

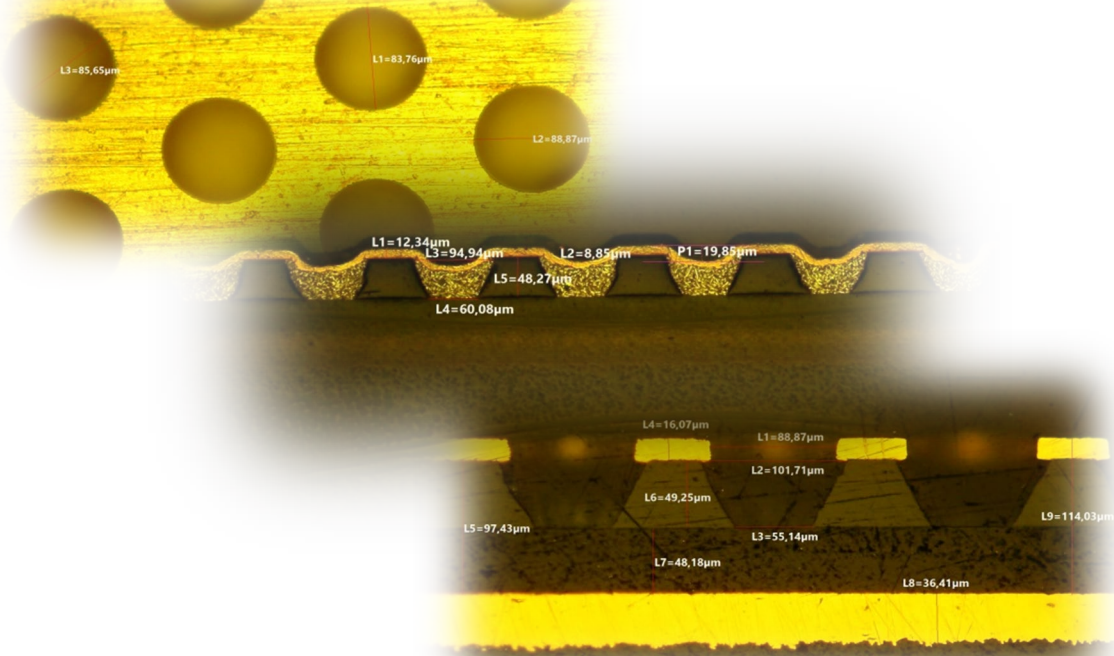
# RD\_FCC: WP7 $\mu$ -RWELLS

## Status & program

M. Poli Lener  
on behalf of

Bo, Fe, LNF, To

programmi 2023-2024



# RD-FCC → $\mu$ -RWELL for tracking and muon system

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  $\mu$ -RWELL technology.

## Detector requirements:

Tiles: 50x50 cm<sup>2</sup> with X-Y readout

Efficiency  $\geq 98\%$

Space resolution  $\leq 100 \mu\text{m}$  (Pre-shower)

$\leq 400 \mu\text{m}$  (Muon)

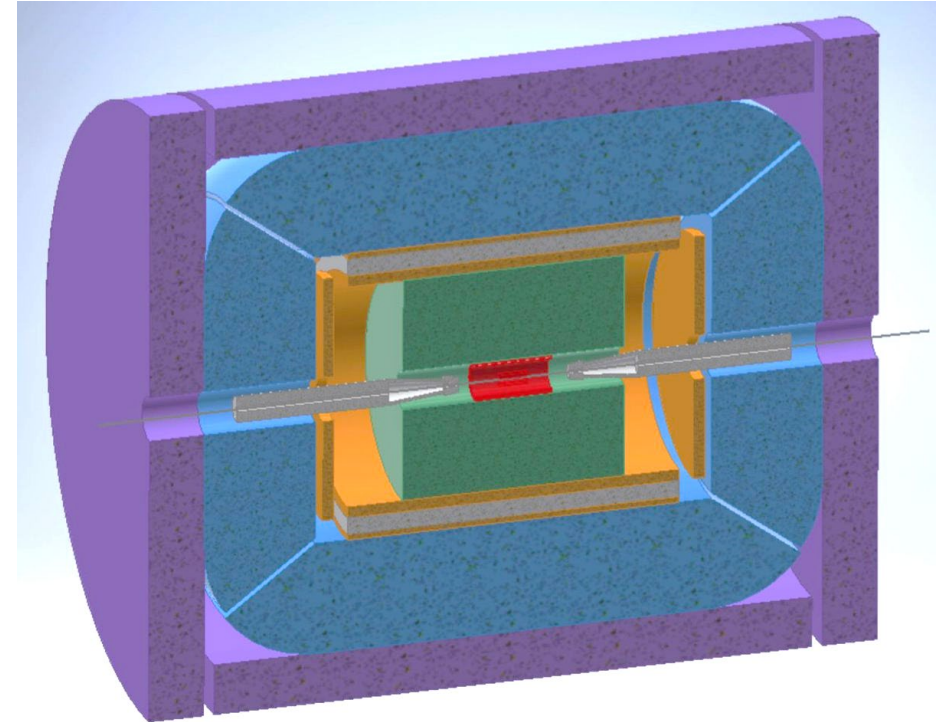
Instrumented Surface/FEE:

130 m<sup>2</sup>, 520 det.,  $3 \times 10^5$  ch. (0.4 mm strip pitch)

1500 m<sup>2</sup>, 1520 det.,  $5 \times 10^6$  ch. (1.2 mm strip pitch)

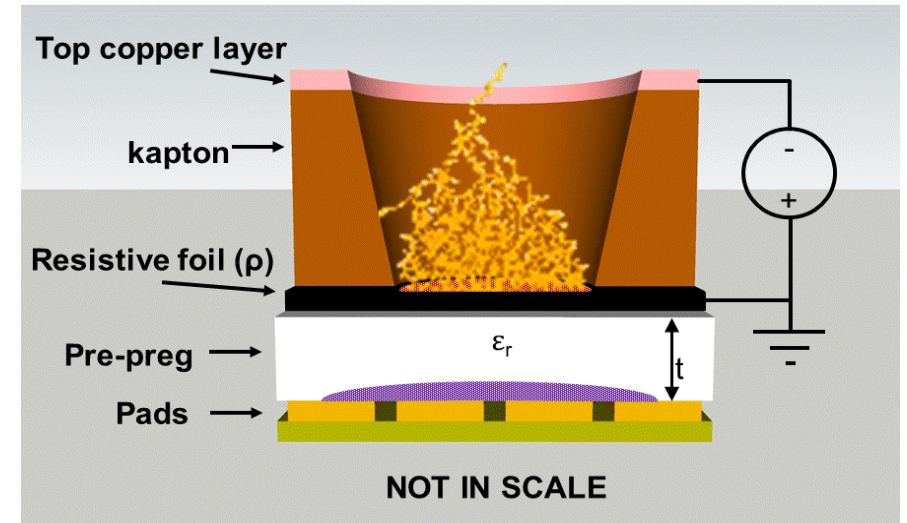
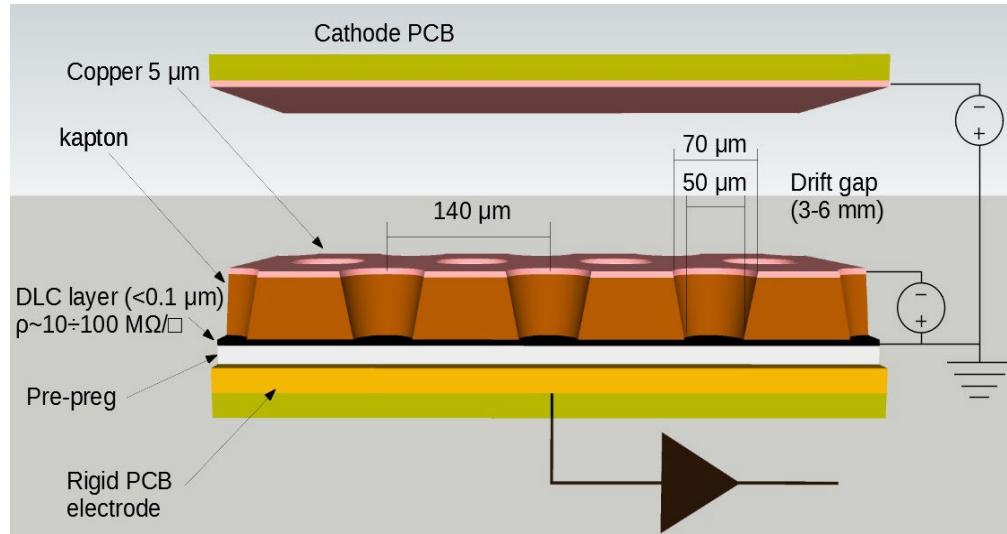
Mass production → Technology Transfer to Industry

FEE Cost reduction → custom made ASIC (TIGER)



# The $\mu$ -RWELL

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



The  $\mu$ -RWELL is a **resistive MPGD** composed of two elements:

- **Cathode**
- **$\mu$ -RWELL\_PCB:**
  - a **WELL** patterned **kapton foil (w/Cu-layer on top)** acting as **amplification stage**
  - a **resistive DLC layer<sup>(\*)</sup>** w/  **$\rho \sim 10 \div 100 \text{ M}\Omega/\square$**
  - a standard **readout PCB** with **pad/strip** segmentation

<sup>(\*)</sup> DLC foils are currently provided by the Japan Company – BeSputter

The “**WELL**” acts as a **multiplication channel** for the ionization produced in the drift gas gap.

The **resistive stage** ensures the **spark amplitude quenching**. **Drawback:** capability to stand high particle fluxes reduced, but **largely recovered** with appropriate **grounding schemes** of the **resistive layer**

# Status and plans 2023

Il programma 2023 può essere riassunto nei seguenti punti:

- ✓ **Gli apparati Preshower & Muon** sono stati implementati in GEANT4
- ✓ **Finalizzazione del setup cosmici con elettronica TIGER/GEMROC + uRWELL (100x100 mm<sup>2</sup>) @ Fe**
- ✓ **Continuazione dello sviluppo del ML per cluster selection, track finding per una migliore separazione del segnale dal fondo al livello di hit/cluster**
- ✓ **Finalizzazione dell'analisi del TB 2022 (NA – H8C, 4-20 ottobre 2022) con prototipi  $\mu$ -RWELL con readout a strip 1D:**
  - 100x100 mm<sup>2</sup> area attiva & strip pitch 0.76 mm
  - 50x400 mm<sup>2</sup> area attiva & strip pitch 0.4÷1.6 mm
- ✓ **Costruzione di due layout  $\mu$ -RWELL con readout a strip 2D (100x100mm<sup>2</sup> area attiva) denominati:**
  - TOP r/out – strip pitch 0.76 mm
  - Charge Sharing r/out – strip pitch 1.2 mm
- ✓ **Test su fascio (NA – H8C, 14-28 giugno 2023) dei layout 2D.** Il test è stato effettuato con elettronica APV25 letta con SRS.

done

- **Realizzazione prototipi 500x500 mm<sup>2</sup>:** layout **TOP r/o** con **strip pitch da 1.2 mm (diminuire la zona inefficiente)**, mentre per la CS r/o non riteniamo necessarie dell'ottimizzazioni sul readout. → Studio della stabilità di operazione 500x500 mm<sup>2</sup> vs 100x100 mm<sup>2</sup>  
**I prototipi** potrebbero essere pronti a **dic-23/gen-24. Seguiranno test @LNF con X-ray & cosmici e successivamente un TB.**

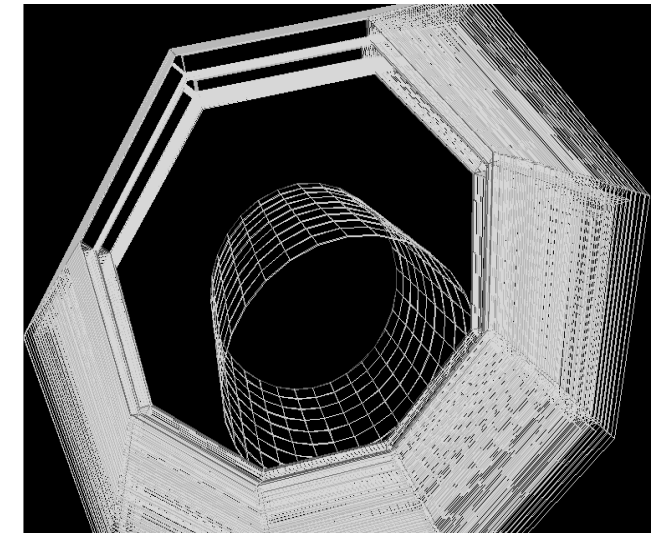
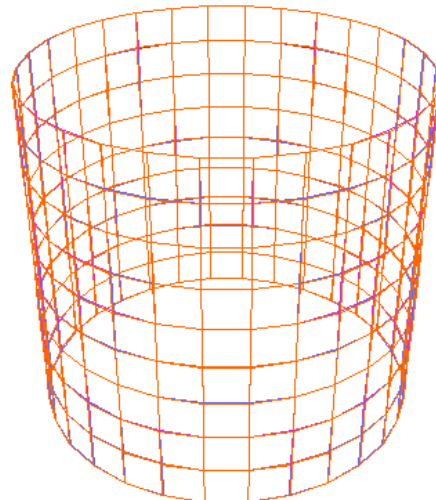
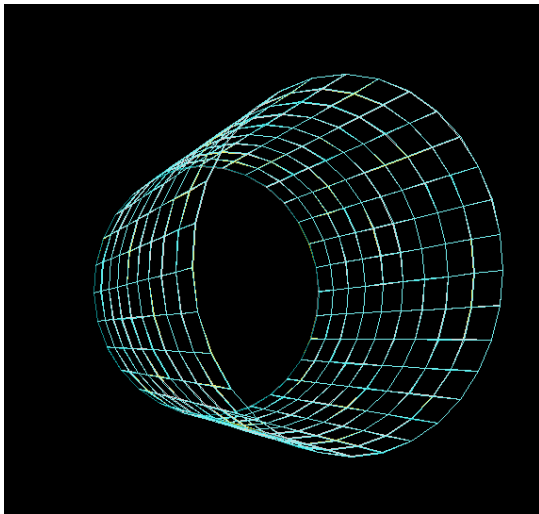
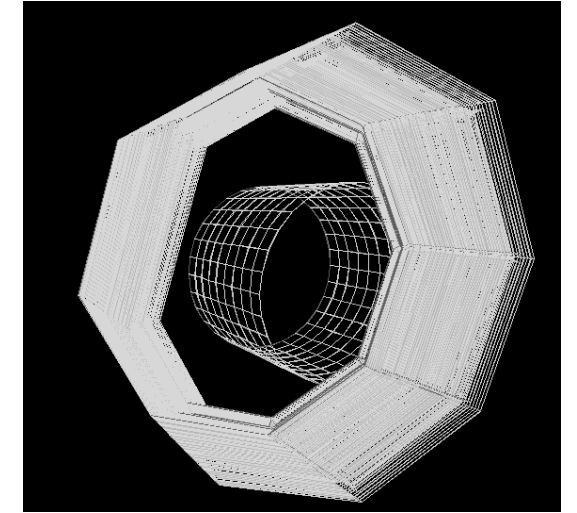
to be done

# Programma WP7 – 2023: detector in GEANT4

The barrel part of the muon system and preshower are fully described in the simulation and can be used in the analysis.

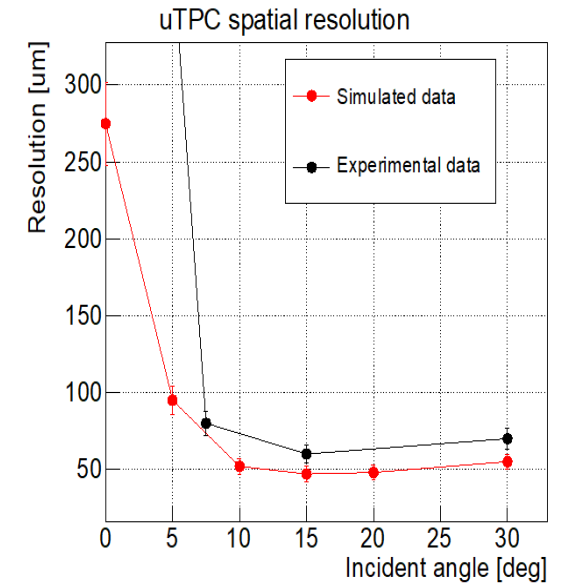
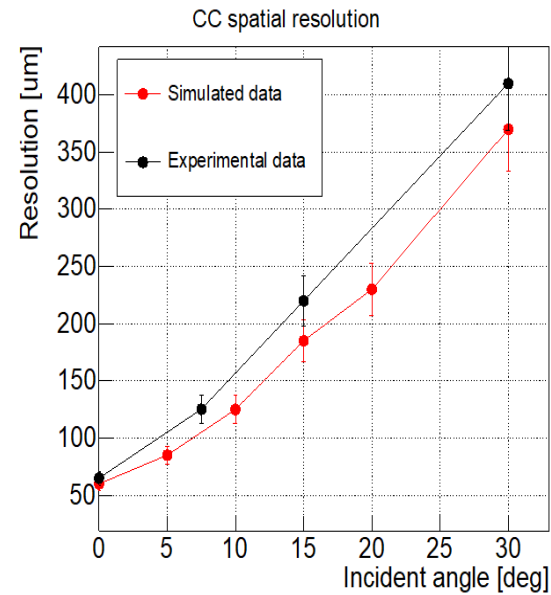
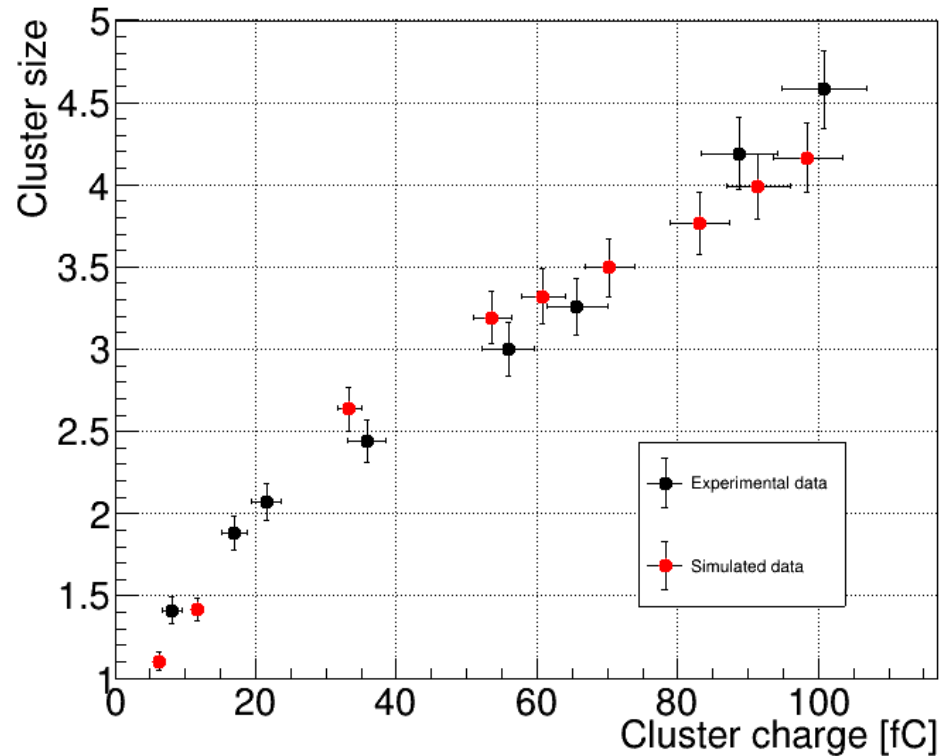
- the preshower is made of an almost cylindrical shape of  $500 * 500$  mm<sup>2</sup> of  $\mu$ RWELL chambers.
- the muon system has an octagon shape.

The  $\mu$ RWELL materials have been successfully implemented into the full simulation with GEANT4 of IDEA



# Simulation tuning with TB data

## comparison data-simulation



Preliminary results presented at ACAT 2022  
Final results presented at CHEP 2023

# Cluster Reconstruction with M. L.

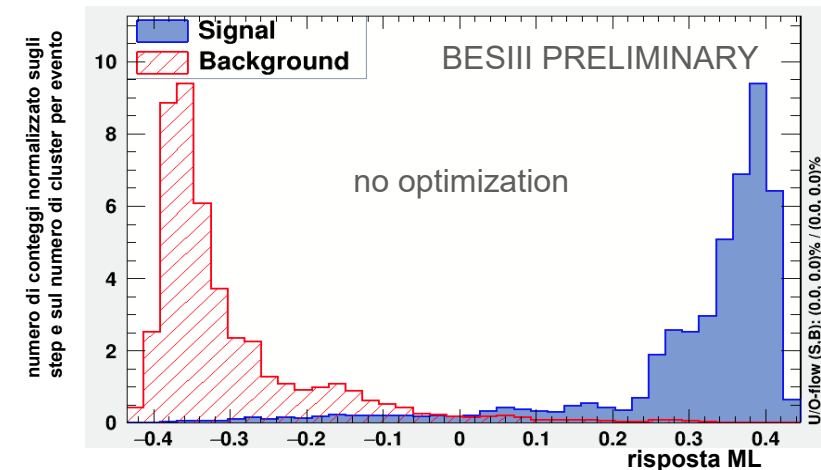
## Preliminary studies

### Aidainnova 4-year program

1. simulation of the  $\mu$ -RWELL resistive layer
2. use of Machine Learning for **cluster selection** and track finding
3. track cleaning and refinement
4. application to IDEA framework



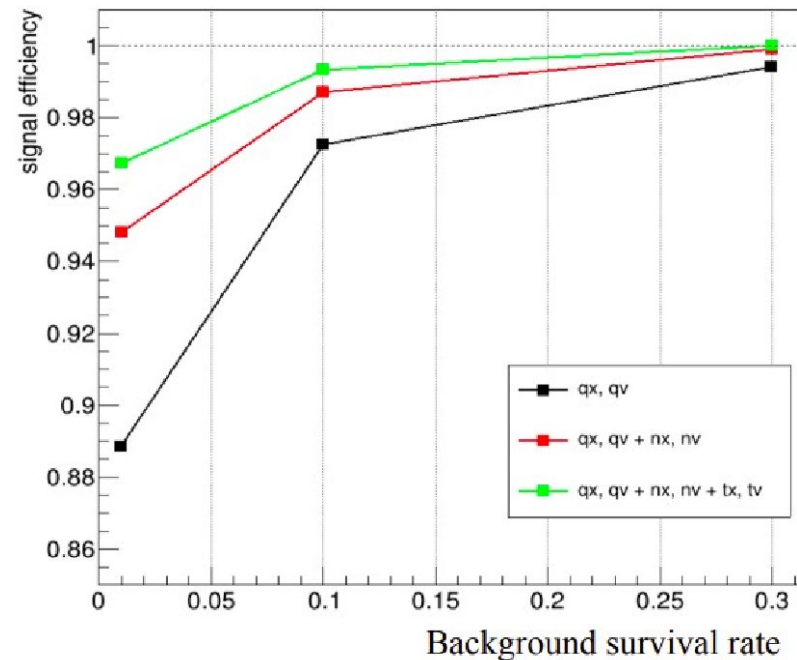
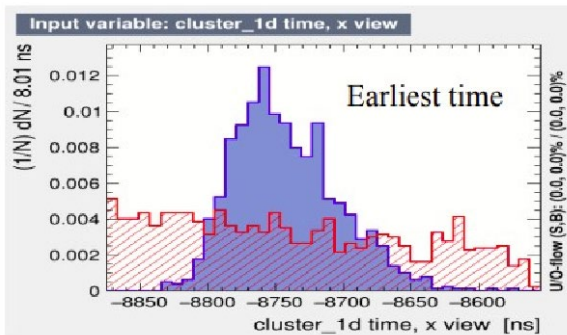
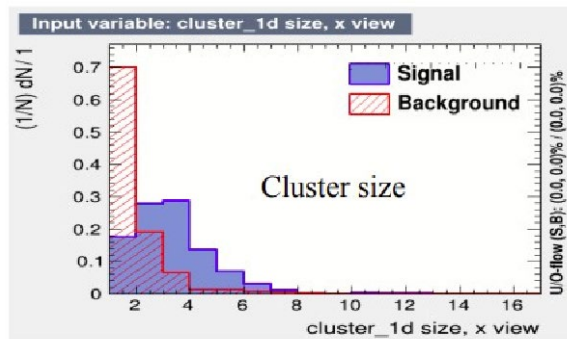
- Work in progress with real data from BESIII CGEM-IT



courtesy of L. Lavezzi

# Cluster Reconstruction with M. L.

- Machine Learning to separate signal from noise at hit/cluster level (classification)
- Use TMVA, Boosted Decision Tree  
cluster 1d Charge  $x$ ,  $v$  + cluster 1d size  $x$ ,  $y$  + fastest hit in cluster 1d  $x$ ,  $y$



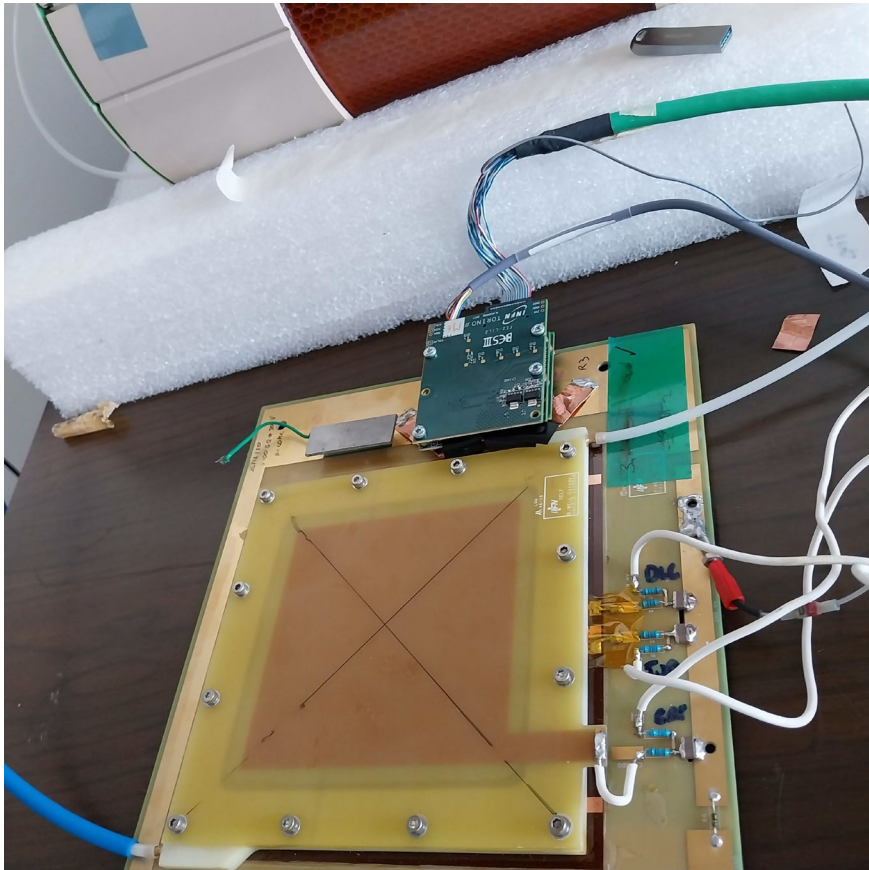
Più sono stringenti questi tagli e maggiore è la frazione di rumore che viene tagliata. Se i tagli sono troppo stringenti allora viene tagliato anche del segnale.

Se invece si usano dei tagli più laschi si ha il 100% del segnale ma anche una buona percentuale di rumore

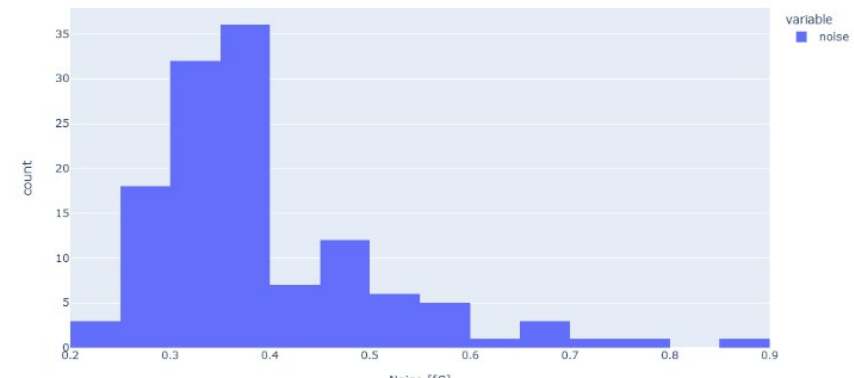


# Programma WP7 – 2023: uRWELL + TIGER/GEMROC fee

- First working setup of TIGER/GEMROC readout installed and tested with a 10x10 cm<sup>2</sup> microRWELL prototype by INFN TO and FE
- Noise level very low ( $\sim 1$  fC)
- Cosmic setup ready
- Delay in the delivery of the Frontend Boards (still using BESIII spares)



Distribution of thresholds of an entire chip (64 channels)

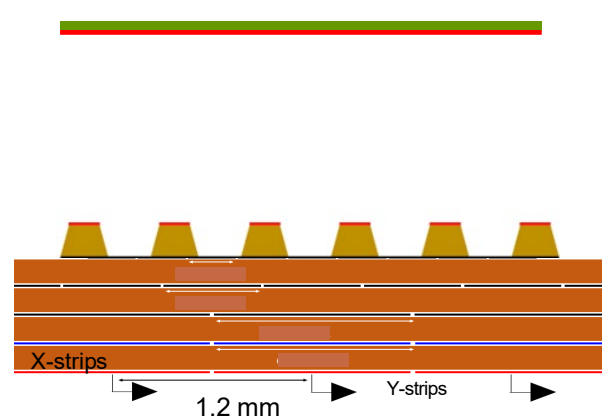


# Programma WP7 – 2023: layout 2D

Studio della **risoluzione spaziale ed efficienza di rivelatori 10x10 cm<sup>2</sup> con lettura 2D X-Y** (resistività del DLC, strip pitch ottimizzati con TB-2021&2022) con un TB @H8 SPS (Giugno 2023)

## I 2 layout per il rivelatore 2D

**u-RWELL bi-dimensionale (Charge Sharing r/o)**



Catodo

Drift gap

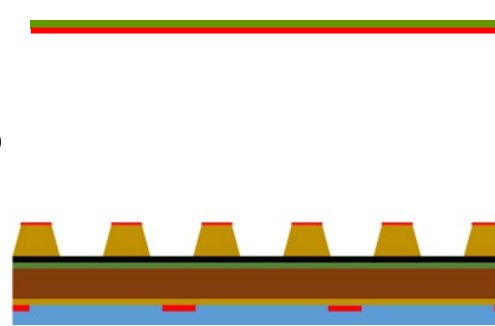
DLC

X-strips

Y-strips

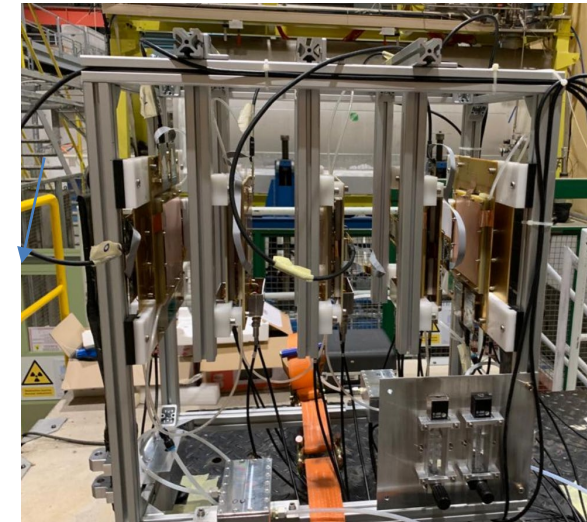
1.2 mm

**u-RWELL bi-dimensionale (TOP r/o)**

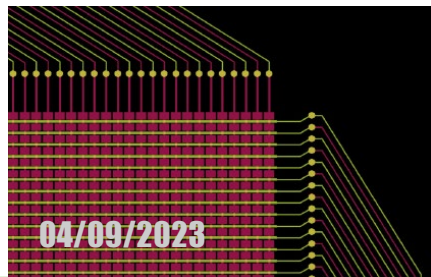


X-strips

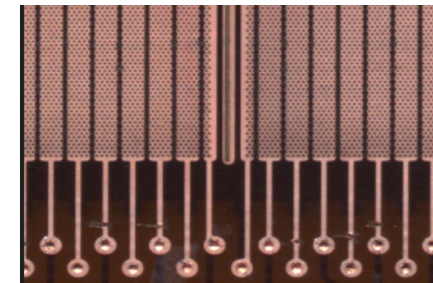
Y-strips



CS Readout board



X coordinate on the TOP of the amplification stage



# TB2023 (APV25) : 2D layouts

preliminary

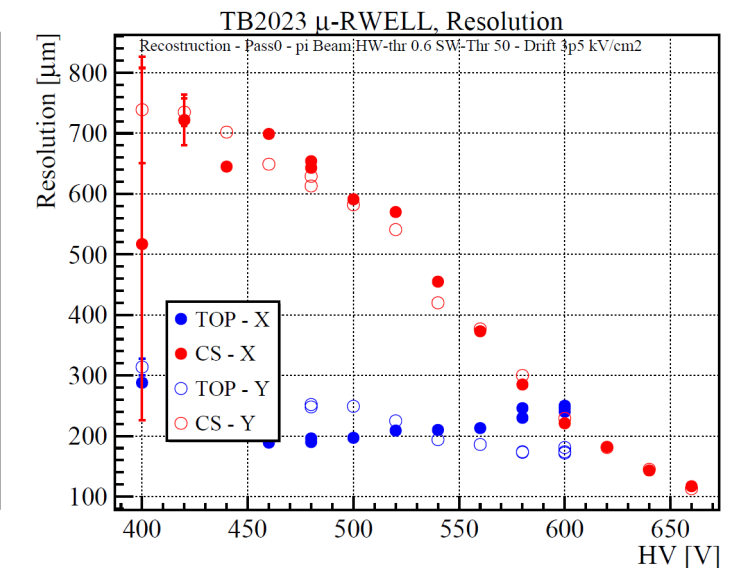
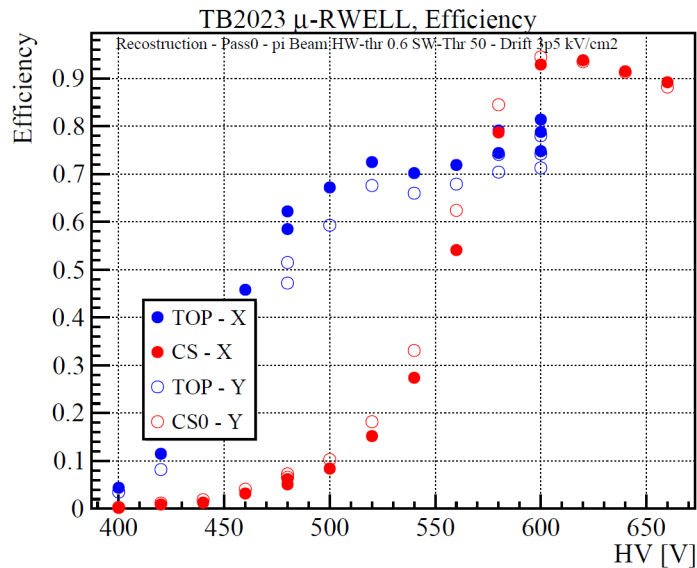
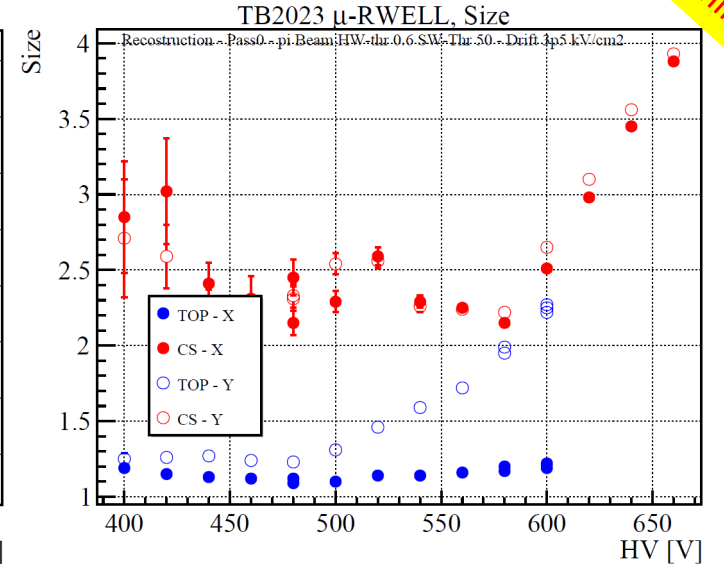
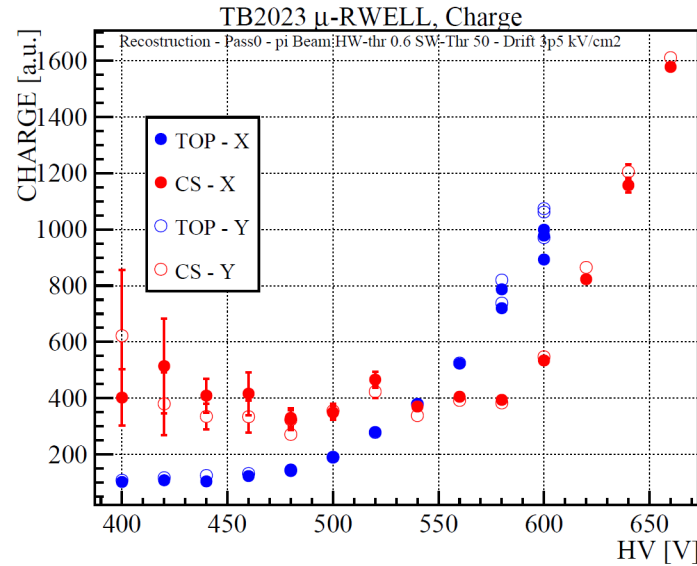
I **risultati** preliminari ottenuti con i due layout 2D r/out sono **incoraggianti** e le viste X-Y hanno mostrato **un'uguale induzione del segnale**.

## TOP r/o:

- **NON DIVIDE** la **carica totale** lungo le 2 viste;
- La cluster size **NON** varia lungo la vista X (TOP), mentre aumenta sulla vista Y (spread del DLC);
- La **risoluzione spaziale è digitale** lungo X (Strip size  $\sim 1.5$ ), mentre migliora lungo Y (spread del DLC)
- Raggiunge il plateau d'efficienza ad **HV più bassi**;

## La CS r/o:

- **DIVIDE** la **carica totale** lungo le 2 viste;
- La cluster size aumenta fino a 4 strip (meccanismo del Charge Sharing funziona)
- La **risoluzione spaziale** migliora all'aumentare del HV (meccanismo del Charge sharing funziona  $\rightarrow$  Strip size  $> 2.5$ ), **raggiungendo i 150  $\mu\text{m}$**
- Raggiunge il plateau d'efficienza ad **HV più alti**;
- Il livello di efficienza  $> 95\%$ ;



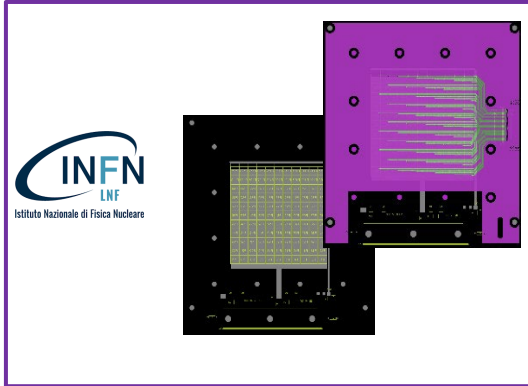
# Programma WP7 – 2024

Il programma 2024 prevede i seguenti punti:

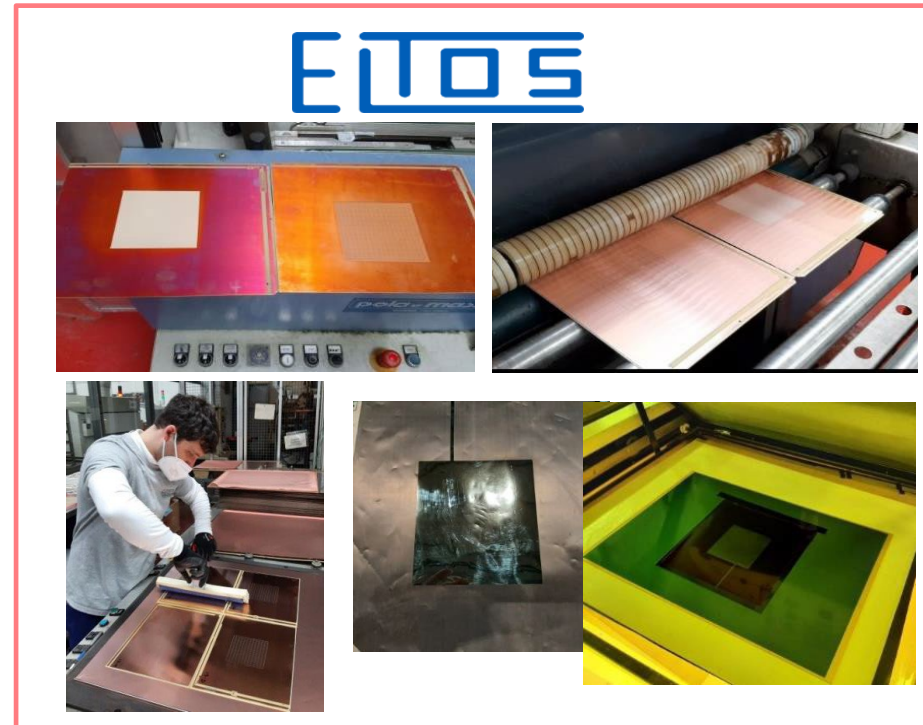
1. Studio/ottimizzazione guadagno con differenti geometrie dello stadio di amplificazione (pitch well, diametro esterno/interno well) con prototipi 100x100 mm<sup>2</sup>. Questo studio è stato fatto con i rivelatori a GEM ma mai con le uRWELL → well pitch da 140 μm a 90 μm con un aumento del guadagno di circa un fattore 2
2. Realizzazione di due prototipi da 500x500 mm<sup>2</sup>: la scelta del layout 2D si baserà sui risultati ottenuti nei precedenti test. **Seguiranno** test @LNF con X-ray & cosmici (con sistema tracciante) e successivamente un TB (sj).
3. 1 settimana di TB (SpS- H4 – RD51/DRD1) uRWELL+TIGER/GEMROC (questo TB è differente rispetto a quelli con i prototipi 2D)
4. Continuazione dei test dei processi di produzione μRWELL presso la ELTOS /CERN e macchina DLC al CERN

# WP7.3.2: Technology Transfer (flow chart)

## LAYOUT design

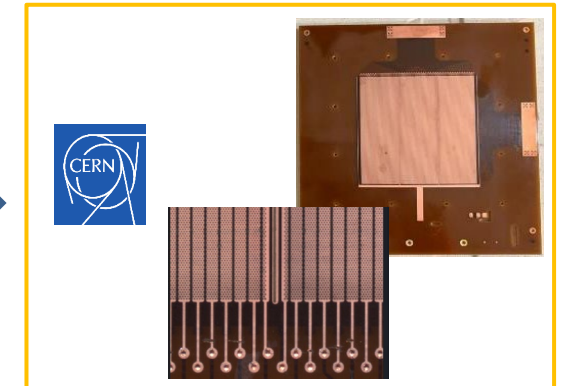


## PCB production



Feedback from tests

## Final detector manufacturing



## DCL foil production (\*)



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

# WP7.3.2: Technology Transfer 2023



Step 0 – Detector PCB design @ LNF

Step 1 – CERN\_INF N DLC sputtering machine @ CERN (+INFN)

- delivered at the end of Oct. 2022
- INFN crew tbd & trained



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

- double 106-prepreg → 2x50μm thick
- PCB planarizing w/ screen printed epoxy → single 106-prepreg



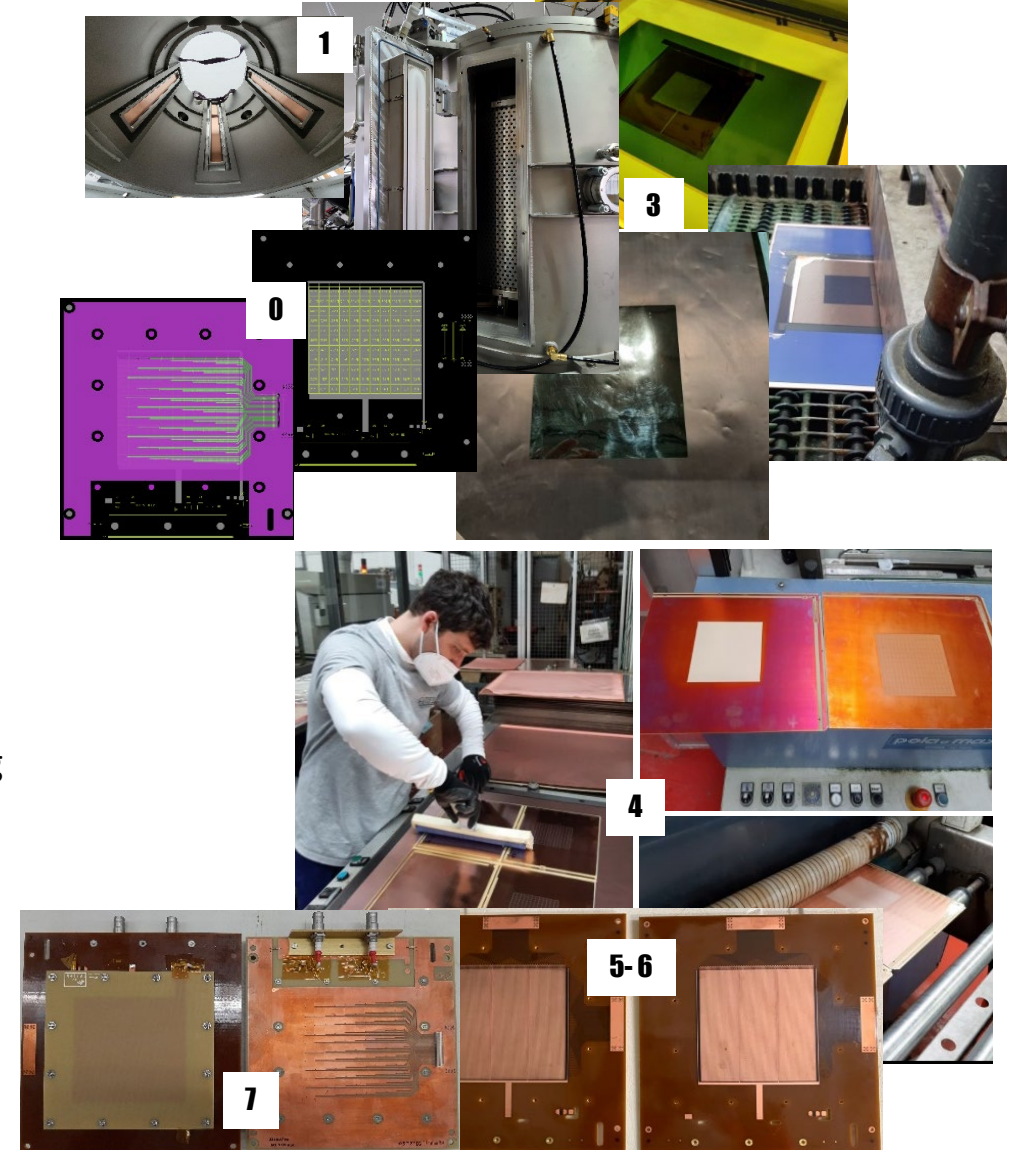
Step 5 – Top copper patterning by CERN (in future by ELTOS)

- Holes image and HV connections by Cu etching

Step 6 – Amplification stage patterning by CERN

- PI etching → plating → ampl-holes

Step 7 – Electrical cleaning and detector closing @ CERN



# WP7.3.2: update on the CERN-INFN DLC machine

31<sup>st</sup> Oct. 2022 – Delivered

31<sup>st</sup> Oct. - 4<sup>th</sup> Nov. 2022 – Commissioning & test training

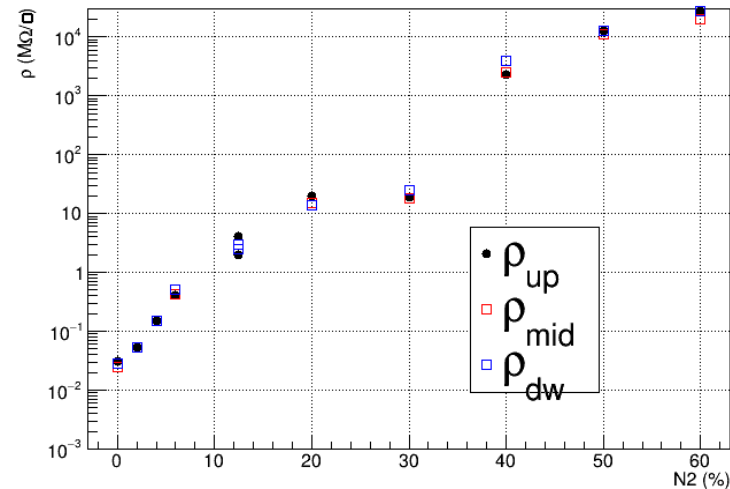
21<sup>st</sup> - 23<sup>rd</sup> Nov. 2022 – First DLC sputtering test

- Ar + N<sub>2</sub> doping

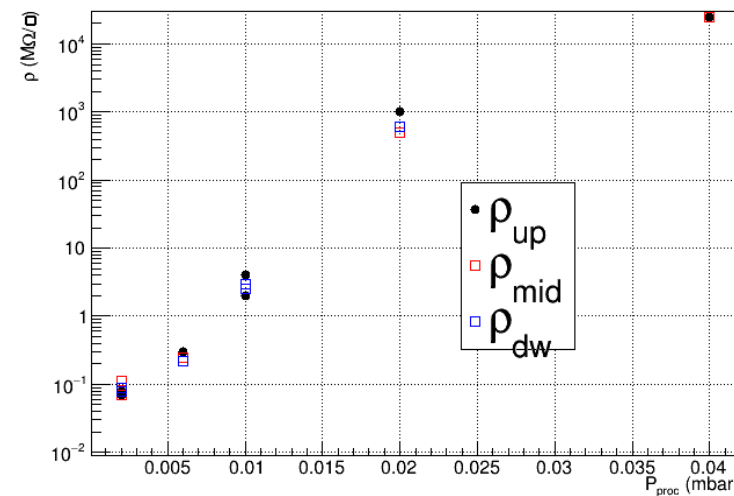
19<sup>th</sup> - 28<sup>th</sup> Jun. 2023 – Second DLC sputtering test (N<sub>2</sub> doping percentage and pressure process scans)

**Uniformity around 30% along the vertical axis**

N<sub>2</sub> scan at  $p_{\text{proc}} = 1.E-2$  mbar and  $\Delta t_{\text{proc}} = 15$  min



$P_{\text{proc}}$  scan at 12.5% N<sub>2</sub> and  $\Delta t_{\text{proc}} = 15$  min

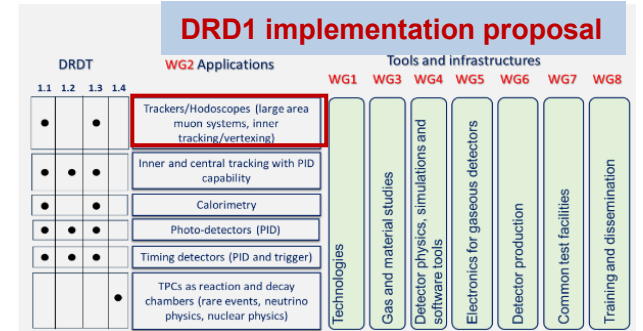


The **resistivity** of the sample is being **monitored** to evaluate the **stability in time**.

The machine can **sputter or co-sputter different materials (due to the presence of five targets)**, creating a layer-by-layer coating

# Detectors in ECFA/DRD1

Further steps in the framework of the proposed **Detector Research and Development Collaboration on gaseous detector (DRD1)**



<https://indico.desy.de/event/34916/contributions/142202/>

## μ-RWELL:

Specific involvement in Work Package 1, related to large area muon systems, on:

**Task 2:** New resistive MPGD structures

**Task 6:** Manufacturing

	Task	Performance goal	WGs	DRDT	Comments	Deri. Next 3 y
T2	New resistive MPGD structures	<ul style="list-style-type: none"> <li>- Stable up to gains of <math>\mathcal{O}(10^6)</math></li> <li>- High gain in a single multiplication stage</li> <li>- High rate capability (1 MHz/cm<sup>2</sup> and beyond)</li> <li>- High tracking performance</li> </ul>	WG1, WG3 (3.1C, 3.2D), WG4, WG6, WG7 (7.1-5)	1.2	- High-rate DLC layout for micro-RWELL	<ul style="list-style-type: none"> <li>- Design, construction and test of prototypes with new resistive materials</li> <li>- Modelling and Simulation (signal induction)</li> <li>- MPGD prototypes based on resistive elements for tracking</li> </ul>
T6	Manufacturing	<ul style="list-style-type: none"> <li>- Construction of large-area detectors at low cost</li> <li>- Modular design</li> <li>- Technology transfer strategy and training center for production</li> </ul>	WG3 (3.2E), WG6, WG8	1.3	- Optimization of the manufacturing procedure to minimize time-consuming or costly steps	<ul style="list-style-type: none"> <li>- Design and manufacturing of large-area detector</li> <li>- Large-area DLC production</li> <li>- CERN: MPGD based manufacturing capabilities and large-area modules (design and prototyping). Note: MPT Workshop</li> </ul>

[https://cernbox.cern.ch/pdf-viewer/public/BKQsu6oiuhPWDaa/RD\\_EXTENDED-PROPOSAL\\_\\_DRD1.pdf?contextRouteName=files-public-link&contextRouteParams.driveAliasAndItem=public%2FBKQsu6oiuhPWDaa&items-per-page=100](https://cernbox.cern.ch/pdf-viewer/public/BKQsu6oiuhPWDaa/RD_EXTENDED-PROPOSAL__DRD1.pdf?contextRouteName=files-public-link&contextRouteParams.driveAliasAndItem=public%2FBKQsu6oiuhPWDaa&items-per-page=100)



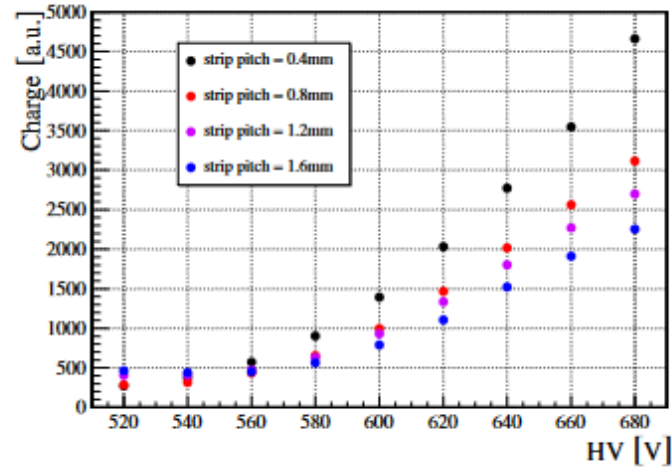
# RICHIESTE 2024

<b>LNF:</b>	
1.1 – Produzione di N.2 50x50 cm2 2D readout (SJ) →DRD1	15 k€ (Consumo)
1.2 – Produzione di N.4 10x10 cm2 pitch hole studies → DRD1	6 k€ (Consumo)
1.3 – Contatti con ELTOS/CERN per costruzione prototipi	5 k€ (Missioni)
1.4 – Bombe pre-miscelate	2 k€ (Altri consumi)
1.5 – Meccanica Cosmici con tracking e movimentazione per le 50x50	5 k€ (Consumo)
1.6 – Test Beam 2024 (SJ) - 2 persone x 2 settimane	5 k€ (Missioni)
<b>Fe:</b>	
2.1 - Bombe pre-miscelate	1.5 k€ (Altri consumi)
2.2 - Upgrade del setup cosmici per il TB	1 k€ (Consumi)
<b>To:</b>	
3.3 - Heatsink external production	3 k€ (SJ to quotation -Consumi)
<b>Fe/To:</b>	
4.1 Missione per TB	3 k€ (FE) + 3 k€ (TO) (SJ to approval of the TB)
<b>Bo:</b>	
5.1 Bombe pre-miscelate	2 k€ (Altri consumi)
5.2 Test Beam 2024 (SJ) ) - 3 persone x 2 settimane	7.5 k€ (Missioni)

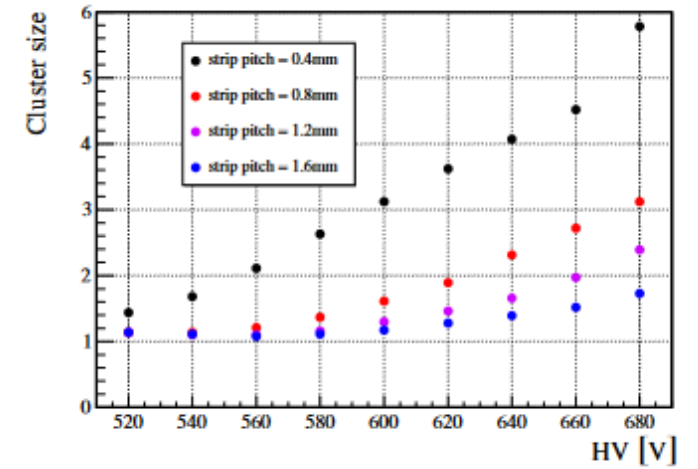
**spare slides**

# TB 2022 results: pitch study

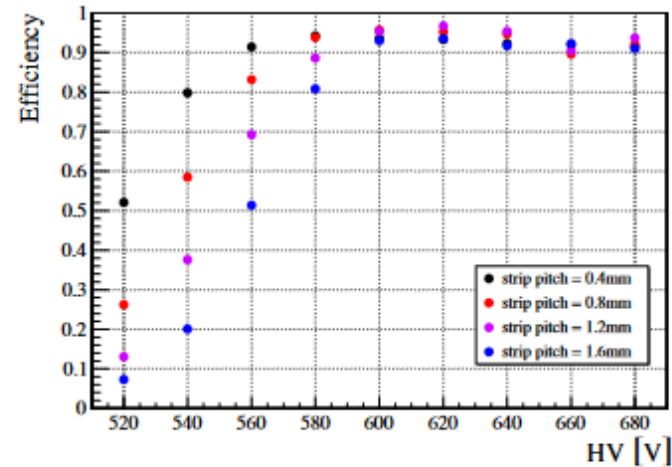
Active area= 400x50 mm<sup>2</sup>  
Pre-preg thickness= 50  $\mu$ m  
Strip width = 0.15 mm  
Strip pitch= 0.4-1.6 mm



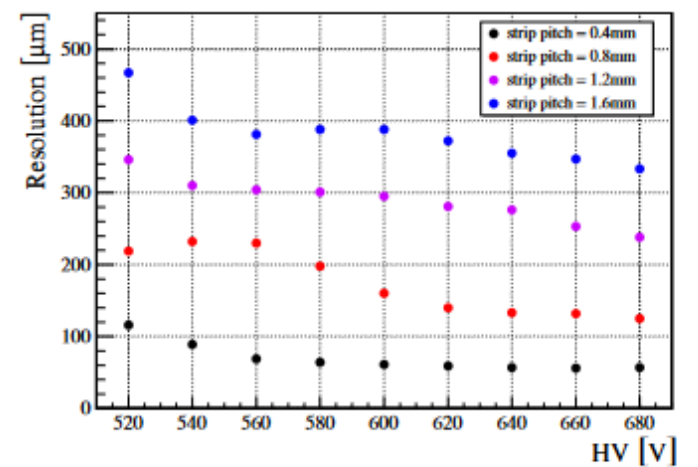
(a) Cluster charge for different HV.



(b) Strip cluster size for different HV.



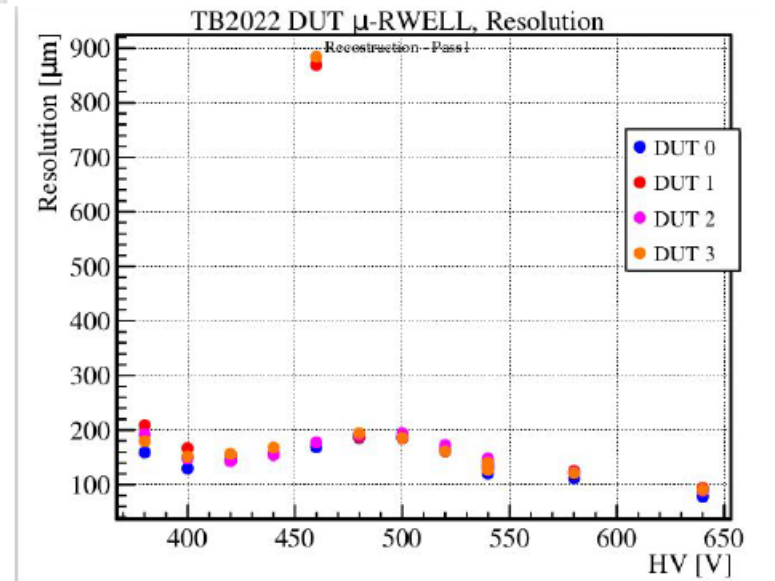
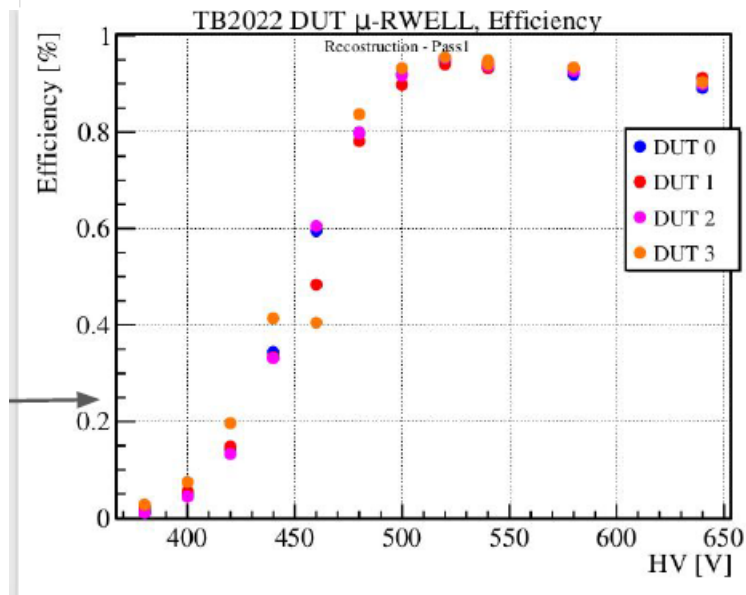
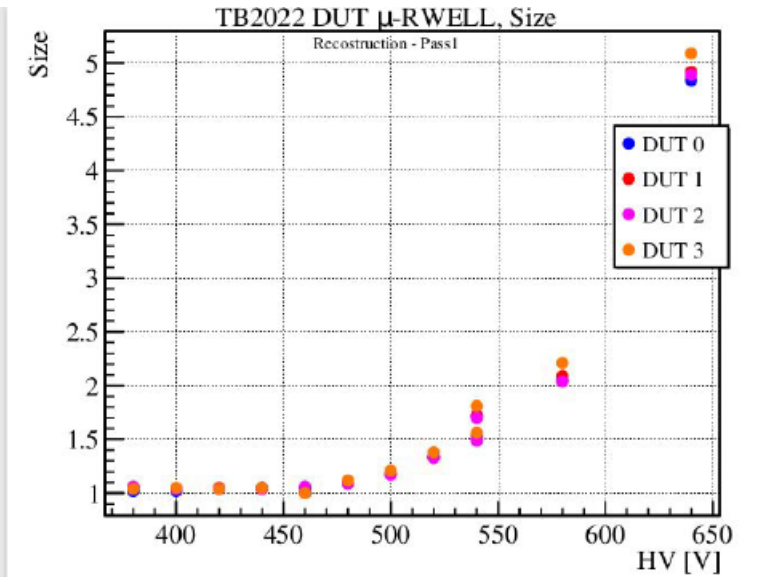
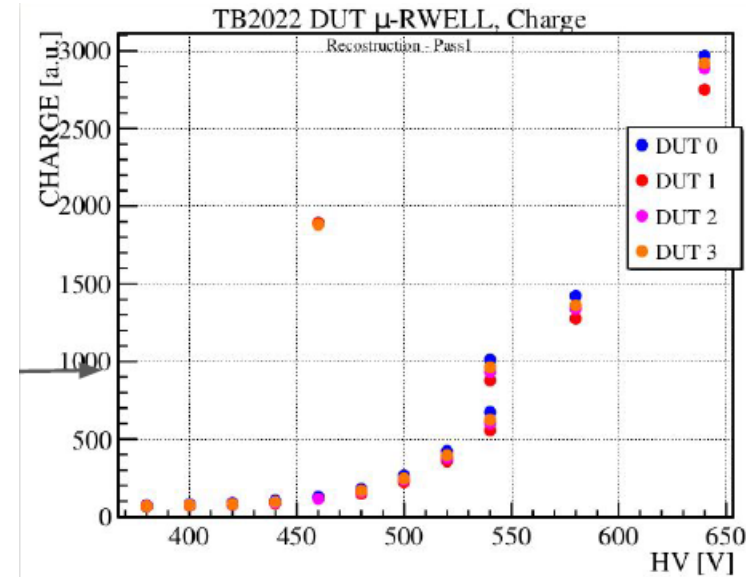
(c) Tracking efficiency for different HV.



(d) Residuals width for different HV.

# TB 2022 results: layout 1D

Active area= 100x100 mm<sup>2</sup>  
Pre-preg thickness= 20  $\mu\text{m}$   
Strip width = 0.3 mm  
Strip pitch= 0.76 mm

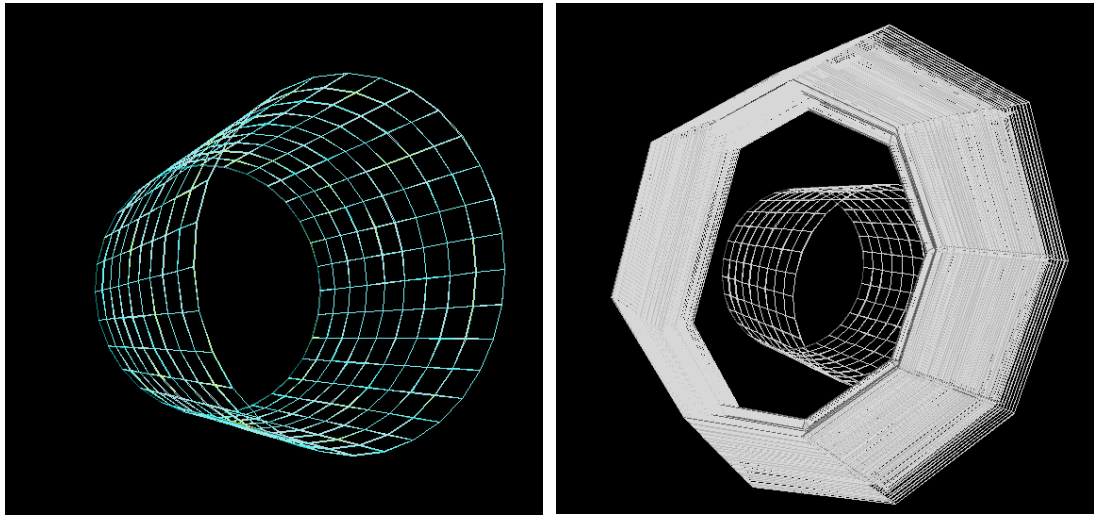


# Programma WP7 – 2023: detector in GEANT4 & ML

The barrel part of the muon system and preshower are fully described in the simulation and can be used in the analysis.

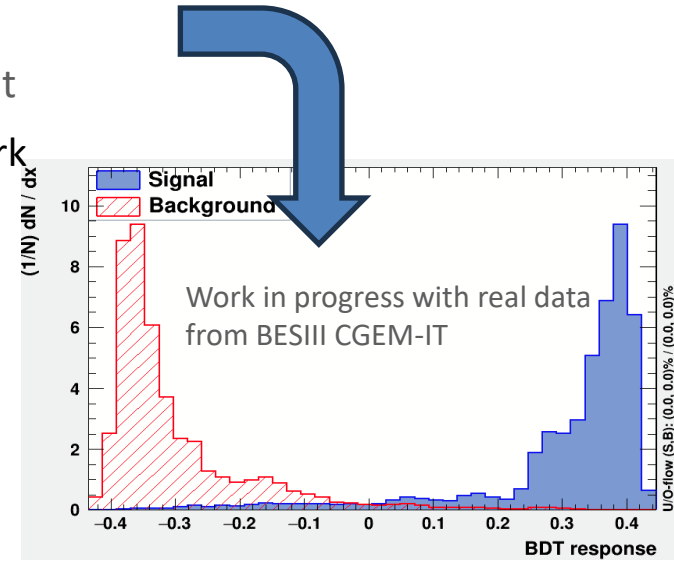
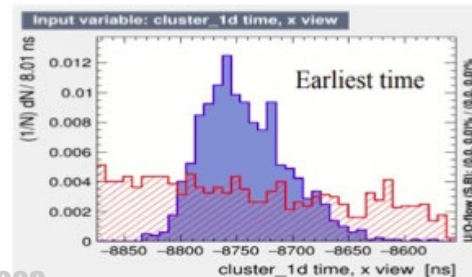
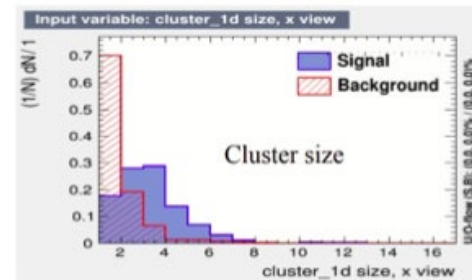
- the preshower is made of an almost cylindrical shape of  $50 * 50 \text{ cm}^2$  of  $\mu$ RWELL chambers.
- the muon system has an octagon shape.

The  $\mu$ RWELL materials have been successfully implemented into the full simulation with GEANT4 of IDEA



Cluster reconstruction with ML

- simulation of the  $\mu$ -RWELL resistive layer
- use of Machine Learning for **cluster selection** and track finding
- track cleaning and refinement
- application to IDEA framework



Machine Learning to separate signal from noise at hit/cluster level (classification)

Use TMVA, Boosted Decision Tree cluster 1d Charge  $x$ ,  $v$  + cluster 1d size  $x$ ,  $y$  + fastest hit in cluster 1d  $x$ ,  $y$

# TB2023 (APV25) : 2D layouts

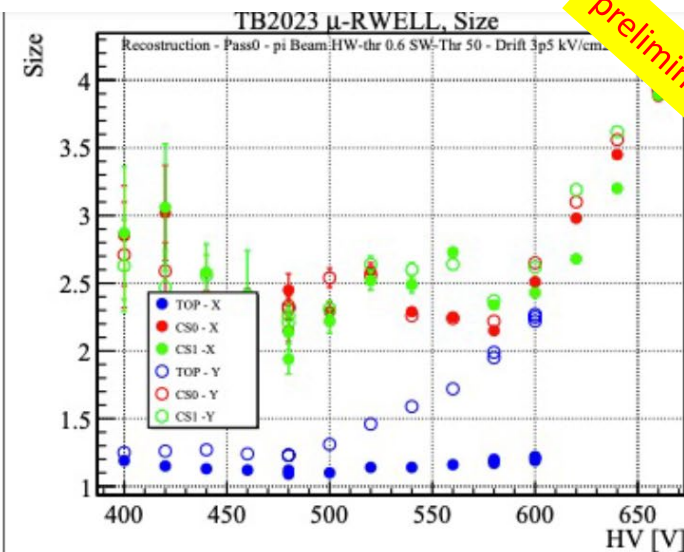
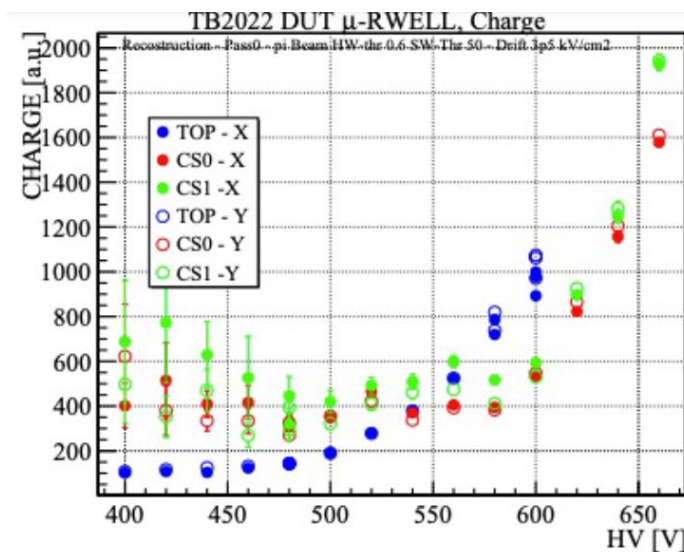
I **risultati** preliminari ottenuti con i due layout 2D r/out sono **incoraggianti** e le viste X-Y hanno mostrato un'uguale induzione del segnale.

- La **TOP r/o** per costruzione **NON DIVIDE** la **carica totale** lungo le 2 viste:

- Raggiunge il plateau d'efficienza ad **HV più bassi**;
- Il livello di efficienza del 70 % è dovuto alle zone morte tra una strip e l'altra della coordinate Y;
- La **risoluzione spaziale è digitale** lungo X (Strip size  $\sim 1.5$ ), mentre migliora lungo Y (dovuto allo spread del DLC)

- La **CS r/o** per costruzione **DIVIDE** la **carica totale** lungo le 2 viste:

- Raggiunge il plateau d'efficienza ad **HV più alti**;
- Il livello di efficienza  $> 95\%$ ;
- La **risoluzione spaziale** migliora all'aumentare del HV (meccanismo del Charge sharing funziona  $\rightarrow$  Strip size  $> 2.5$ ), **raggiungendo i 150  $\mu\text{m}$**



preliminary

