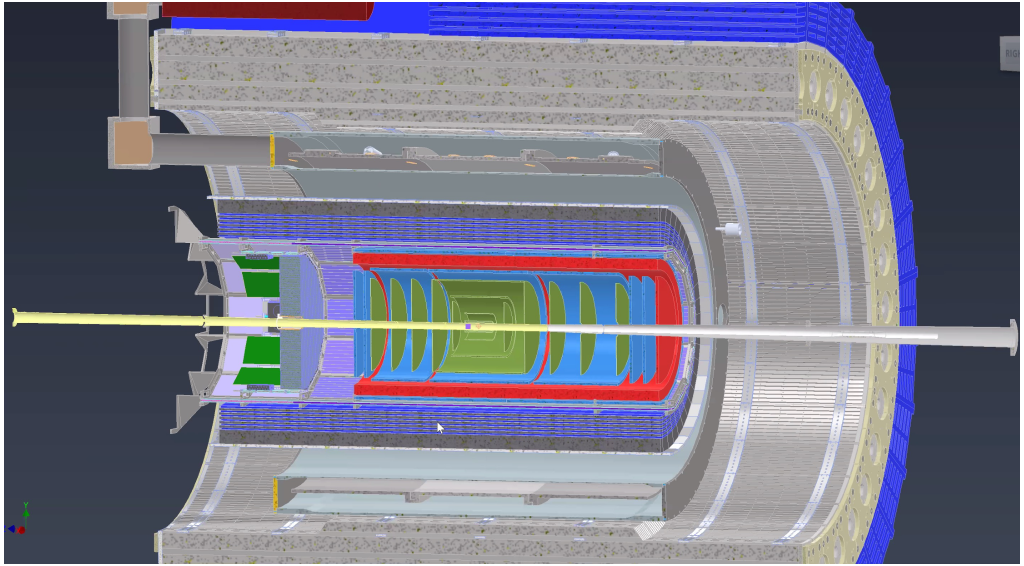


$\mu-$Rwell detectors for the EPIC tracking at EIC

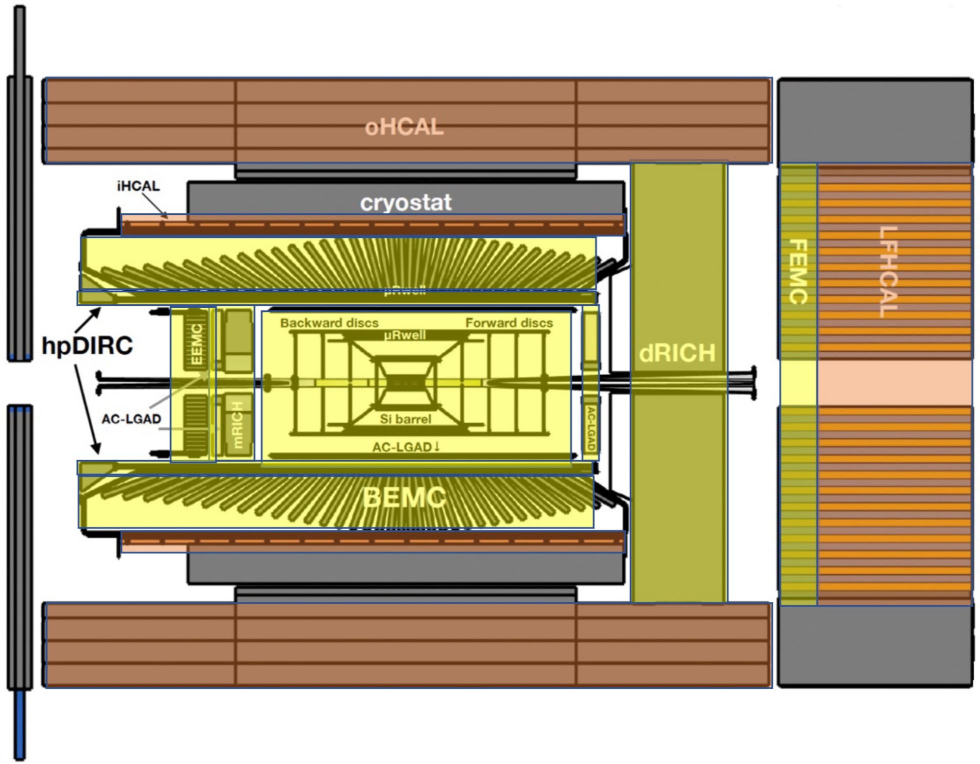
eRD108 – DRD-1

Annalisa D’Angelo
University of Rome Tor Vergata & INFN Rome Tor Vergata Rome – Italy

Outline

- The MPGD scope in the EPIC detector: latest tracking configuration (June 15th 2023)
- μ −Rwell technology
- Ongoing developments
  - High-rate capability and improved grounding scheme
  - 2D readout scheme: capacity sharing and strip width optimization
  - Large area detectors
- Future developments for EPIC@EIC tracking
  - μTPC reconstruction vs thin drift gap
- Possible involvement of INFN groups: Roma Tor Vergata (with LNF support), *Genova?*
  - Synergies with on-going activities at JLab12
  - Collaboration with Gianni Bencivenni′s Group
  - EIC MPDG WG– e RD108 and the tracking WG welcomes the possible contribution
  - A possible INFN scope can be easily identified with the available budget
- A decision should be made in ~ 1 year timeframe
- 2024 Financial Requests o INFN

The Latest Configuration of ePIC detector tracking



Tracking:

- **New 1.7T solenoid**
- Si MAPS (65nm) Tracker
- MPGDs (μRWELL/μMegas)

PID:

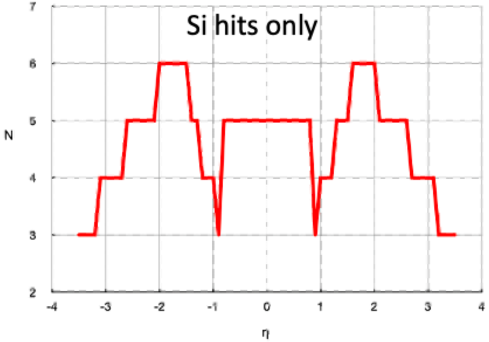
- hp-DIRC
- mRICH/pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

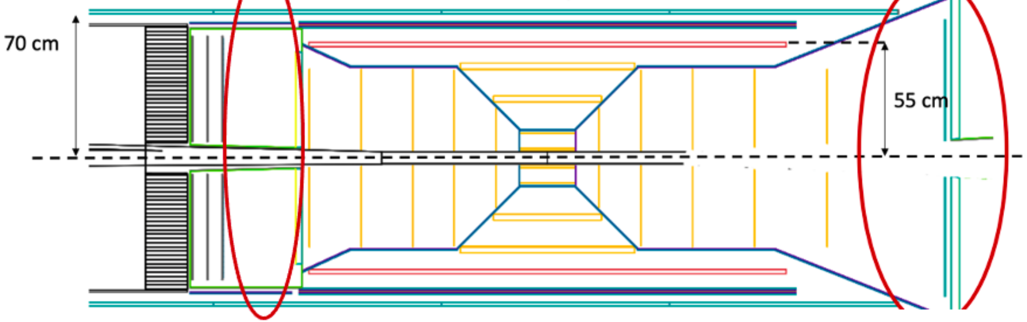
Calorimetry:

- SciGlass/Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)

Motivation for MPGD endcaps in ePIC detector tracking

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

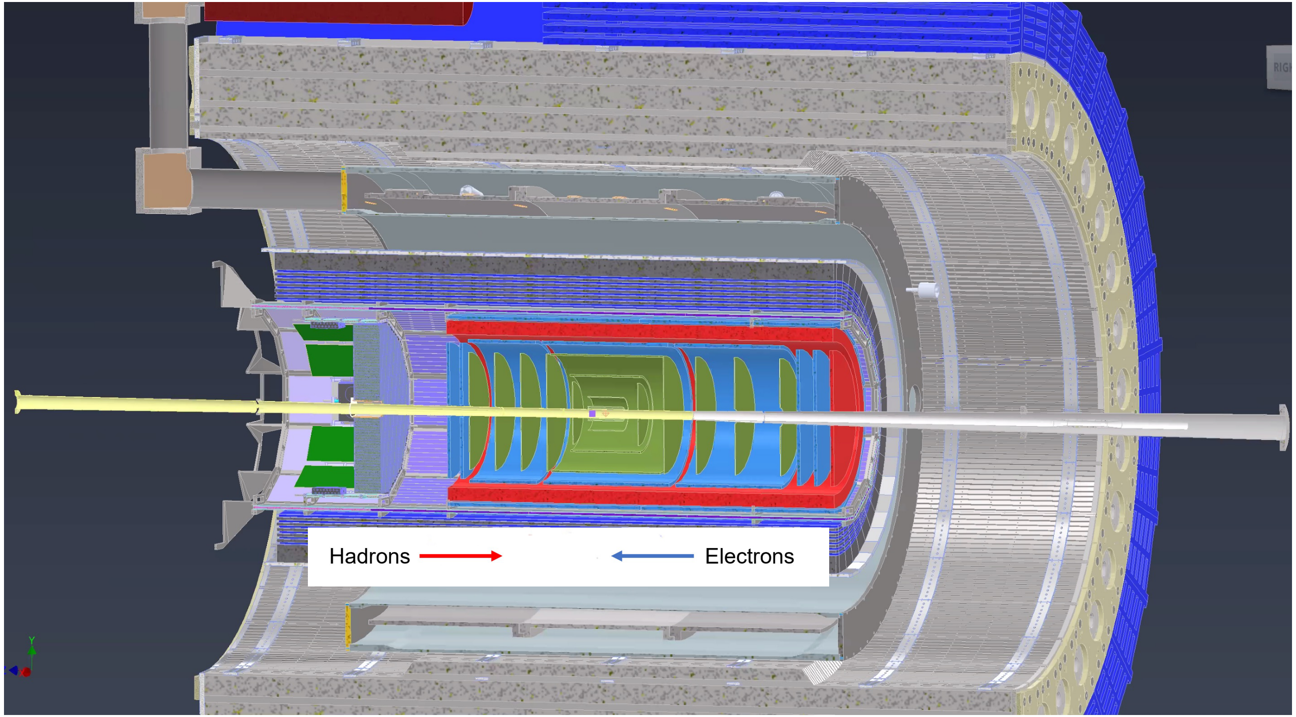




ePIC tracker geometry before June 2023

The Latest Configuration of ePIC detector tracking

June 15th 2023 – Tracking working group meeting – **re-enforced role of MPGD**



Colour code:

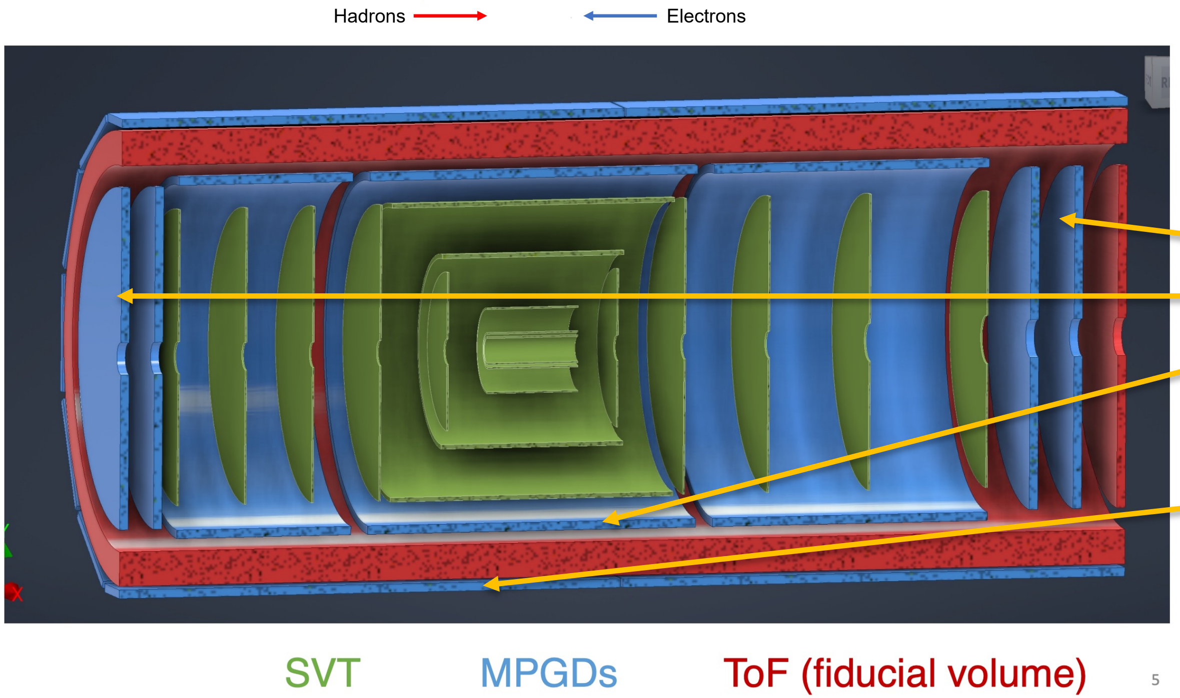
green → silicon trackers

light blue → MPGDs

red → Time of Flight

purple → DIRC

The Latest Configuration of ePIC detector tracking



Colour code:

green → Silicon Vertex Trackers

red → Time of Flight

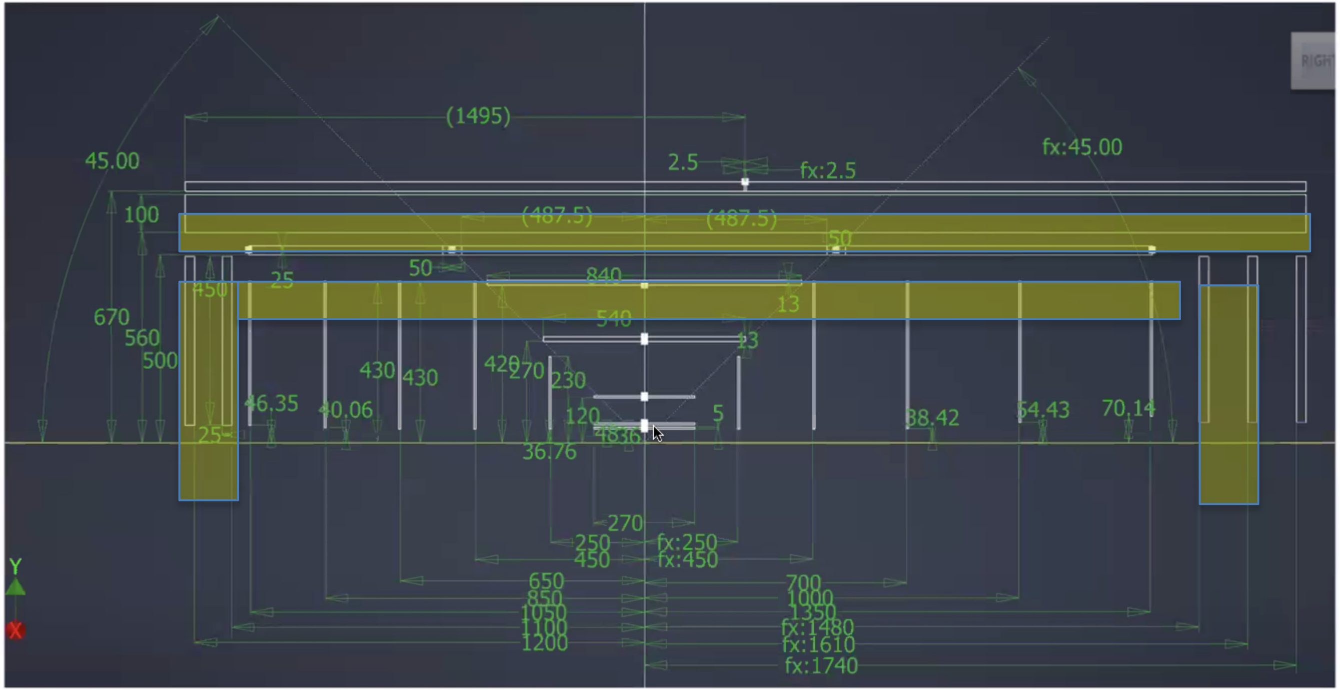
light blue → MPGDs

- Two forward discs
- Two backward discs
- Cylinder inside the ToF, segmented in three longitudinal sectors
- Barrel inside the DIRC: same DIRC segmentation in planar tiles, divided into two longitudinal sectors

re-enforced role of MPGD

Its primary roles are : - Provide additional fast points for pattern recognition
- Aid tracking into the PID subsystems

The Latest Configuration of ePIC detector tracking



Tentative:

- Two forward discs
  50 cm radius → $\mu Rwell$
- Two backward discs
  50 cm radius → $\mu Rwell$
- Cylinder inside the ToF, segmented in three longitudinal sectors
  56 cm radius
  → Micro Megas
- Barrel inside the DIRC:
  67 cm radius → Micro Megas/$\mu Rwell$

On-going studies (eRD-108)

- re-enforced role of MPGD
- we are considering to construct the two forward disks facing the dual RICH

The µ-RWELL features & performances

The µ-RWELL exhibits several interesting features:

- Compactness
- Easy assembly
- Easy powering
- Intrinsic spark quenching

µ-RWELL performances:

- Gas gain → 10^4
- Rate capability HR version →10 MHz/cm2
- Spatial resolution → down to 60 µm
- Time resolution → 5-6 ns

The µ-RWELL (Micro Resistive Well Detector)

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

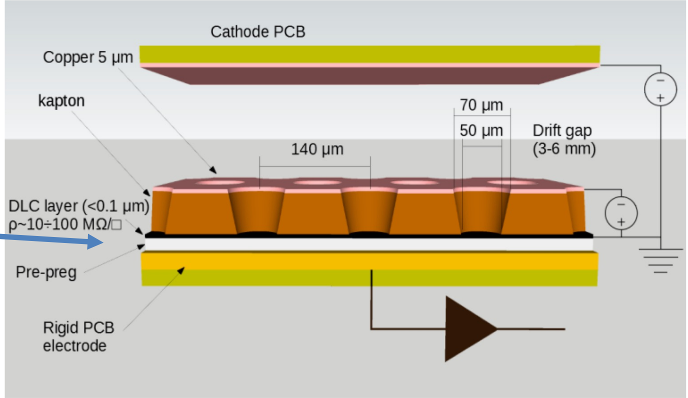
Used Gas : $Ar{:}CO_2{:}CF_4$ 45:15:40 mixture (it also works with $Ar{:}CO_2$ «green» mixture)

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

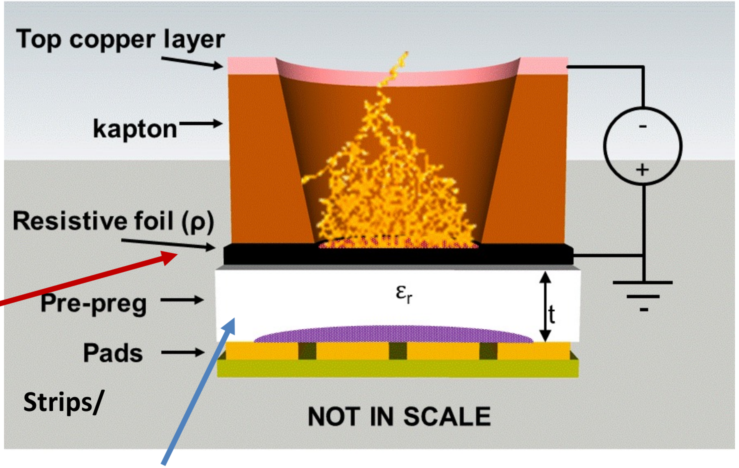
The resistive layer strongly suppresses the transition from streamer to spark

*=> 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

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

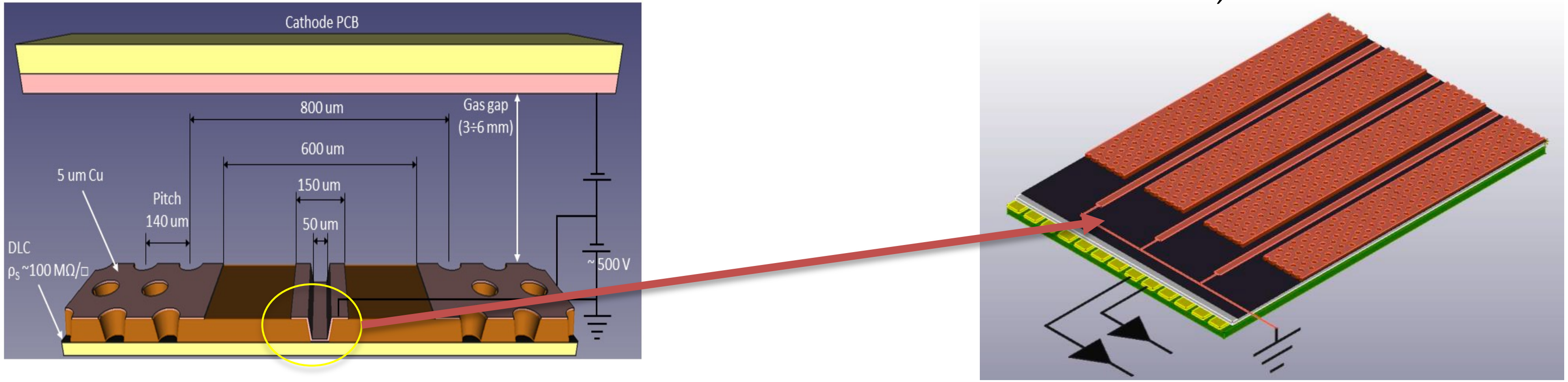
- The resistive stage ensures the quenching of the spark amplitude
- As a *drawback,* the capability to stand high particle fluxes is reduced, but appropriate grounding schemes of the resistive layer solves this problem

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



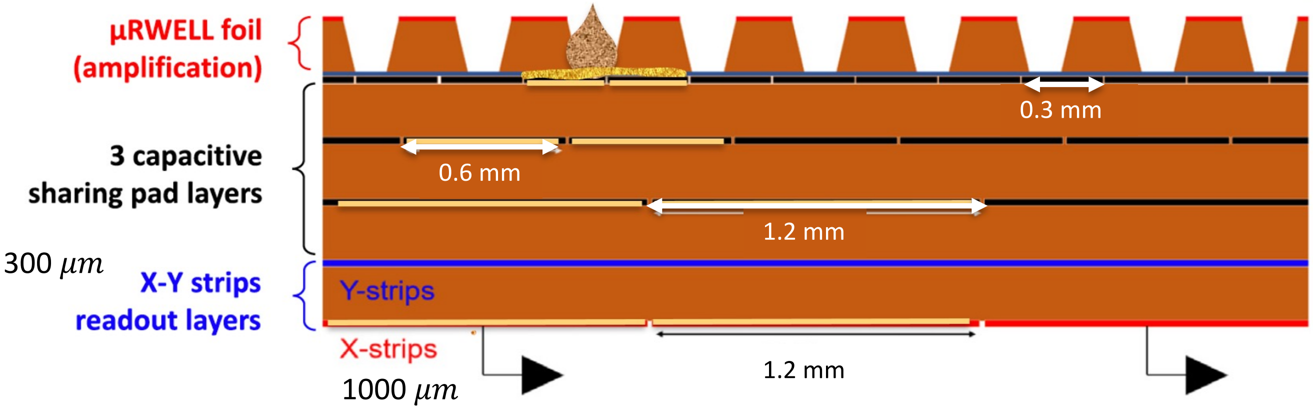
The active area is discontinued by grooves that uncover the DLC; then a copper plating, carefully separated from the copper in the active sectors, is disposed to connect the DLC to the ground.

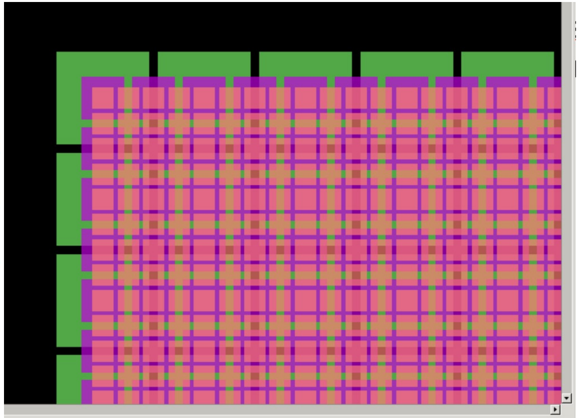
A small dead zone on the amplification stage must be introduced for high stability operation

The µ-RWELL Technology

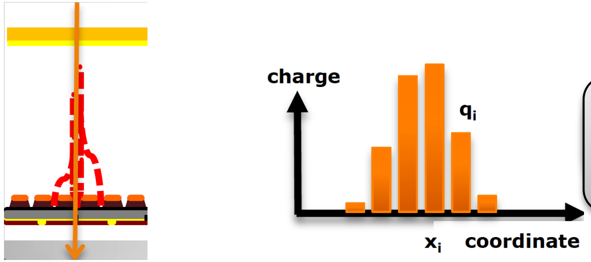
"capacitive-sharing readout structures" for electronic channels reduction

- Charge transfer and charge sharing for large pitch (strip or pad) anode readout PCB layers, using capacitive coupling between a stack of layers of pads.
- Capacitive-sharing readout structures offer a very good spatial resolution capability with significant reduction of electronic channels required to read out large-area MPGD trackers





The μ-RWELL Technology



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

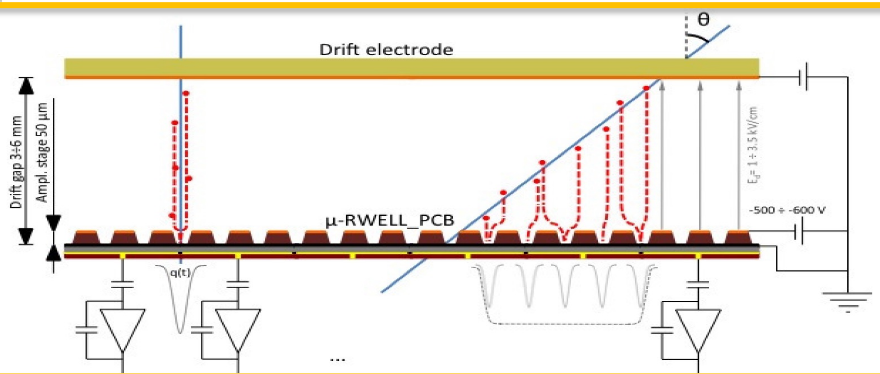
Charge Centroid reconstruction method

↓

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.

The µ-RWELL features & performances

INFN R&D phase is addressing the following topics, in a strep-by-step strategy:

- **2D readout scheme:** 2 x 1D vs 2D à la “COMPASS” vs Bottom/Top Readout
- **Electronics channels reduction:** minimum pitch compatible with 100μm resolution vs capacity sharing
- **High-rate** capability and improved grounding scheme
- **Large area** detectors
- **EIC disks design** optimization

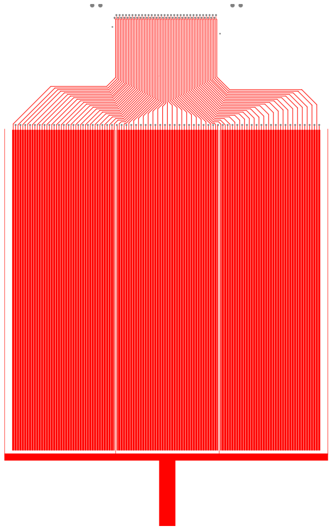
EIC R&D is synergic with JLAB12 activity

2D Readout Scheme

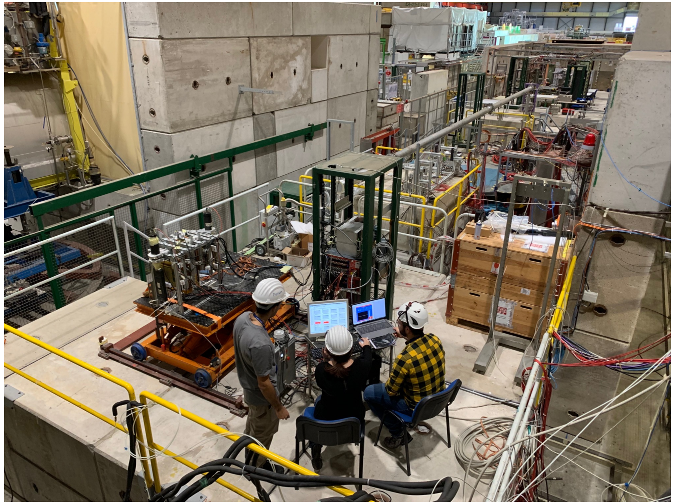
2D – readout: step by step approach

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



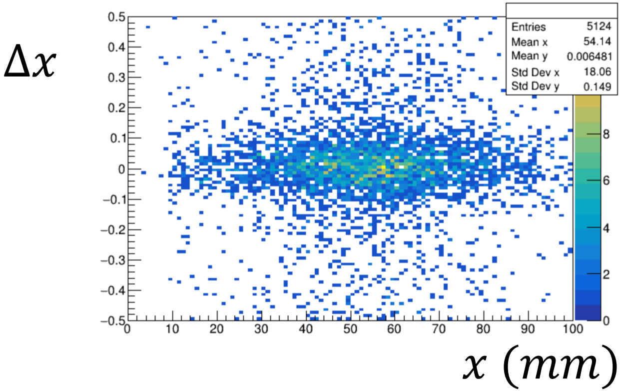
5 – 19 October 2022

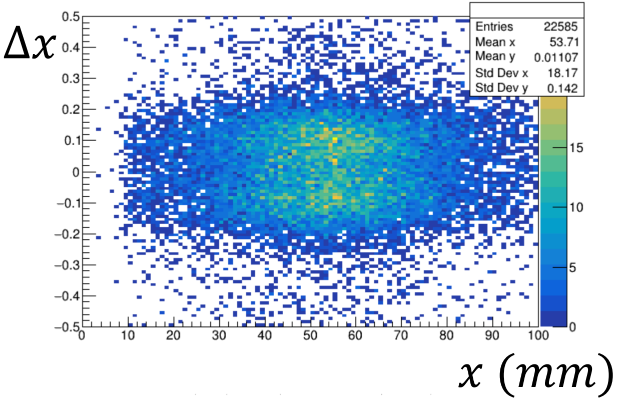


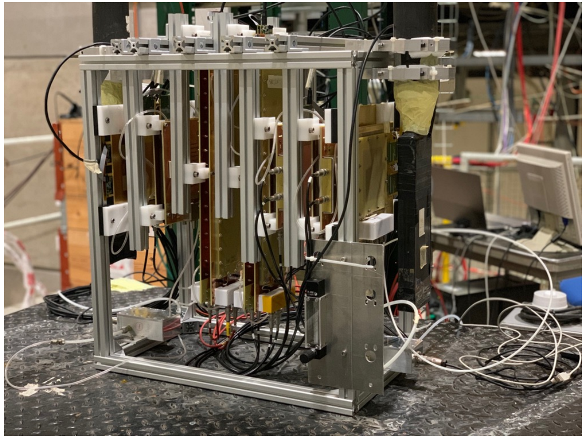
Test Beam: SPS North Area H8

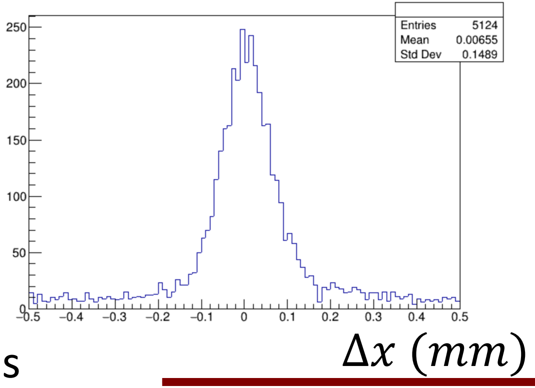
2D Readout Scheme

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

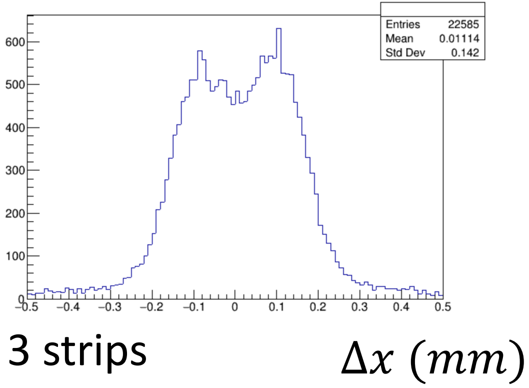








4 strips



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**

2D Readout Scheme

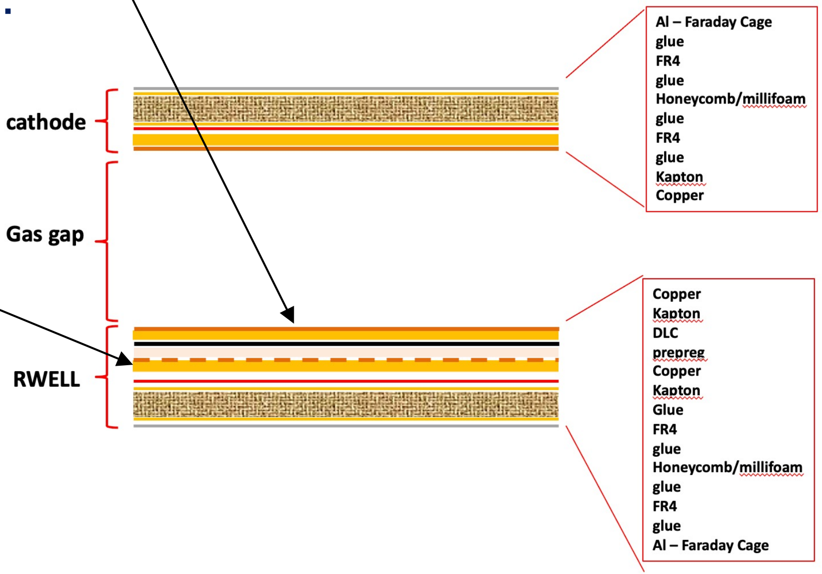
2D – readout: step by step approach

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.

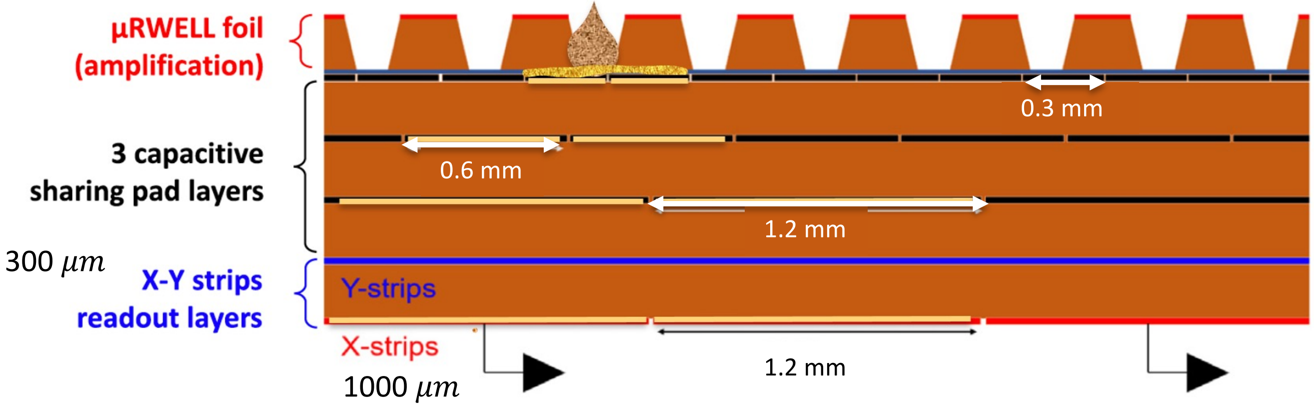


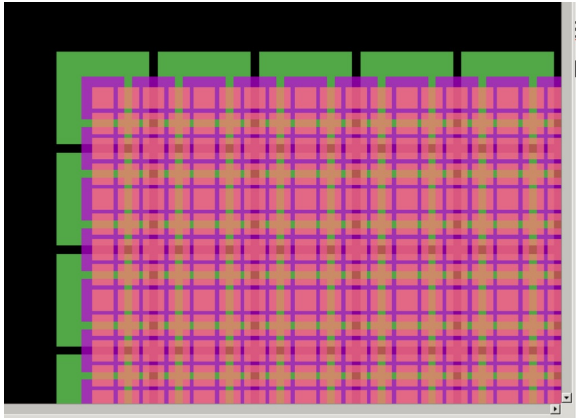
2D Readout Scheme

2D – readout: step by step approach

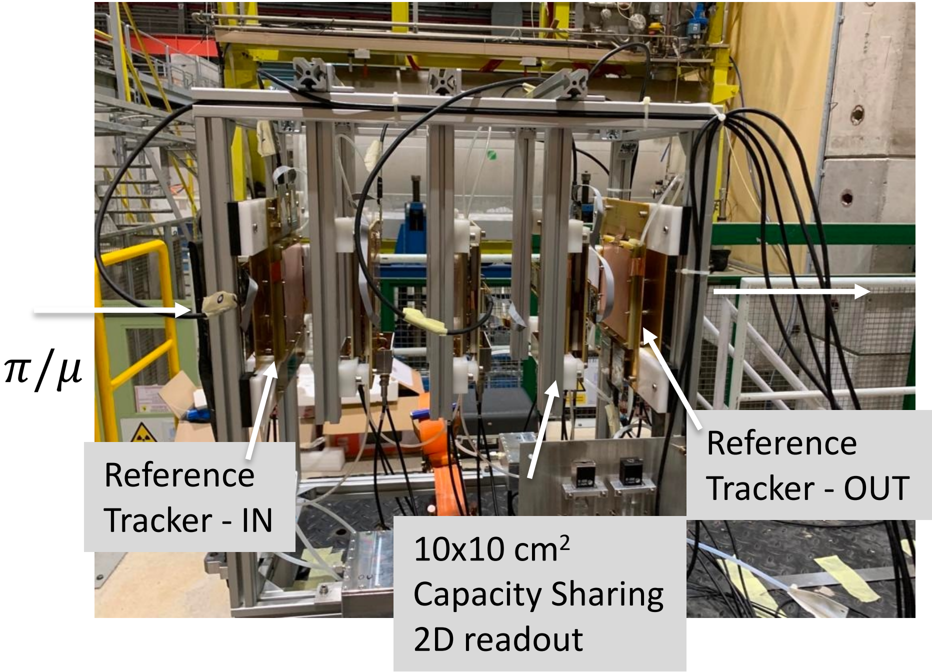
3. The third prototype reads both coordinates on the bottom in "COMPASS-like" strips configuration with capacity sharing read-out:

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





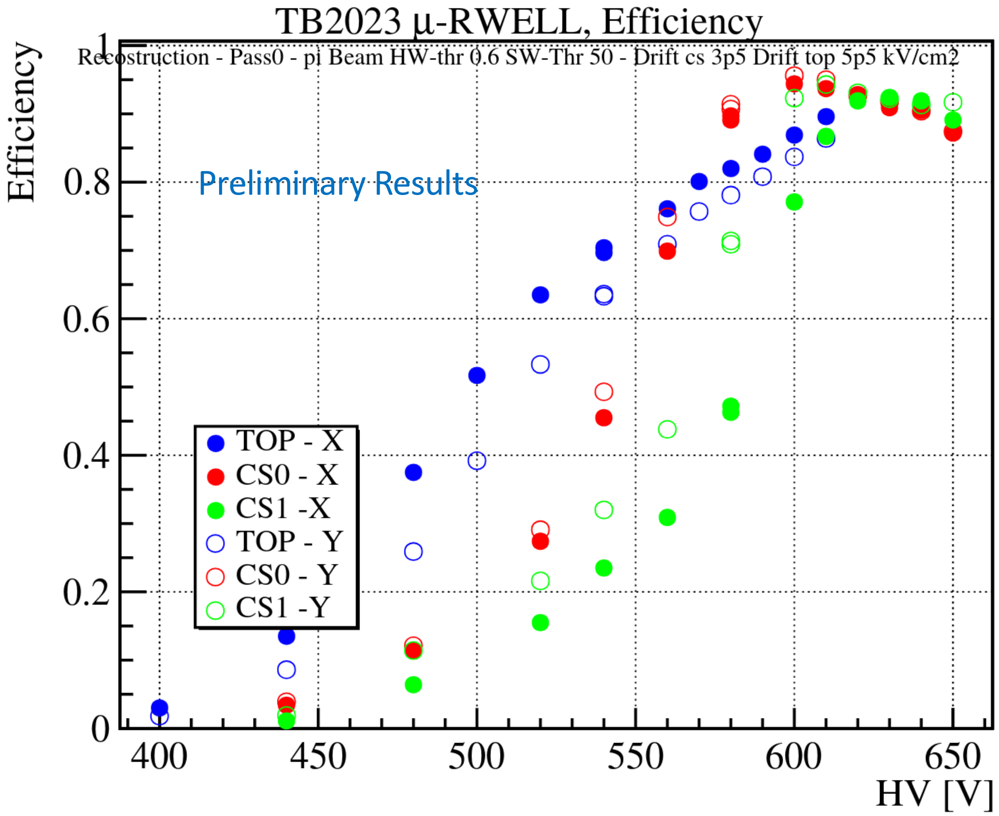
On-going Activities



TEST BEAM at CERN SPS North Area H8:
14 – 28 June 2023

Photo taken during 5 – 19 October 2022 test beam

Preliminary results from June test beam

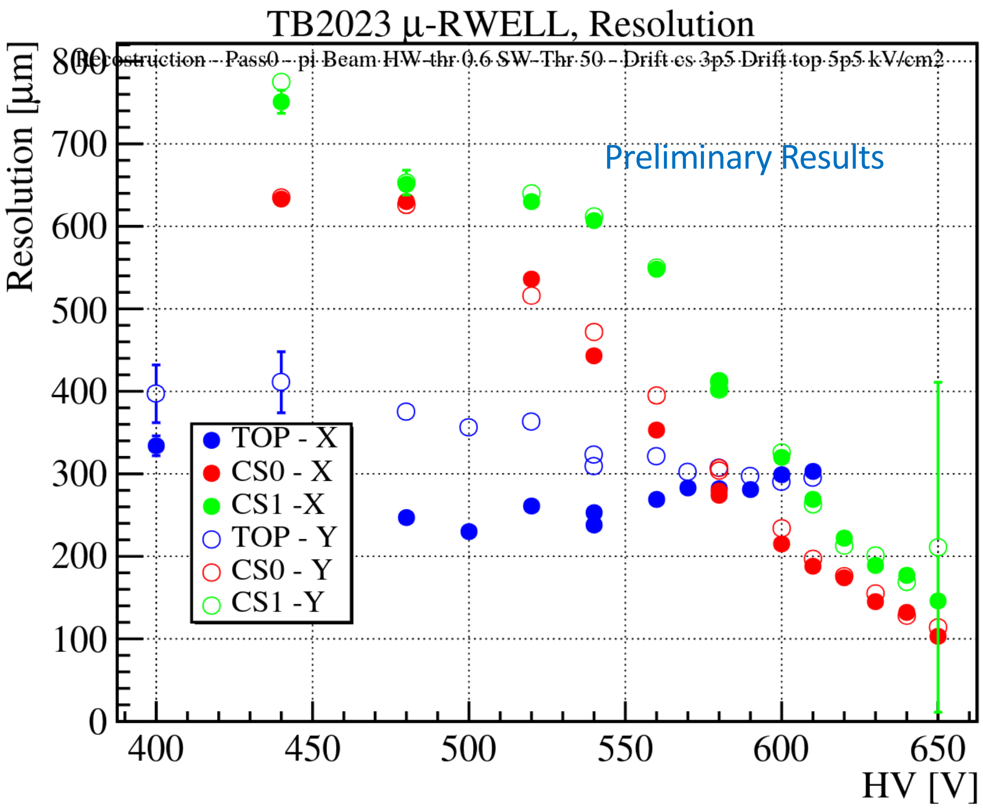


Efficiency

- 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 to to be raised to higher values)

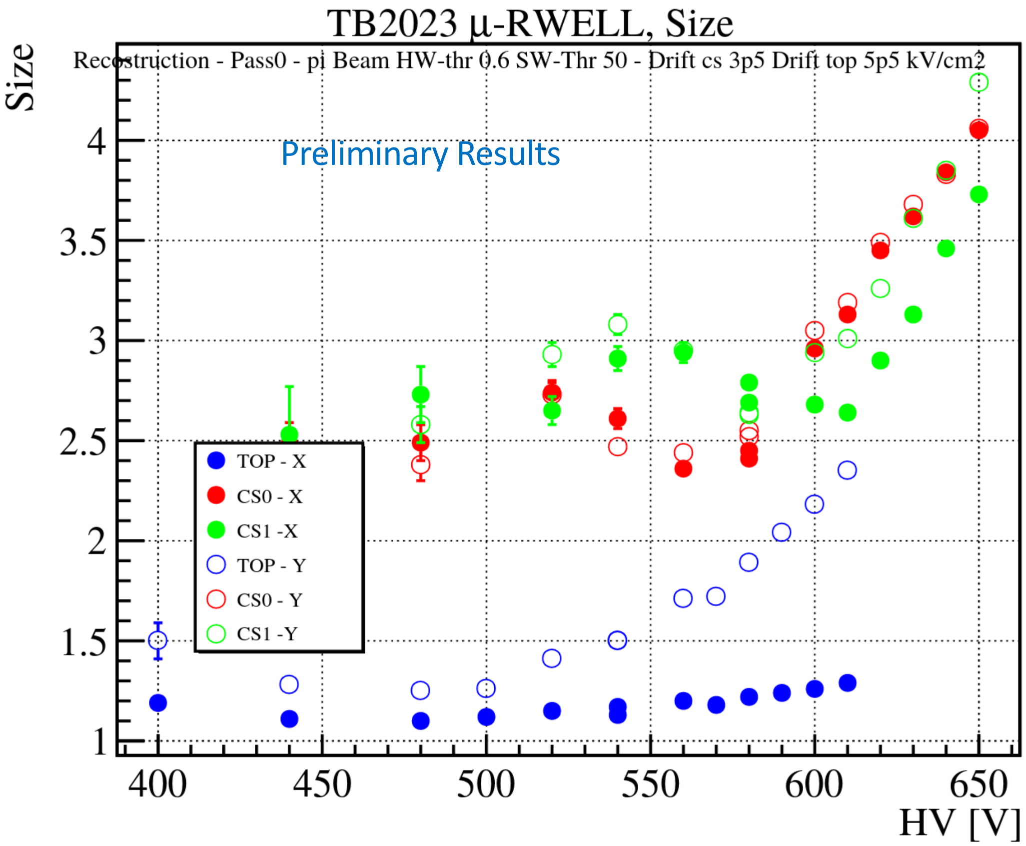
Preliminary results from June test beam



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

Summary of results from June test beam

TOP read-out

- The Top-readout efficiency is 80-82% (compatible with the geometrical acceptance of 87%).
- The efficiency does not show the plateau below 600V HV. The signal produced does not suffer from sharing between the 2 readout views.
- Spatial resolution is 250-350 µm, compatible with pitch/√12

Capacity Sharing read-out

- The CS shows an efficiency plateau at 92-93% as a function of HV from 600 to 660V (too high!)
- The charge spread allows a very good spatial resolution, <100 µm (at high HV).
- The average cluster size increases with HV.

FUTURE ACIVITIES

2D read-out optimization:

- The CS readout could be improved by eliminating one layer of sharing, going from the actual 3 capacitive ones (0.3 - 0.6 - 1.2 mm) down to 2 (0.4 - 0.8 mm).

Large Area Detector prototype

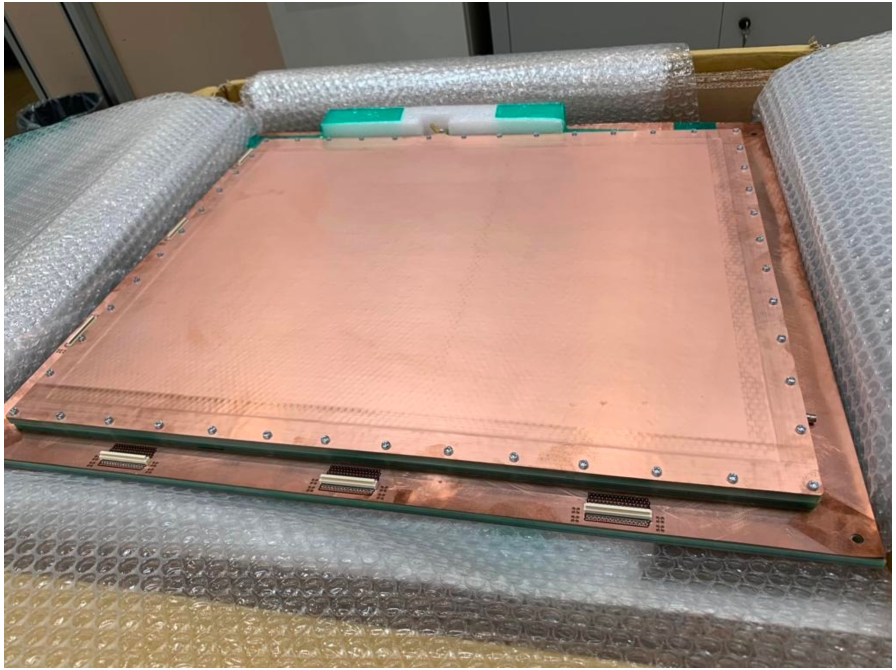
- A first large area 40 x 46 cm ^{2} detector has been delivered to Roma Tor Vergata and is being characterized **in collaboration with the LNF group lead by Gianni Bencivenni**

$1200\ \mu m\ pitch$

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

6 mm gas gap

No object selected. Objects can only be selected in the active layer.



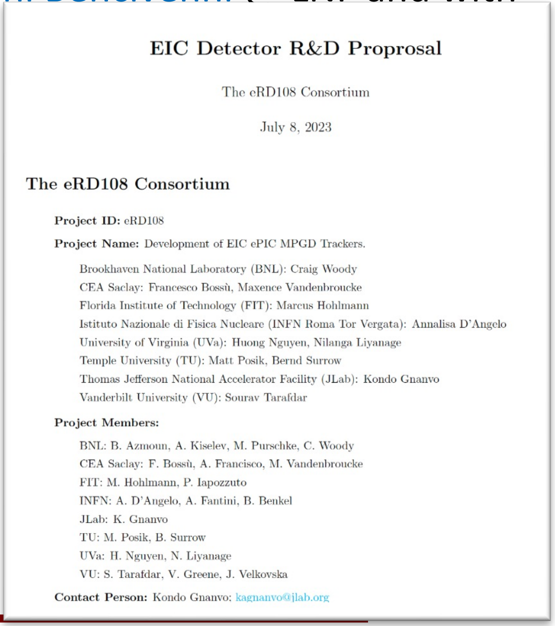
Possible collaboration with EIC MPDG group

INFN Manpower:

- **Roma Tor Vergata:** A. D'Angelo (PO), R. Di Salvo (I ric), A. Fantini (RU), L. Lanza (RTDa), E. Sidoretti (PhD)
- **Genova:** M. Battaglieri (DR), Paolo Musico (INFN) -> Readout electronics (SALSA)
- Roma 1: Evaristo Cisbani (GEM expert) – Catania: Mariagela Bondi'
- The work would be performed in close connection with the group of Gianni Bencivenni @ LNF and with the JLab detector group (Kondo Gnanvo)

Strategy towards the integration in the MPDG Community

- We have explored the space for INFN in the EIC MPGD working group:
  - We joined the eRD108 call for 2024 FY for the R&D on endcap disks
  - We participate to the EIC MPGD weekly meetings
- We have explored the space for the INFN Roma TV group to DRD-1
  - We have submitted the request to join the DRD-1 gaseous detectors WP1 – T2
  - We are in contact with the INFN reference persons



EIC Detector R&D Proprosal

The eRD108 Consortium

July 8, 2023

The eRD108 Consortium

Project ID: eRD108

Project Name: Development of EIC ePIC MPGD Trackers.

Brookhaven National Laboratory (BNL): Craig Woody
CEA Saclay: Francesco Bossù, Maxence Vandenbroucke
Florida Institute of Technology (FIT): Marcus Hohlmann
Istituto Nazionale di Fisica Nucleare (INFN Roma Tor Vergata): Annalisa D'Angelo
University of Virginia (UVa): Huong Nguyen, Nilanga Liyanage
Temple University (TU): Matt Posik, Bernd Surrow
Thomas Jefferson National Accelerator Facility (JLab): Kondo Gnanvo
Vanderbilt University (VU): Sourav Tarafdar

Project Members:

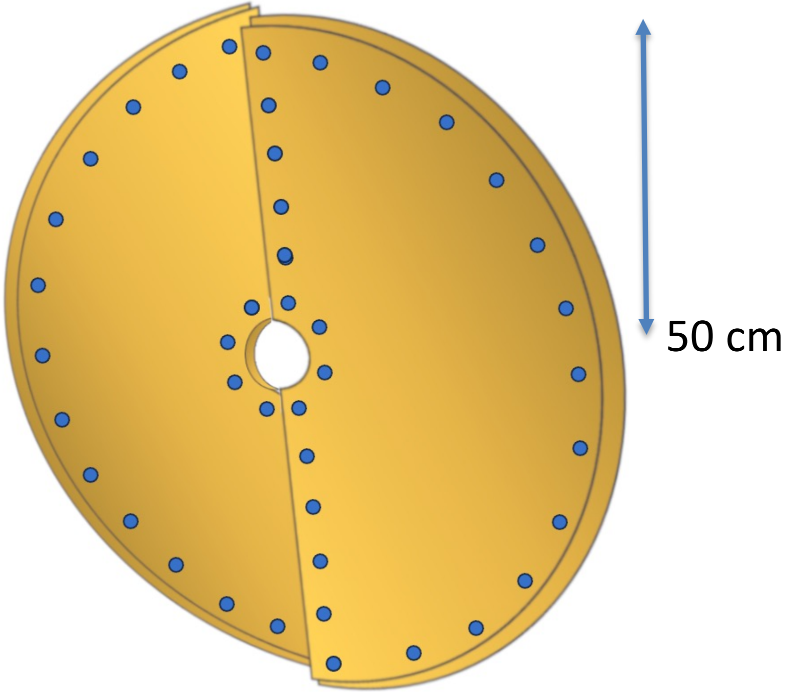
BNL: B. Azmoun, A. Kiselev, M. Purschke, C. Woody
CEA Saclay: F. Bossù, A. Francisco, M. Vandenbroucke
FIT: M. Hohlmann, P. Iapozzuto
INFN: A. D'Angelo, A. Fantini, B. Benkel
JLab: K. Gnanvo
TU: M. Posik, B. Surrow
UVa: H. Nguyen, N. Liyanage
VU: S. Tarafdar, V. Greene, J. Velkovska

Contact Person: Kondo Gnanvo: kagnanvo@jlab.org

Large Area Detector Development for EIC

R&D Studies for EIC disks within eRD108 (in collaboration with TU)

- **readout segmentation**: radius and azimuthal coordinates vs. (X,Y) geometry;
- **reduced number of readout channels:** capacity sharing vs. traditional charge collection;
- **2D-readout optimization:** charge sharing among 2 readout layers vs. two 1D readout layers;
- **performance impact of electronics position layout:** on-detector vs. off-detector using flex cabling.



Conceptual design example for an MPGD endcap disk with stacked overlapping half-disks to maximize acceptance.

2024 Activity

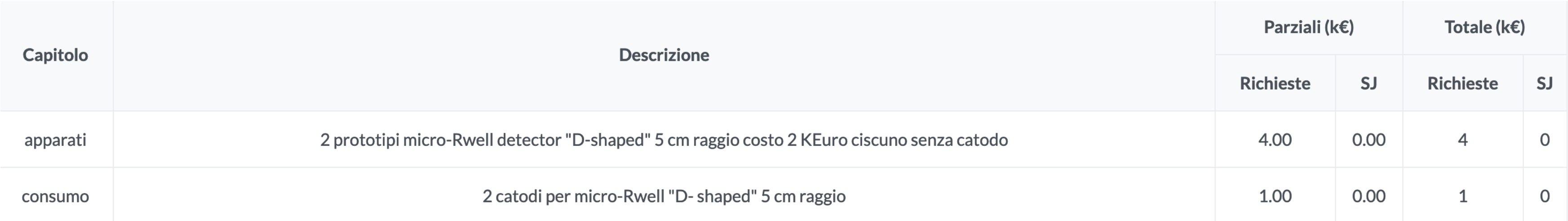
- Identifying the optimal technical solution for the 2D read-out scheme:
  - small-scale D-shaped prototypes development to assess the chosen solution

- Address the position resolution issues due to particles impinging at different angles
  - thin drift gas region vs $\mu\mathrm{TPC}$

- Make the final decision about the INFN responsibility of the endcap construction

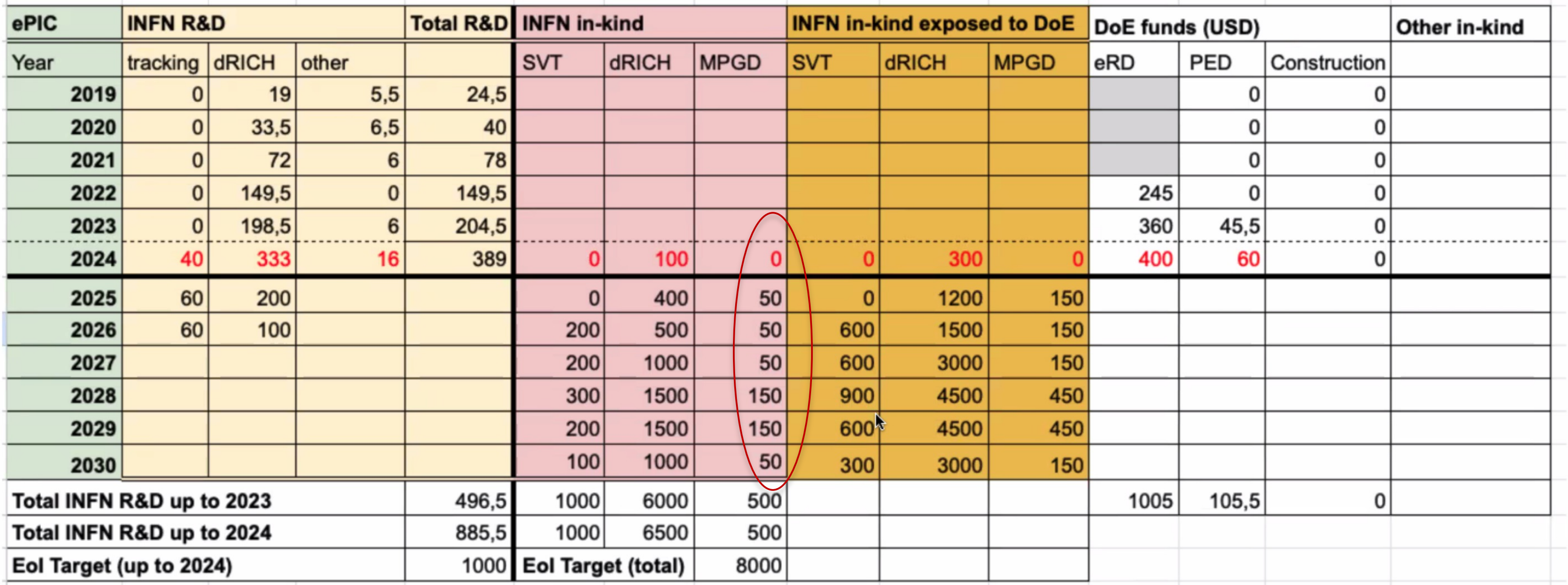
- Contribute to the TDR

2024 Financial Requests



Capitolo	Descrizione	Parziali (k€)		Totale (k€)	
		Richieste	SJ	Richieste	SJ
apparati	2 prototipi micro-Rwell detector "D-shaped" 5 cm raggio costo 2 KEuro ciscuno senza catodo	4.00	0.00	4	0
consumo	2 catodi per micro-Rwell "D- shaped" 5 cm raggio	1.00	0.00	1	0

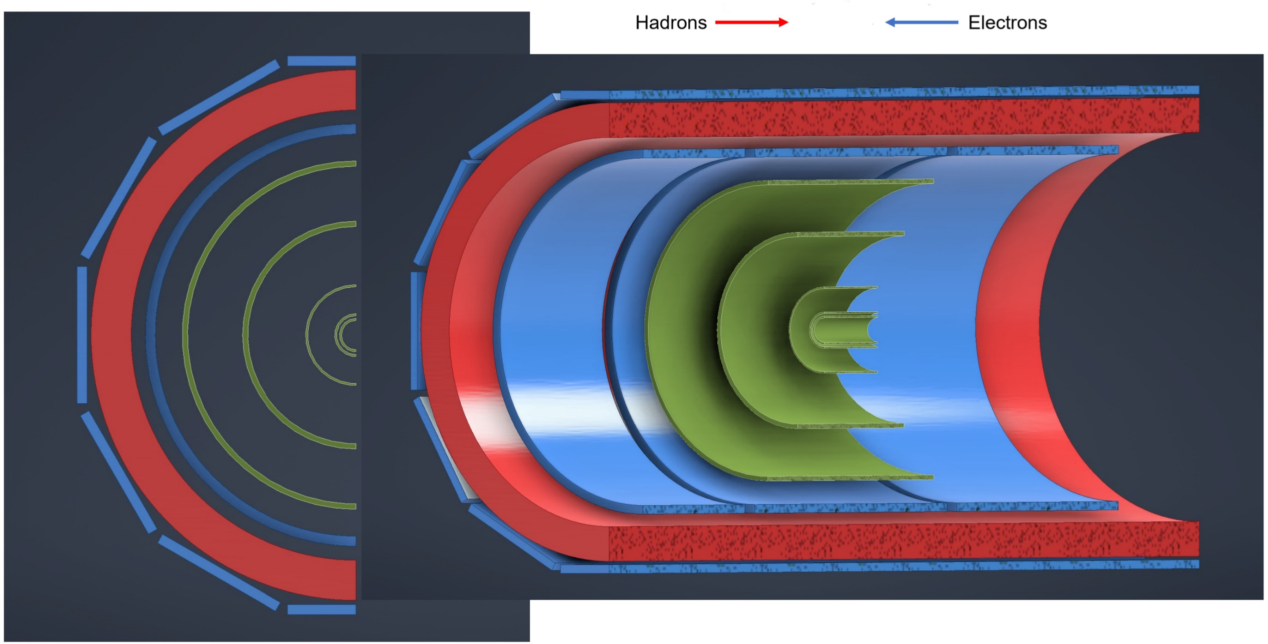
Long Range Implications



ePIC	INFN R&D			Total R&D	INFN in-kind			INFN in-kind exposed to DoE			DoE funds (USD)			Other in-kind
Year	tracking	dRICH	other		SVT	dRICH	MPGD	SVT	dRICH	MPGD	eRD	PED	Construction	
2019	0	19	5,5	24,5								0	0	
2020	0	33,5	6,5	40								0	0	
2021	0	72	6	78								0	0	
2022	0	149,5	0	149,5							245	0	0	
2023	0	198,5	6	204,5							360	45,5	0	
2024	40	333	16	389	0	100	0	0	300	0	400	60	0	
2025	60	200			0	400	50	0	1200	150				
2026	60	100			200	500	50	600	1500	150				
2027					200	1000	50	600	3000	150				
2028					300	1500	150	900	4500	450				
2029					200	1500	150	600	4500	450				
2030					100	1000	50	300	3000	150				
Total INFN R&D up to 2023				496,5	1000	6000	500				1005	105,5	0	
Total INFN R&D up to 2024				885,5	1000	6500	500							
EoI Target (up to 2024)				1000	EoI Target (total)		8000							

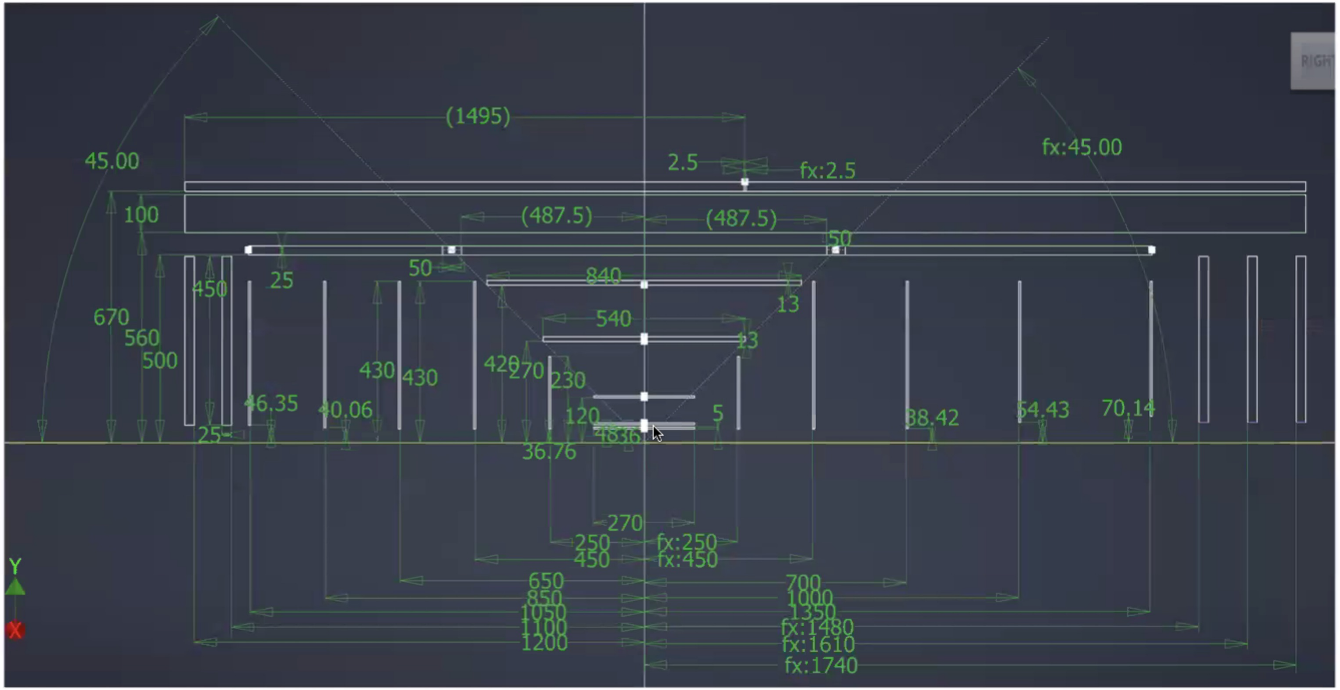
Back-up Slides

The Latest Configuration of ePIC detector tracking



re-inforced role of MPGD

The Latest Configuration of ePIC detector tracking



- Two forward discs
  50 cm radius
- Two backward discs
  50 cm radius
- Cylinder inside the ToF, segmented in three longitudinal sectors
  56 cm radius
- Barrel inside the DIRC: same DIRC segmentation in planar tiles, divided into two longitudinal sectors
  67 cm radius

re-inforced role of MPGD

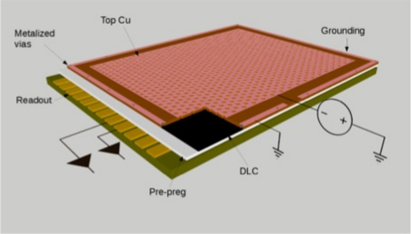
The µ-RWELL Developments: *High-rate capability and improved grounding scheme*

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

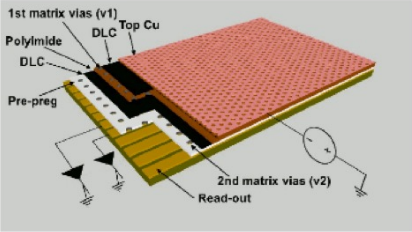
R&D on high-rate layout *(grounding network also in the active area)*



SRL_Single-Resistive-Layer

the DLC grounding is provided all around the active area.

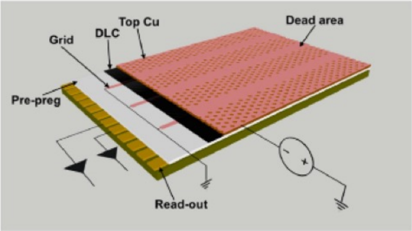
detection efficiency: $\frac{G}{G_0} \sim 1$ up to 35 kHz/cm^2



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

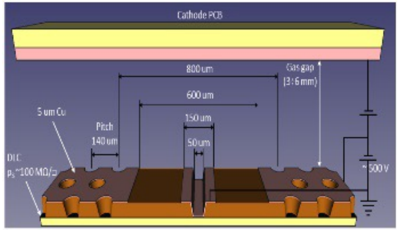
$\frac{G}{G_0} > 0.90$ up to 3MHz/ cm^2



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

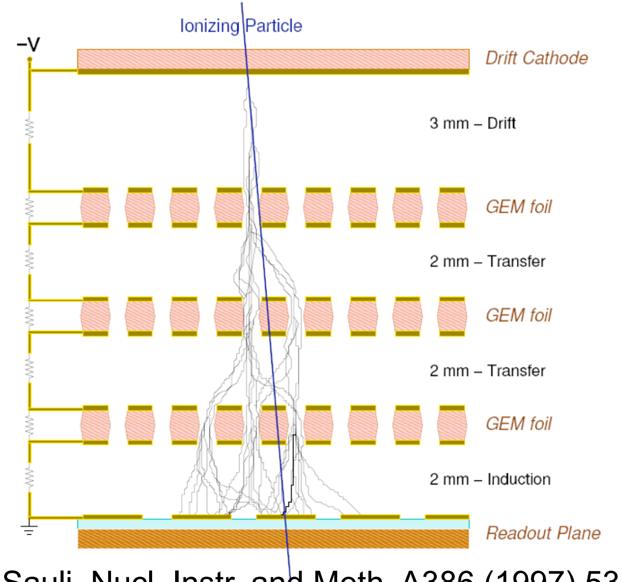
the grounding grid of the DLC is patterned by ***etching a groove in the base material from the top***

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

The CLAS12 DC TRACKING UPGRADE

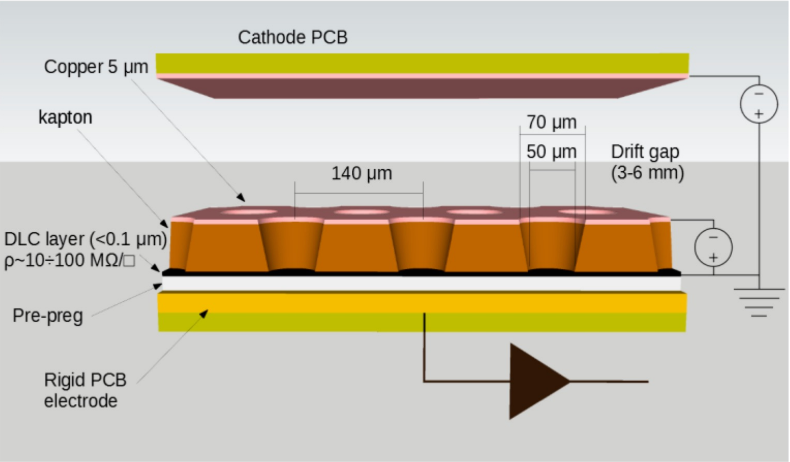
Two MPGD detector technologies have been discussed, triple-GEM and μ-RWELL

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



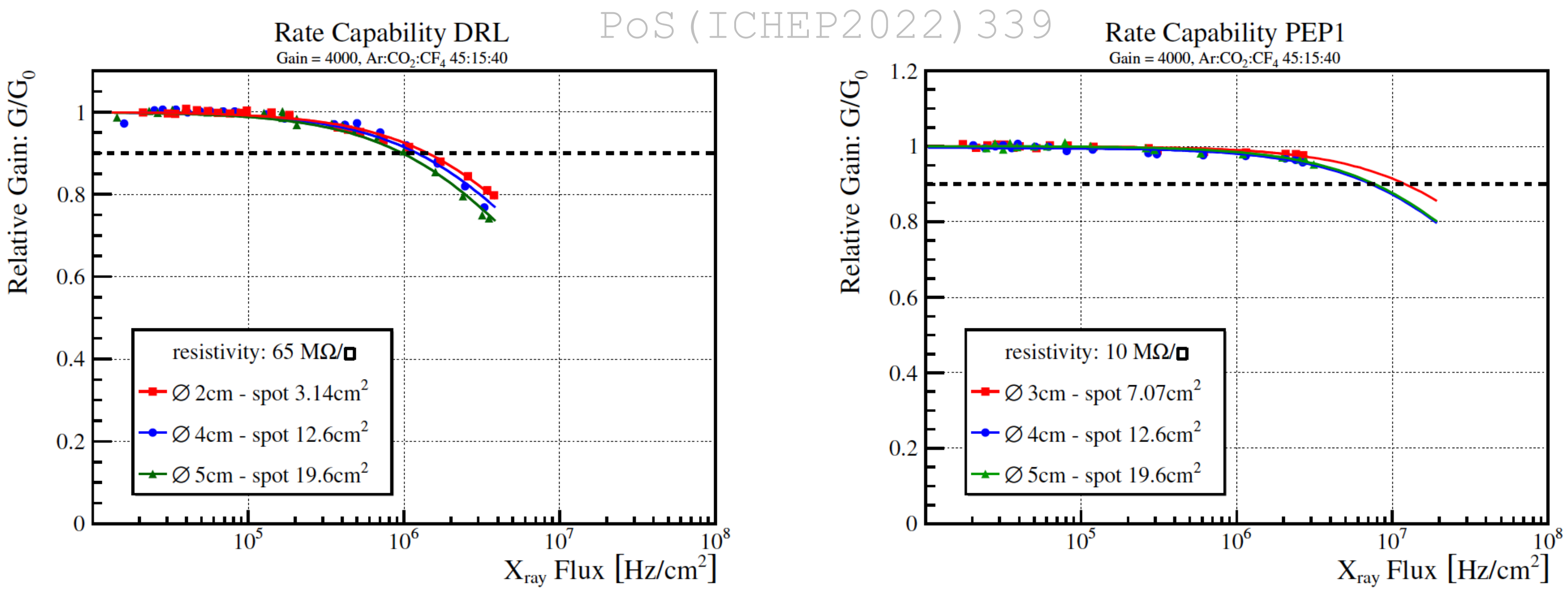
F. Sauli, Nucl. Instr. and Meth. A386 (1997) 531

- 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



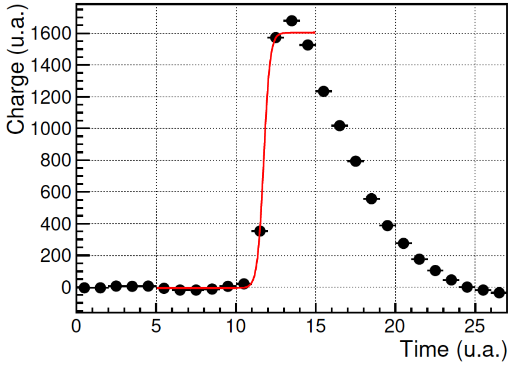
Rate capability measured with 5.9 keV X-rays with Double Layer µ-RWELL (DRL) and with PEP

NB: a photon flux around 1 MHz/cm², which corresponds to a m.i.p. rate of 3 MHz/cm².

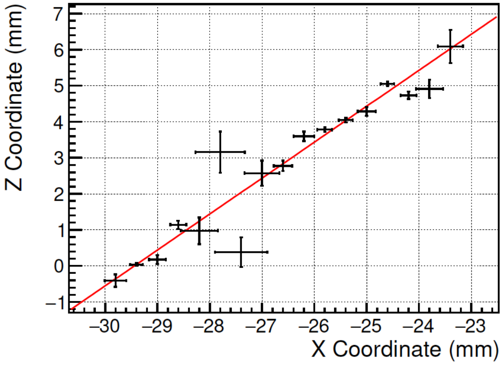
The μ-RWELL Development for Large Area Detectors : Spatial resolution → ***μ*TPC reconstruction**

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

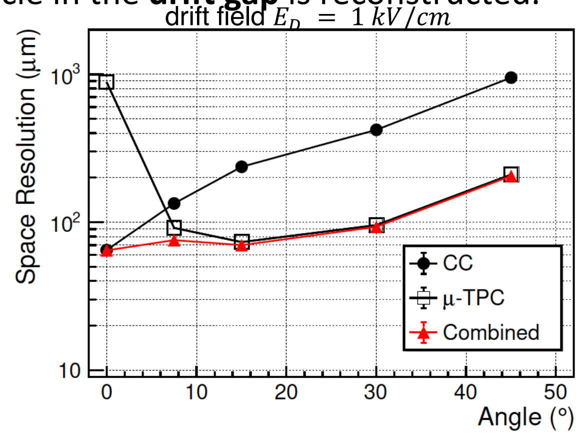
- The electrons created by the ionizing particle drift towards the amplification region
- In the μTPC mode from the **knowledge of the drift time** and the **measurement of the arrival time of electrons**, the **track segment in the gas gap is reconstructed**
- The **fit of the analog signal** gives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