MPGD - ECT

μ – Rwell endcap trackers for the EPIC detector at EIC

Annalisa D'Angelo

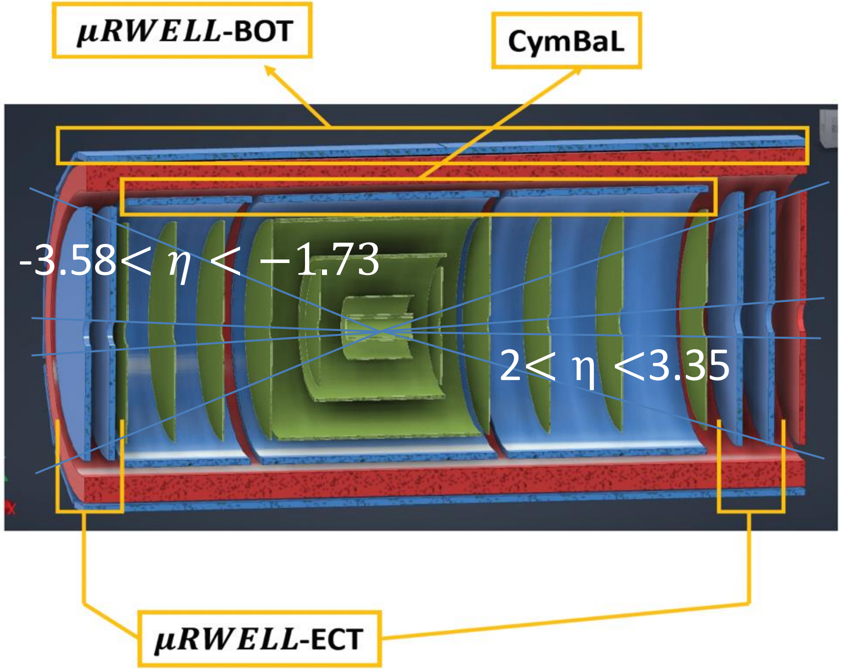
University of Rome Tor Vergata & INFN Rome Tor Vergata Rome – Italy

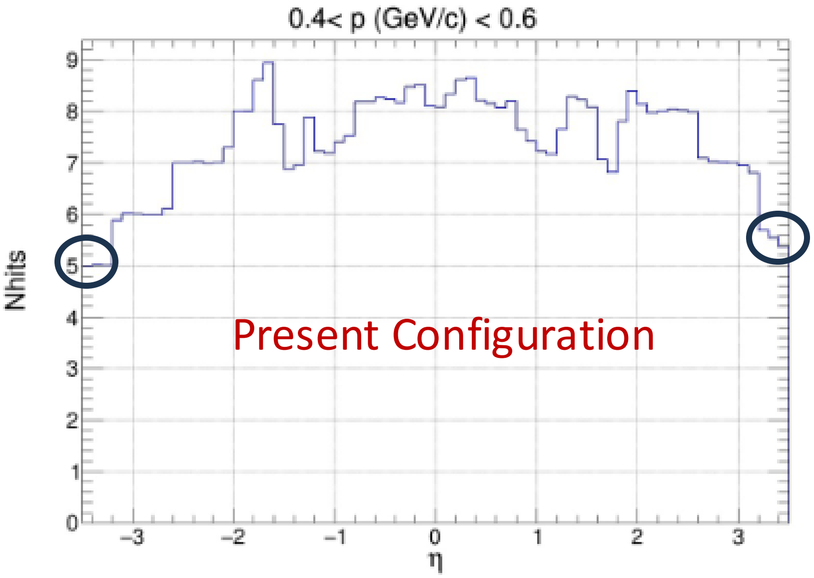
M. Bondi', A. Fantini, L. Lanza E. Sidoretti, L. Torlai

INFN – LNF (G. Bencivenni, M. Poli Lener, M. Giovannetti, G. Morello) – CERN/INFN-Napoli G. Sekhniaidze

Scope of the MPGD endcaps in ePIC detector tracking

- Adding **two MPGD Endcap Tracking (ECT) disks** both in the **hadronic** and in the **leptonic regions** increased the number of hits in the $|\eta| > 2$ region to improve pattern recognition.





Present ePIC tracker geometry

Technical Performance Requirements

Time resolution ~10 ns or less to provide tracking timing

- Fast rise time ~ 20 ÷ 50 ns
- Peaking time 50 ns
- Sampling faster than 50 MHz

Low material budget

- <1 % X_0 - it will be the minimum compatible with the chosen technology

Spatial resolution: 150 μm or better

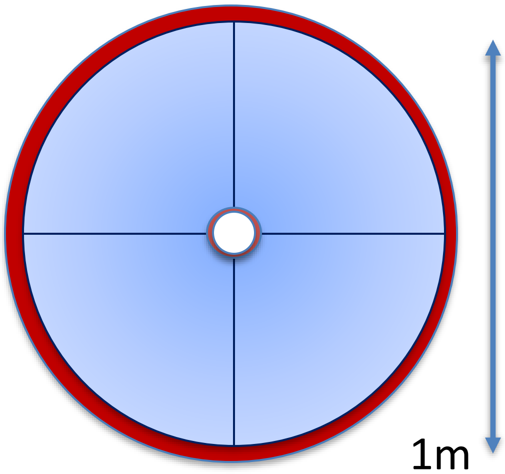
- <150 μm intrinsic spatial resolution for perpendicular tracks
- Technological optimizations to retain 150 μm resolution for inclined/curved tracks

High Efficiency

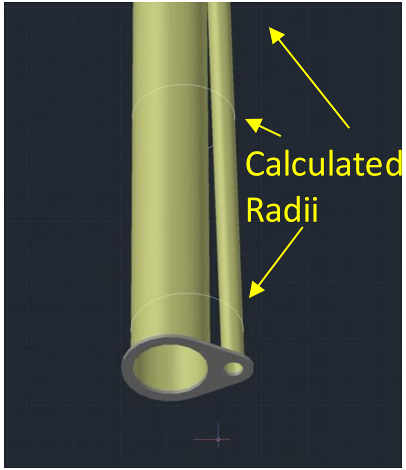
- Single detector efficiency ~ 96 –97 % → 92 –94 % combined efficiency for two disks

Detector Geometry: Envelope and Active Regions

MPGD Disk	Max Z Pos (cm)	Disk Outer Radius (cm)	Outer Active Reg. radius (cm)	Disk Inner Radius (cm)	Inner Active Reg. radius (cm)	η range
HD MPGD 2	163.5	50	45	9	10.5	2 $<\|\eta\|<$ 3.43
HD MPGD 1	150.5	50	45	9	10.5	1.92 $<\|\eta\|<$ 3.35
LD MPGD 1	-112.5	50	45	4.85	6.25	1.65 $<\eta<$ 3.58
LD MPGD 2	-122.5	50	45	4.85	6.25	1.73 $<\eta<$ 3.66

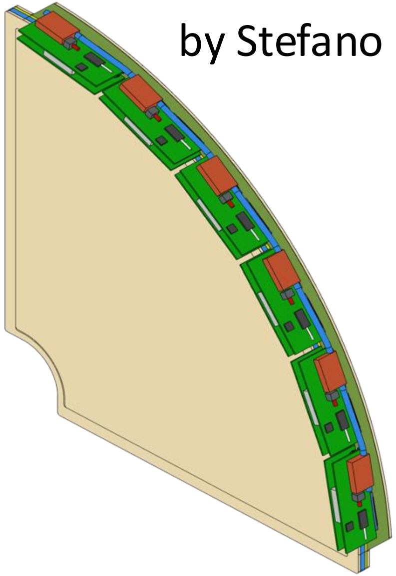


- Two couples of disks: Lepton/Hadron Disks
- The geometric envelope should **include the electronics front-end boards**
- 50 cm external radius/45 cm active region radius – including 5cm outer ring for services.
- Different internal hole dimensions due to divergent beam pipes: 4.5 cm (LD)/9 cm(HD)



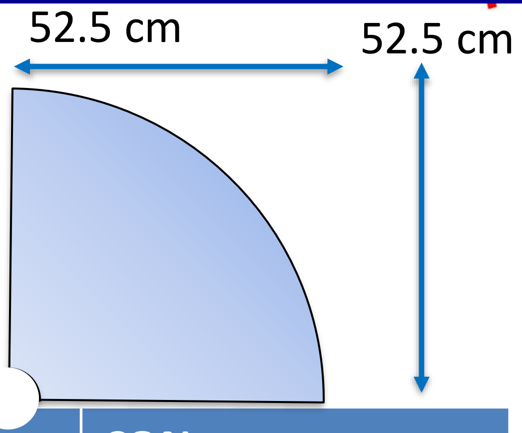
ePIC Endcaps – segmentation and readout choices

6 FEB for each quadrant



by Stefano Gramigna

4 Quadrants



PROs	CONs
Smaller dimensions are easier to handle -> easier integration	Two vertical and horizontal overlapping regions – more material budget
Each endcap is intrinsically symmetric	We need to study how to attach quadrants to form the disks
Strips length are shorter	
GEM foils easier to stretch	

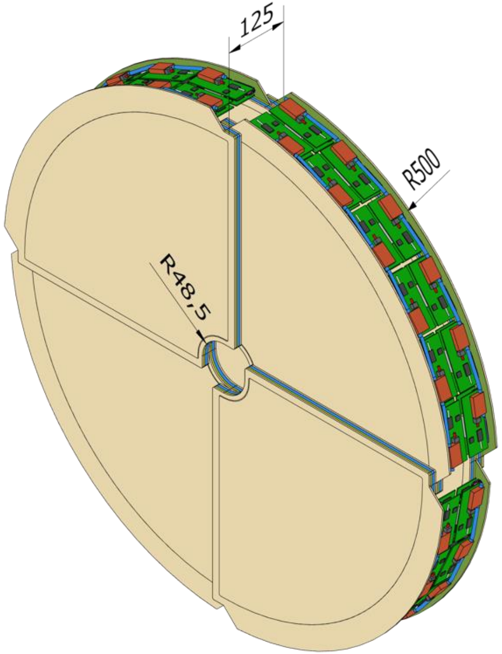
- (X, Y) readout is preferred vs (R,φ) – no FEB on the active area
- 620 μm pitch $\rightarrow$ better than 150 μm intrinsic position resolution

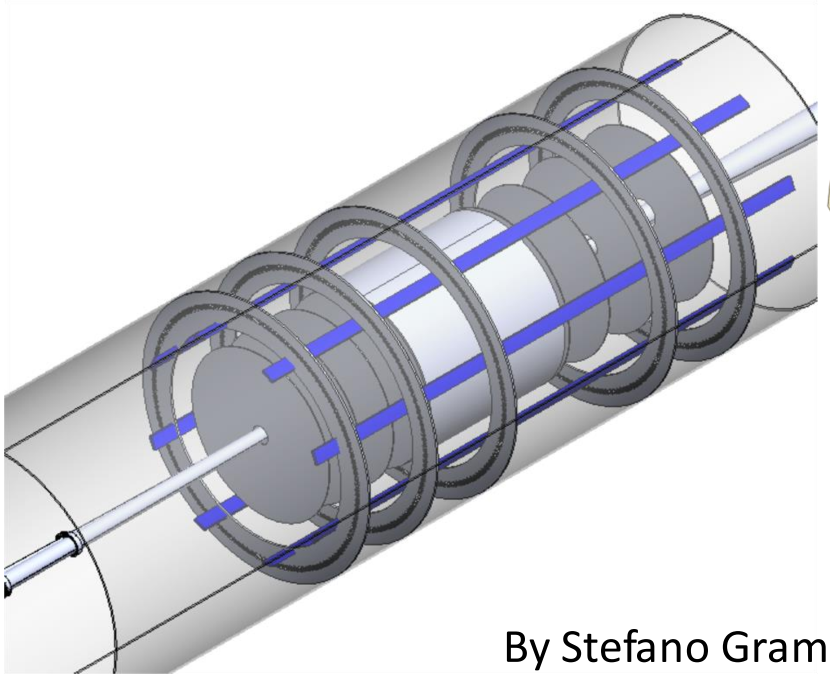
- **First prototype being designed**

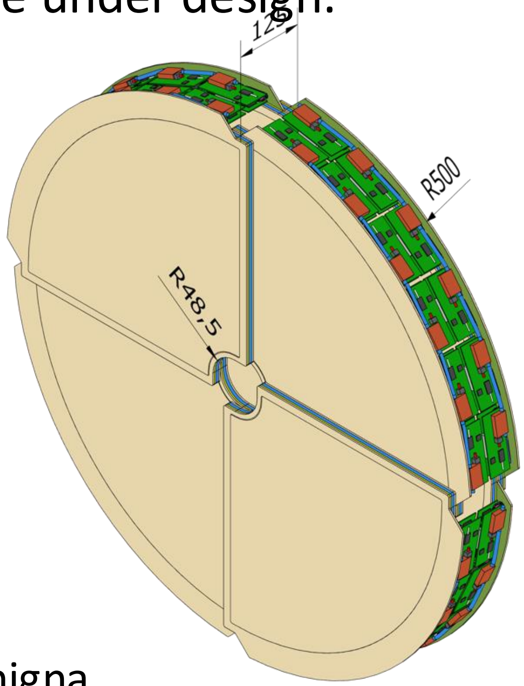
Endcap Detectors Integration in ePIC

The assigned envelope will include the detectors and the FEB electronics.

The disks will be attached together and to the support frame under design.



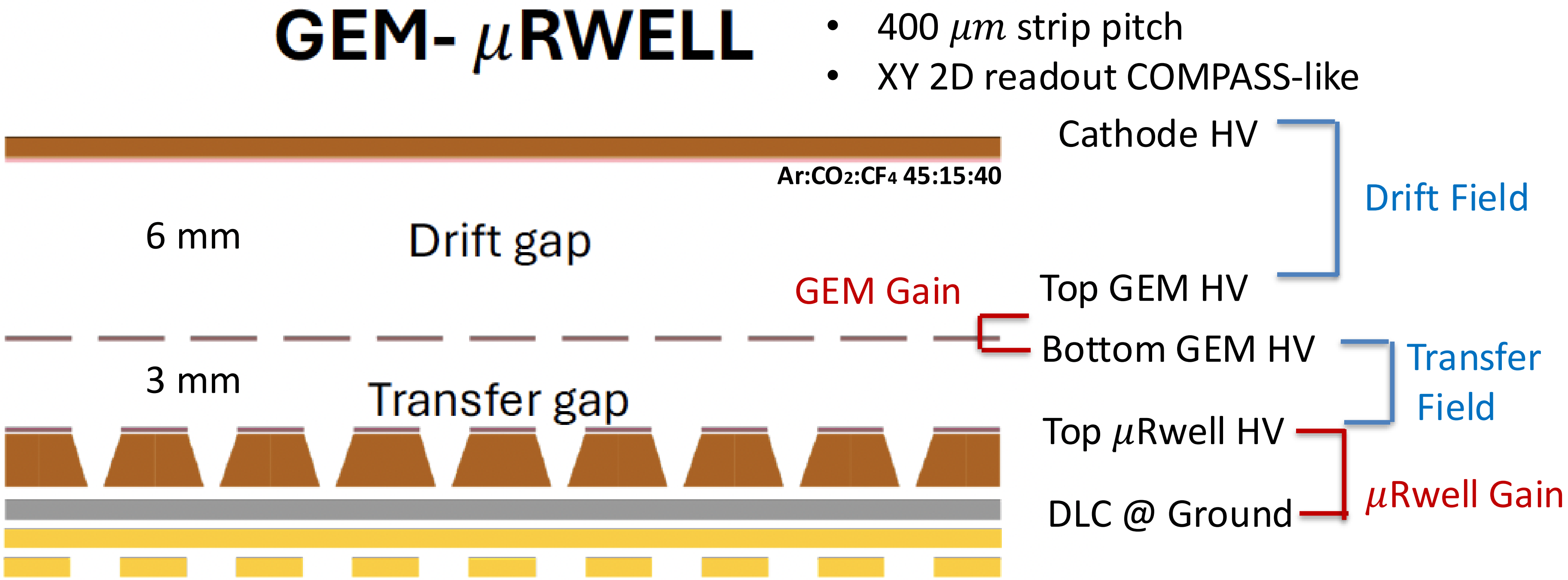




By Stefano Gramigna

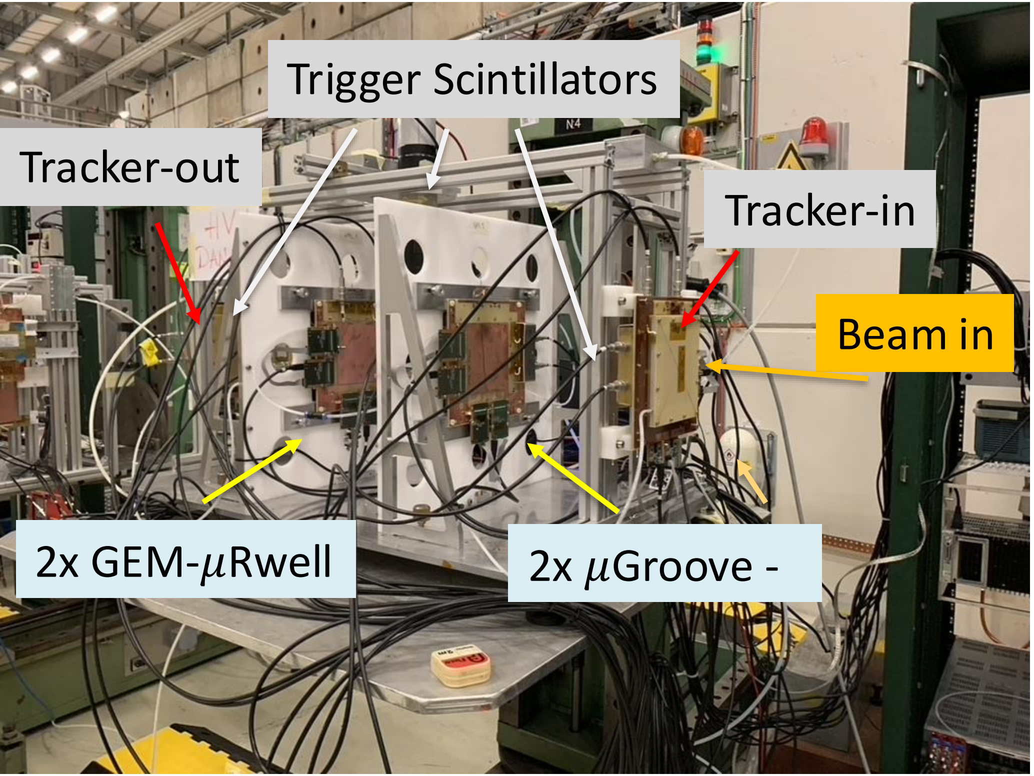
Test Beam Nov 2024

- 10 x 10 cm^2 active area
- 400 μm strip pitch
- XY 2D readout COMPASS-like



4 independent parameters to study: GEM gain, μRwell Gain, Drift Field, Transfer Field

Test Beam Set-up



Tracker-In : μRwell – 3 mm drift
2D COMPASS-like readout
(a hybrid GEM- μRwell with GEM foil used as a cathode)

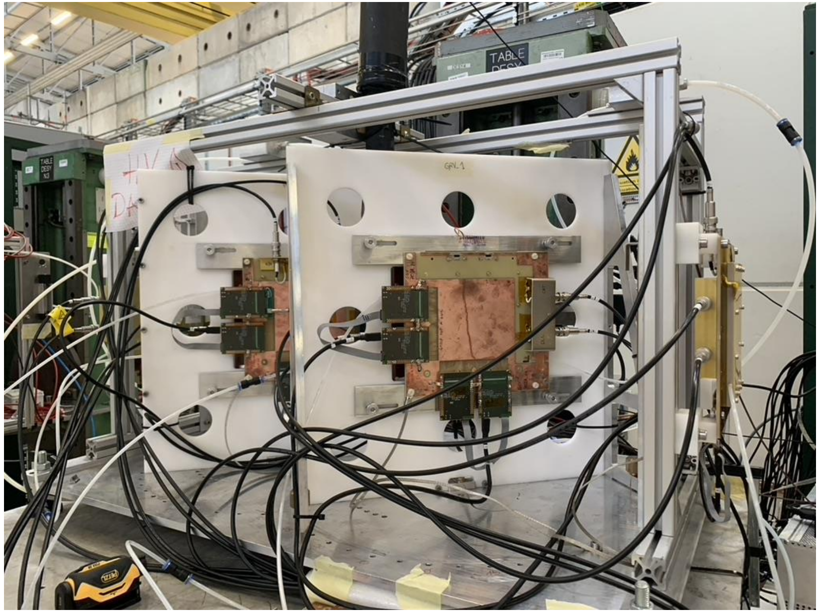
Tracker-Out : GEM-μRwell
2D COMPASS-like readout

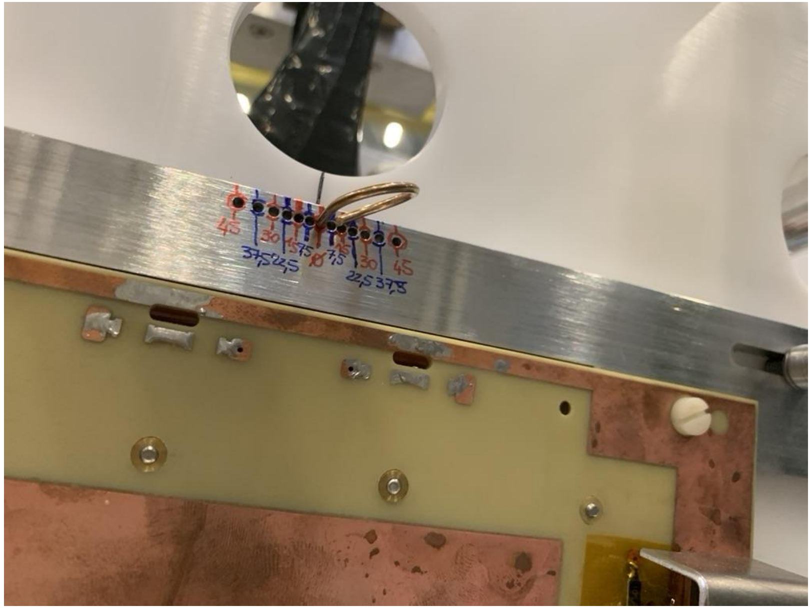
Detectors Under Study (DUT)

- in mirror configuration
  → "Enemy"
- 2 GEM- μRwell - 2D COMPASS-like readout
- 2 μGroove: Y TOP – X bottom readout

Detectors Set-up

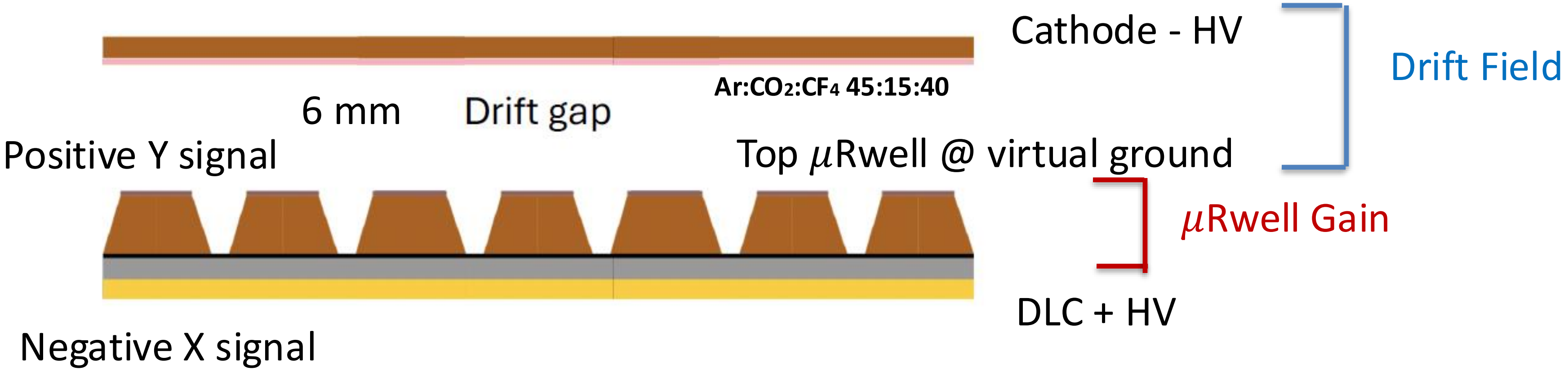
- DUT may be rotated to study their characteristics for inclined tracks.
- θ= 0°, 7.5°, 15°, 30°, 45°





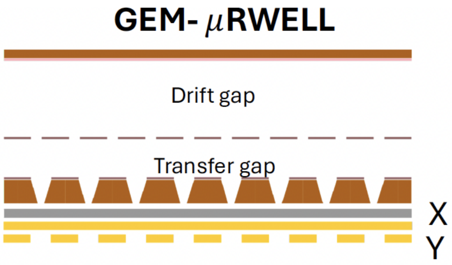
Detectors parameters under study

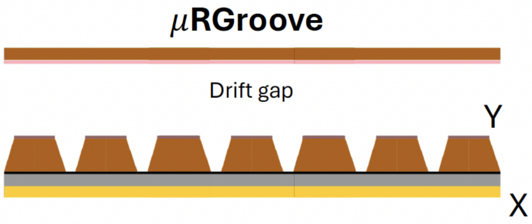
μGroove



2 independent parameters to study: μRwell Gain, Drift Field

Detectors parameters under study





	GEM-μRWELL	μRGroove
SCAN HV 0°	ΔV_{GEM} scan ΔV_{WELL}= 550 V, E_{drift}= 1 kV/cm, $E_{transfer}$= 4 kV/cm	ΔV_{WELL} scan E_{drift}= 1 kV/cm
SCAN HV 30°	ΔV_{GEM} scan ΔV_{WELL}= 550, V E_{drift}= 1 kV/cm, $E_{transfer}$= 4 kV/cm	ΔV_{WELL} scan E_{drift}= 1 kV/cm
SCAN gap field 30°	E_{drift} and $E_{transfer}$ scan ΔV_{WELL}= 550 V, ΔV_{GEM} = 440 V	E_{drift} scan ΔV_{WELL}= 670 - 720 V
SCAN θ	θ scan ΔV_{WELL}= 550 V, ΔV_{GEM} = 440 V, E_D= 1 kV/cm, E_T= 4 kV/cm	θ scan ΔV_{WELL}= 670 - 720 V, E_{drift}= 1 kV/cm

We studied the performance of the μRWELL when the GEM is turned off at different angles to check if it is possible to still perform μTPC calculations with 3 mm gas gap.

by Elena Sidoretti: DRD-1 Collaboration meeting

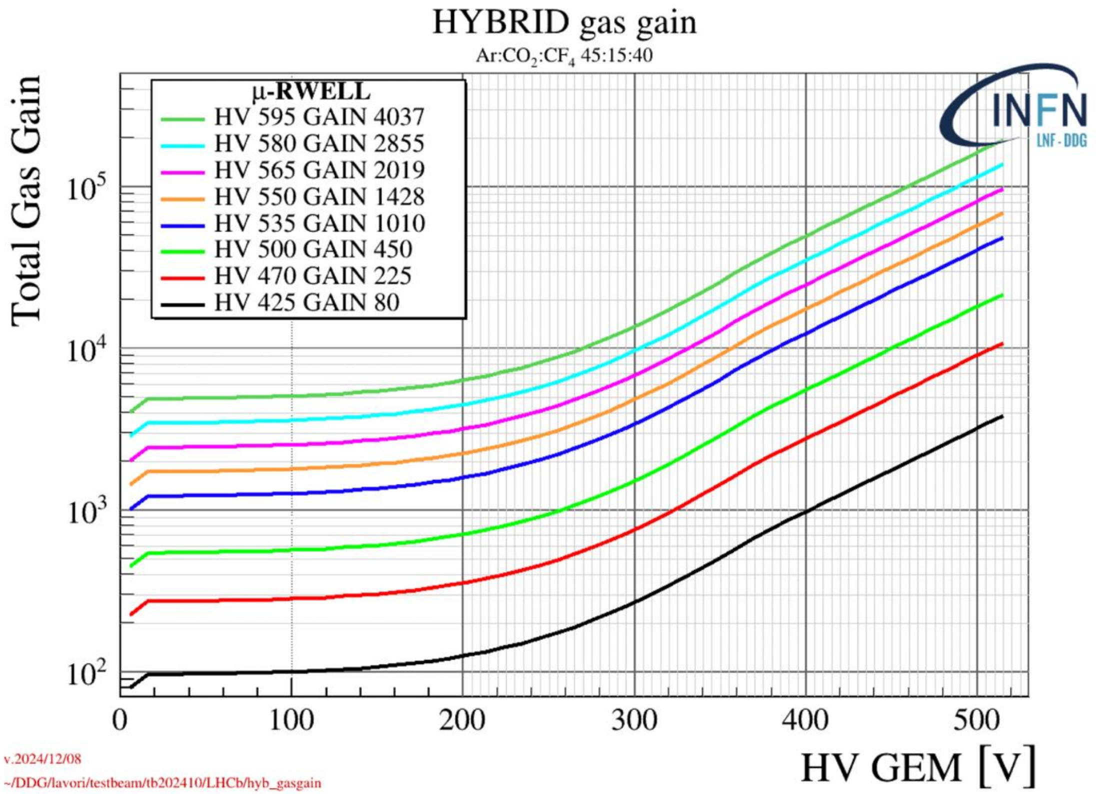
Gas Gain measurements @ LNF

by Matteo Giovannetti

Gas Gain plot for GEM- μRWELL
- high gain is reached even for low WELL HV

Gas Gain plot for μRGroove was not performed before the test beam

Fixing the μRwell Gain:
GEM HV ↔ Total gas Gain



First Results: GEM-μRwell – GEM HV scan @ 0°

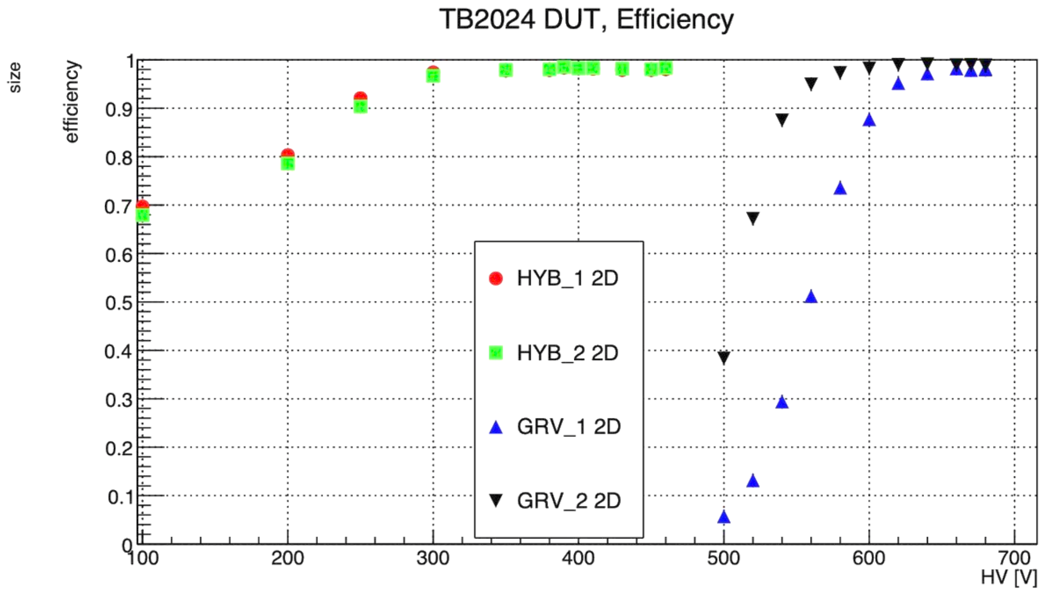
Efficiency is calculated as:

$$\frac{\#\ tracks\ with\ associated\ cluster\ on\ the\ DUT}{\#\ tracks\ passing\ trought\ the\ DUT}$$

with cluster association performed for a 1 cm x 1 cm window.

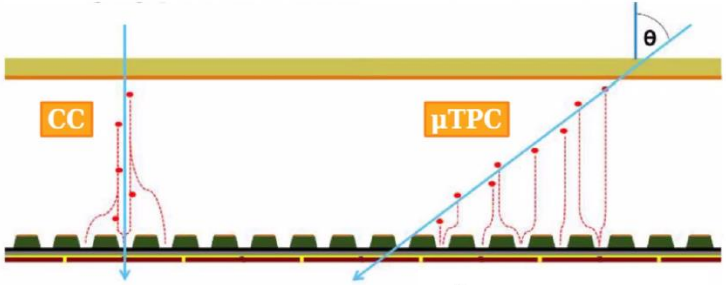
GEM-μRWELL

- ΔV_{WELL}= 550 V corresponding to ~1500 gas gain in the WELL
- high efficiency are reached for ΔV_{GEM} ~380 V (eff 97%) corresponding to ~5200 gas gain in total



by Elena Sidoretti

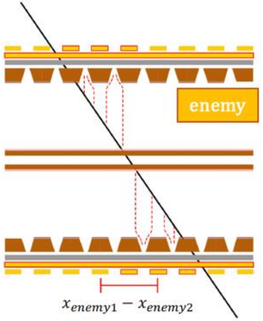
First Results: on-going analysis

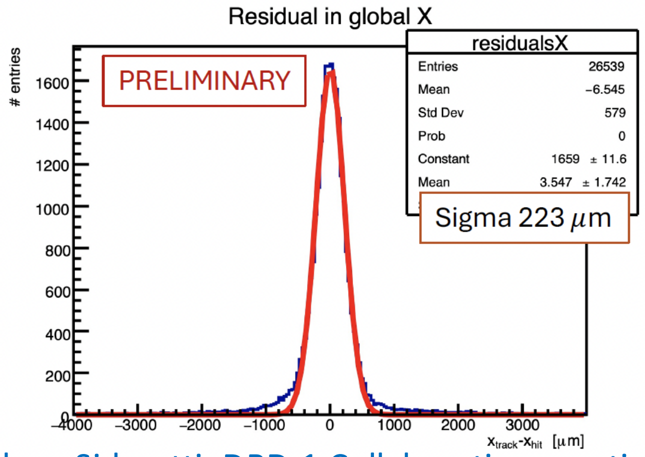


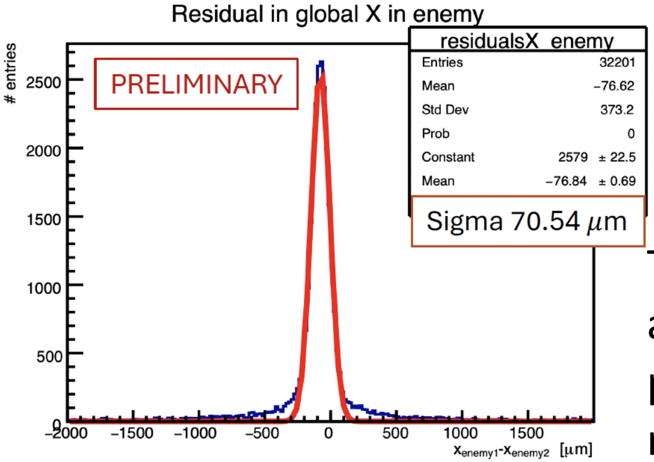
Charge Centroid method is currently used as the first step of spatial resolution study.

On-going data analysis implementations:

- The "**enemy**" method
  - calculates the distance between the clusters' centre on each readout as residual







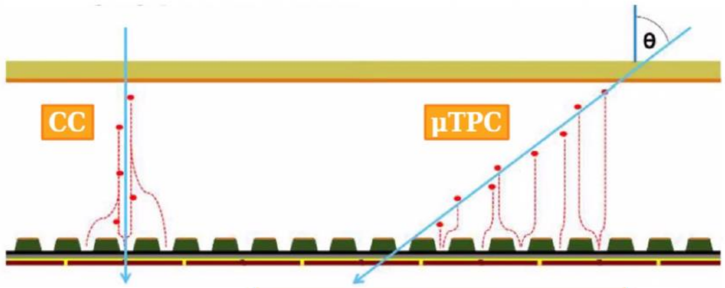
The "enemy" configuration allows to determine position resolution with reduced systematic errors

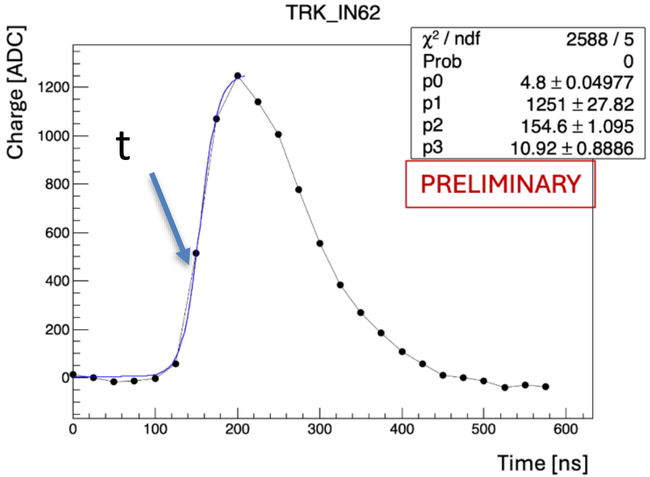
by Elena Sidoretti: DRD-1 Collaboration meeting

First Results: on-going analysis

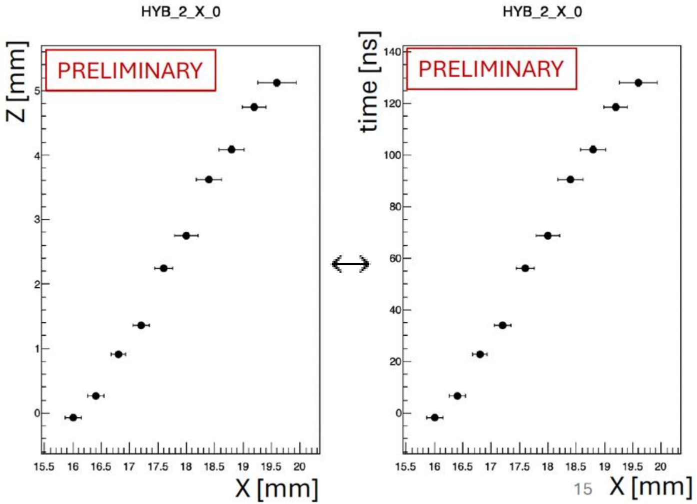
Implementation to study **inclined tracks:**

- The "μ**TPC**" method
  - time of the hit on the strip is used with the drift velocity in the gap, to perform μTPC and select the position along z in the gas gap in which the particle passed





$Z = v_d\, t$

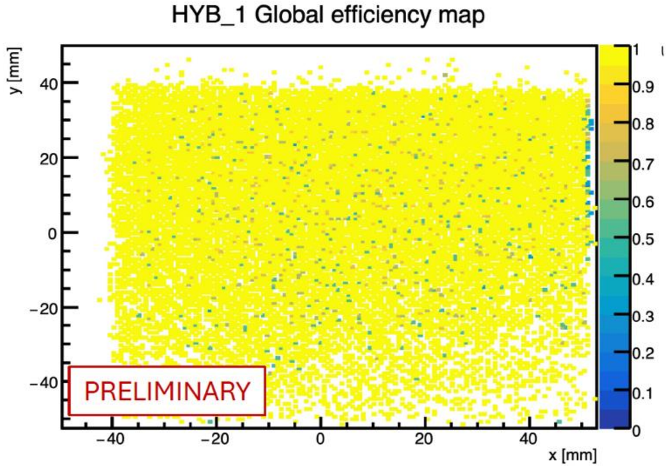


by Elena Sidoretti: DRD-1 Collaboration meeting

First Results: on-going analysis

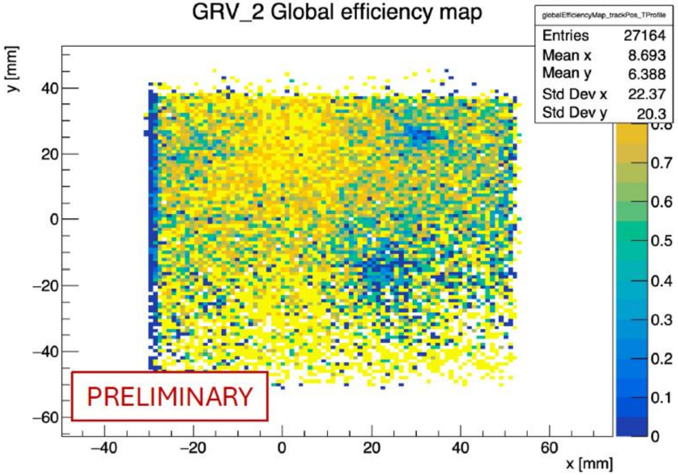
Efficiency 2D map:

GEM-μRWELL in HV plateau (ΔV_{GEM} = 430 V)



Average efficiency ~97%

μRGroove (ΔV_{WELL} = 590 V)



Average efficiency ~71%

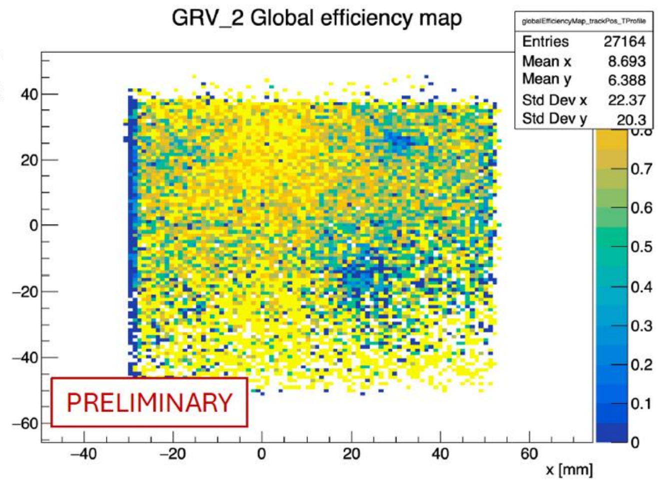
by Elena Sidoretti: DRD-1 Collaboration meeting

First Results: on-going analysis

Efficiency 2D map:

- after a few days of data taking, for one of the two μRGroove the current on electrodes reached ~800 nA (HV filter on the TOP with resistivity of 2 MΩ)
- The detector is still operational with only a relatively small inefficient region in the efficiency map (an effect also reported by Kondo Gnanvo with μRWELL)
- Efficiency lowers from ~94 % to ~71 %

μRGroove (ΔV_{WELL} = 590 V)



Average efficiency ~71%

Summary

GEM-μRwell Technology

- High gas gains may be obtained with low (safe) HV GEM and μRwell settings, minimizing current sparks.

- GEM-μRwell may also work as μRwell detectors with high efficiency (>90%), should the GEM section be degraded.

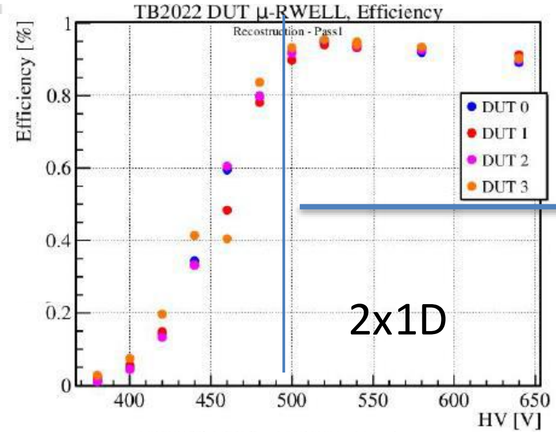
- Single stage μRwell and μGroove detectors retain relative high efficiency even when driving high currents, due to local defects causing shorts.

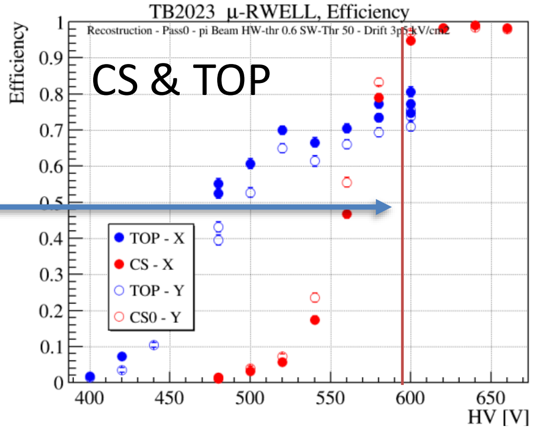
MPGD – ECT status

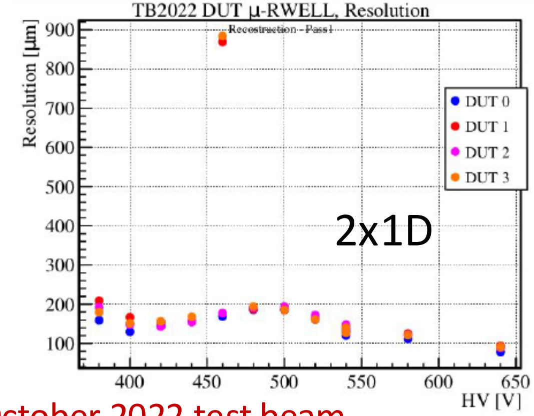
- Discussion on electronic SALSA based FEB optimization is on-going
- First quadrant prototype is under design
- Pre-TDR has been completed and is under second review

Backup Slides

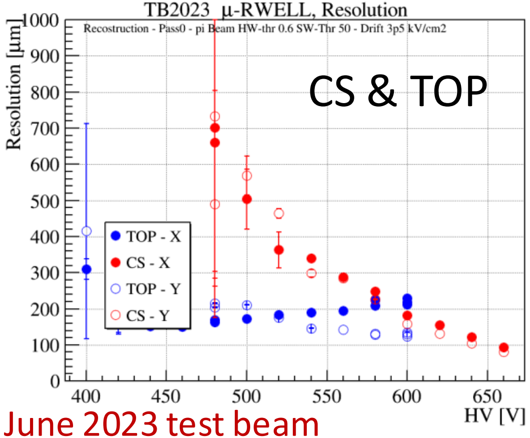
MPGD Technology - 2-D Tracking layout tests







October 2022 test beam



June 2023 test beam

1D pitch 0.78 mm

Reference performances:

- 96% efficiency
- 120 μm resolution

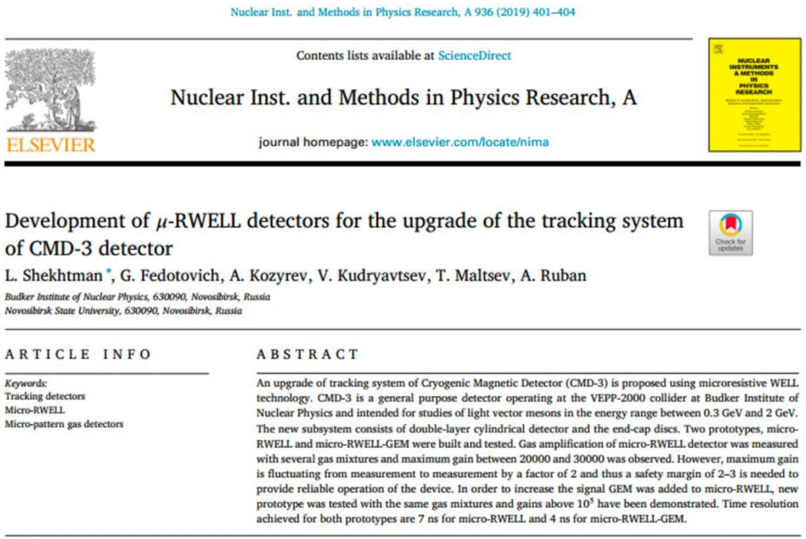
CS pitch 1.2mm

- Due to the charge spread the working point is shifted to high voltage/gain
- Spatial resolution improves at high gain reaching 150 μm with a strip pitch of 1.2 mm

Top-r/out pitch 0.78 mm

- low-voltage/gain operation but low efficiency level (80%) due to the geometrical dead zone on the segmented amplification stage

µ-RWELL + GEM



Nuclear Inst. and Methods in Physics Research, A 936 (2019) 401–404

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Development of μ-RWELL detectors for the upgrade of the tracking system of CMD-3 detector

L. Shekhtman *, G. Fedotovich, A. Kozyrev, V. Kudryavtsev, T. Maltsev, A. Ruban

Budker Institute of Nuclear Physics, 630090, Novosibirsk, Russia
Novosibirsk State University, 630090, Novosibirsk, Russia

ARTICLE INFO

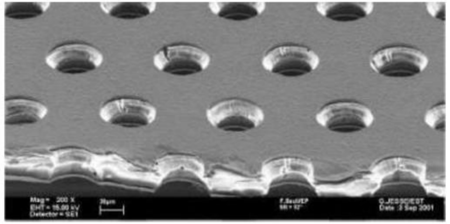
Keywords:
Tracking detectors
Micro-RWELL
Micro-pattern gas detectors

ABSTRACT

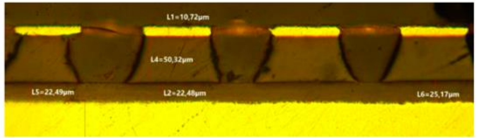
An upgrade of tracking system of Cryogenic Magnetic Detector (CMD-3) is proposed using microresistive WELL technology. CMD-3 is a general purpose detector operating at the VEPP-2000 collider at Budker Institute of Nuclear Physics and intended for studies of light vector mesons in the energy range between 0.3 GeV and 2 GeV. The new subsystem consists of double-layer cylindrical detector and the end-cap discs. Two prototypes, micro-RWELL and micro-RWELL-GEM were built and tested. Gas amplification of micro-RWELL detector was measured with several gas mixtures and maximum gain between 20000 and 30000 was observed. However, maximum gain is fluctuating from measurement to measurement by a factor of 2 and thus a safety margin of 2–3 is needed to provide reliable operation of the device. In order to increase the signal GEM was added to micro-RWELL, new prototype was tested with the same gas mixtures and gains above 10^5 have been demonstrated. Time resolution achieved for both prototypes are 7 ns for micro-RWELL and 4 ns for micro-RWELL-GEM.

L. Shekhtman, Nuclear Inst. and Methods in Physics Research, A 936 (2019) 401–404

Drift Gap: Shekhtman **3mm** – LNF+Roma2 **6mm**



Transfer Gap: Shekhtman **3mm** – LNF+Roma2 **3mm**



Developed for **CMD3 upgrade disks** (4 sectors 50×50cm^2)

The GEM **must be** stretched: sizes larger than 50×50cm^2 could be critical (depending on the gas gaps size).

µ-RWELL + GEM – Gain

L. Shekhtman, Nuclear Inst. and Methods in Physics Research, A 936 (2019) 401–404

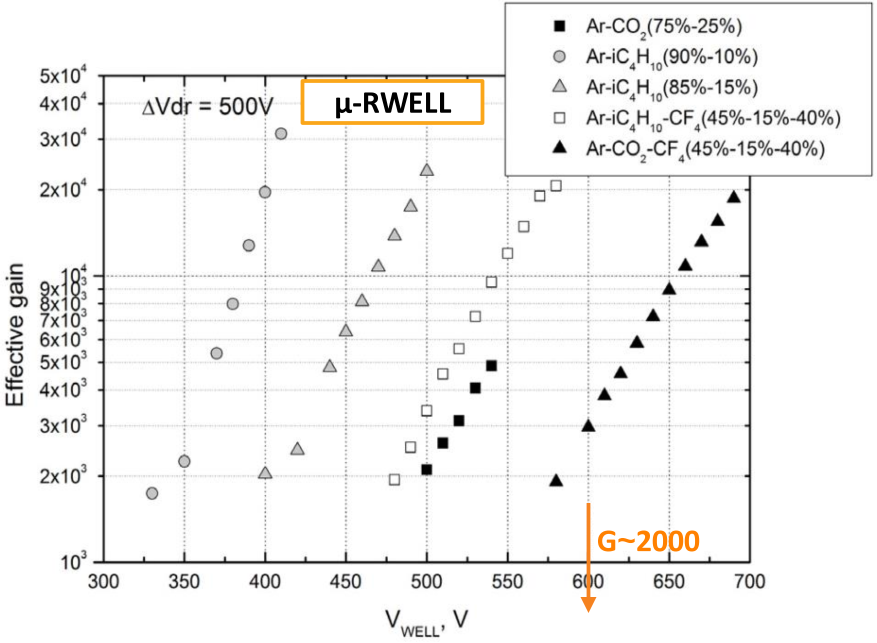


Fig. 4. Gain as a function of voltage on the top electrode of μ-RWELL for different gas mixtures. Voltage across the drift gap is 500 V.

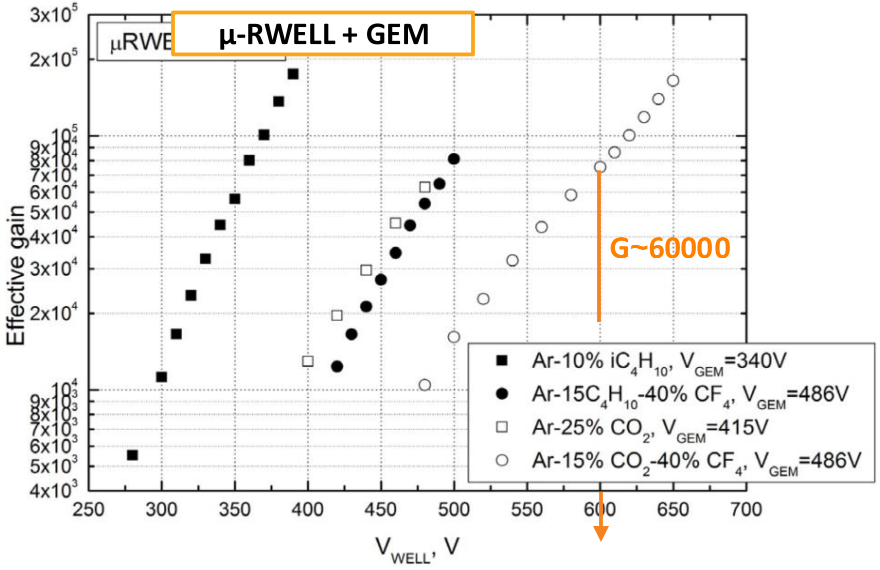
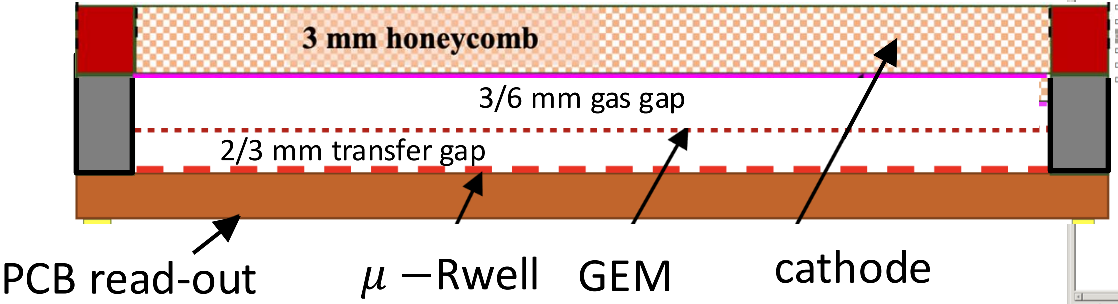
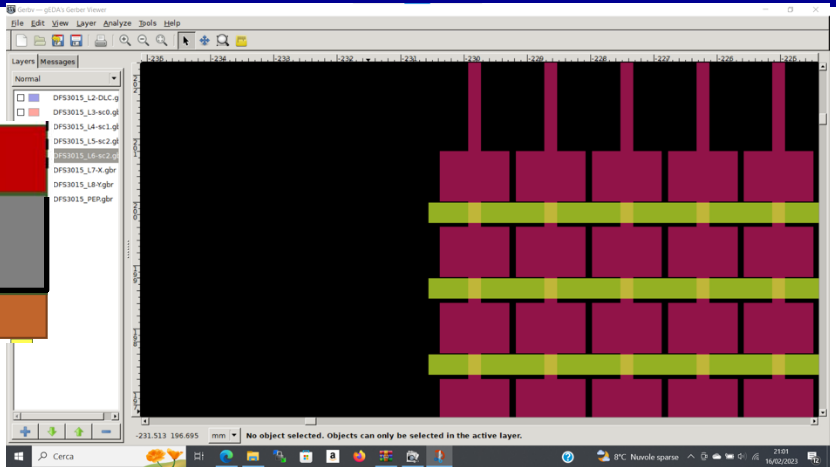


Fig. 5. Gain as a function of voltage on the top electrode of μ-RWELL for GEM voltages providing additional gain of 50–100 and for different gas mixtures. Voltage across the drift gap is 500 V.

Detector Technology Choices: GEM+μRwell

GEM - μRwell Technology

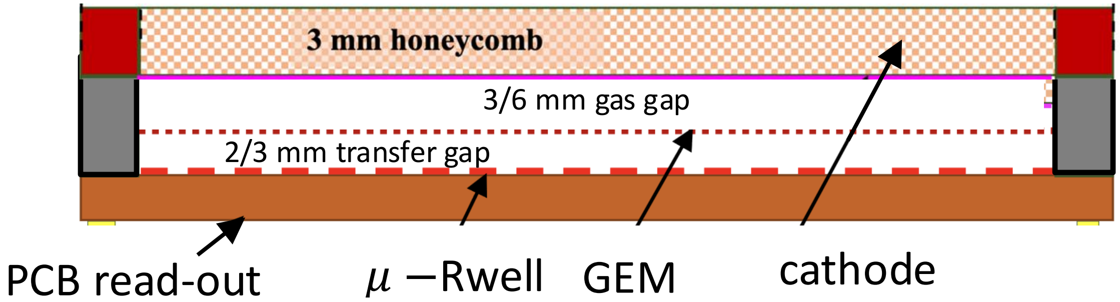




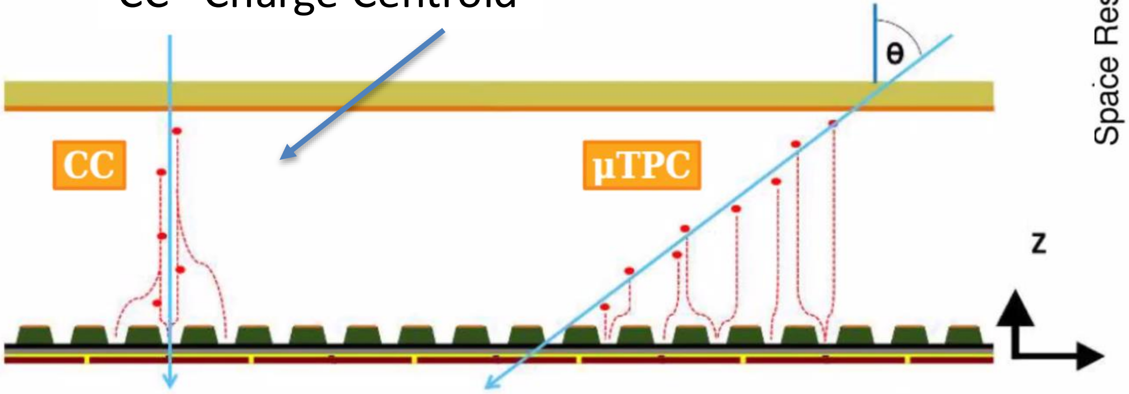
- 2D CS readout reduces the gain from 10^4 to 3-4 10^3 → the detector stability is put at risk
- GEM- μRwell hybrid configuration has been chosen to increase the gain in the 10 000 ÷ 20 000 range
- 2D strip read-out using a "COMPASS-like" scheme
- 500 μm pitch guarantees a spatial resolution better than 150 μm (no need of capacitive sharing))
- A gas gap lager than 3 mm is compatible with single detector efficiency larger than 96%

Detector Technology Choices: GEM+μRwell+ μ TPC

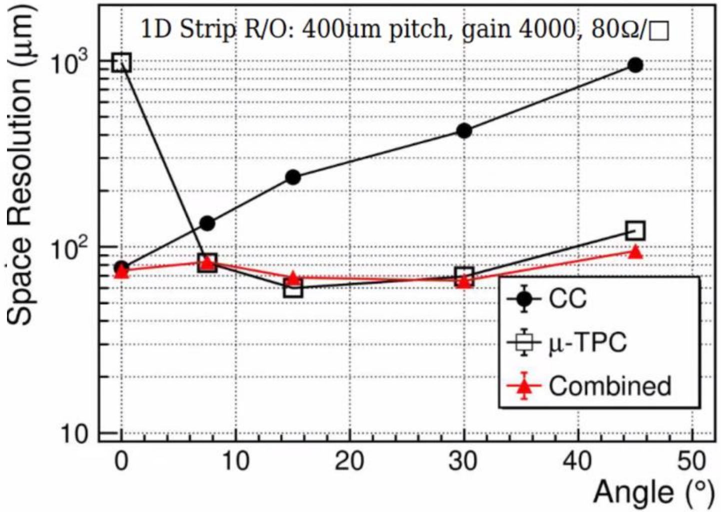
GEM - μRwell Technology



CC= Charge Centroid



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.

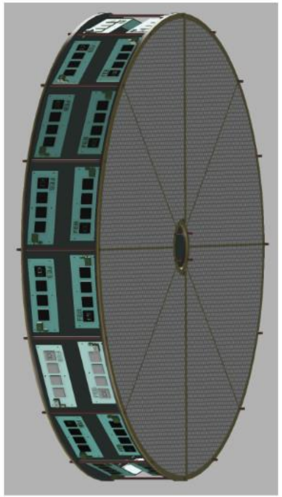


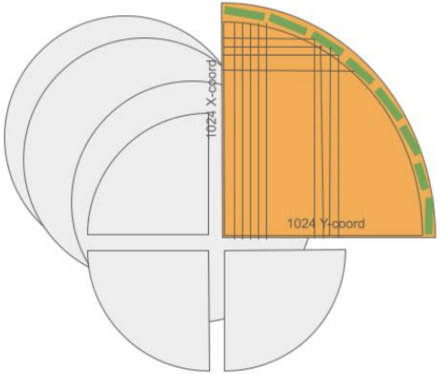
Nov 2024 test beam

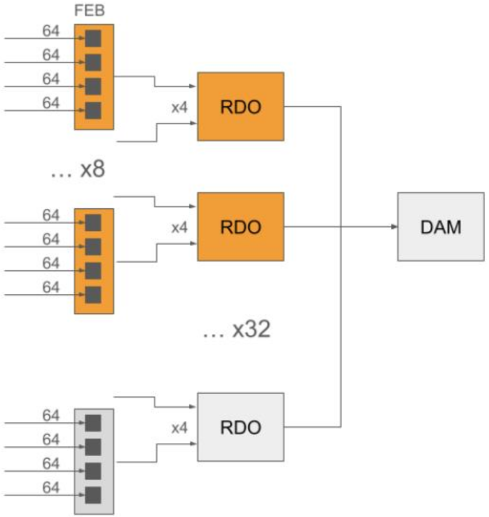
FEB – RDO – DAQ electronics

End Cap Tracker figures

- 4 disks each composed of 4 quadrants
- each quadrant has 1024 X-strip and 1024 Y-strip (2048 channels)
- assuming FE ASIC is 64 channels, grouped in 4 chips FEB, 4 to 1 connection FEB-RDO
- each quadrant will need 32 ASICs, 8 FEBs, 2 RDOs
- total amount is 32kChannels, 512 ASICs, 128 FEBs, 32 RDOs







MPGD in ePIC Simulation

epic

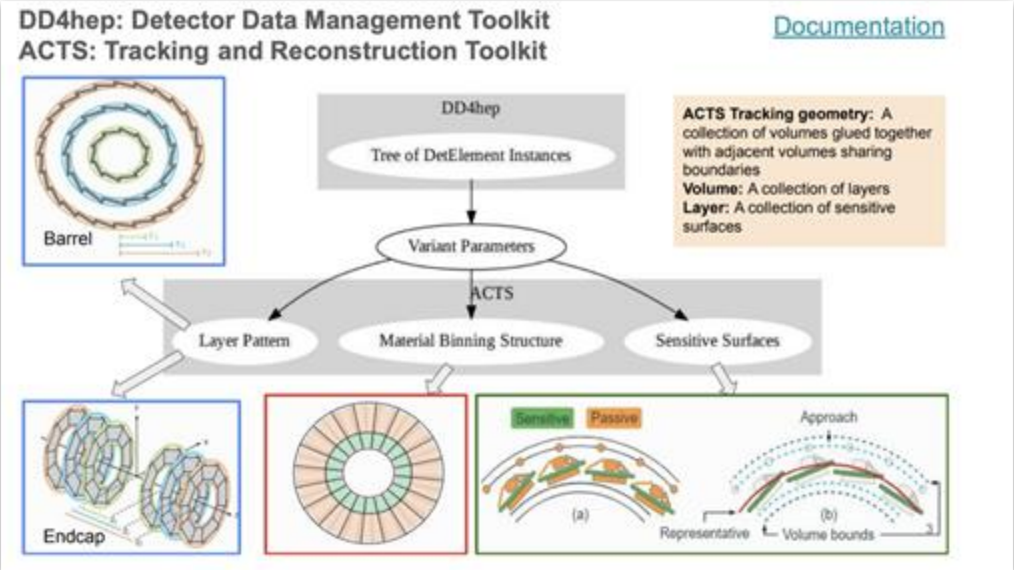
Geometry
Simulation
Readout segmentation

Digitization
Reconstruction
Tracking

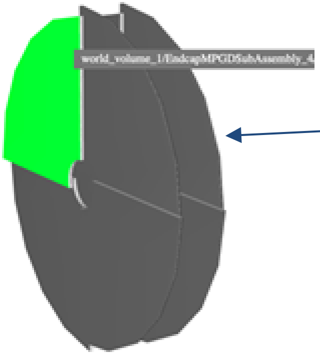
EICrecon

By Mariangela Bondi’

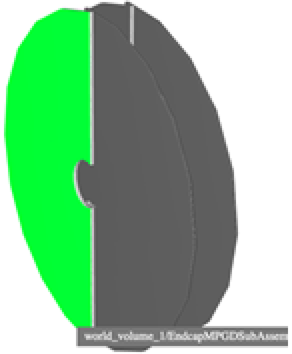
- ePIC geometry is based on DD4HEP
- ACTS is a toolkit for charge particle track reconstruction in hep experiments
- All digitization and reconstruction is done in EICrecon based on JANA



MC simulation of EndCap MPGD Disks geometry



1 configuration



2 configuration

- Pairs of disk in electron and hadron endcaps based on uRWell technology
- 2 configuration under development:
  - 1 configuration : 4 quarters
  - 2 configuration: 2 semi-ellipses
- Currently disk made of subtracted solid
  - No overlaps ✅
  - DD4hep-ACTS conversions fail ❌
    - Disk approximation with trapezoid: working in progress

By Mariangela Bondi’

Involved Institutions & Workforce

INFN Workforce:

- **Roma Tor Vergata – Also member of the DRD-1 WP1**

Coordinator: A. D'Angelo,

Detector Hardware and QA: E. Sidoretti (PhD) A. Fantini, L. Lanza, Post Doc

Simulation & Reconstruction: L. Lanza, A. Fantini, R. Di Salvo

FEB Electronics: R. Ammendola

- **Genova**

FEB Electronics: Paolo Musico, M. Battaglieri (streaming ro)

- **Catania**

Simulation & Reconstruction: Mariagela Bondi'

INFN coordinates the GEM-μRwell MPGD ECT – for both the Hadron and Lepton Disks

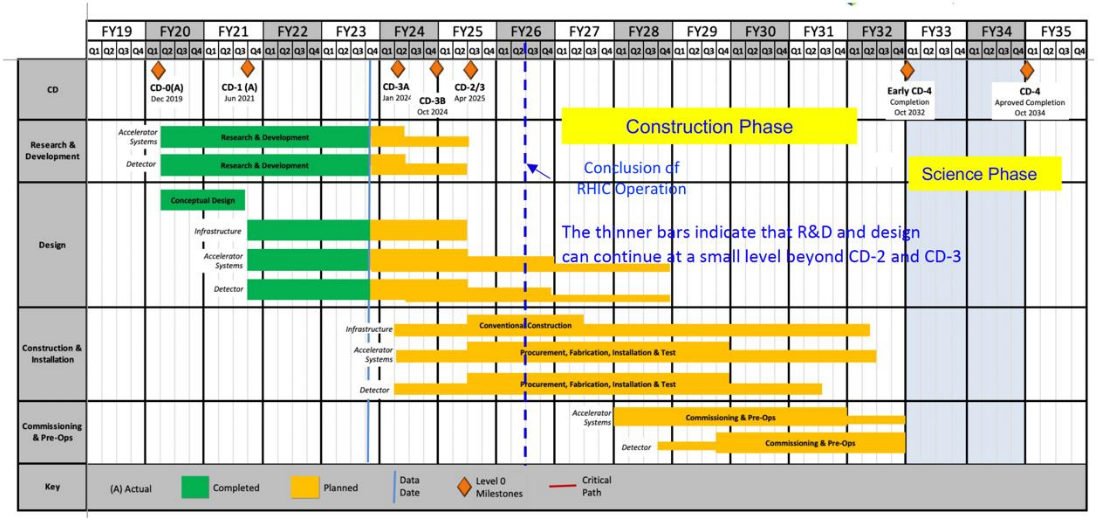
- **INFN will provide the Hadron Disks and related electronics as In-kind contributions**
- **Temple U.** (Bernd Surrow , Matt Posik, ….) are interested taking the responsibility of the Lepton Disks.

The is being performed in close connection with:

the group of Gianni Bencivenni @ INFN LNF and with the JLab detector group (Kondo Gnanvo, Seung Joon Lee)

Fabrication and Assembly Plans

- Design by end of 2024
- 2025 - 2026 Engineering Test Article and Pre-Production
- 2027 - 2029 production & QA
- 2030 Commissioning & Installation



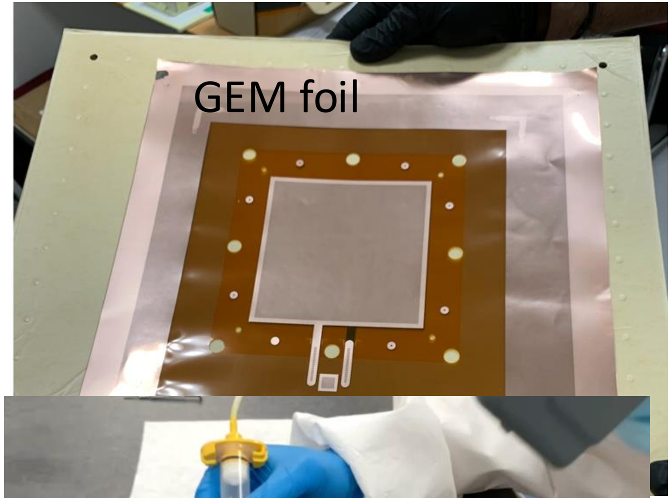
MPGD – ECT Timeline			DURATION (years)
START DATE	END DATE	DESCRIPTION	
3/1/24	12/31/24	Detectors Overall Design	<1
1/1/25	12/31/26	Engineering Test Article & Pre - Production	2
1/1/27	31/12/29	Production & QA	3
1/1/30	6/1/30	Commissioning & Installation	0.5

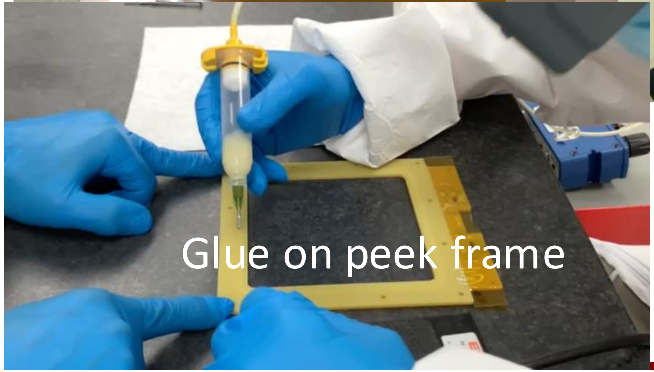
On-going activities

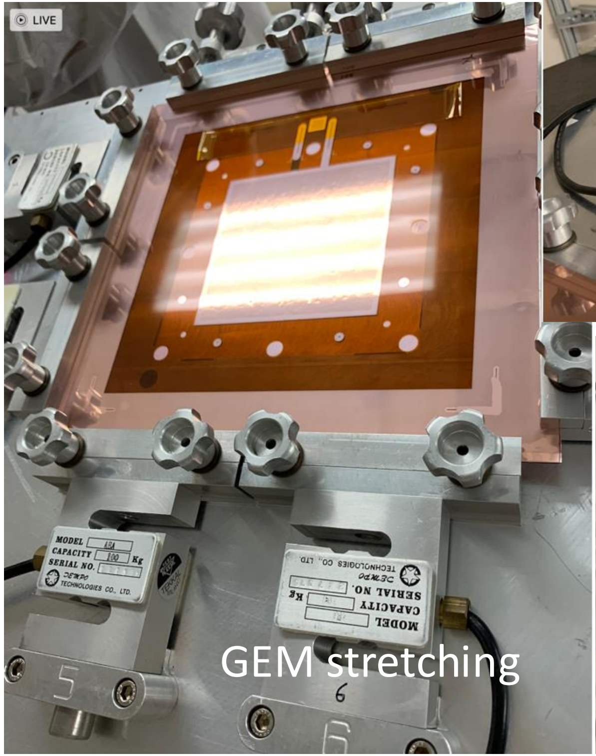
First 10x10 cm^2 GEM-μRwell prototype – synergies with JLAB12

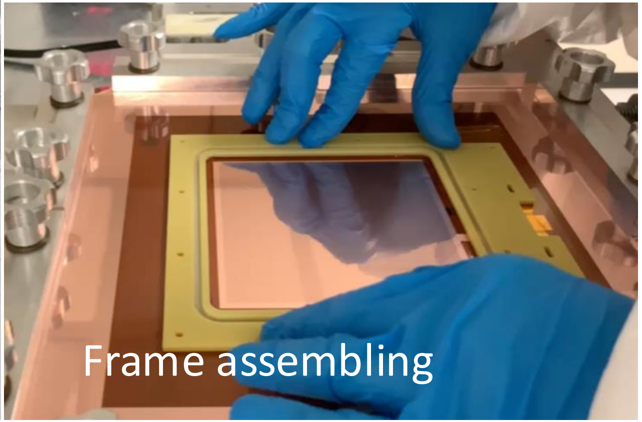
First GEM-μRwell 10x10 cm ^{2} prototypes assembly

CERN Test Beam – November 13 – 27 2024.

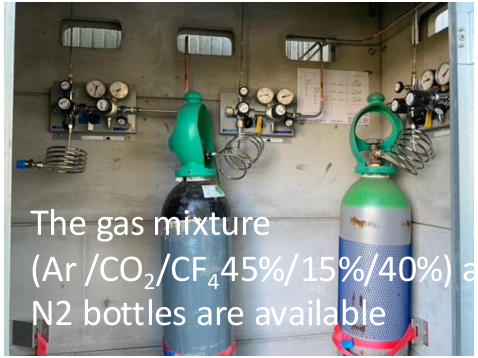








Infrastructures – synergies with JLAB12

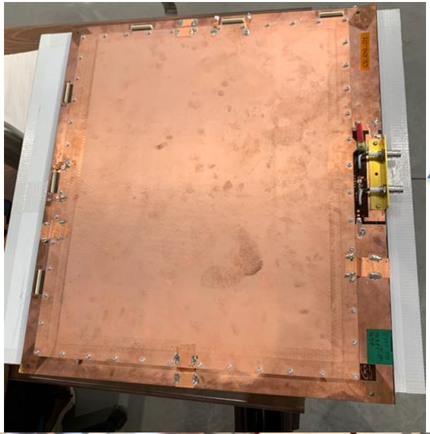


- GEM layer for 50x50 cm^2 Large area detector with Capacitive sharing
- X-Ray gun and shielding
- GEM stretcher components

Infrastructures and Tests – synergies with JLAB12

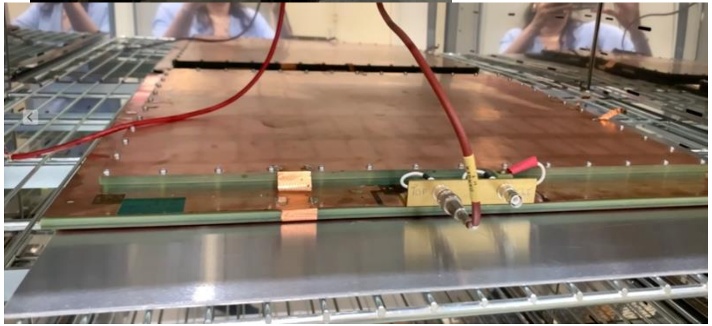
Test of Large Area Prototype steps @ LNF: CS - 40x46 cm ^{2}

Data analysis is ongoing



HV filter on

Conditioning In the Oven



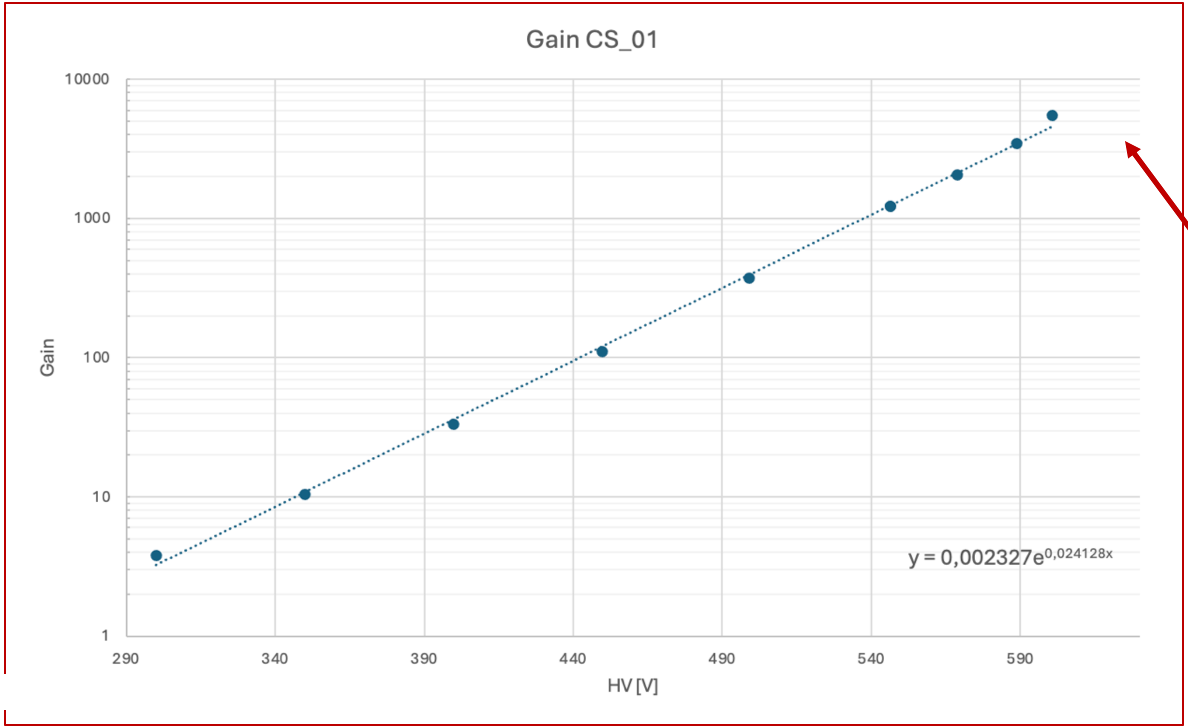
X-Ray characterization

Cosmic-rays Data Acquisition

Prototypes Tests – synergies with JLAB12

Test of Large Area Prototype steps @ LNF: CS - 40x46 cm ^{2}

Data analysis is ongoing



First results confirm that maximum gain is **~ 6000**

INFN- Workforce

Roma Tor Vergata		
Researchers	**Position**	**FTE**
Annalisa D'Angelo	P.O.	50%
Lucilla Lanza	RTDb	30%
Roberto Amendola	Tecnologo	20%
Alessia Fantini	Ric. Univ.	30%
Rachele Di Salvo	I Ric. INFN	10%
Bruno Benkel *	Assegnista Tec.	100%
Gaetano Salina	Dir. Ricerca INFN	20%
Karolina Armonaite	Assegn. altro ente	20%
Totale FTE		**2.8**

Catania		
Researchers	**Position**	**FTE**
Mariangela Bondì	Tecnologo	10%

Genova		
Researchers	**Position**	**FTE**
Marco Battaglieri	INFN DR	10%

Synergic JLAB12 techs		
Giovanni Nobili	Coll. Tecnico E.R. INFN	50%
Daniele Pecchi	Associazione Tecnica – UToV	30%
Enzo Reali	Incarico di Coll. Tecnica– UToV	30%
Enrico Maria Tusi	Incarico di Coll. Tecnica – UToV	30%
		1.4 FTE

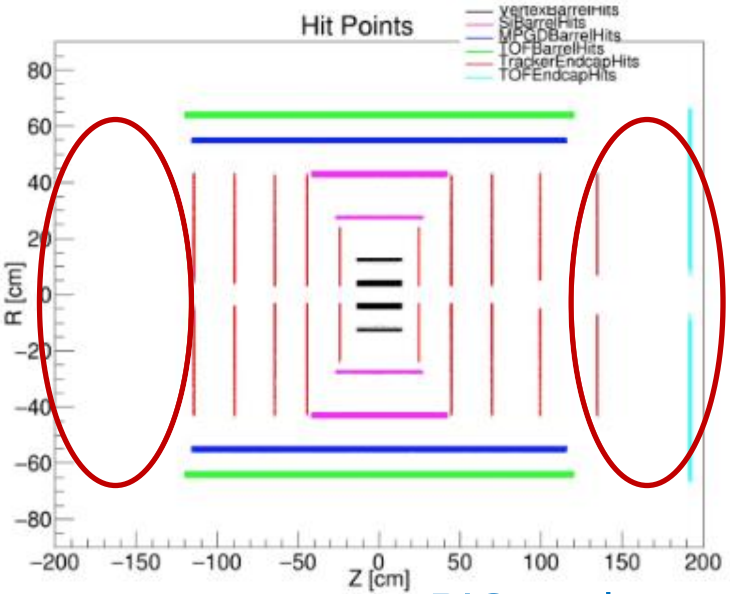
* A new experienced post-doc has been selected (DOE- PED2024)

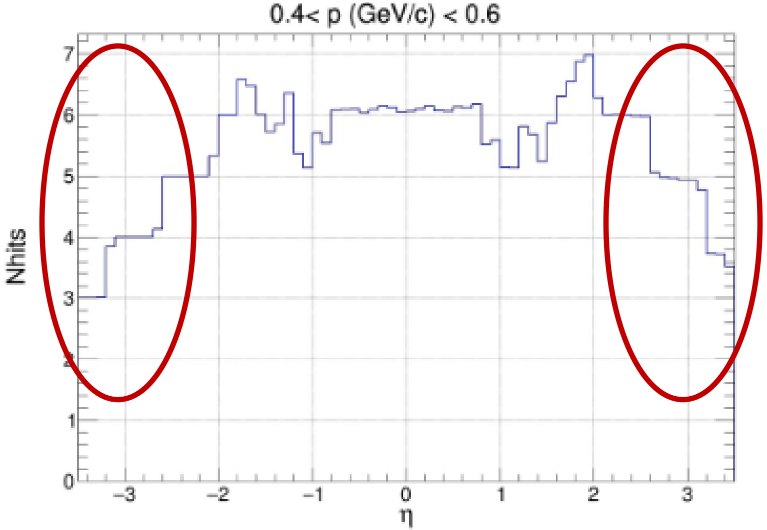
2025 ePIC μRwell Activity

- Coordinate the MPGD endcap tracking project
- Complete the analysis of GEM-μRwell 10x10 cm^2 test beam data:
  - characterization of detector gain, efficiency and position resolution
- Study the detector response to bend/inclined tracks:
  - analysis of μTPC mode in 2D
- Design and procure the first large area Engineering Test Articles
- Implement an emulator of the SALSA chip response to the GEM-μRwell detector
- Contribute to the TDR
- Organize the January 2025 ePIC General Meeting at Villa Mondragone

Scope of the MPGD endcaps in ePIC detector tracking

- In May 2023, MC simulations showed that the **tracking** configuration in the **endcap** regions of the ePIC detector, which will experience the **highest backgrounds** in the experiment, **would not provide enough hit points** in the |η| > 2 region for good pattern recognition.

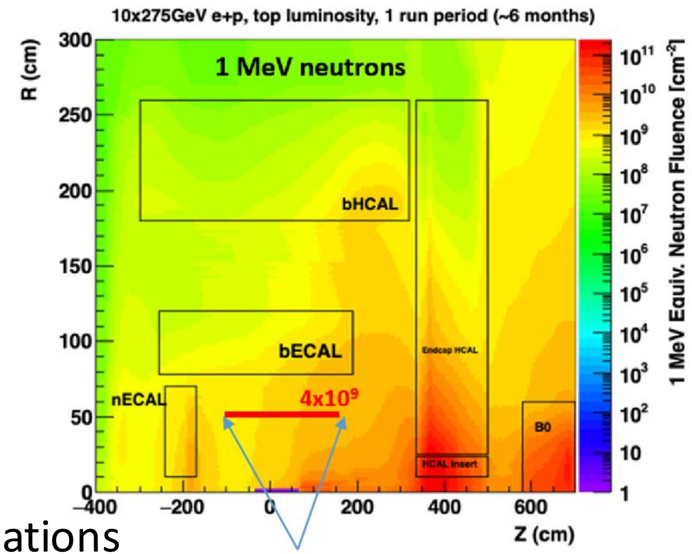




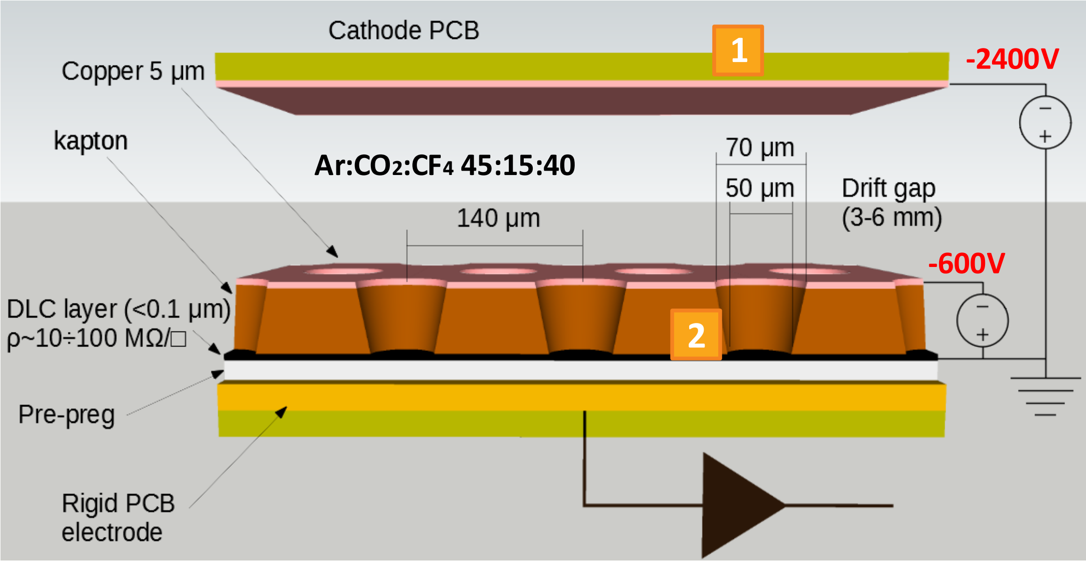
ePIC tracker geometry before June 2023

More on Technical Performance Requirements

- **Rate Capability**
  - Not critical ~ 1 kHz/cm^2 or less
- **Radiation Hardness**
  - Not critical for the detectors
  - Important for FEBs and RDO electronics boards
- **Temperature Stability**
  - Not critical for the detector performances
  - Detector calibration should consider gas pressure variations
- **Electronics power consumption and cooling**
  - SALSA ASIC consumption ~ 15 mW/channel at 1.2V → 60 W/disk
  - Air vs liquid cooling is under study at Saclay



Detector Technology Choices µ-RWELL



The **µ-RWELL** is a Resistive MPGD detector (Micro Pattern Gas Detector)

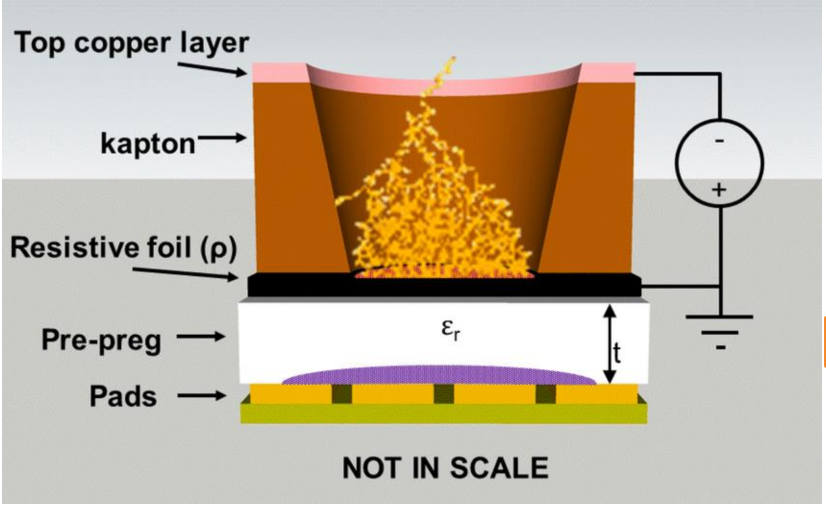
The device is composed of two elements:

1. drift/cathode PCB defining the gas gap ($5\mu m\ Cu$ layer on the bottom side)
2. µ-RWELL_PCB (detector core) Multilayer circuit: $Well\ Pattered\ Polyimide$ ⊕ resistive film ⊕ readout PCB

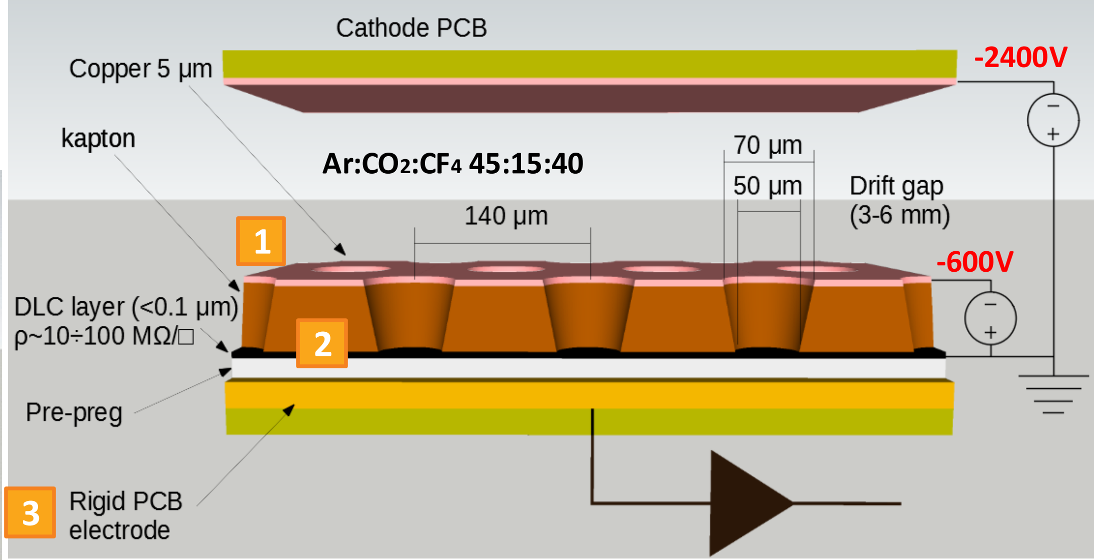
Standard Gas mixture: $Ar:CO_2:CF_4$ 45:15:40 mixture (it also works with $Ar:CO_2$ «green» mixture)

Detector Technology Choices μ-RWELL

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.



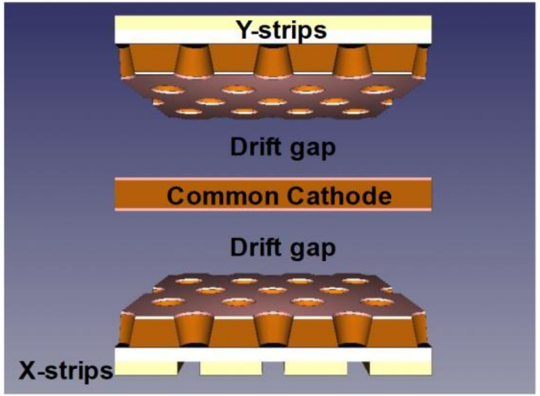
1 **a WELL** patterned kapton foil acting as **amplification stage** (GEM-like)

2 a **resistive DLC layer (Diamond-Like-Carbon)** for discharge suppression with surface resistivity ~ 50÷100 MΩ/□

3 a standard readout PCB

2-D Tracking layouts

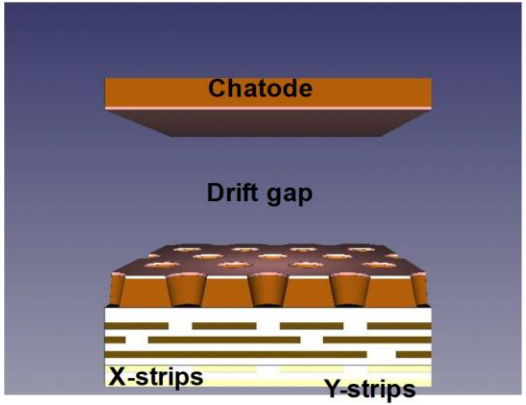
N.2 u-RWELLs 1D (2⊗1D)



October 2022 test beam

- 780 mm pitch
- 300 mm width
- 10 x 10 cm^2 active surface
- 128 channels

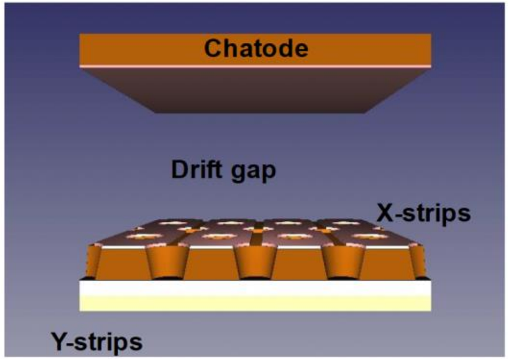
u-RWELL - Capacitive Sharing r/out



June 2023 test beam

- 1200 μm pitch
- 300 μm vs 1000 μm strips width
- 10 x 10 cm^2 active surface
- 83 channels
- "Compass-like" strip configuration
- Capacitive sharing

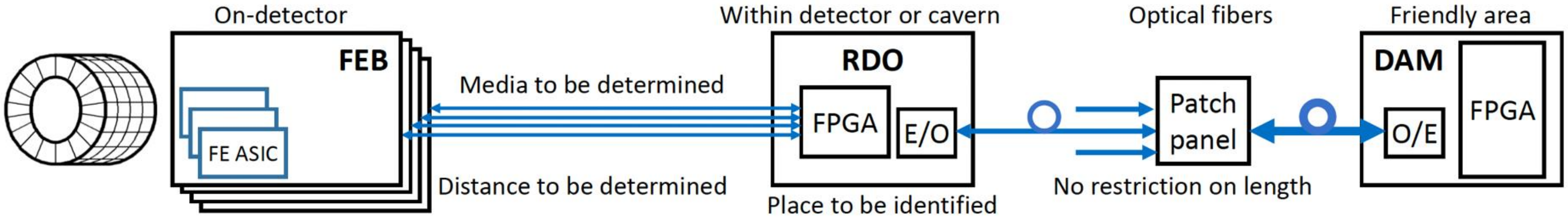
u-RWELL TOP r/out



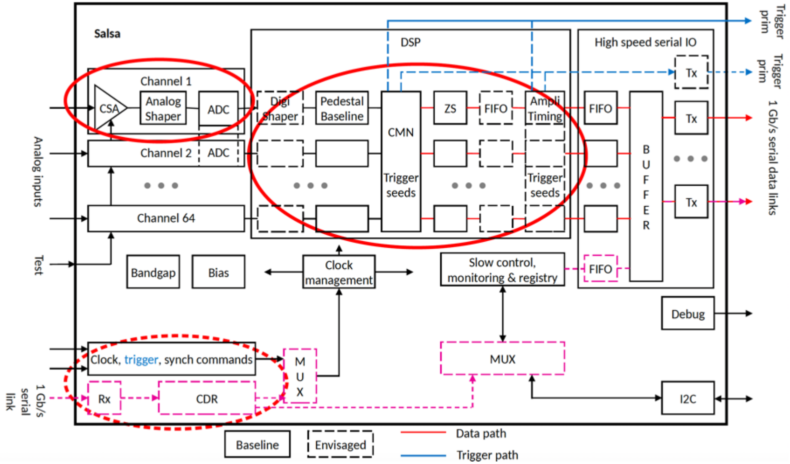
June 2023 test beam

- 780 μm pitch
- 300 μm width
- 10 x 10 cm^2 active surface
- 128 channels
- X –strips Top read-out
- Y – strips standard read-out

FEB – RDO – DAQ electronics

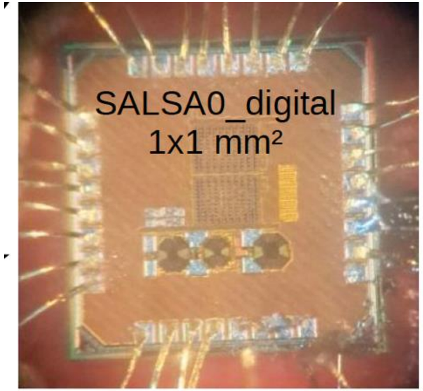


Preliminary design of SALSA



- FEB is based on new **SALSA** chip designed and produced by the **Saclay/San Paulo group** for all MPGD detectors

- Specific FEB form factor must be designed to fit each detector requirements



Roberto Ammendola
Paolo Musico

INFN Involvement timeline

August 2023: Interest of INFN groups to contribute to the MPGD trackers

- 1 year time to make the final decision about the INFN responsibility of the endcap construction
- Joined DRD-1 and eRD108 communities

December 2023: Direct contact with ePIC management (Rolf Ent)

- ePIC/DOE management agreed that INFN takes the leadership of MPGD ECT
- eRD108 → PED project: 30 k$ from DOE to provide a design by the end of 2024.

March 2024: Incremental Design and Safety Review (PDR)

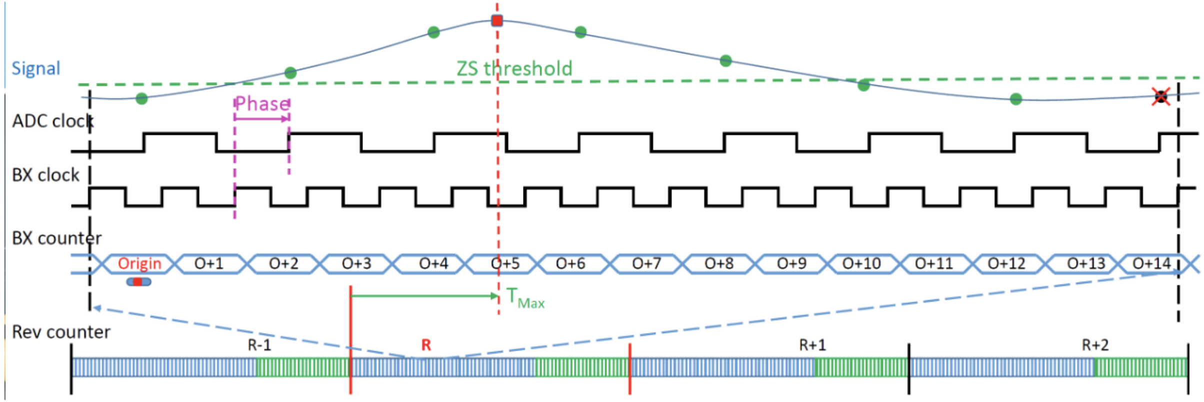
- Detector technical choices and project design communicated to the management
- Very positive feedback

May 2024: MPGD ECT working group reinforced

- Interest expressed by Paolo Musico (INFN GE) and local RM TV digital electronic group to contribute to the FEB design
- Interest expressed by Temple University to contribute to the Lepton Disks construction
- **Support from the local INFN Director: electronics workshop and clean room**

FEB – RDO – DAQ electronics

Readout Strategies



- Signal is continuously sampled with an ADC
- Signal samples above threshold are retained
- Nominal (physics data) readout: signal amplitude and timing is derived → Time of max (as on example) or time of arrival (fitting samples on rising edge)
- On demand readout: signal shapes or raw non ZS data are provided → Calibration, detector studies
- Guarantees best noise immunity and thus best S/N ratio → Allows on line common mode noise (CMN) subtraction before ZS

FEB – RDO – DAQ electronics

EndCap Tracker Data Bandwidth Estimations

- Physics Data: support two zero suppression modes
  - Nominal: peak finding readout → 12 bit amplitude, 12 bit time of max, 8 bit ToT
  - On demand: full signal shape readout → All samples (12 bit) above threshold (typically 15-25 samples)
- Estimated Physics data bandwidth per Salsa ASIC with channel rate 10 kHz:
  - Peak finding 40 Mbit/s
  - Signal shape 265 Mbit/s
- On line calibration: on demand readout
  - Programmable number of non ZS samples
  - Estimated calibration data bandwidth per ASIC ∼ 6 Mbit/s
- FEB RDO link occupancy: ∼30 % of one 1 Gbit link
- Overall physics frontend data of ECT:
  - ∼ 130 Gbit/s for on demand mode
  - ∼ 37 Gbit/s for nominal mode

FEB – RDO – DAQ electronics

SALSA ASIC Characteristics

- Versatile front-end characteristics
  - Dedicated to MPGD detectors and beyond
  - 64 channels
  - Large range of peaking times: 50-500 ns
  - Large choice of gain ranges: 0-50, 0-250, 0-500 fC or 0-5 pC
  - Large range of input rates, up to 100 kHz/ch with fast CSA reset (limit assumed for EPIC: 25 kHz/ch)
  - Front-end elements can be by-passed
- Digital stage
  - Fast sampling ADC for each channel on 12 bits (¿ 10 effective bits) at up to 50 MS/s
  - Possibility under study to double rates by coupling pairs of channels
- Integrated DSP for internal data processing and size reduction, treatment processes to be selected according to user needs
  - Continuous readout compatible with streaming DAQ foreseen at EIC, triggered mode also available
  - Several 1 Gb/s output data links (will use one)
- General characteristics
  - $\sim$1 cm^2 die size, implemented on modern TSMC 65nm technology
  - Low power consumption 15 mW/channel at 1.2V
  - Radiation hardened (SEU, TID)

The µ-RWELL (Micro Resistive Well Detector)

The **µ-RWELL** is a Resistive MPGD detector (Micro Pattern Gas Detector)

Used Gas : $Ar:CO_2:CF_4$ 45:15:40 mixture (it also works with $Ar:CO_2$ «green» mixture)

The device is composed of two elements:

- drift/cathode PCB defining the gas gap ($5\mu m\ Cu$ layer on the bottom side)
- µ-RWELL_PCB (detector core)
  - Multilayer circuit: $Well\ Pattered\ Polyimide \oplus$ resistive film $\oplus$ readout PCB

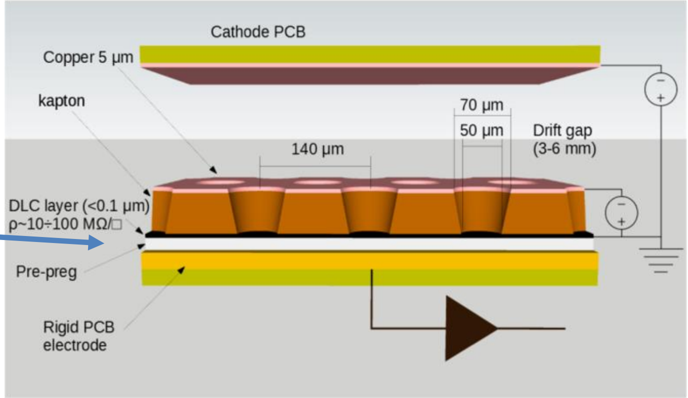
Amplification stage: → 50 µm thick Kapton (Apical®) foil
With a 5 µm Cu layer on the top side

Resistive stage: → DLC (*Diamond-Like-Carbon*) film sputtered on the bottom side of the polyimide foil

Surface resistivity: $\rho = 10 \div 100\ M\Omega/\square$

↳ the resistivity is function of DLC thickness

The resistive layer strongly suppresses the transition from streamer to spark
*=> Allows to achieve **large gains** (> 10^4), without affecting the capability to operate under **high particle fluxes***



G. Bencivenni et al.; 2015_JINST_10_P02008

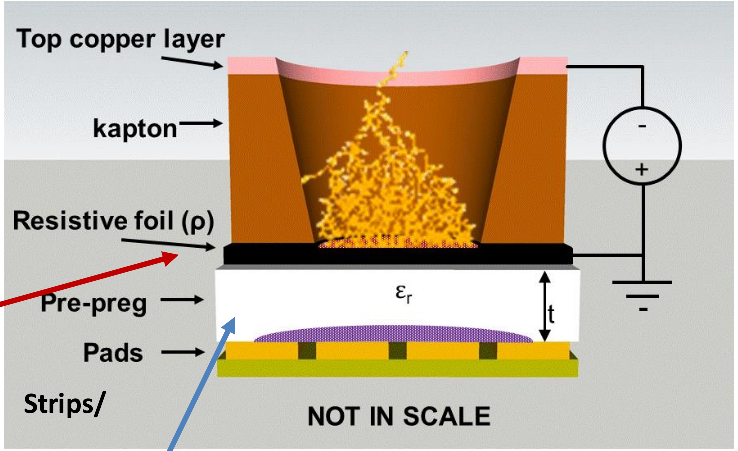
The μ-RWELL principle of operation

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

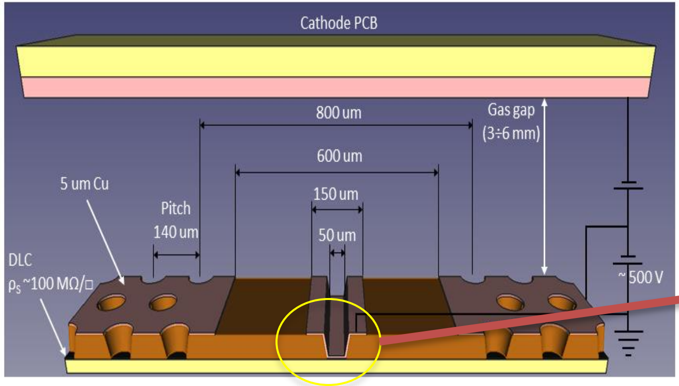
$$C = \varepsilon_0 \times \varepsilon_r \times \frac{S}{t} = 120\, pF \times L(m) \quad - \quad w = 0.2\, mm, \;\; p = 0.4\, mm \;\; \text{strip read-out}$$

- The resistive stage ensures the quenching of the spark amplitude
- As a *drawback,* the capability to stand high particle fluxes is reduced, but appropriate grounding schemes of the resistive layer solves this problem

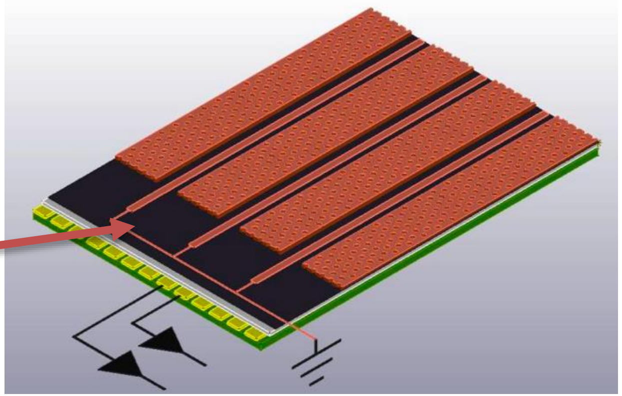
The μ-RWELL Technology

Studies have been focused on the DLC grounding layout to increase the rate capability while maintaining a safe resistivity => The solution is to reduce as much as possible the current path towards the ground connection introducing a high density "**grounding network**" on the resistive stage of the detector

PEP – Patterning-Etching-plating



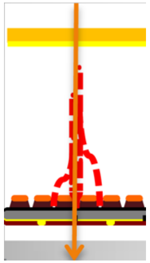
The micro-RWELL layouts for high particle rate, G.Bencivenni et al., 2019-JINST-14-P05014

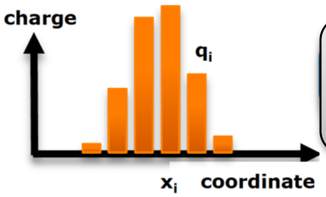


The active area is discontinued by grooves that uncover the DLC; then a copper plating, carefully separated from the copper in the active sectors, is disposed to connect the DLC to the ground.

A small dead zone on the amplification stage must be introduced for high stability operation

The µ-RWELL Technology





$$x_{hit} = \frac{\sum x_i \cdot q_i}{Q_{tot}}$$

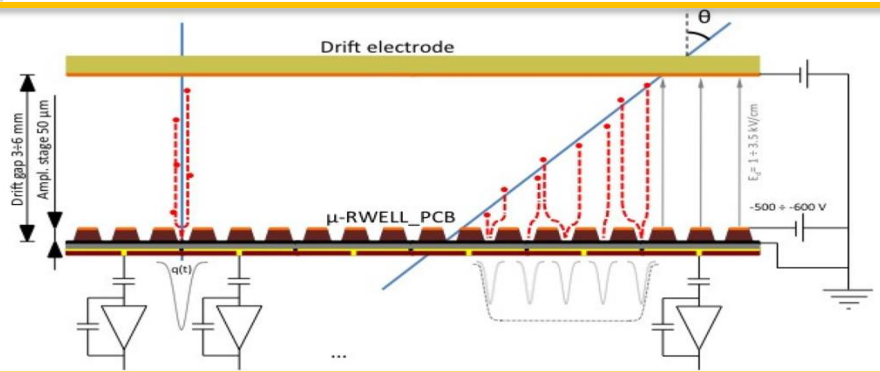
Charge Centroid reconstruction method

↓

The track position is determined as a weighted average of fired strips

↓

GOOD FOR ORTHOGONAL TRACKS



FOR INCLINED TRACKS &/or HIGH B FIELD

the Charge Centroid method gives a very broad spatial distribution on the anode-strip plane.

↓

µTPC reconstruction

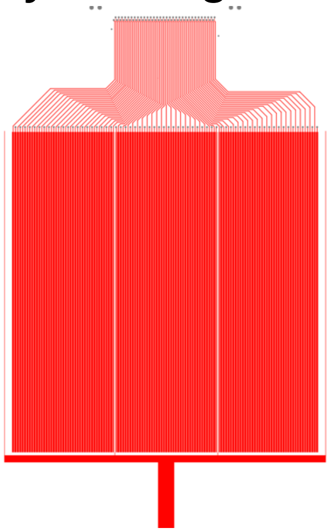
The spatial resolution is strongly dependent on the impinging angle of the track → A non-uniform resolution in the solid angle covered by the apparatus → Large systematical errors.

2D Readout Scheme

2D – readout: step by step approach

1. The first prototype was a set of 2x1D detectors each having the following specs, rotated by 90 degrees:

- 780 μm pitch
- 300 μm width
- 10 x 10 cm^2 active surfa
- 128 channels

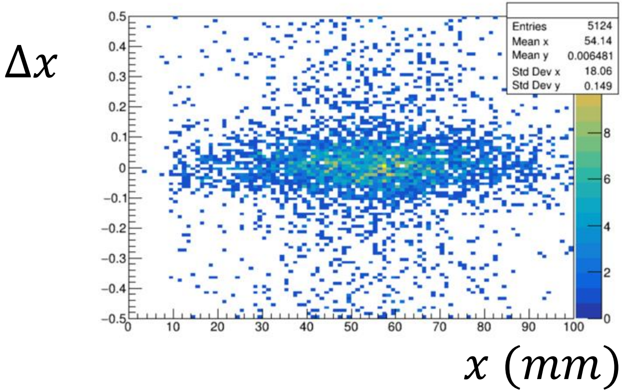


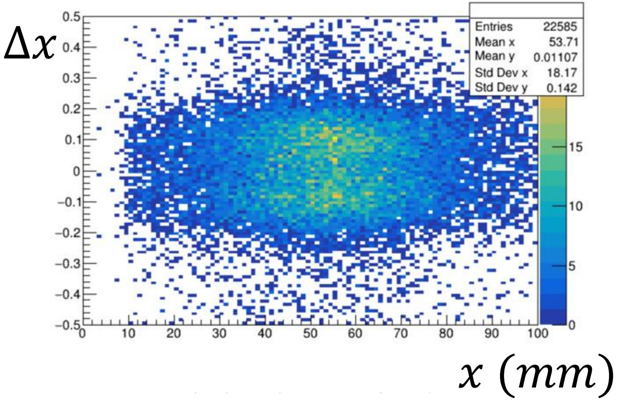
5 – 19 October 2022

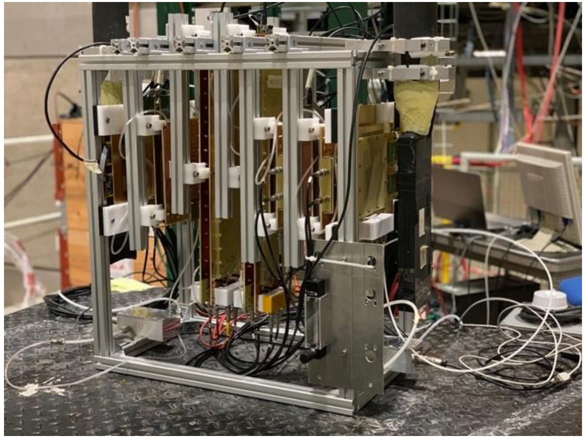
Test Beam: SPS North Area H8

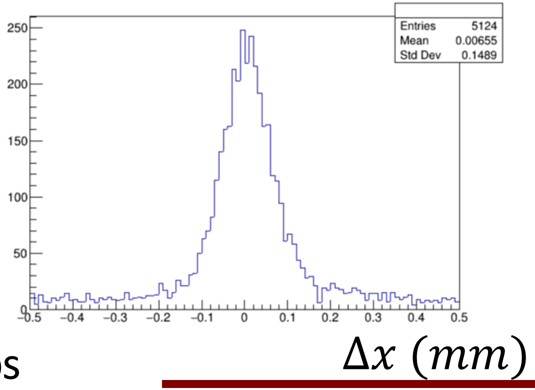
2D Readout Scheme

2D – readout: 780 μm pitch-300 μm width - 10 x 10 cm^2 active surface

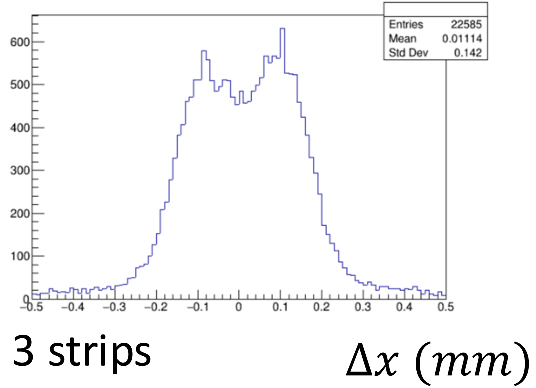








4 strips



3 strips

Increasing the pitch read-out the resolution is strongly affected by the number of strips among which the charge is distributed

2D Readout Scheme

2D – readout: step by step approach

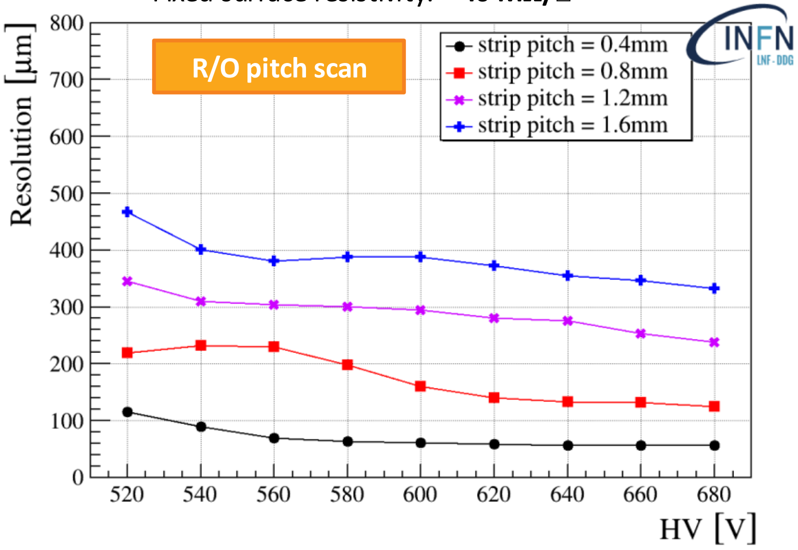
1. 2x1D detectors.

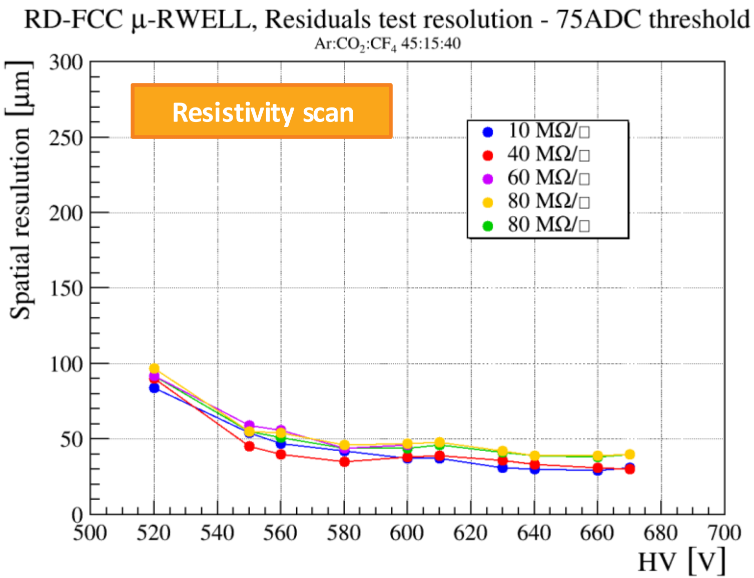
The 2022/2023 tests show that the optimal pitch to obtain 100 μm resolution is the following:

- **400 μm pitch**
- **300 μm width**

1D - Rho e pitch scan

Fixed surface resistivity: **~ 40 MΩ/□**





Fixed strip pitch (0.4 mm) and width (0.15 mm)

Increase the R/O **pitch**
=
As expected: reduction of the space resolution.

No effects in **this resistivity range**.
→ DLC resistivity uniformity is not a crucial parameter for space resolution

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

2D Readout Scheme

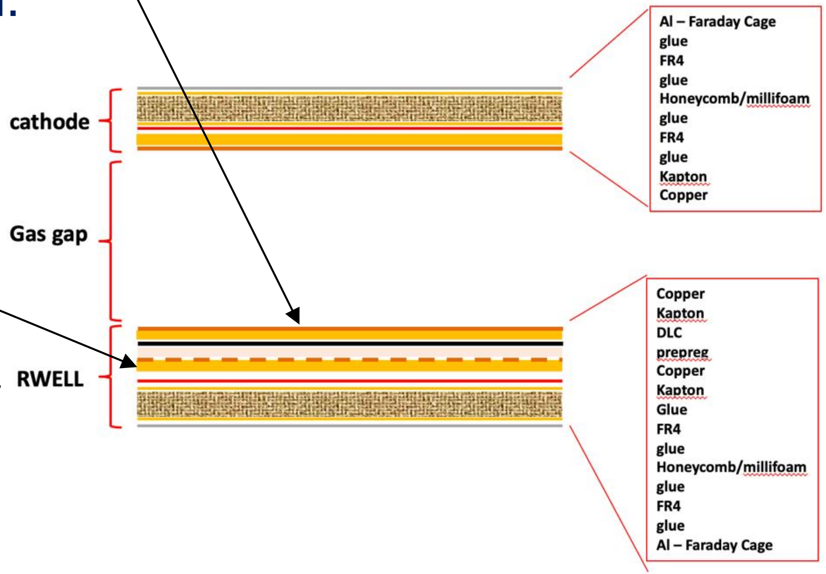
2D – readout: step by step approach

2. The second prototype reads the 2-nd coordinate on the "top" copper layer

Same readout geometry as in the bottom:

- 780 μm pitch
- 300 μm width
- 10 x 10 cm^2 active surface
- 128 channels

The effect charge collection on the «top» layer is the object of investigation.

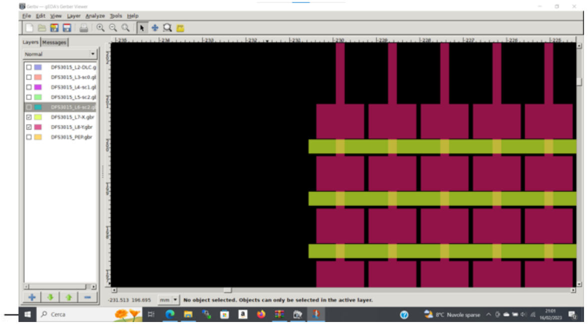


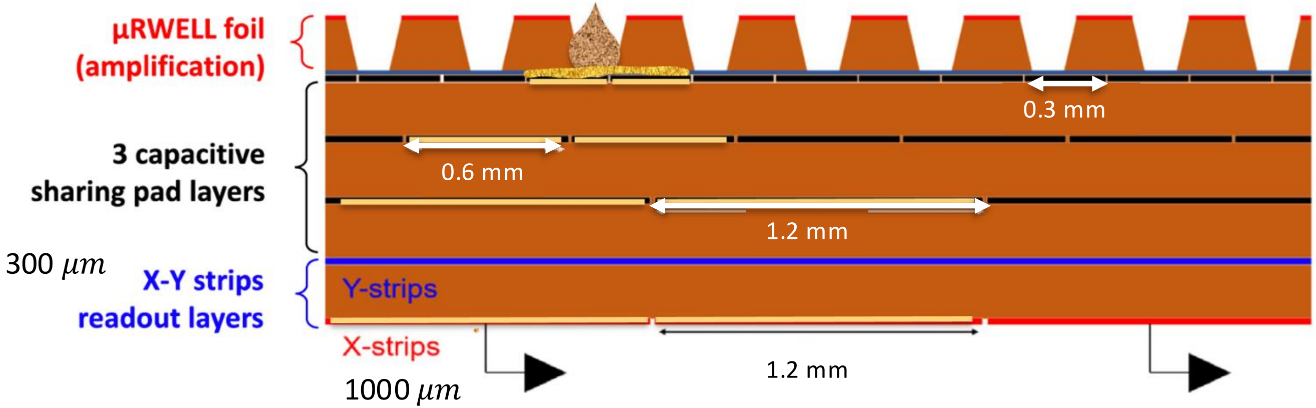
2D Readout Scheme

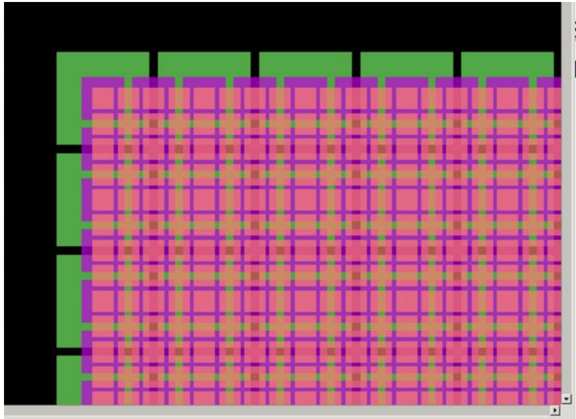
2D – readout: step by step approach

3. The third prototype reads both coordinates on the bottom in “COMPASS-like” strips configuration with capacity sharing read-out:

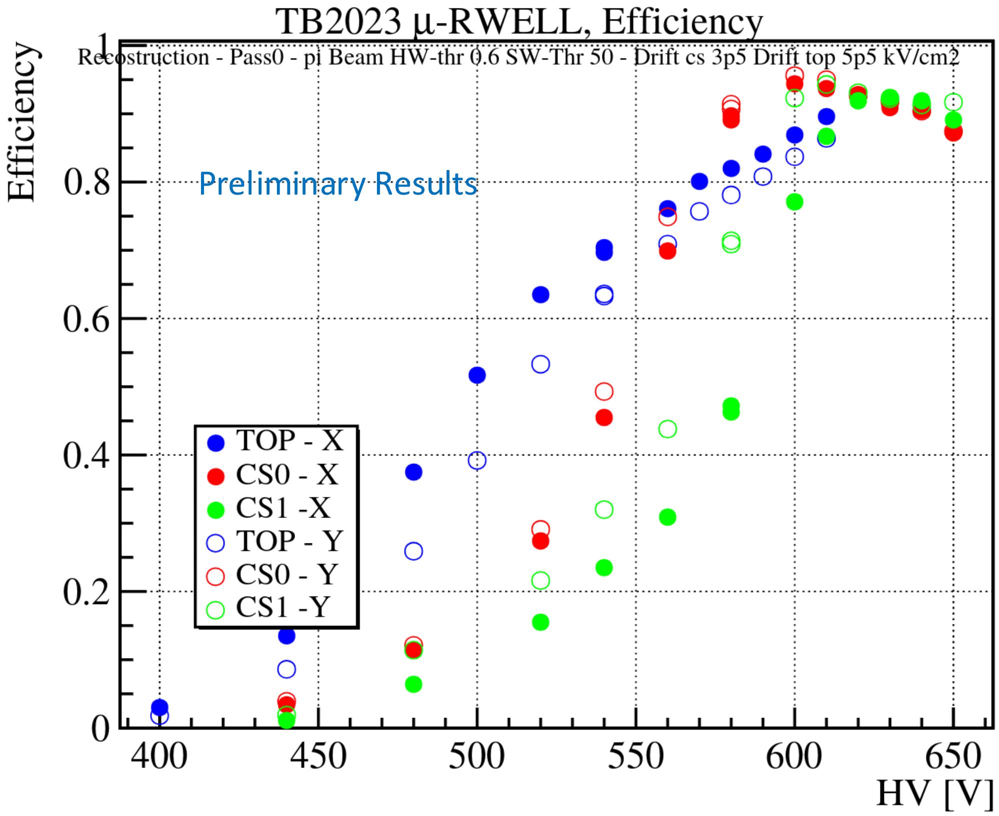
- 1200 μm pitch
- 300 μm vs 1000 μm strips width
- 10 x 10 cm^2 active surface
- 83 channels







Preliminary results from June test beam

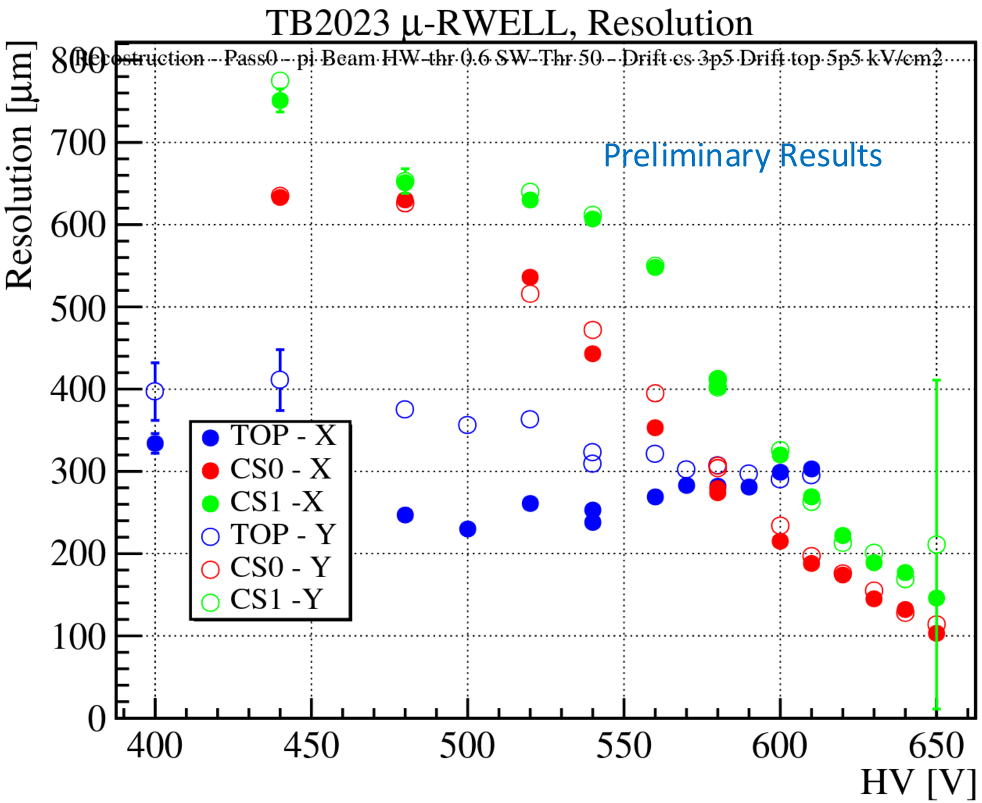


Efficiency

- CS readout reaches a plateau at higher HV values than standard readout scheme.
- TOP readout is not yet at plateau at 600 V

(HV was chosen not to to be raised to higher values)

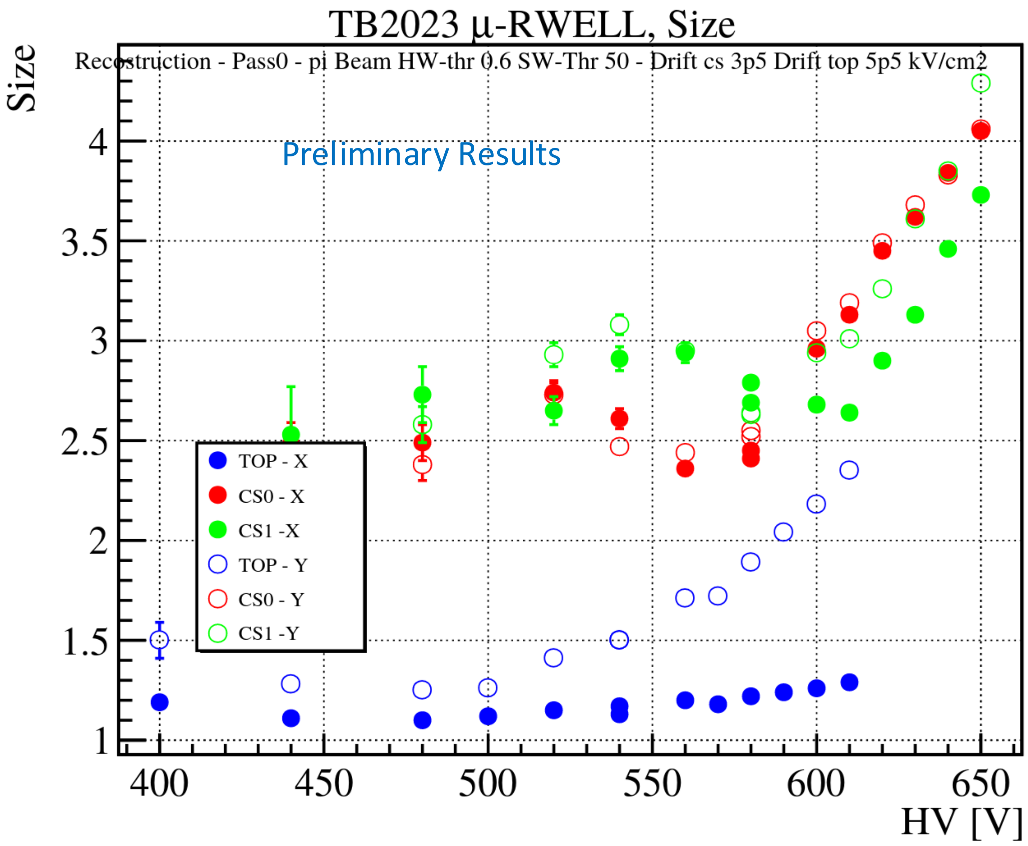
Preliminary results from June test beam



Resolution

- CS readout reaches 100 μm resolution at highest HV values (starting from 1200 μm pitch)
- TOP readout resolution is fixed at 250-300 μm (pitch is 780 μm)

Preliminary results from June test beam



Cluster Size

- CS readout Cluster Size is not lower than 2.5 strips and increases to 4 at higher HV.
- higher cluster size → better resolution
- TOP readout cluster size is fixed at 1.3
- Bottom readout cluster size increases from 1.5 to 2.3 with HV

On-going Activities

TEST BEAM at CERN SPS North Area H8:
16 - 30 October 2024

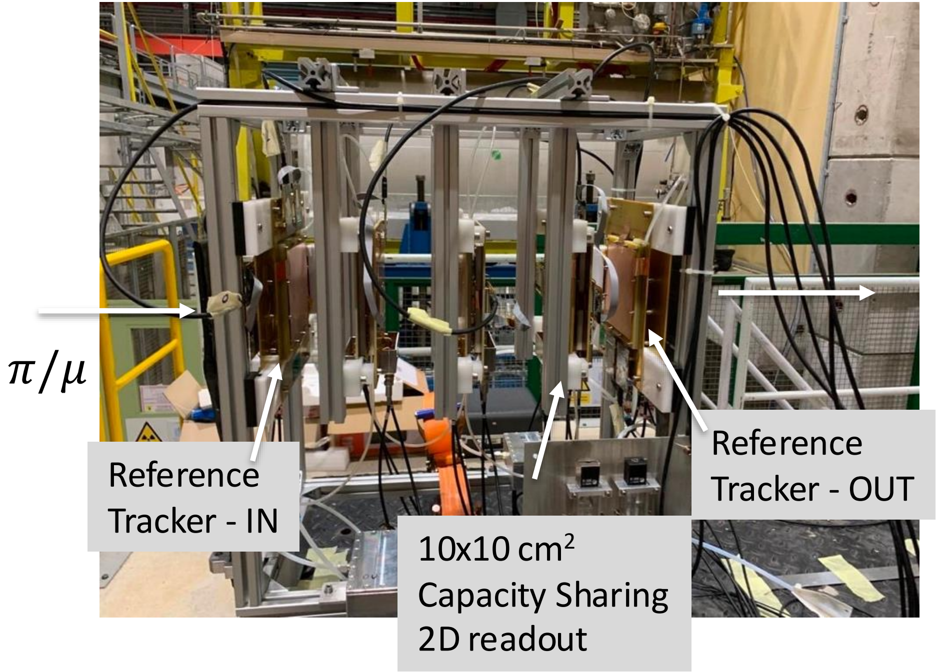


Photo taken during 5 – 19 October 2022 test beam

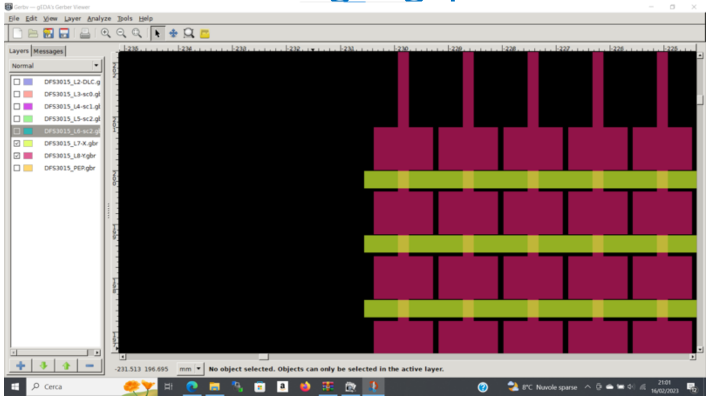
First Large Area Detector prototype

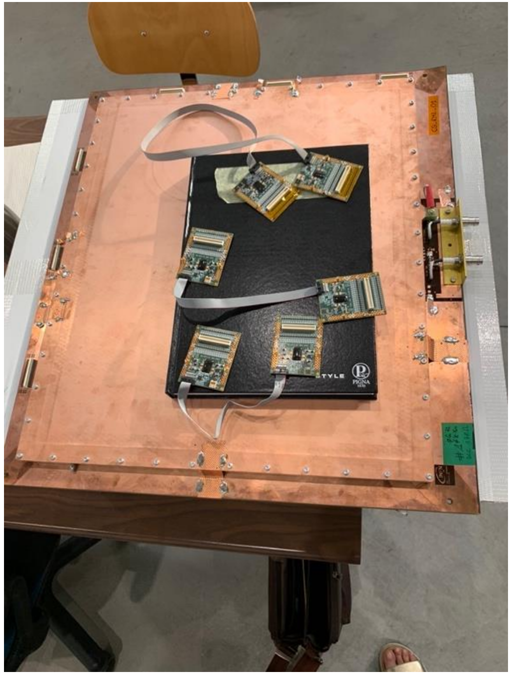
A first large area 40 x 46 cm [2] detector has been delivered to Roma Tor Vergata and is being characterized **in collaboration with the LNF group lead by Gianni Bencivenni**

$1200\ \mu m\ pitch$

300 $\mu m\ \ vs\ \ 1000 \mu m$ strips

6 mm gas gap





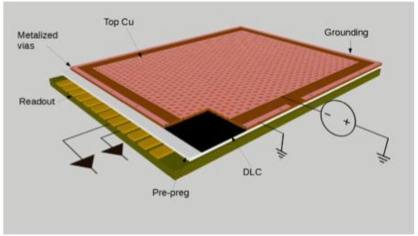
The μ-RWELL Developments: *High-rate capability and improved grounding scheme*

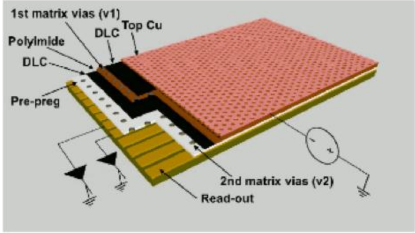
Studies have been focused on the DLC grounding layout to increase the rate capability while maintaining a safe resistivity => The solution is to reduce as much as possible the current path towards the ground connection introducing a high density "grounding network" on the resistive stage of the detector

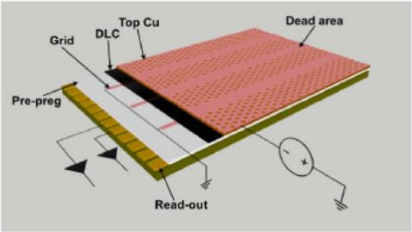
2015 2017 2018 2020 time

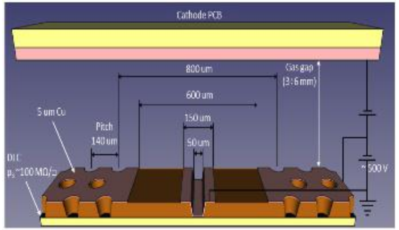
R&D on low-rate layout

R&D on high-rate layout *(grounding network also in the active area)*









SRL_Single-Resistive-Layer

the DLC grounding is provided all around the active area.

$detection\ efficiency$:

$\frac{G}{G_0} \sim 1\ up\ to\ 35\ kHz/cm^2$

DRL-DoubleResistive Layer

Two DLC layers connected by a matrix of conductive vias and grounded by a further matrix of vias to the readout electrodes

$\frac{G}{G_0} > 0.90\ up\ to\ 3MHz/\ cm^2$

SG –Silver Grid

a SRL with a 2-D grounding conductive strip lines realized on the DLC layer.

$\frac{G}{G_0} > 0.90\ up\ to\ 20MHz/\ cm^2$

PEP-Patterning-Etching-plating

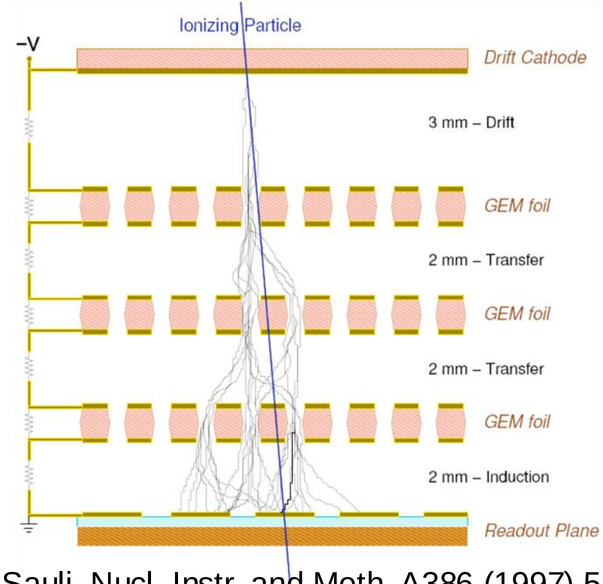
*the grounding grid of the DLC is patterned by **etching a groove in the base material from the top***

$\frac{G}{G_0} > 0.90\ up\ to\ 20MHz/\ cm^2$

The CLAS12 DC TRACKING UPGRADE

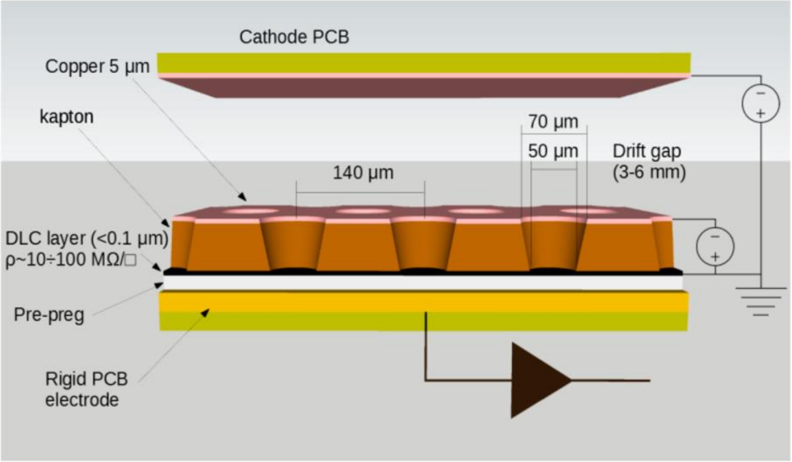
Two MPGD detector technologies have been discussed, triple-GEM and μ-RWELL

- Large area triple-GEM detectors have been used in experiments (PRad, SBS, …).



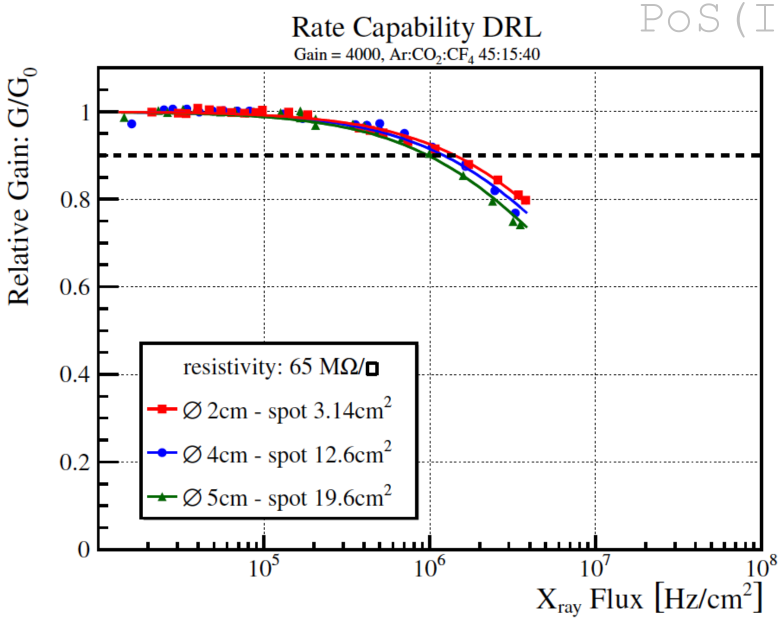
F. Sauli, Nucl. Instr. and Meth. A386 (1997) 531

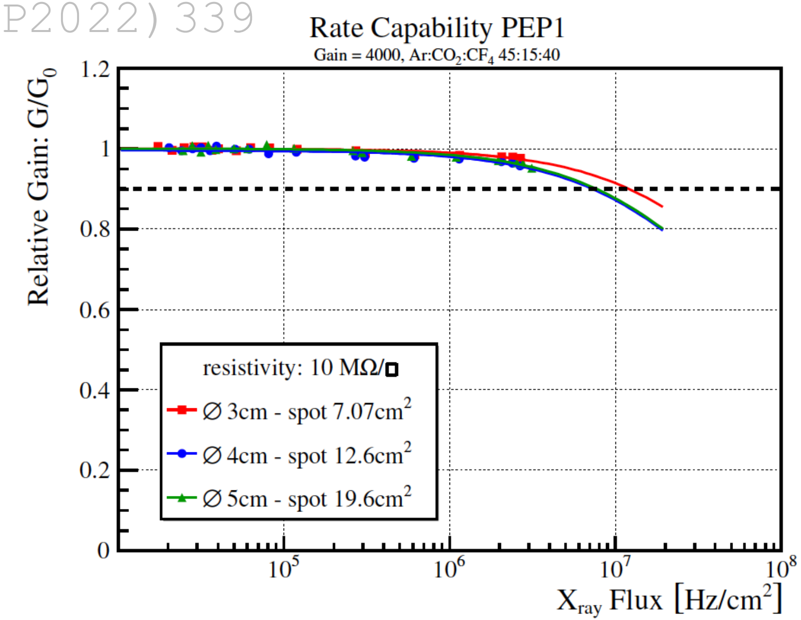
- μ-RWELL technology is new, only small prototypes have been tested:
  → will require extensive R&D.
- μ-RWELL detector is best suited for CLAS12:
  – low material budget, easy to build, less support structures in the active volume of the detector.



G. Bencivenni et al.; 2015_JINST_10_P02008

The High-Rate solution: PEP



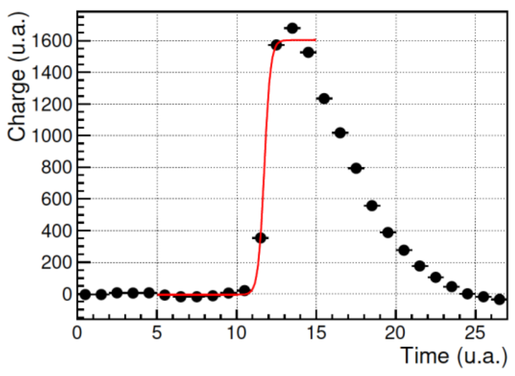


Rate capability measured with 5.9 keV X-rays with Double Layer μ-RWELL (DRL) and with PEP

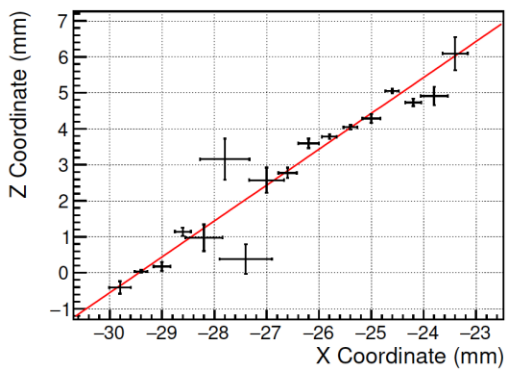
NB: a photon flux around 1 MHz/cm^2, which corresponds to a m.i.p. rate of 3 MHz/cm^2.

A possible solution : ***μTPC reconstruction***

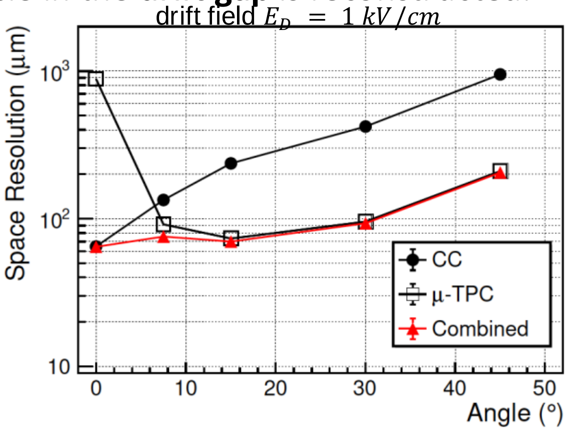
- The electrons created by the ionizing particle drift towards the amplification region
- In the μTPC mode from the **knowledge of the drift time** and the **measurement of the arrival time of electrons**, the **track segment in the gas gap is reconstructed**
- The **fit of the analog signal** gives **the arrival time of drifting electrons**.
- By the knowledge of **the drift velocity,** the 3D trajectory of th ionizing particle in the **drift gap** is reconstructed.



Integrated charge as a function of the sampling time



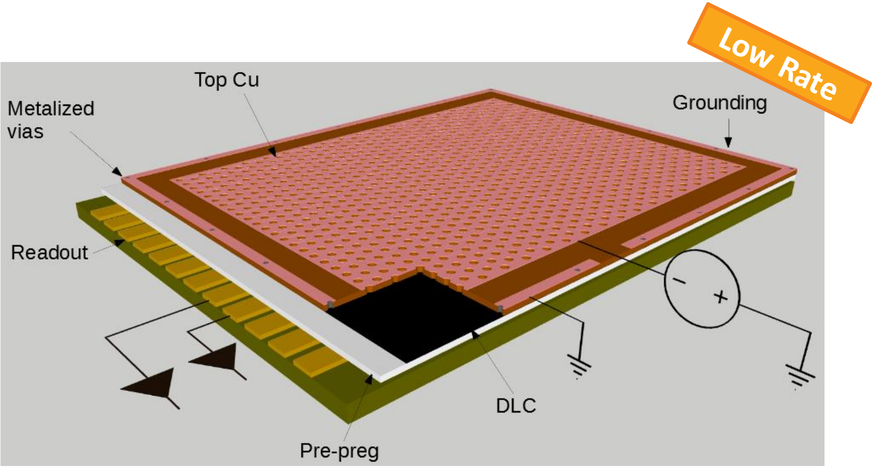
Example of a track reconstruction using the TPC algorithm.



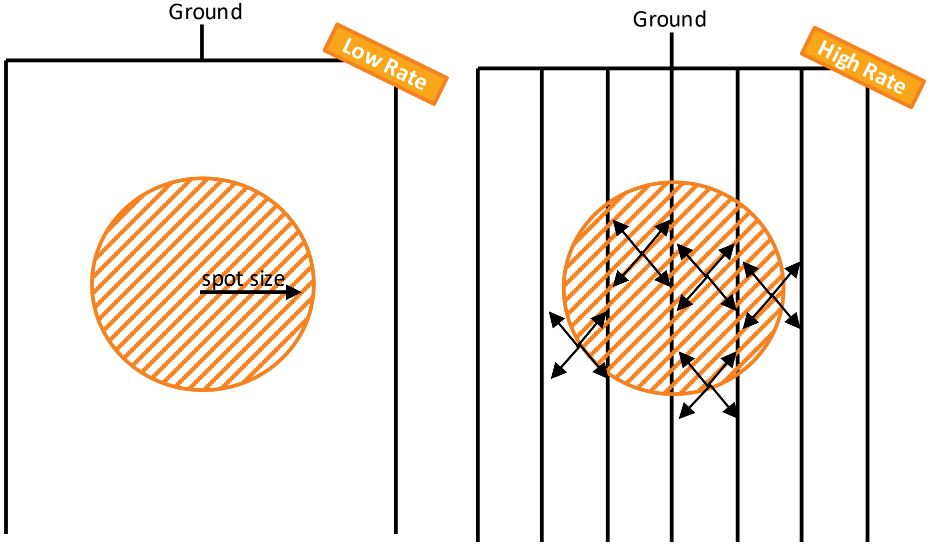
Comparison of the **CC** and ***μTPC*** reconstruction algorithms in function of the impinging angle

The µ-RWELL – High Rate scheme

To overcome **the intrinsic rate limitation** of the Single Resistive layout: introduction of an **high density “grounding network”**.



Single Resistive Layout (SRL)



A sort of tiling with smaller low rate schemes.

Spot Effect for SRL – Manufacturer plot

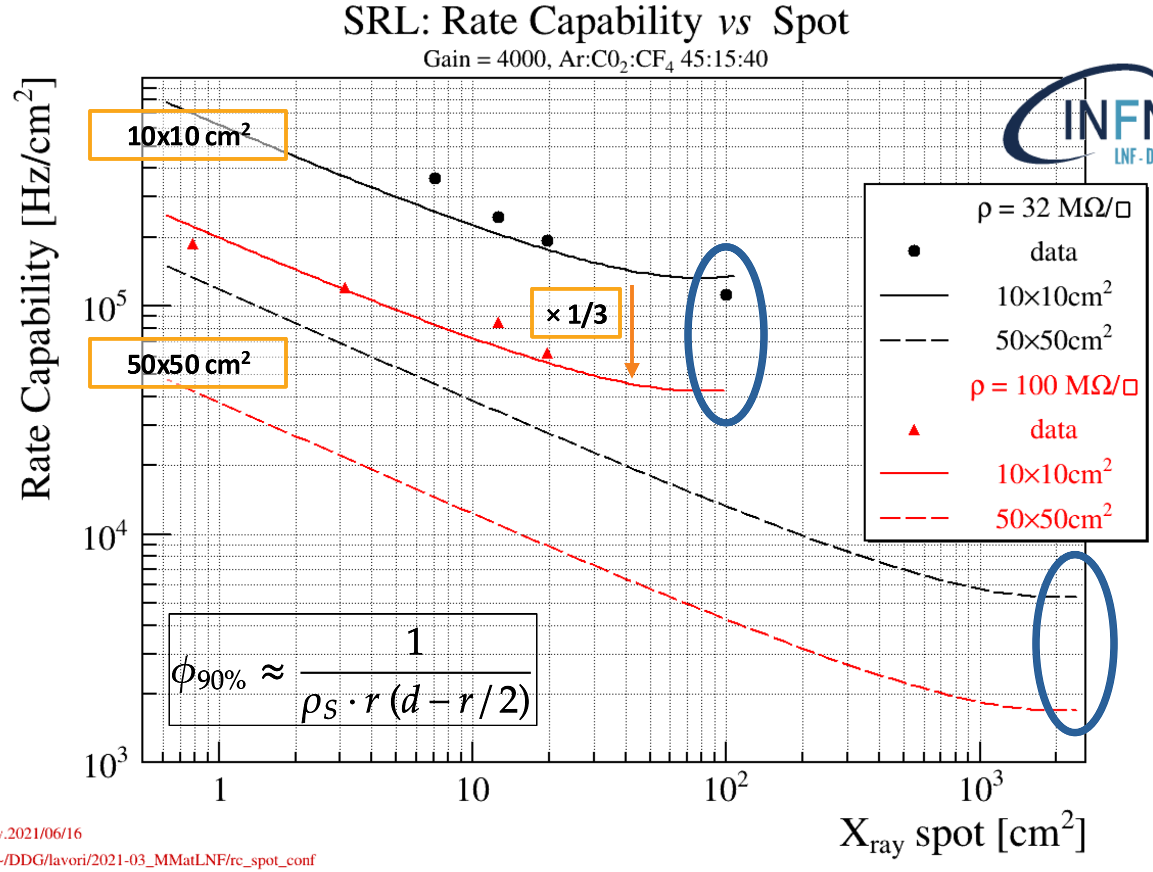
From the mathematical model:

1. detectors with same size but **different resistivity** exhibit a rate capability scaling as the inverse of their resistivity: × 1/3

2. for the SRL, **increasing the active area** from 10×10 cm^2 to 50×50 cm^2 the rate capability should go down to few kHz/cm^2

3. thus using a DLC **ground sectoring** every 10/20/30 cm, detectors could achieve rate capability up to $100kHz/cm^2$ (with X-ray)

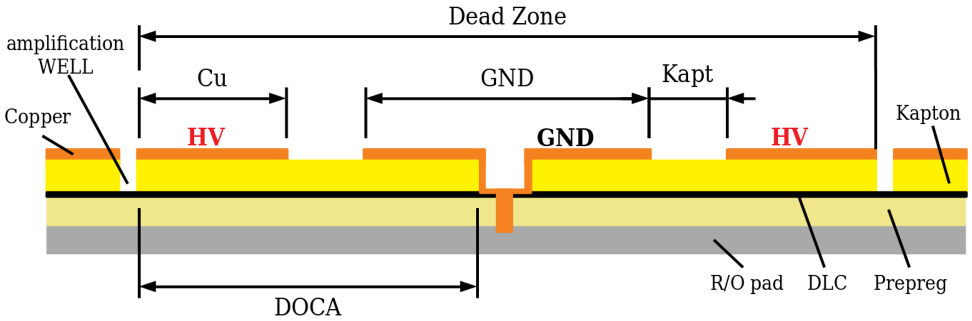
Different primary ionization ⇒ Rate $Cap._{m.i.p.}$ = 3×Rate $Cap._{X\text{-}ray}$

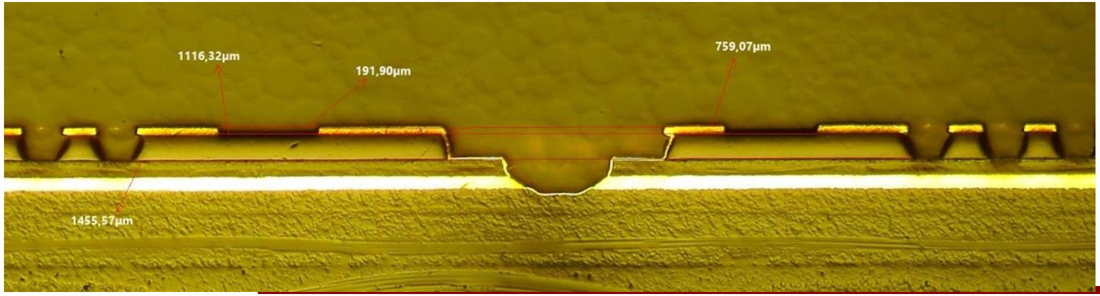


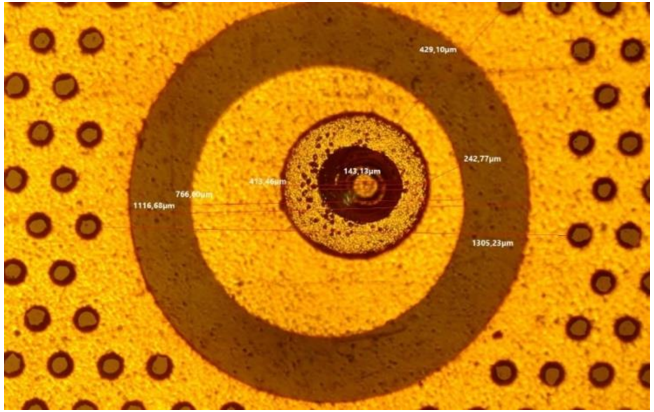
The PEP-dot µ-RWELL

DLC-GND pitch [mm]	Dead Zone [mm]	GND width [mm]	Insulation gap [mm]	DOCA [mm]
9	1.1 (2%)	0.6	0.25	0.7

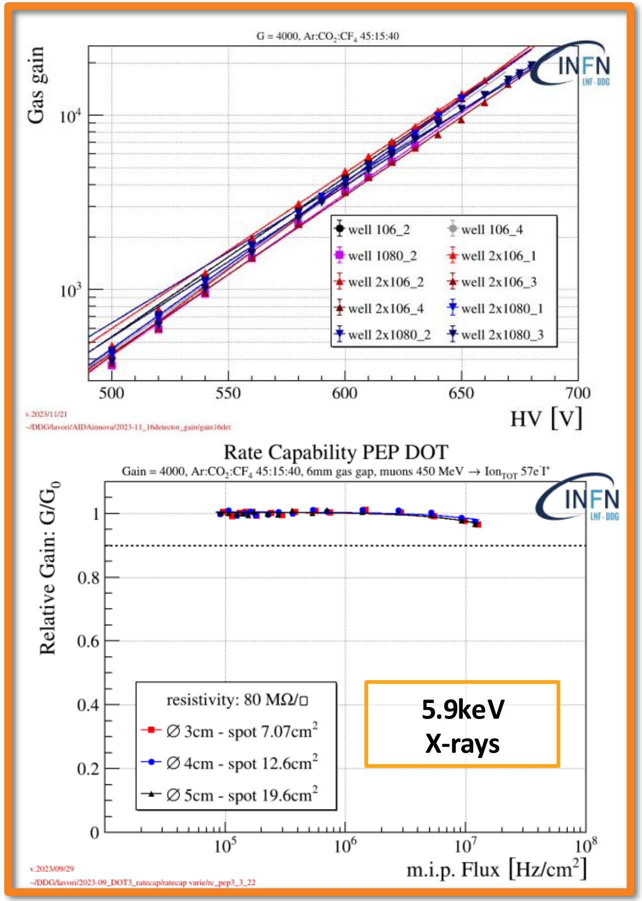
- The most recent high rate layout
  - **P**atterning–**E**tching–**P**lating
- The DLC ground connection is established by creating **metalized vias from the top Cu layer through the DLC**, down to the pad-readout of the PCB
- The dead zone is ~2%

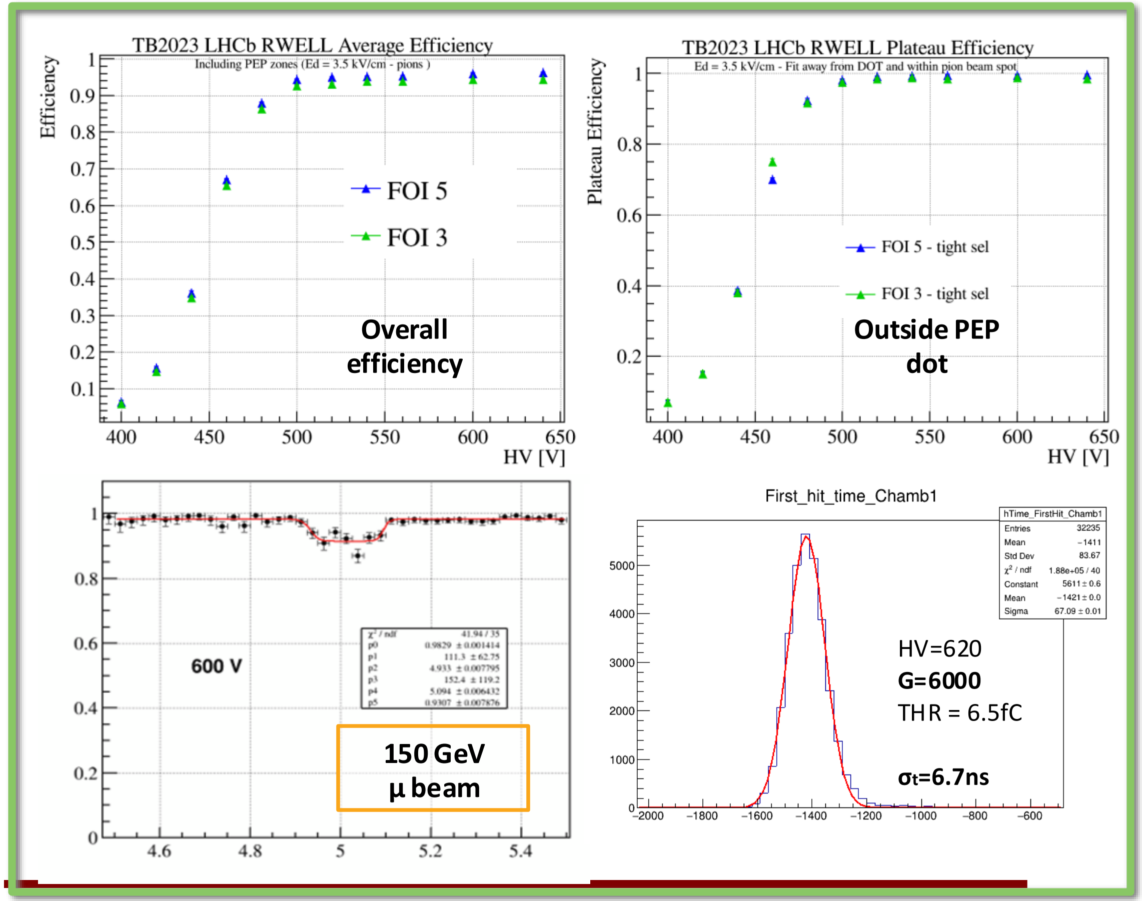






PEP-dot – results





Thank you