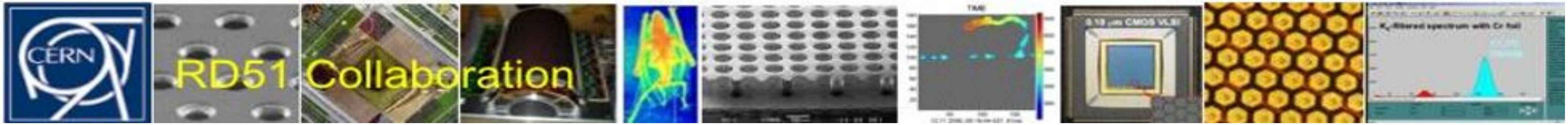
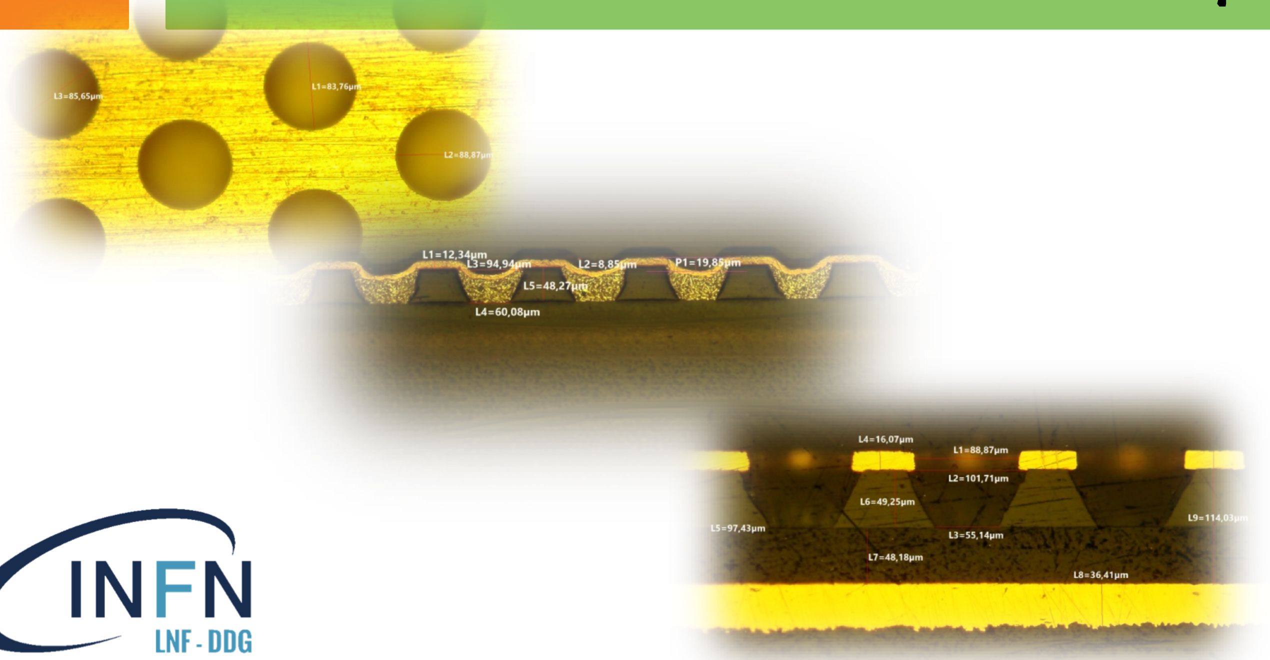


The state of art of the μ-**RWELL** technology

M. Poli Lener

G. Bencivenni, R. De Oliveira, G. Felici,
M. Gatta, M. Giovanetti, G. Morello



INFN
LNF - DDG

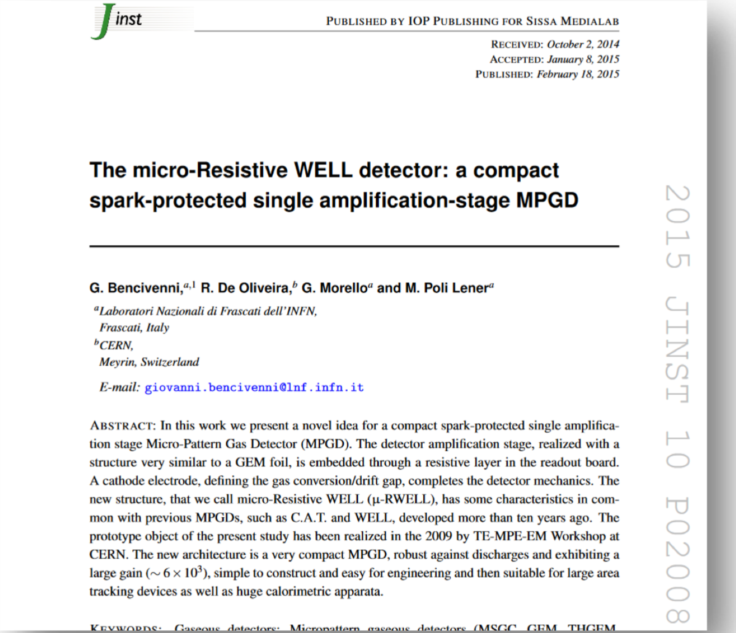
Why a new Micro-Pattern Gas Detector

The R&D on µ-RWELL detector(*) is mainly motivated by the wish of improving

stability under irradiation → discharge containment

& simplify as much as possible the

construction/assembly → time consuming/complex operation/mass production



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The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD

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[a] *Laboratori Nazionali di Frascati dell'INFN, Frascati, Italy*
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Abstract: In this work we present a novel idea for a compact spark-protected single amplification stage Micro-Pattern Gas Detector (MPGD). The detector amplification stage, realized with a structure very similar to a GEM foil, is embedded through a resistive layer in the readout board. A cathode electrode, defining the gas conversion/drift gap, completes the detector mechanics. The new structure, that we call micro-Resistive WELL (µ-RWELL), has some characteristics in common with previous MPGDs, such as C.A.T. and WELL, developed more than ten years ago. The prototype object of the present study has been realized in the 2009 by TE-MPE-EM Workshop at CERN. The new architecture is a very compact MPGD, robust against discharges and exhibiting a large gain ($\sim 6 \times 10^3$), simple to construct and easy for engineering and then suitable for large area tracking devices as well as huge calorimetric apparata.

Keywords: Gaseous detectors; Micropattern gaseous detectors (MSGC, GEM, THGEM

2015 JINST 10 P02008

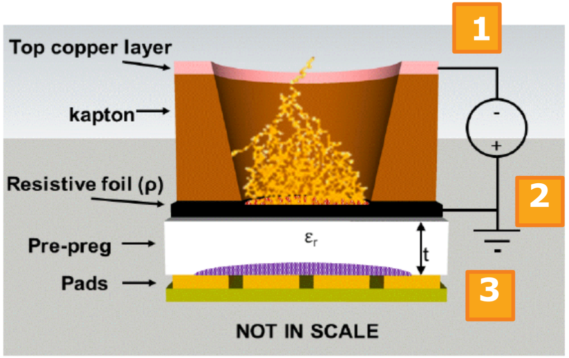
(*) G. Bencivenni et al., "**The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD**", 2015 *JINST* **10** P02008

The μ-RWELL

The **μ-RWELL is a resistive MPGD** composed of two elements:

- **μ-RWELL_PCB**
- **Cathode**

The μRWELL_PCB is realized by coupling the **amplification stage** with the **readout PCB** through a **resistive layer.**



1 a **WELL** patterned **kapton foil** (with a **Cu-layer on the top**) acts as **amplification stage**

2 a **resisitive DLC** layer(*) (Diamond-Like-Carbon), with **ρ~20÷100 MΩ/□**

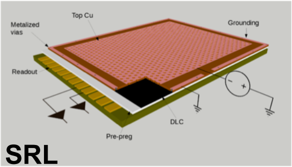
3 a standard **readout PCB** with **pad/strip** segmentation

(*) DLC foils are currently provided by the Japan Company – BeSputter. New DLC machine @ CERN (Max DLC size: 50x200 cm2)

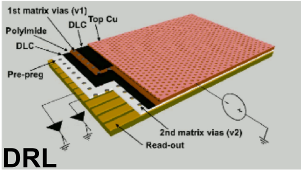
µ-RWELL R&D History

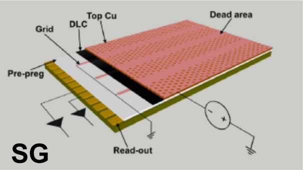
New MPGD idea in collaboration with GDD

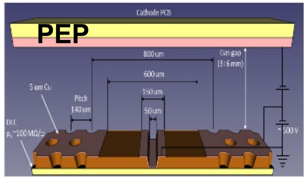
R&D on low-rate layout



R&D on high-rate layout



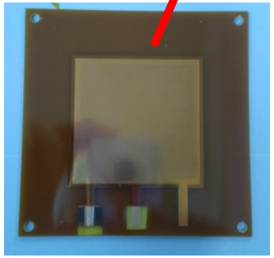




R&D start

TT @ ELTOS

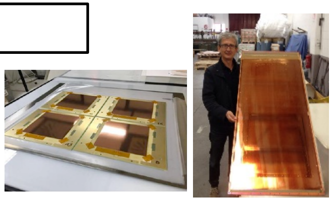
2009 – 2014 – 2015 – 2016 – 2017 – 2018 – 2019 – 2020 – 2021 – 2022 – 2023



TB @ CERN

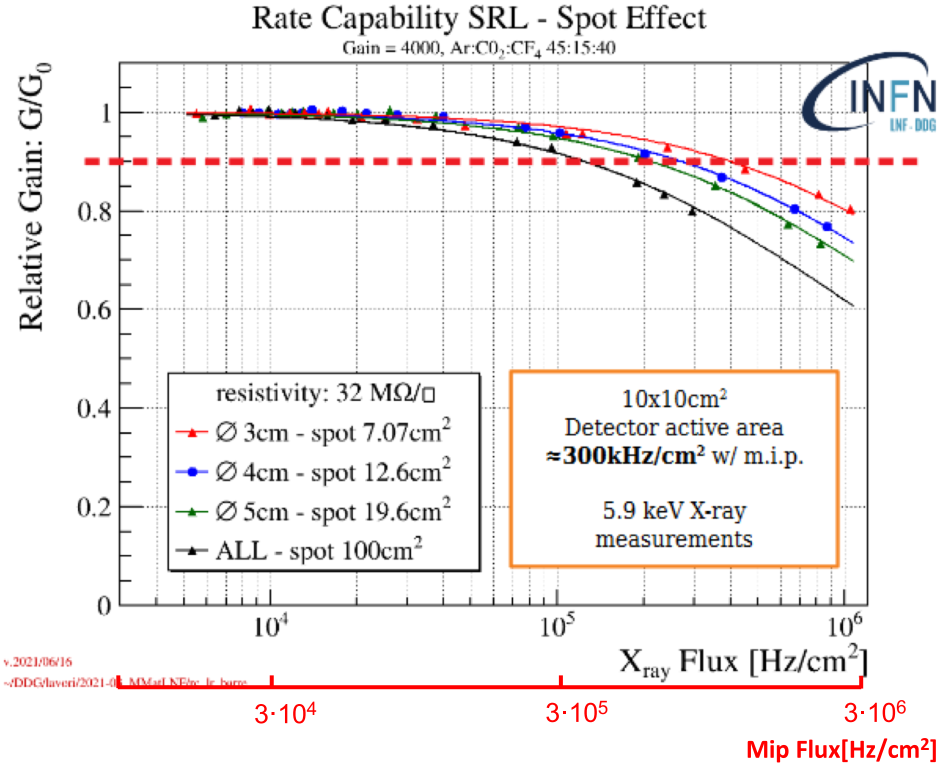
TB @ high rate @ PSI

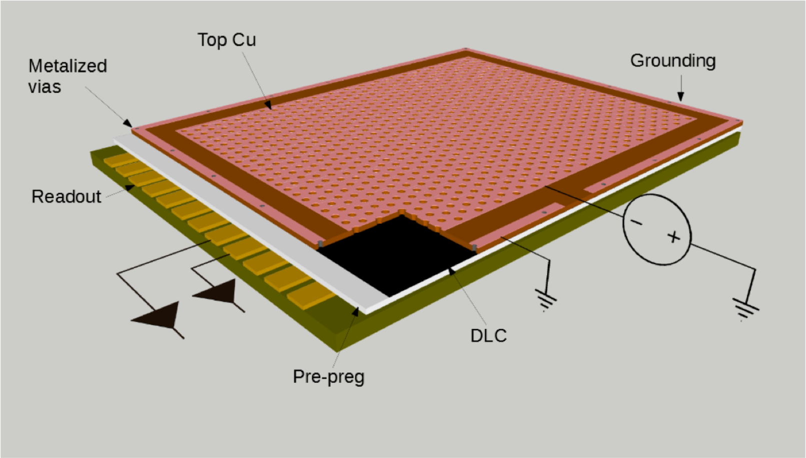
TB @ CERN



TT @ ELTOS

The low-rate layout: SRL

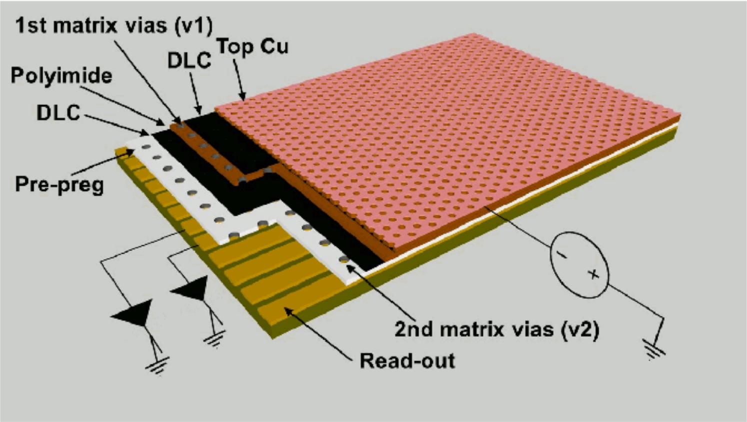




Single Resistive Layer (SRL)

- **2-D current evacuation scheme based on a single resistive layer**
- grounding around the perimeter of the active area
- limitation for large area: the path of the current towards ground connection depends on the particle incidence point → detector response inhomogeneity → **limited rate capability <100 kHz/cm²**

High-rate layouts: DRL

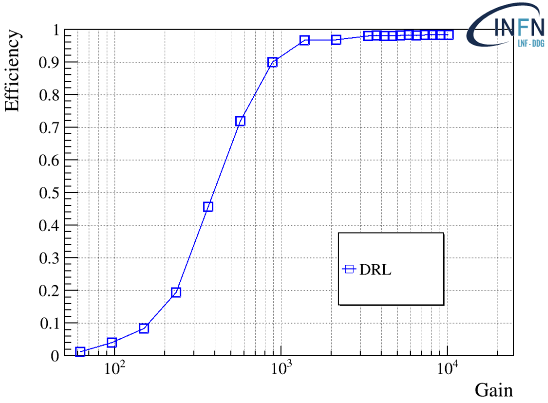


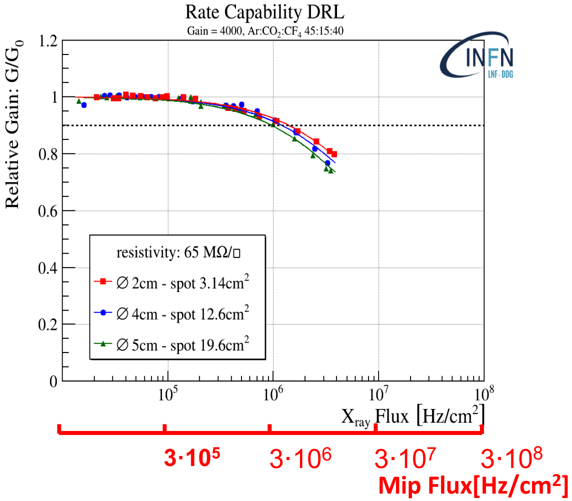
Double Resistive Layer

- 3-D current evacuation scheme
- two stacked resistive layers connected through a matrix of conductive vias
- Resistive stage grounding through a further matrix of vias to the underlying readout electrodes
- pitch of the vias with a density of the order of 1/cm^2
- No- dead zone in the active area

Performance vs manufacturing

DRL shows **very good performance**, but it has production **limitations due to the double matrix of vias which** requires complex manufacturing

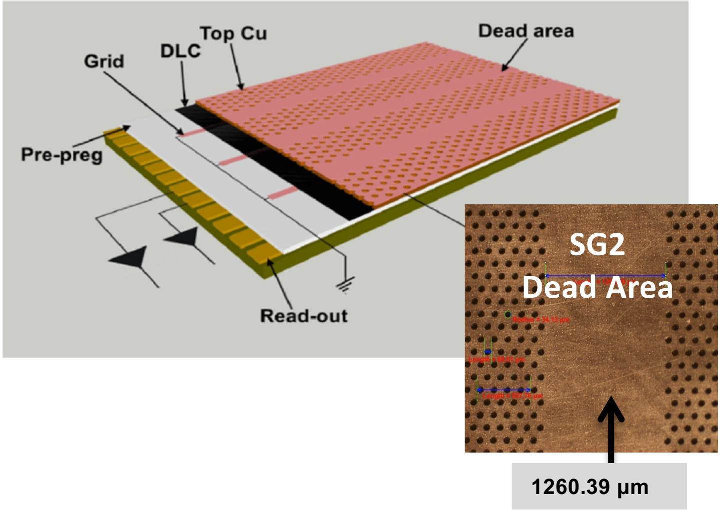


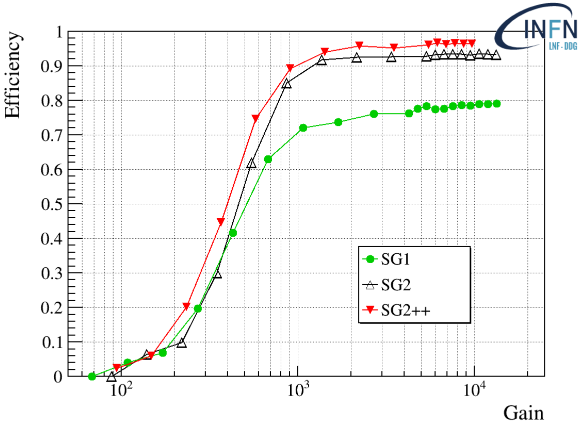


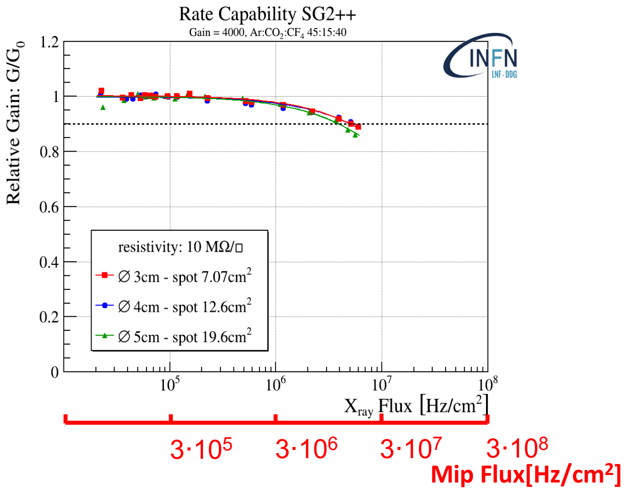
High-rate layouts: SG

The Silver Grid

- simplified HR scheme based on a SRL
- 2-D evacuation scheme by means a conductive grid realized on the DLC layer
- grid lines can be screen-printed or etched by photo-lithography
- pitch of the grid lines of the order of 1/cm
- Dead zone of 2 mm (**SG1**), 1.2 mm (**SG2**) and 0.6 mm (**SG2++)**



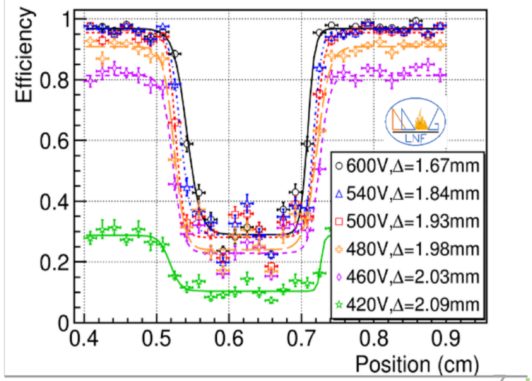




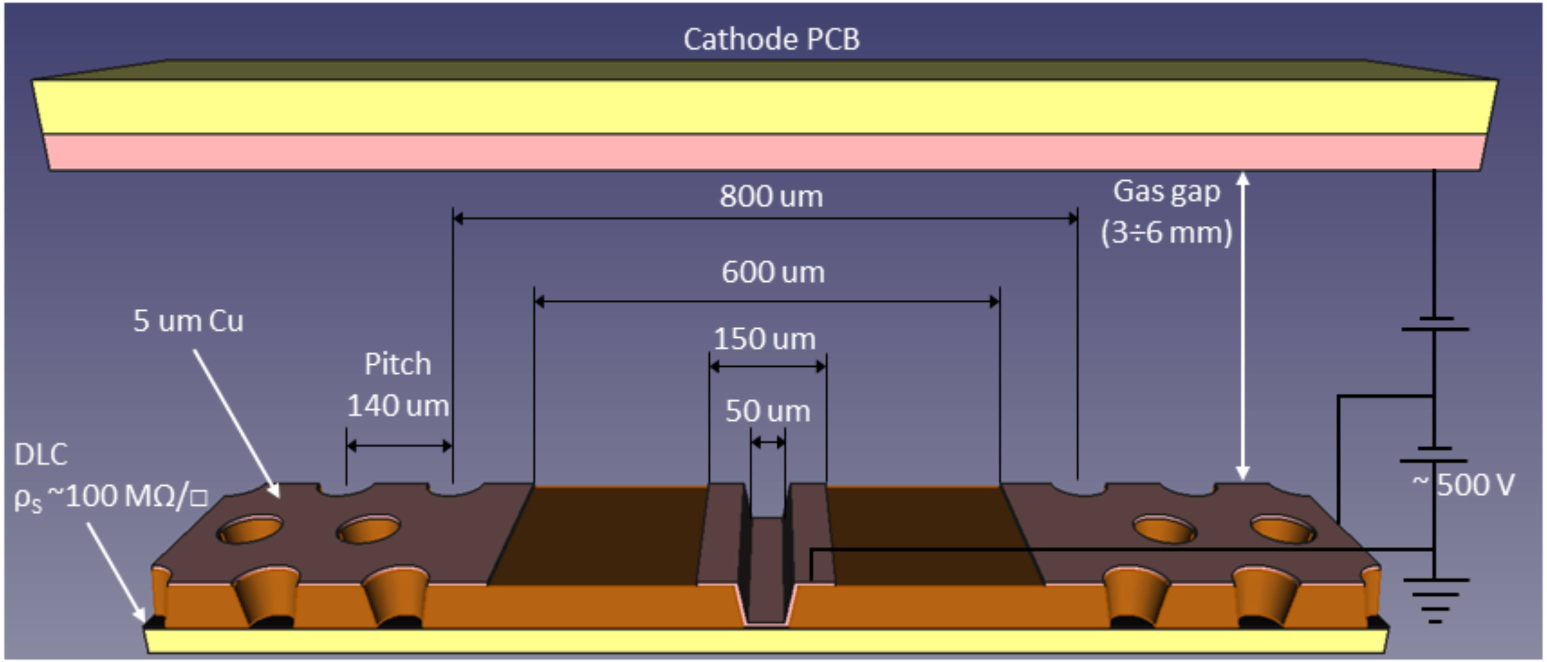
Performance vs manufacturing

The SG2++ shows **good performance** and it is more simple than **DRL, BUT the alignment** of the **conductive grid pattern on DLC** wrt the **amplification pattern on the top is** a bit **critical**

Effect of SG1 dead zone



High-rate layouts: PEP, the idea

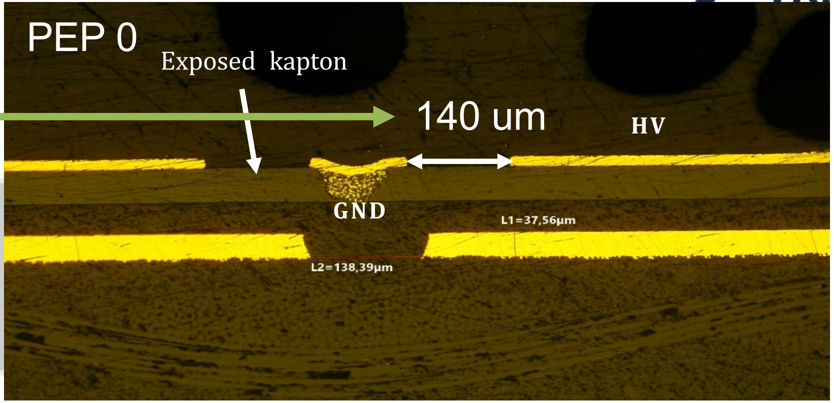


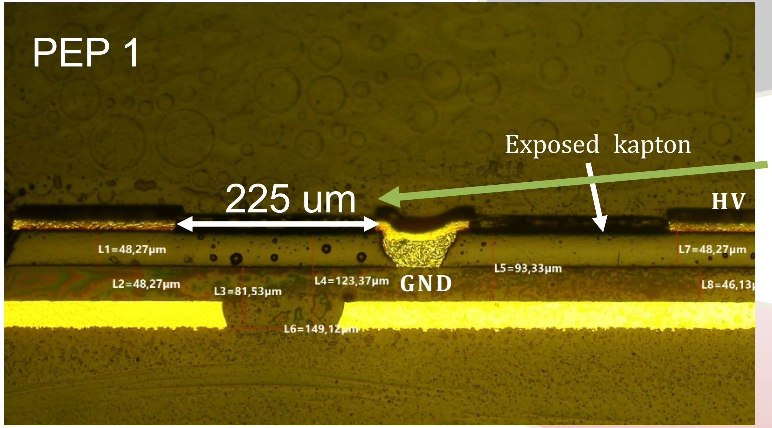
PEP (Patterning – Etching – Plating)

- Single DLC layer
- DLC grounding from top by kapton etching and plating
- No alignment problems
- **Scalable to large size**

High-rate layouts: PEP, the evolution

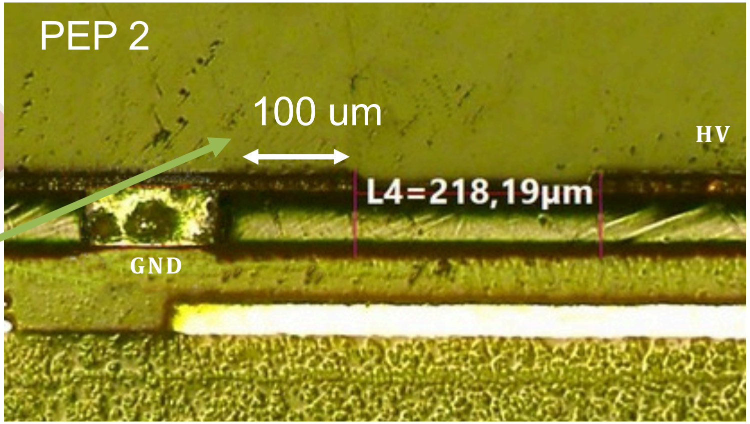
PEP0 layout:
- distance between GND and HV too short → MSGC-like effect (current instabilities)
- good copper plating of the PEP





PEP1 layout:
- distance between GND and HV increased → detector stable up to gain of 8000
- good copper plating of the PEP

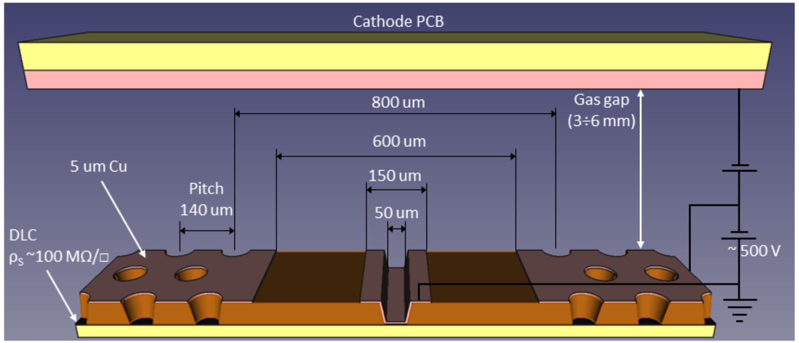
PEP2 layout:
- distance between GND and HV increased → detector stable up to gain of 10000
- Increased Cu area around the PEP → larger dead zone

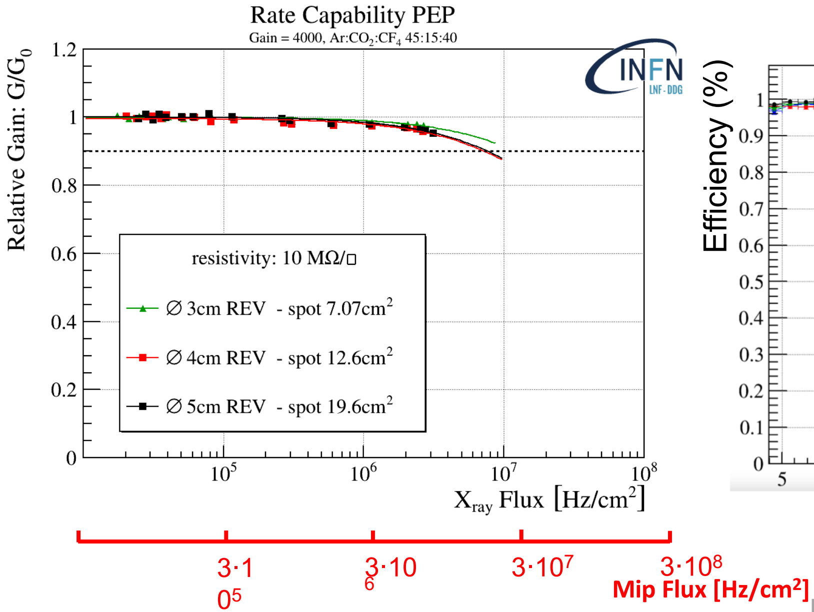


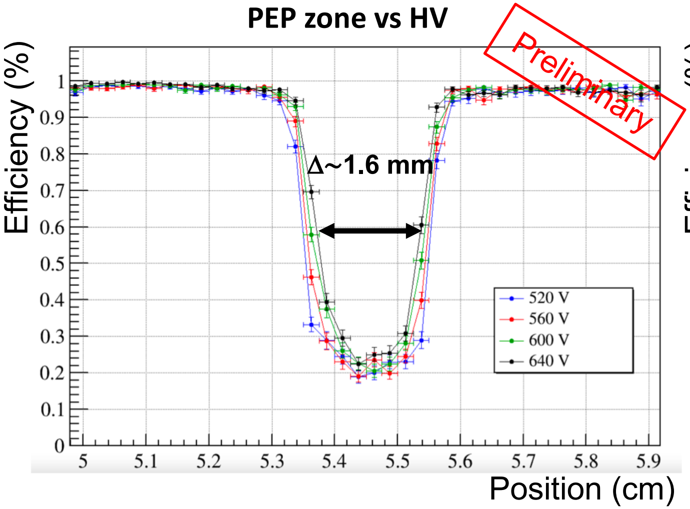
High-rate layouts: PEP

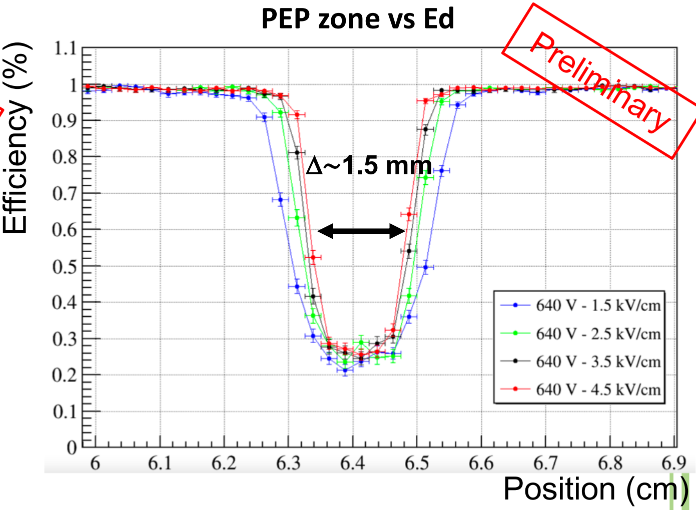
The PEP (Patterning – Etching – Plating)

- Single DLC layer
- Grounding from top by kapton etching and plating
- No alignment problems
- **Scalable to large size**
- **Measured dead zone > 1.6 mm wrt 0.8 mm (by design)**









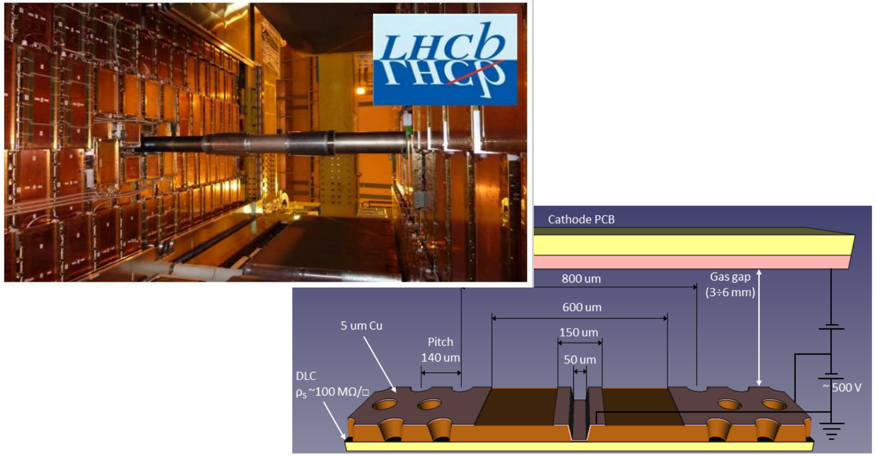
In collaboration with E. De Lucia & M. Bondi

μ-RWELL for Muon triggering (LHCb)

Inner regions of the Muon system for the LHCb Upgrade II are designed to be instrumented with μ-RWELL technology.

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

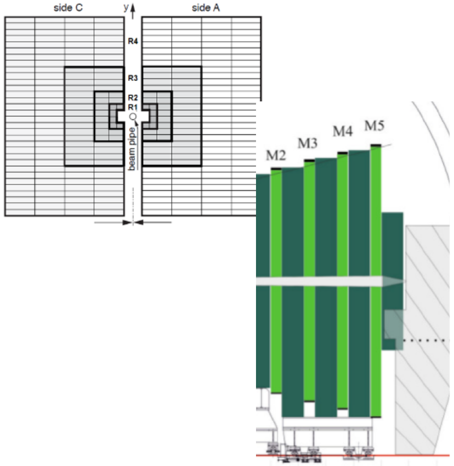
- Rate up to 1 MHz/cm^2 per single detector gap
- Efficiency (4-gaps) 99% within a BX (25 ns)
- Stability for 10 y of operation up to 1 C/cm^2



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



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

- **576 gaps, size 30x25 to 74x31 cm^2, 90 m^2 det., 130 m^2 DLC**

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

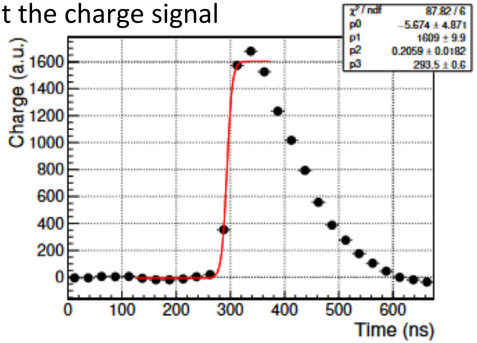
(*) CERN-LHCC-2021-012 ; LHCB-TDR-023
http://cds.cern.ch/record/2776420?ln=it

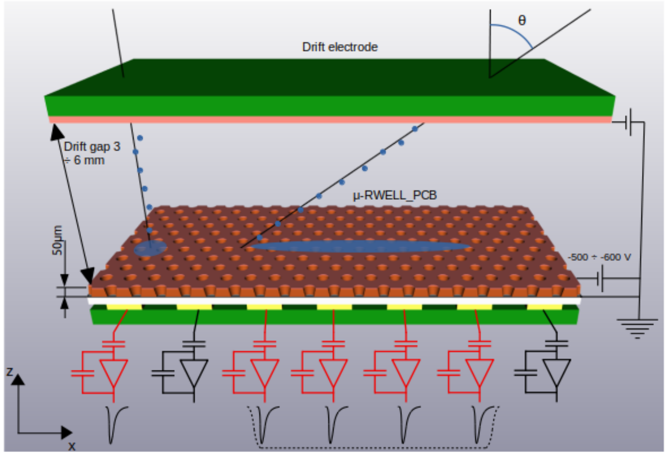
μ-RWELL as tracking device (I)

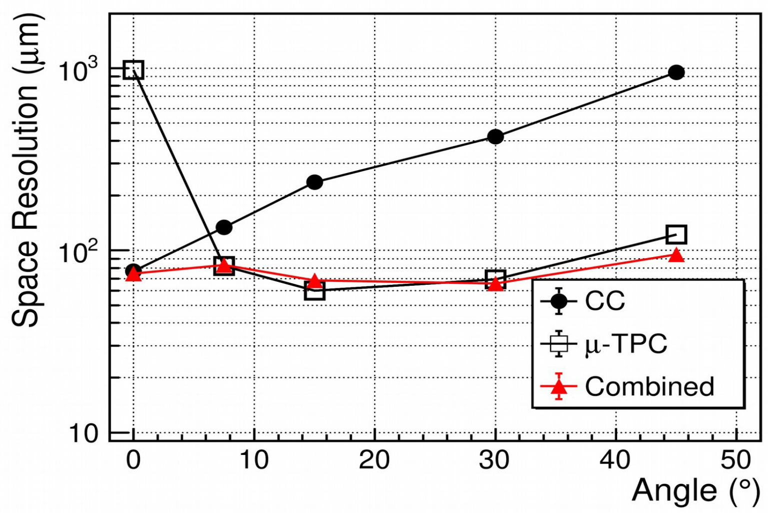
For inclined tracks and/or in presence of high B field, **the charge centroid method gives a very broad spatial distribution** on the anode-strip plane.

An improvement of the position reconstruction is given by the μTPC algorithm(*): 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

μTPC example: Fermi-Dirac is used to fit the charge signal



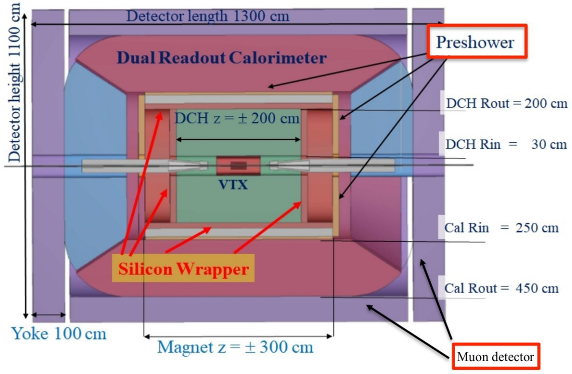




(*) *T. Alexopoulos et al., NIM A 617 (2010) 161*

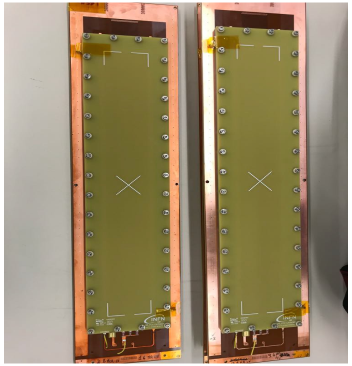
In collaboration with G. Cibinetto, R. Farinelli, L. Lavezzi

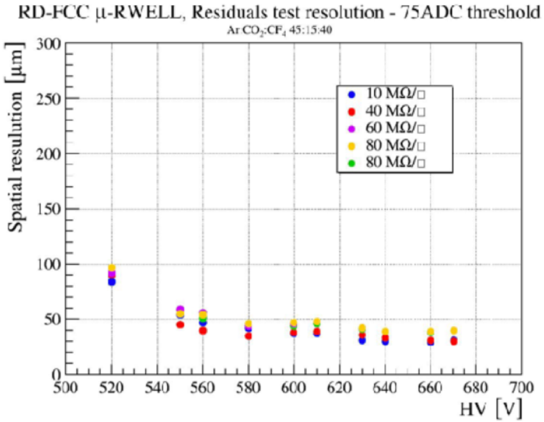
µ-RWELL as tracking device (II)



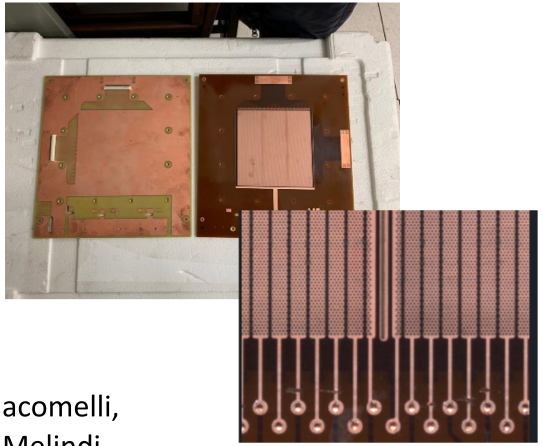
The IDEA detector is a general purpose detector designed for experiments at future e+e- colliders (FCCee and CepC). Pre-shower detector and the Muon system are designed to be instrumented with µ-RWELL technology.

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

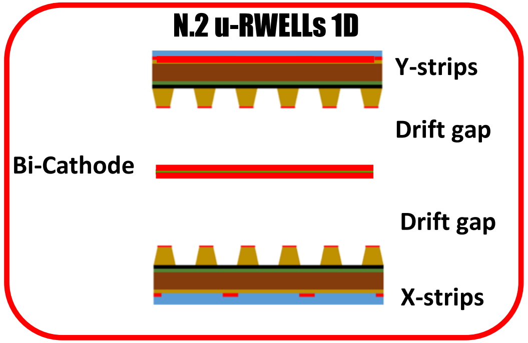


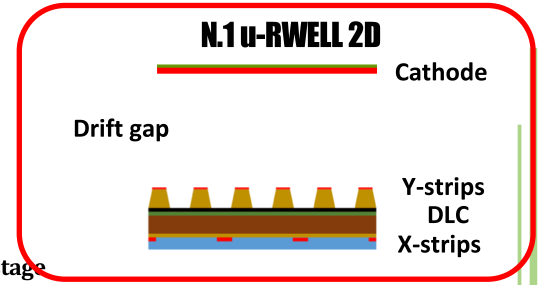


TB 2022 campaign
µ-RWELL prototypes with strip pitch varing between 0.4 to 1.6 mm
µ-RWELL with 2D readout



Y coordinate on the TOP of the ampl. stage

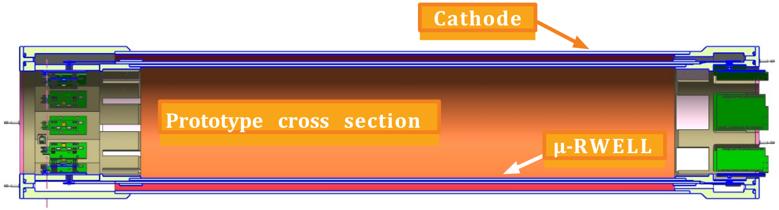


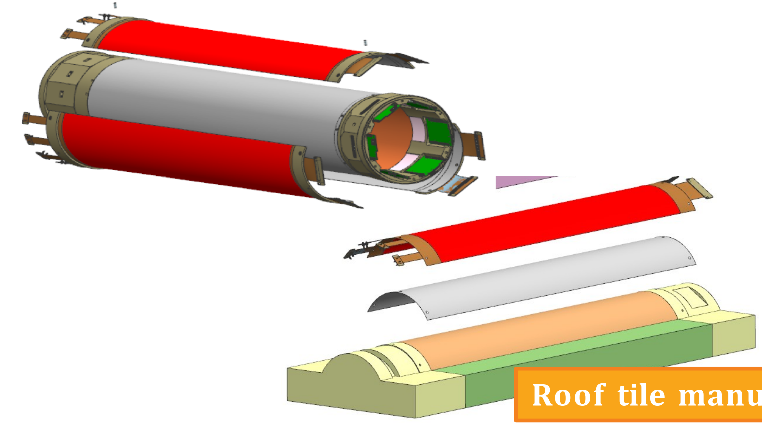


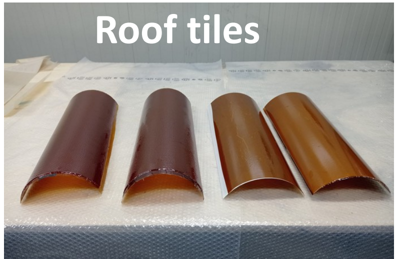
In collaboration with G. Cibinetto, R. Farinelli, L. Lavezzi, M. Gramigna, P. Giacomelli, E. De Lucia, D. Domenci, A. D'angelo, M. Bondi, M. Scodeggio, I. Garzia, M. Melindi

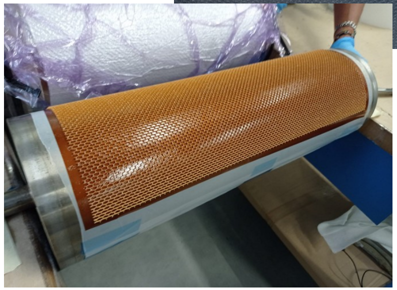
μ-RWELL as tracking device (III)

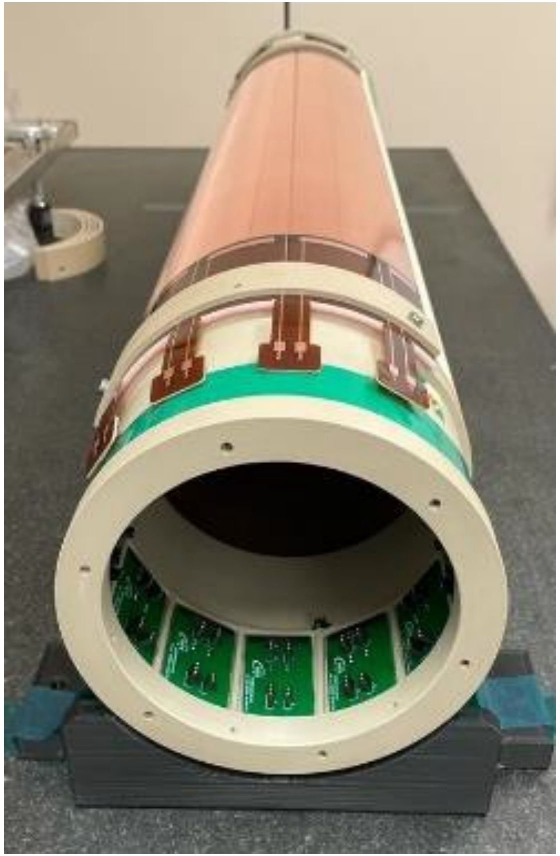
Development of an ultra-light modular **cylindrical μ-RWELL** as **inner tracker** for the Super Charm Tau factory (EURIZON project).
The B2B layout (a double radial TPC) is designed to have a **very low material budget** (0.86÷0.96% X_0) and **modular roof-tile shaped components**: in case of failure/damage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











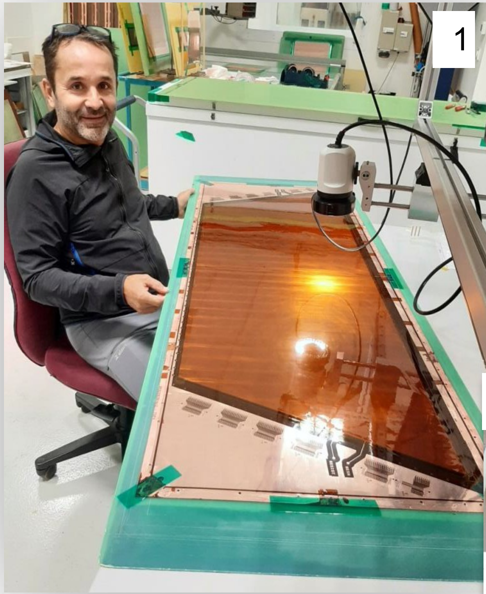
The first cylindrical low mass uRWELL

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

μ-RWELL technology spread

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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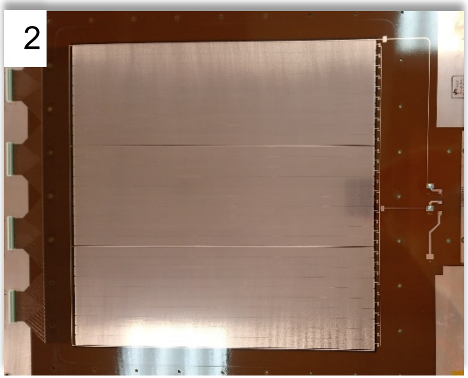
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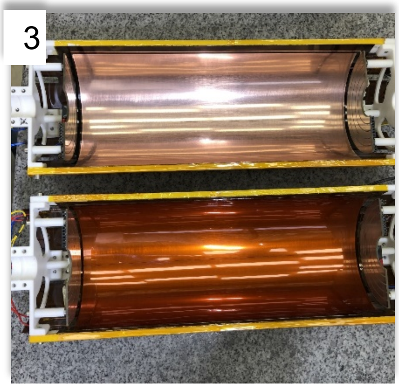
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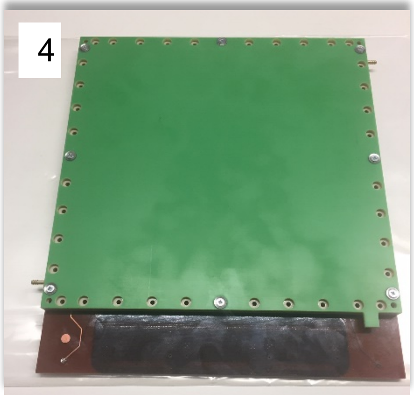
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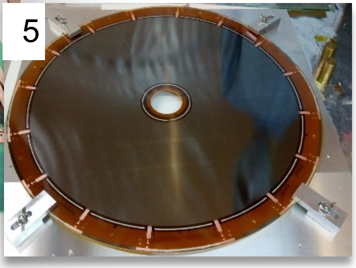
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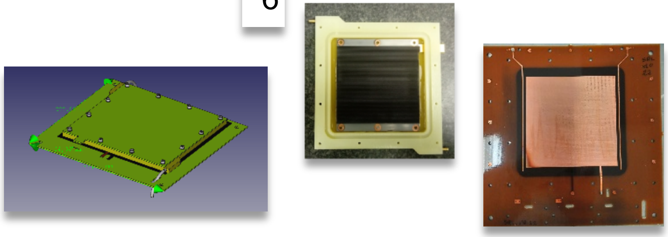
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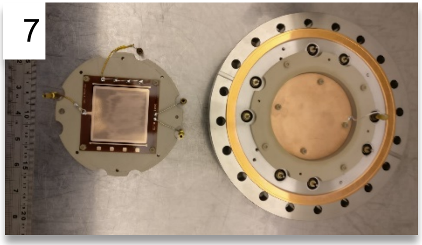
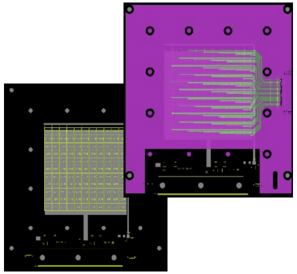

7

Technology transfer (I)

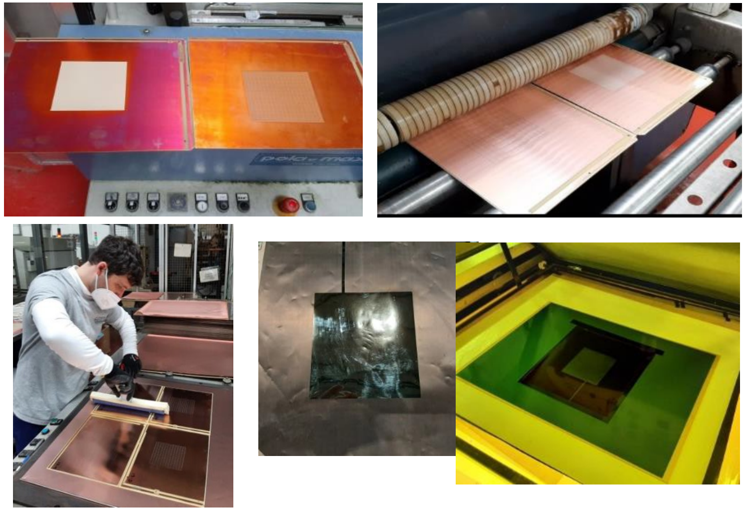
AIDA innova
EU-project

LAYOUT design

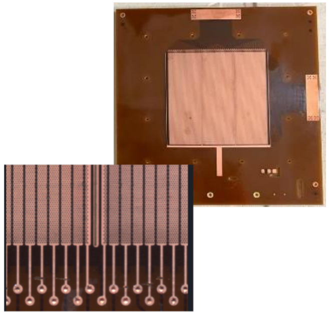


DCL foil production (*)

PCB production



Final detector manufacturing



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

Technology transfer (II)

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

Step 1 - CERN_INFN DLC sputtering machine @ **CERN**
Installed and commissioned beginning of Nov 2022
Operated by CERN + LNF (& INFN) staff

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

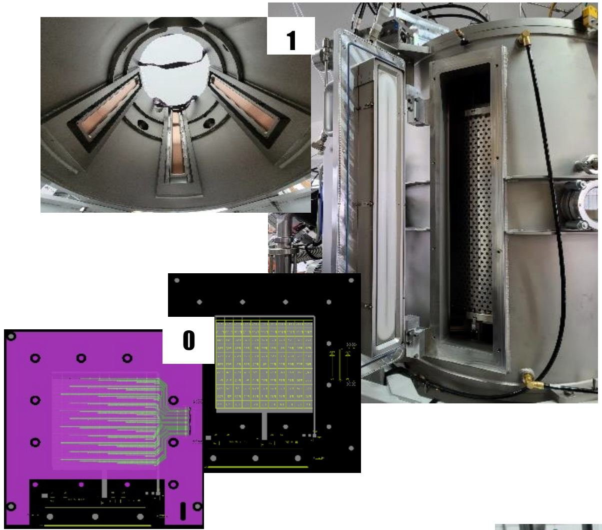
Step 3 - DLC patterning by **ELTOS**
photo-resist ⊕ patterning with BRUSHING-machine

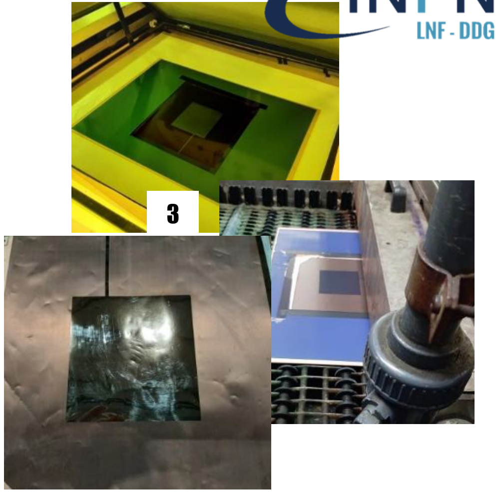
Step 4 - DLC foil gluing on PCB by **ELTOS**
PCB planarizing w/ screen printed epoxy ⊕ single 106-prepreg

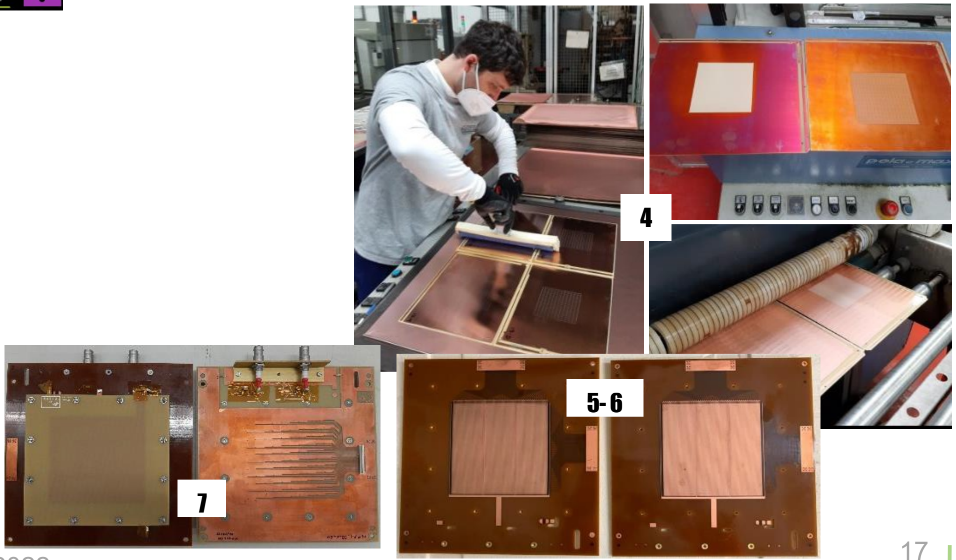
Step 5 - Top copper patterning by **CERN** (in future by **ELTOS)**
Holes image and HV connections by Cu etching

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

Step 7 – Final electrical cleaning and detector closing @ **CERN**



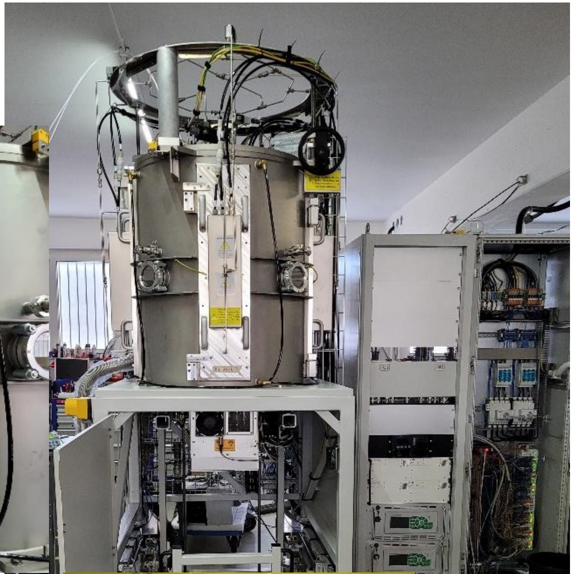




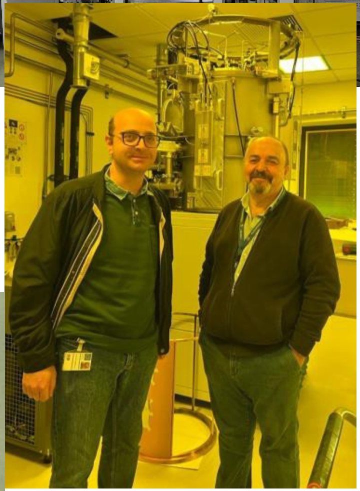
CID: the CERN-INFN DLC machine

DREAM TEAM: Rui, Gianni, Mauro, Gianfranco, Givi, Serge

- **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



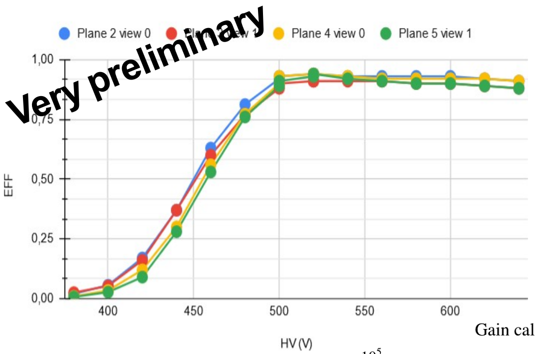
- **Installation,** week 43
- **Commissioning** & **training** of the CERN-INFN teams, week 44
- **Test-phase**, week 47
- **1 week/month** joint CERN-INFN test runs



QA & QC

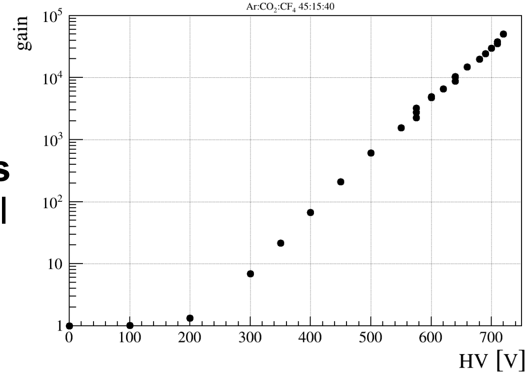
The technology has been **largely improved** in the last year, thanks to the introduction of the **“dry-electrical-cleaning”,** a sort of a hot HV conditioning leading to a soft clean of the residual imperfections of the detector manufacturing.

Detector stability improved → up to **200V** large plateau, **estimated gain up to 5×10⁴**

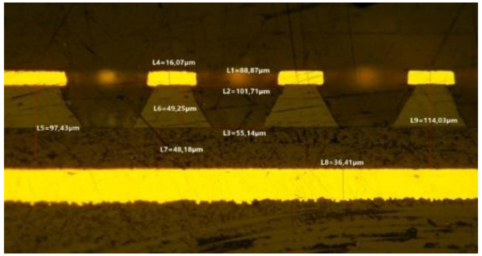


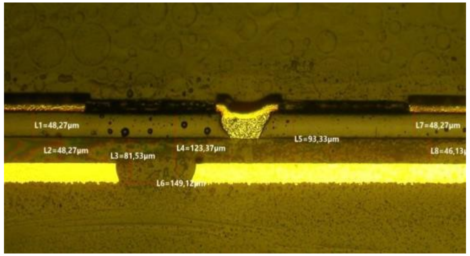
Gain calibration of μ-RWELL DUT2

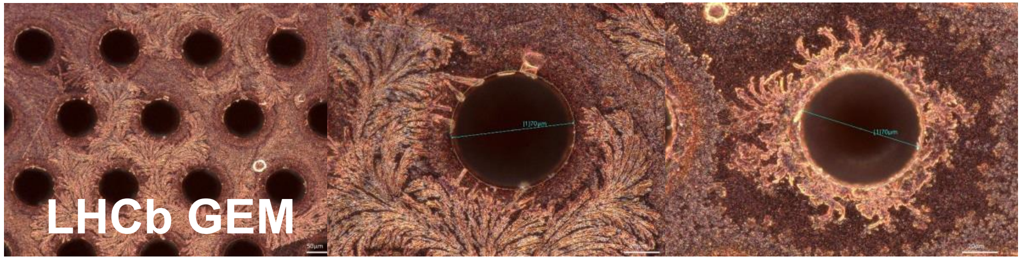
Ar:CO$_2$:CF$_4$ 45:15:40



Optical metallographic survey (in ELTOS) as well as **SEM analysis** (at CERN) are used to take all construction steps under control as well as checking effects for possible aging/etching (by fluorine …).







Summary

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 TT to PCB industry. A key-point has been the acquisition of the DLC sputtering machine co-funded by CERN and INFN.

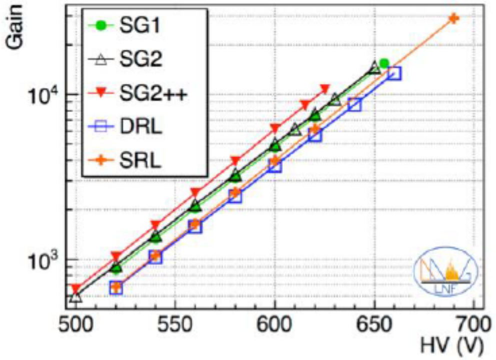
Additional tasks:

- Eco-gas mixture studies
- Stability tests (X-ray, gamma/neutron irradiation)
- Integration with FEE (Fatic, VMM3, etc)

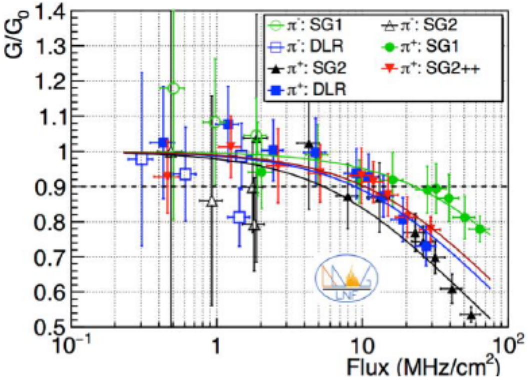
Many Thanks

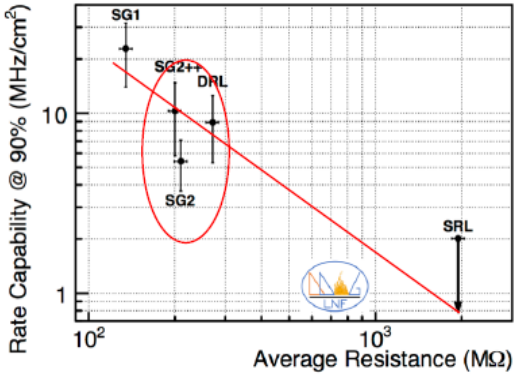
High-rate layouts: performance w/m.i.p.

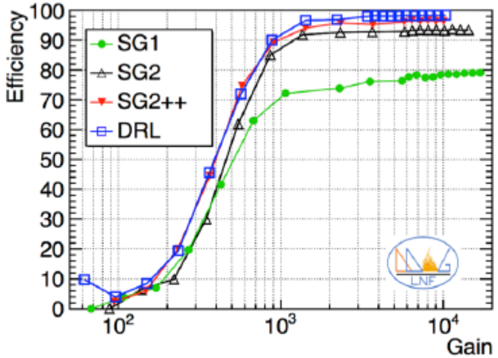
Gain up to ~ 10^4



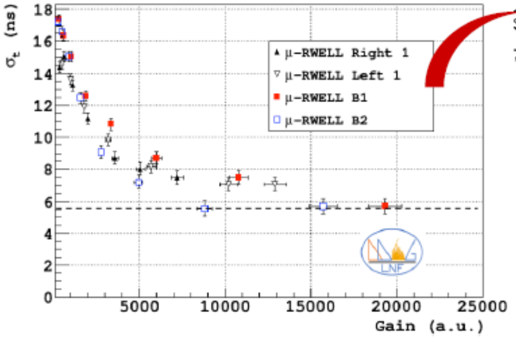
Rate capability (@ G = 5000) ~ 5-10 MHz/cm²



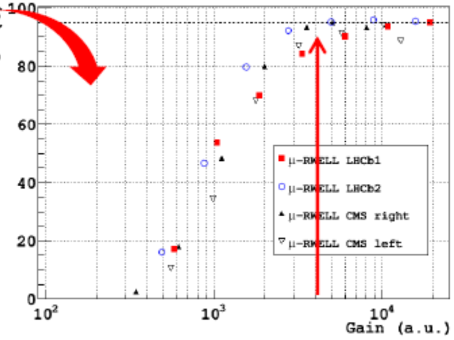




Efficiency ~ 98%

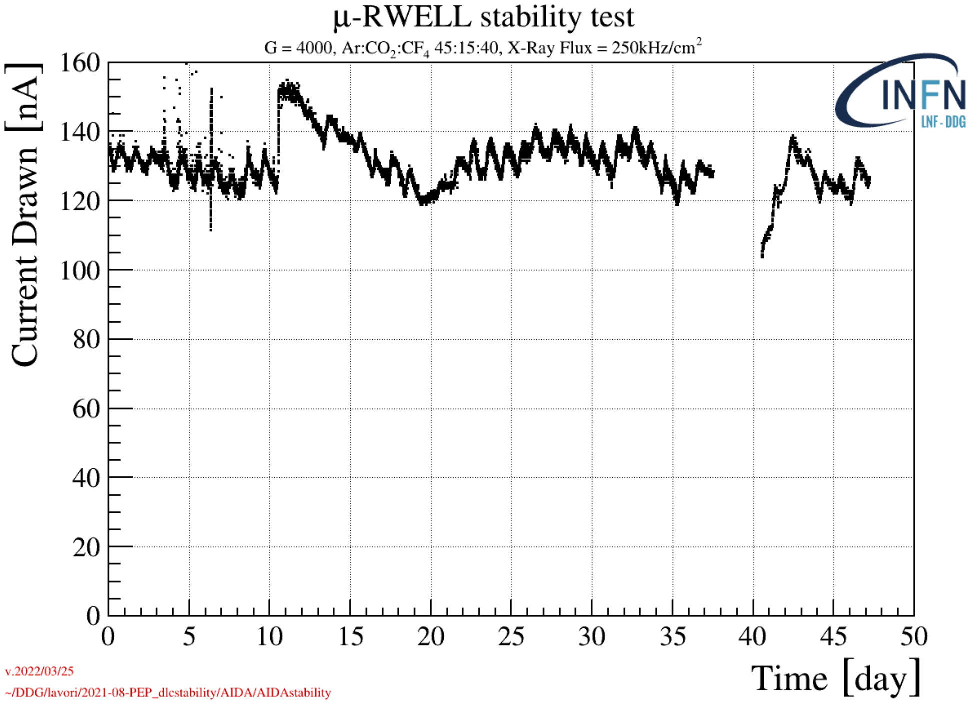


σ_t ~ 5-6 ns



Efficiency in 25 ns

PEP-1 layout performance

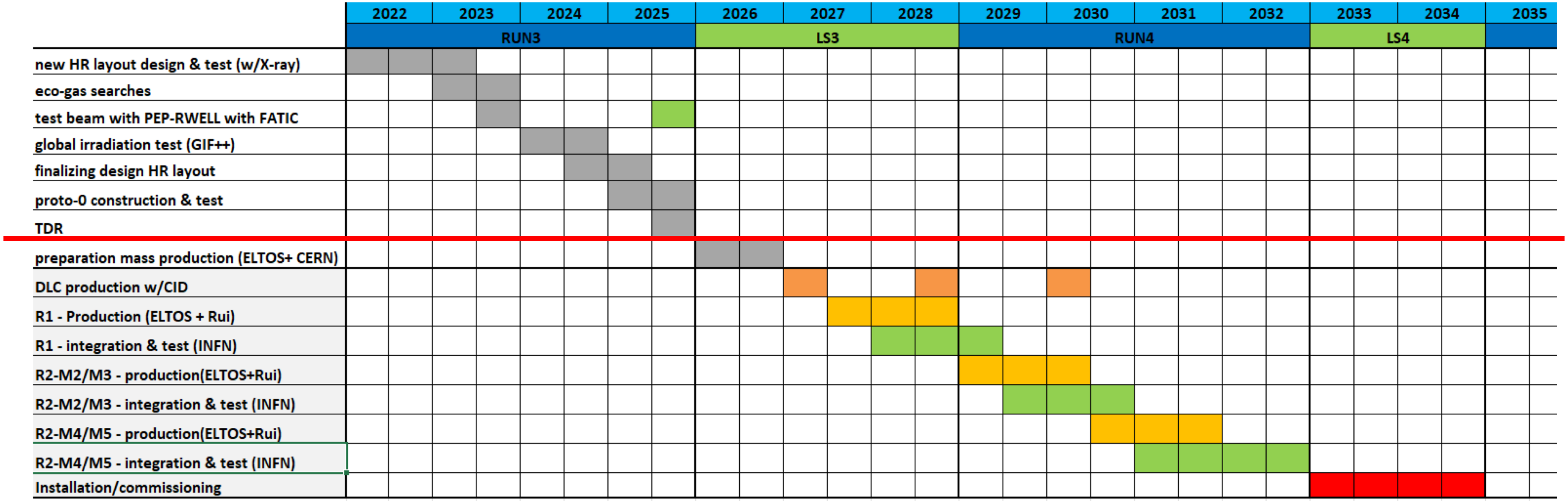


A long-term X-ray irradiation is on-going: the current of the detector electrodes (Itop, Icat) as well as ambient parameters (T, P, RH) are constantly monitored.

$Q_{int.}$ ~ 100mC over all the test period (irradiated area= 20 cm^2).

Because of the common effort in the scientific community to reduce the F-based components, we are changing the gas mixture to Ar:CO$_2$:iC$_4$H$_{10}$ 68:30:2 and starting the stability measurement

Tentative schedule μ-RWELL in LHCb (only one «integration group»)



	2022		2023		2024		2025		2026		2027		2028		2029		2030		2031		2032		2033		2034		2035	
	RUN3								LS3						RUN4								LS4					
new HR layout design & test (w/X-ray)	▨	▨	▨																									
eco-gas searches			▨	▨																								
test beam with PEP-RWELL with FATIC				▨				🟩																				
global irradiation test (GIF++)					▨	▨																						
finalizing design HR layout						▨	▨																					
proto-0 construction & test							▨	▨																				
TDR								▨																				
preparation mass production (ELTOS+ CERN)									▨	▨																		
DLC production w/CID											🟧			🟧			🟧											
R1 - Production (ELTOS + Rui)												🟨	🟨	🟨														
R1 - integration & test (INFN)													🟩	🟩	🟩													
R2-M2/M3 - production(ELTOS+Rui)															🟨	🟨	🟨											
R2-M2/M3 - integration & test (INFN)																🟩	🟩	🟩										
R2-M4/M5 - production(ELTOS+Rui)																		🟨	🟨	🟨								
R2-M4/M5 - integration & test (INFN)																			🟩	🟩	🟩	🟩						
Installation/commissioning																							🟥	🟥	🟥	🟥		

The construction steps::
- CERN→ DLC production with CID machine
- Eltos → PCB, DLC patterning & gluing
- CERN → final detector manufacturing (RUI)
- CERN → hot dry conditioning (RUI)
- CERN → final detector test e FEE integration (personale INFN)

Open R&D

Gas related R&D:

- **CF4 is not an eco-gas, responsible of strong kapton etching** observed on GEM detectors (*STUDY OF ETCHING EFFECTS ON TRIPLE-GEM DETECTORS OPERATED WITH CF_4-BASED GAS MIXTURES, M. Alfonsi et al., IEEE Trans.Nucl.Sci.52 (2005) 2872-2878.*)
- F^- (responsible of kapton etching) is produced with any small CF4 concentration (Studies on fluorine-based impurity production in Triple-GEM detectors operated with C-based gas mixture, B. Mandelli et al., NIM A 1004 (2021) 165373.)
- **Old GEM detectors at LHCb** will be **analysed** to check for **CF4 etching effects** (we can learn from this study)
- **PEP μ-RWELL** irradiated with X-Rays at LNF will be **analysed to check for possible CF4 etching effects**
- **Eco-gas mix for RWELL: looking for collaboration (Gas – CERN group will provide support for gas analysis)**
- **Long-term test of a PEP μ-RWELL will be started soon with Ar/Co2 gas mix** (no CF4): **X-Rays** (LNF) & **GIF++** (**looking for collaboration**)

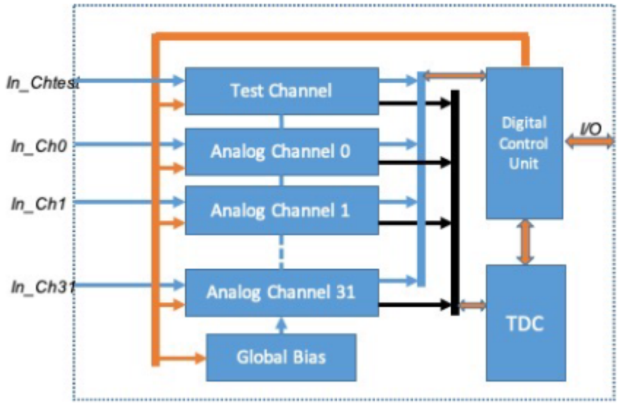
Mechanics raleted R&D:

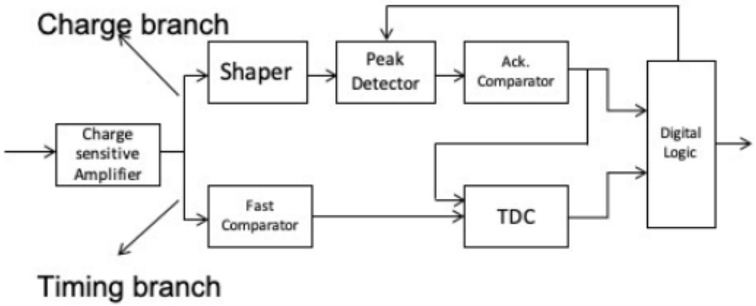
- **Defining a safe assembly/testing procedure: DI-washing+electrical hot-cleaning, humidity control in the gas line, detector conditioning** (in strict collaboration with Rui)
- **Replacing FR4 frames with PEEK frames,** more expensive BUT not hygroscopic and then compatible with CF4 (eventually only in closed mode)

Electronics & detector design:

- **FATIC design and integration with detector**
- **Detector layout optimization (FEE & HV connectors, gas pipe, ect)**

FATIC ASIC (New Development)





Analog Section:

- 32 Front-end channels:
  - Fast output: designed for timing measurements
  - Slow output: input signal acknowledgement and charge measurement
  - Global Bias: temperature and power supply independent, internal calibration, bias monitoring

Digital Section:

- Control Unit:
  - 320 MHz SLVS I/O link
  - Channel & Global bias adj. bits
  - TDC control

CSA settings:

- Input signal polarity: positive & negative
- Gain: High ≈ 50mV/fC, Low ≈ 10 mV/fC
- Recovery time: adjustable

Shaper settings:

- Peaking time: 25ns, 50ns, 75ns, 100ns (polarity adj)

TDC resolution:

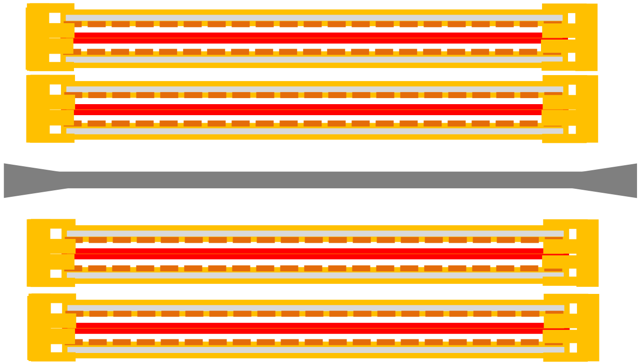
- 100ps (5 bits fine + 16 bits coarse)

Cdet< 200 pF

Possible layouts

preliminary

- N.2 small gap B2B C+layers → 1.5÷1.9% X0
- 1 cm gas gap/layer
- 4 cm global sampling gas



- N.1 large gap B2B C+layers → 0.75÷0.95% X0
- 5 cm gas gap/layer
- 10 cm global sampling gas

Operation of large gas gap to be verified

Material budget estimated taking into account different material choices for the mechanics, cathode and faraday cage.
All these layouts require the design, construction and test of a C+RWELL prototype.
The prototype under discussion is based on the innovative concept of the **modular roof-tile shaped detector.**

A Radial Time Projection Chamber for α detection in CLAS at Jlab, R. Dupré et al., 10.1016/j.nima.2018.04.052

ANODE & CATHODE LAYERING (*preliminary*)

single layer

ANODE Dia-int=153.8mm; Dia-ext=162mm

		Thikcness (um)		X0 (cm)	% X0
Cyl. Support Anode	Cu Ground FEE	3		1,43	0,021
	kapton	50		28,6	0,017
	glue	25		33,5	0,007
	FR4	100		19,3	0,052
	glue	25		33,5	0,007
	MILLIFOAM/honeycomb	3000		1312,5	0,023
	glue	25		33,5	0,007
	FR4	100		19,3	0,052
					0,187
Amplif.	Cu	3		1,43	0,021
	kapton	50		28,6	0,017
	DLC	0,1		12,1	0,000
	Pre-preg (106)	50		19,3	0,026
					0,064
Anode 2D	Cu	3		1,43	0,021
	kapton	50		28,6	0,017
	glue	25		33,5	0,007
	Cu	3		1,43	0,021
	kapton	25		28,6	0,009
					0,076
Tile BaseLine	Glue (KREMPEL)	25		33,5	0,007
	kapton	50		28,6	0,017
	Glue	25		33,5	0,007
	Honeycom	2000		1312,5	0,015
	Glue	25		33,5	0,007
	Kapton	50		28,6	0,017
					0,073
				Tot. Anode	**0,400**

CATODHE Dia-int=180mm; Dia-ext=188mm

Cyl Support + Cathode	Cu	3		1,43	0,021
	kapton	50		28,6	0,017
	glue	25		33,5	0,007
	FR4	100		19,3	0,052
	glue	25		33,5	0,007
	MILLIFOAM/honeycomb	3000		1312,5	0,023
	glue	25		33,5	0,007
	FR4	100		19,3	0,052
Far. Cage	glue	25		33,5	0,007
	kapton	50		28,6	0,017
	Cu Ground	3		1,43	0,021
					0,233

In case of

- *high module FR4*
- *cathodes made of low resistivity DLC*
- *Faraday cage in Aluminum*

The material budget of the *single layer* option
→ *from 0,63% to 0,47% X0*

For the *B2B (large gap)* option
→ *from 0,93% to 0,75%*

work in progress