with the two chambers with PAD-segmented readout

Grooved cathodes for neutron detection