Liverpool (Online), FCC physics workshop

# IDEA Preshower and Muon Detector

Status update and future plans

G Mezzadri (INFN Ferrara) on behalf of the working group

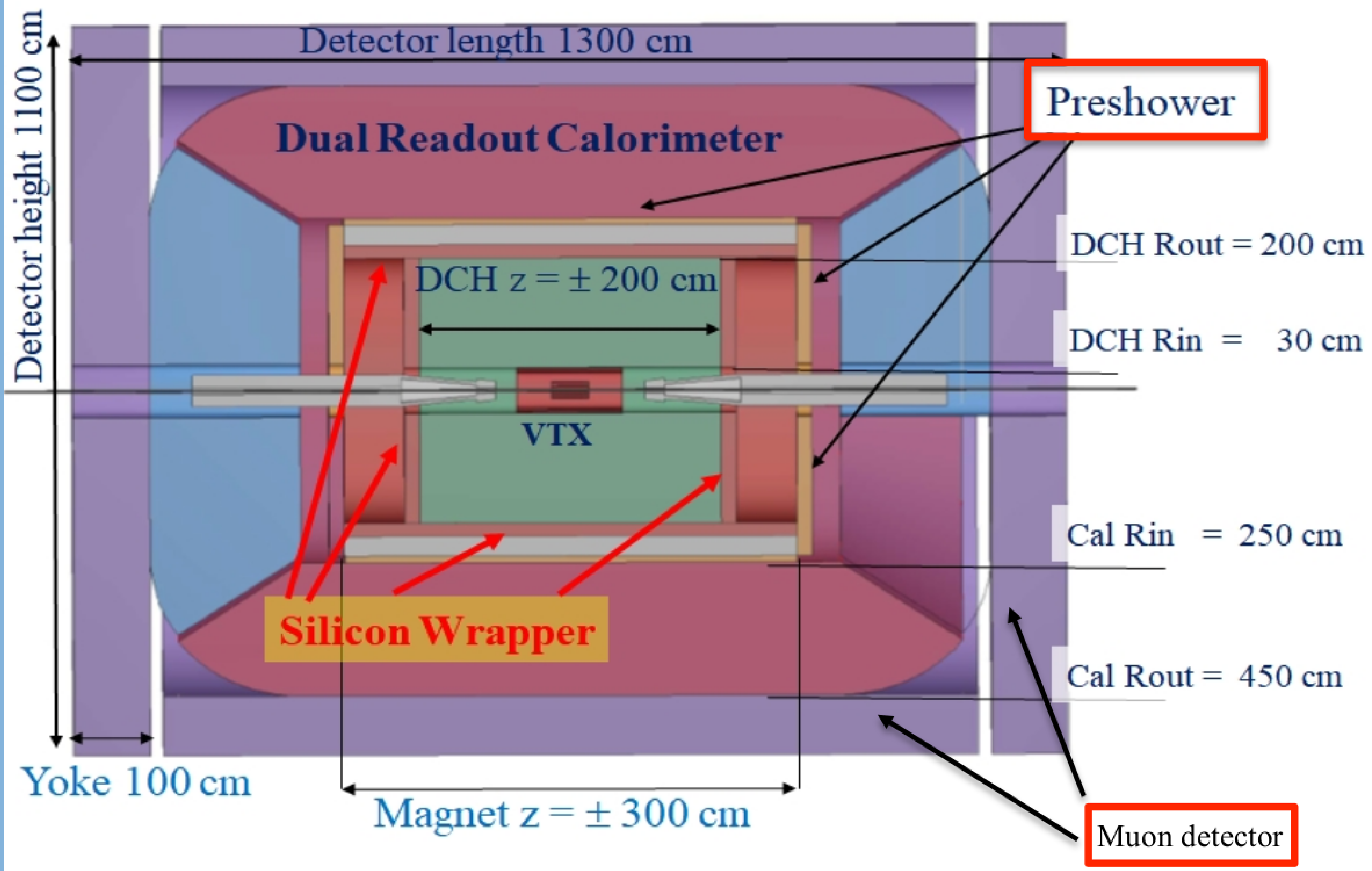
February 9, 2022

# Outline

IDEA Detector @ FCC-ee

Pre Shower and Muon Detector

On going activities




# IDEA

Innovative
Detector
Electron-positron
Accelerator

# Preshower Detector

High resolution after the magnet
to improve track reconstruction

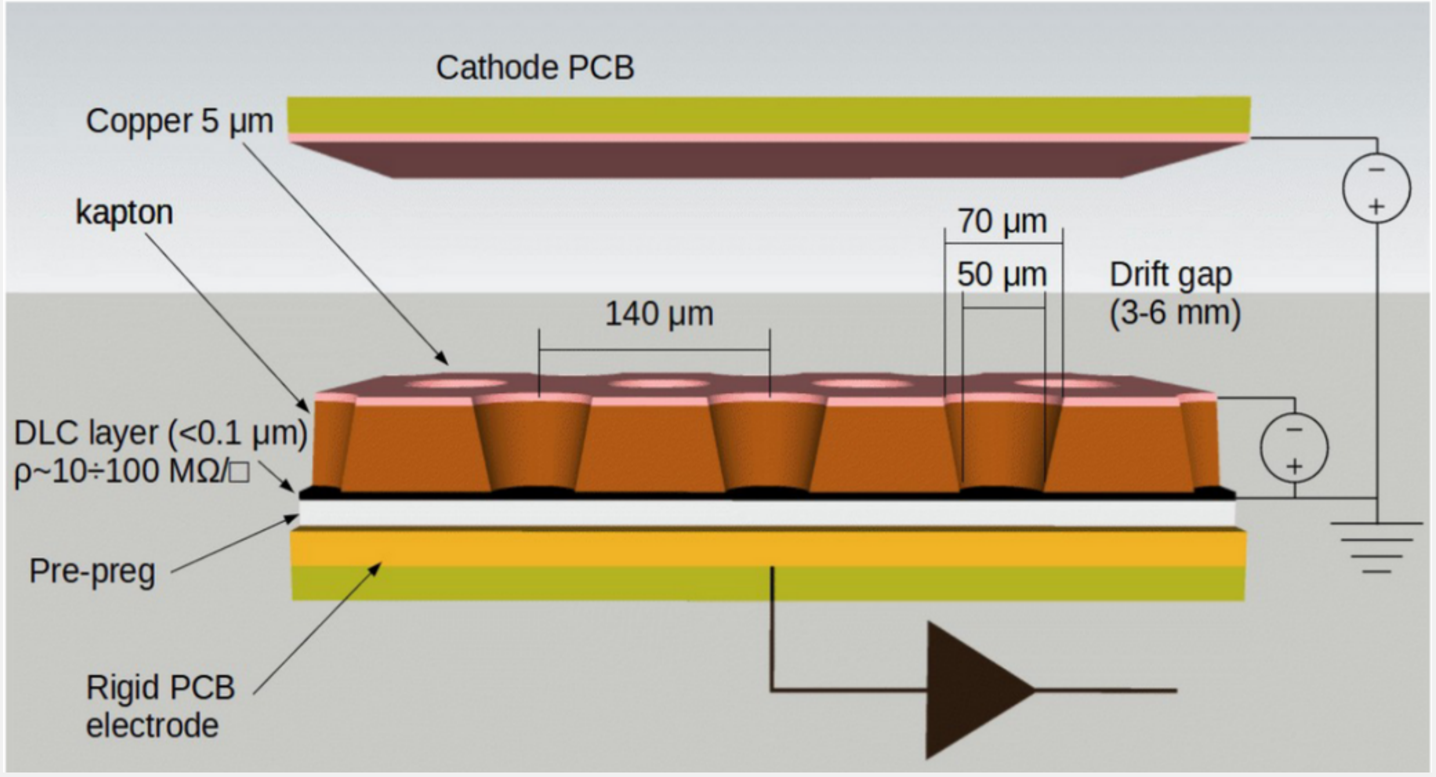
Efficiency > 98%
Space Resolution < 100 um
Mass production
Optimization of FEE channels/cost

# Muon Detector

Identify muons and search for LLP

Efficiency > 98%
Space Resolution < 400 um
Mass production
Optimization of FEE channels/cost

# micro-RWELL detector



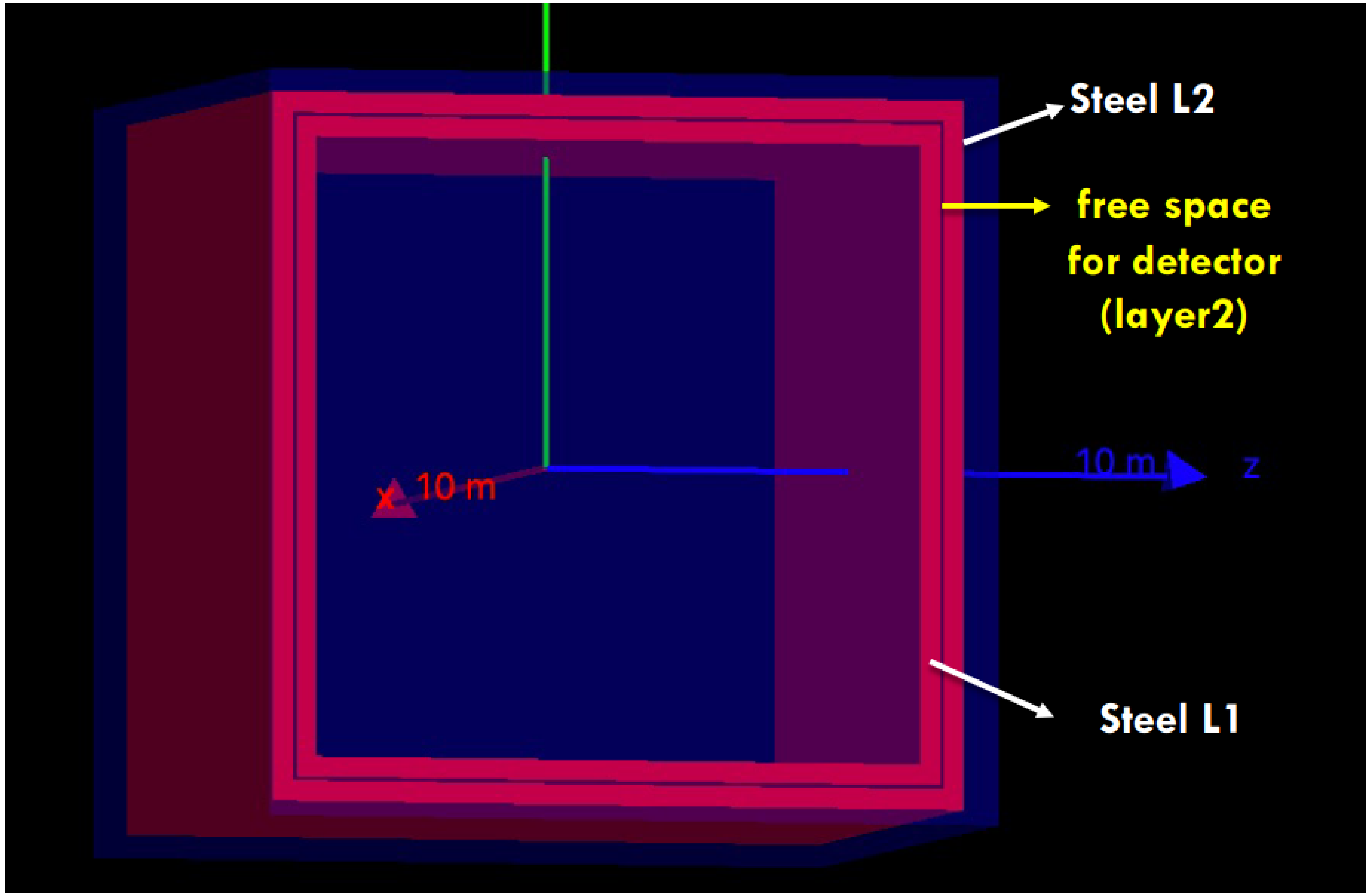

50x50 $cm^2$ 2D tiles to cover more than 4330 $m^2$

**Preshower**
pitch = 0.4 mm
FEE capacitance = 70 pF
1.5 million channels

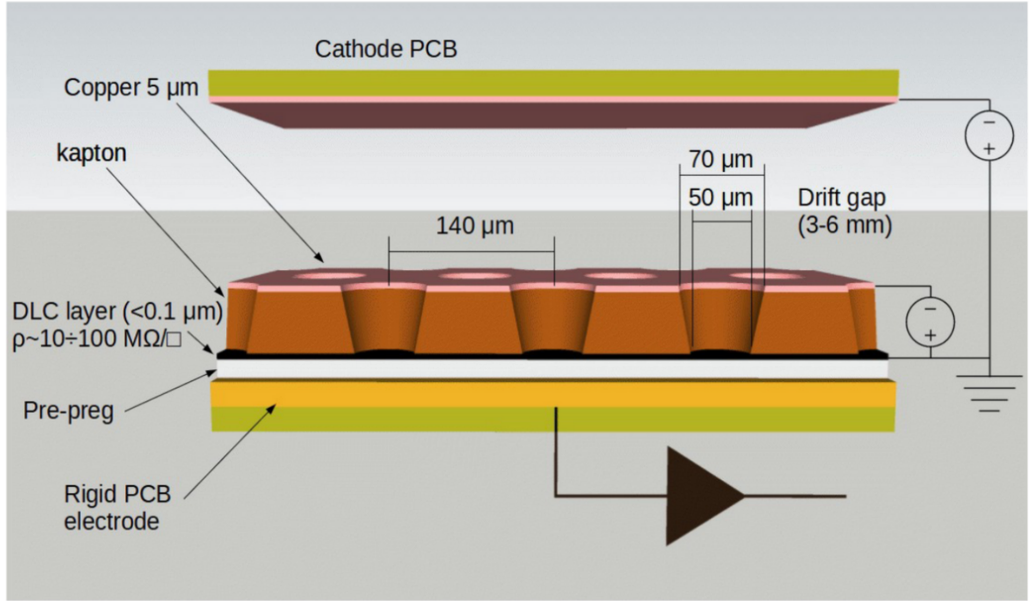
**Muon**
pitch = 1.5 mm
FEE capacitance = 270 pF
5 million channels


# On going activities

# Standalone Simulation of the muon detector

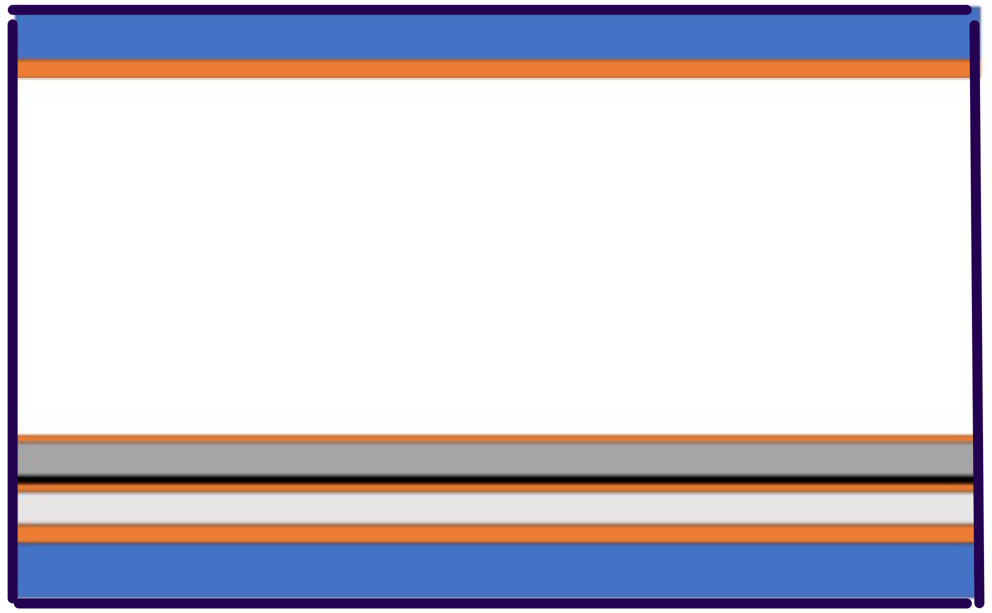



To be inserted in official simulation.
Endcap in preparation



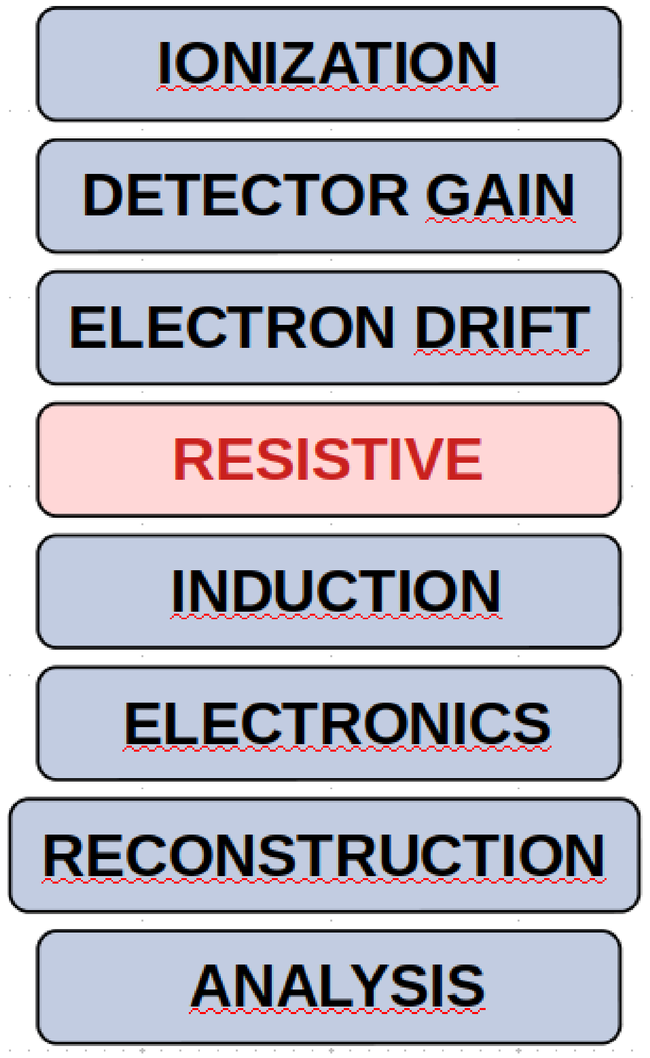

From sketch

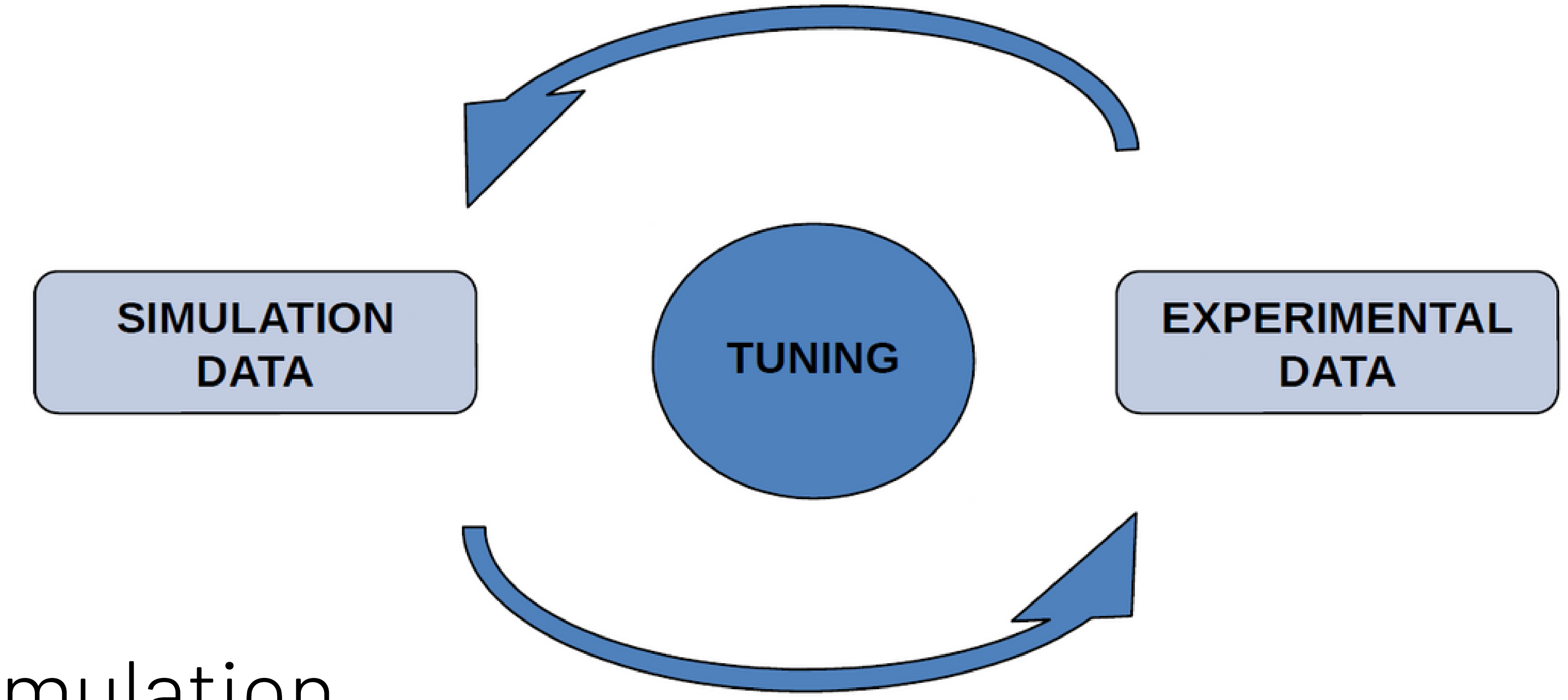
to simulation



Different layers

# micro-RWELL parametrization in simulation




Use test beam data to tune the simulation

### Resistivity

Simulate the charge spread dispersion at the anode using approach of *NIM A 566 (2006) 281-285*

### Interstrip cross talk

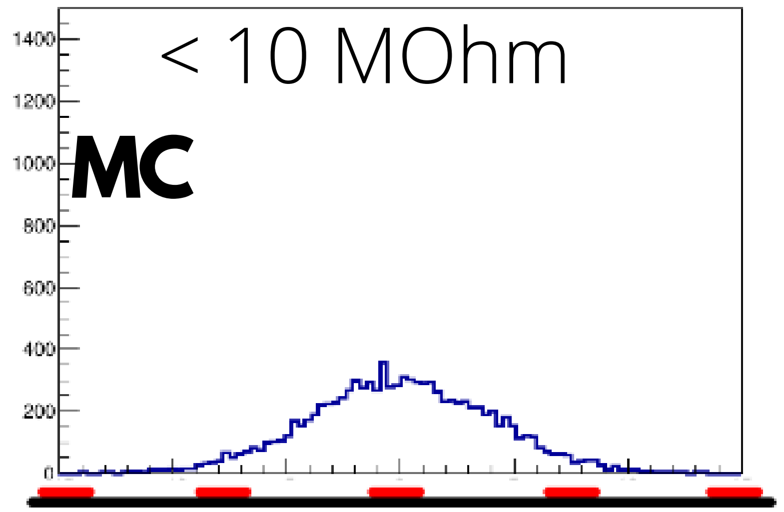
Study the probability to induce a signal on neighbor strip as a function of
- charge in the central strip
- relative time delay

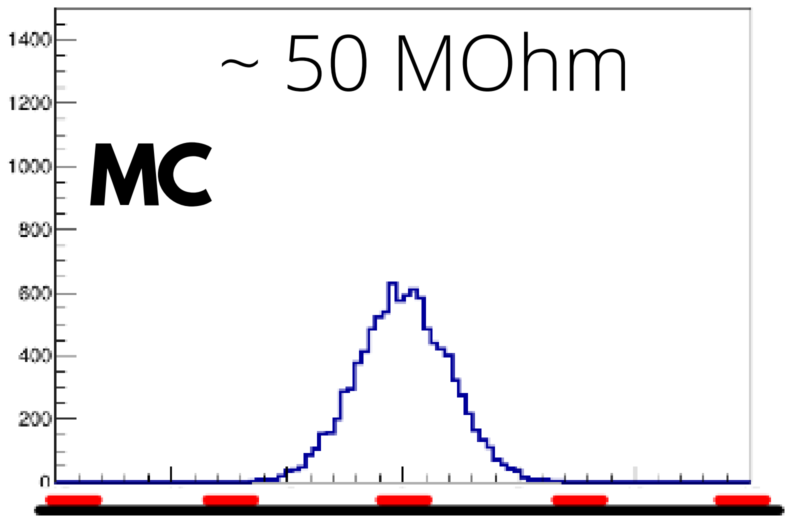
# Resistivity scan

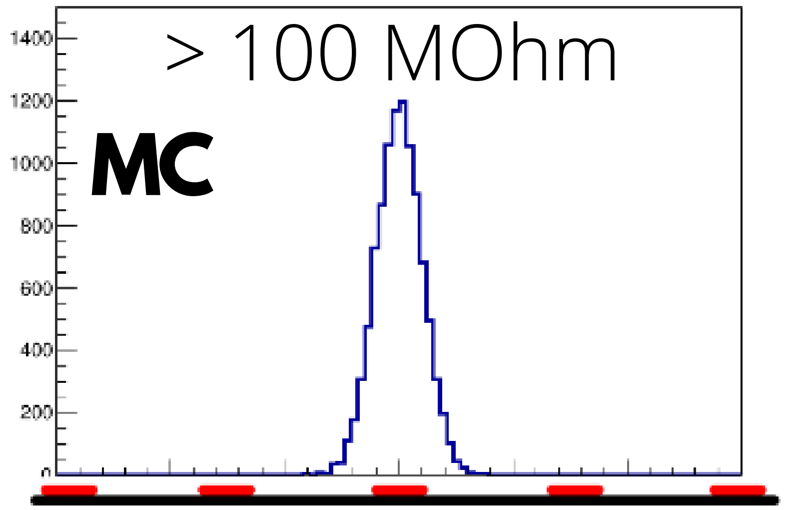
R&D to identify optimal DLC resistivity by studying spatial performance

Preshower: 10, 30, 50, 70, > 100-200 MOhm/square
Muon:15, 35 MOhm/square

**Effect of resistivity on charge spread**



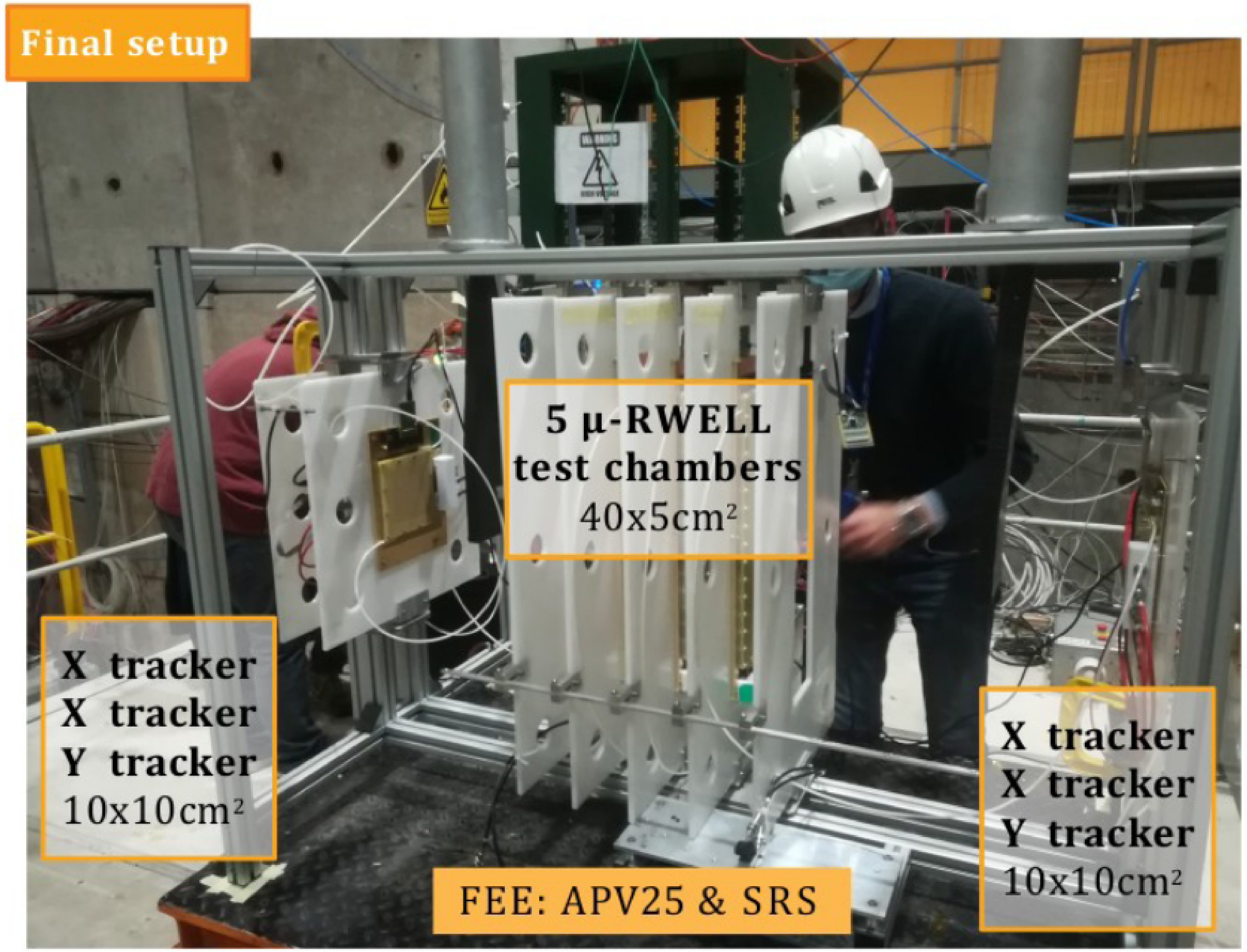




Test beam performed in October 2021 at SPS-H8-CERN line

Instrumented 5x40 $cm^2$ 1D micro-RWELL modules with SRS DAQ and APV readout to have a comparison with previous results

# Test beam

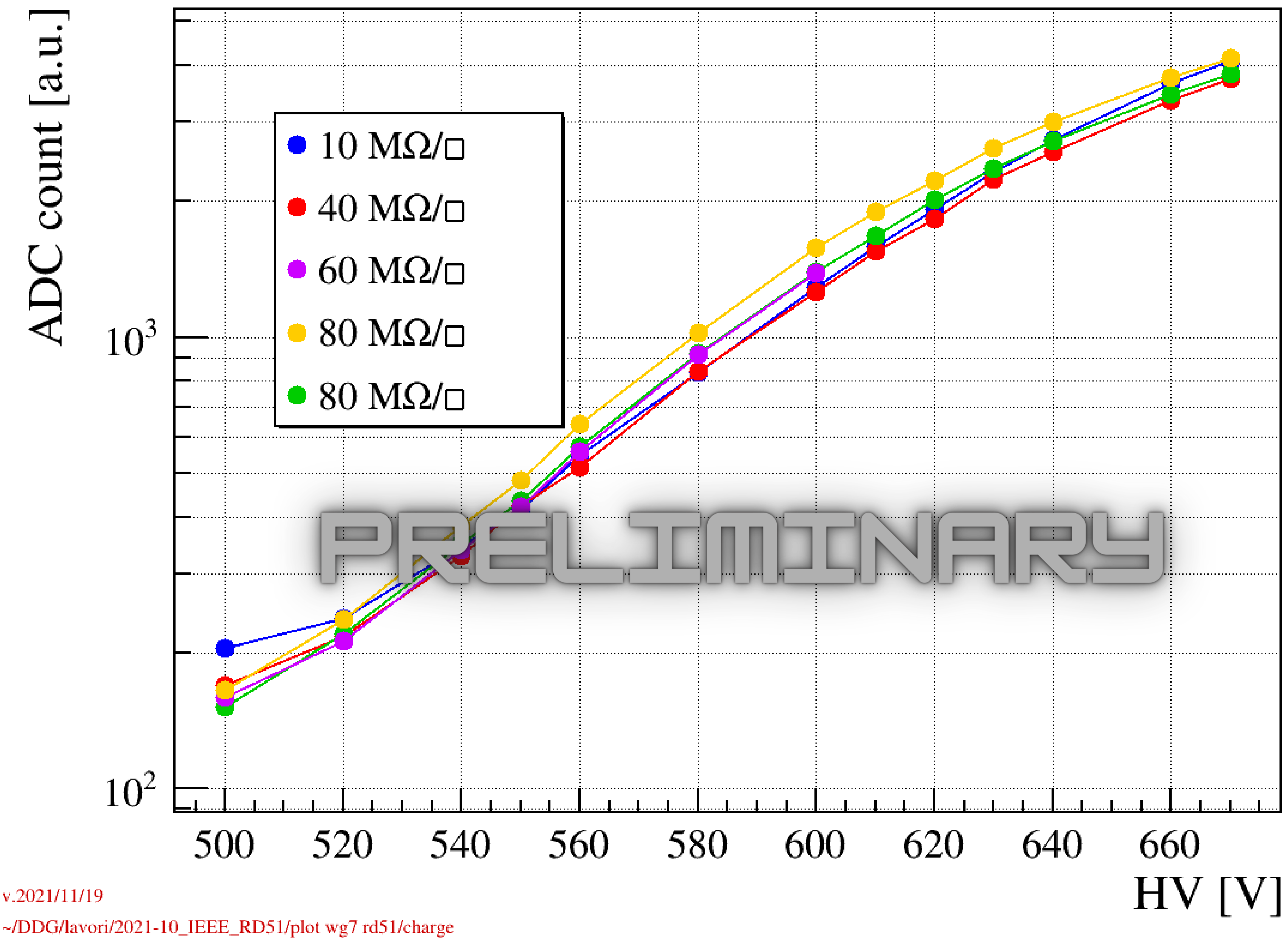



140-180 GeV/c muon and pion beam
Operated in $Ar/CO_2/CF_4$ (45/15/40)

a) **Design optimization**:
- different HV filter applied

b) **Detector characterization**
- HV scan at 0°
- HV scan at different angles and drift field

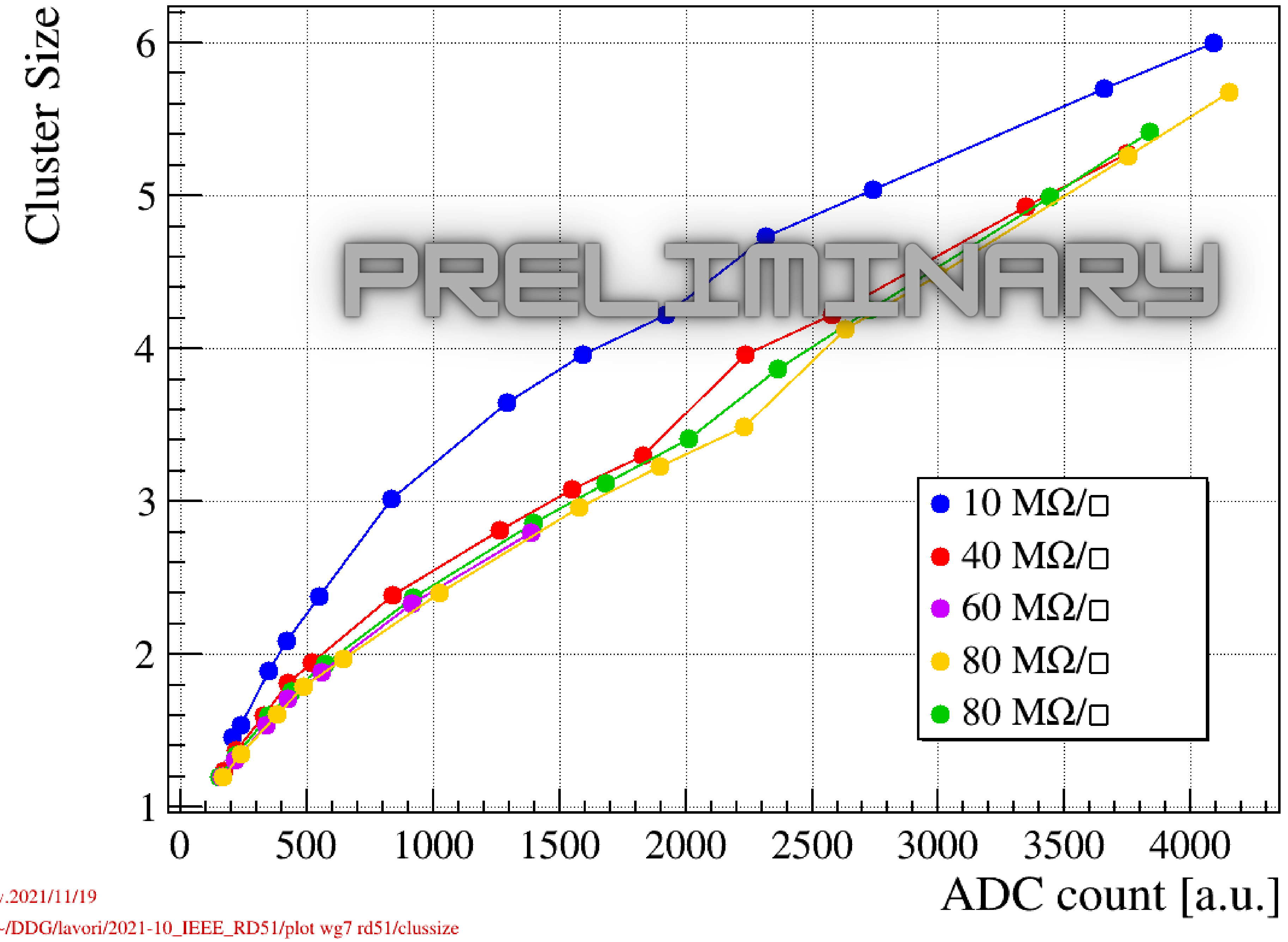
1- **Signal shape**
(cluster charge, cluster size)
2 - **Detector performance**
(efficiency, resolution)




# HV scan

**Similar behaviour for all the prototypes**

Ok, since the resistivity shall not influence the gain, that depends mostly on HV settings




# Cluster size

10 MOhm/square chamber has larger cluster size even with smaller HV settings

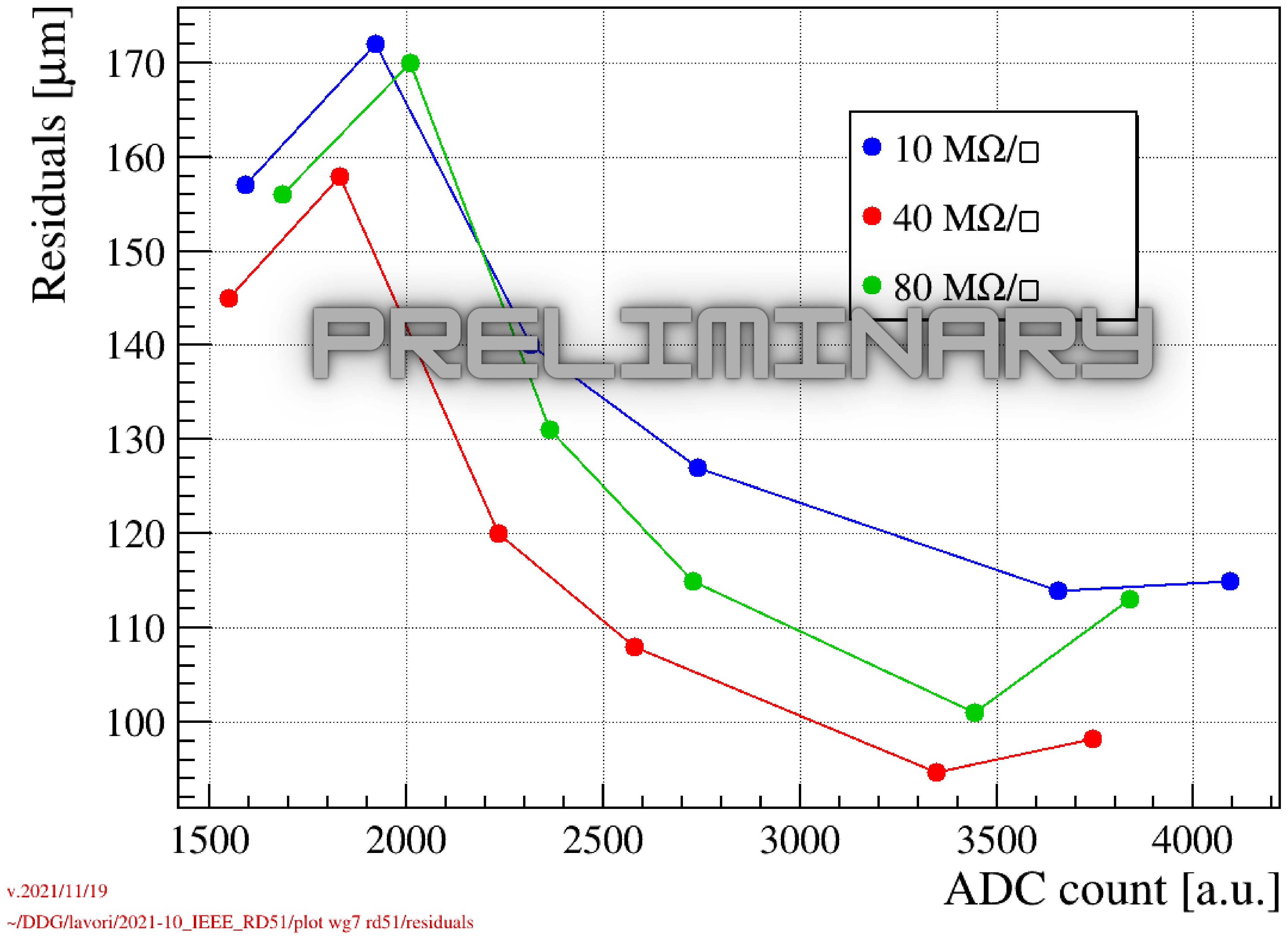
Other shows common behavior. No prototypes above 100 MOhm/square due to material shortage

# Residual distribution

**Residual shrinks with increasing HV settings**

The best resolution is for intermediate resistivity:
40 MOhms/square better than the others

**No Alignment and tracking contribution not subtracted**

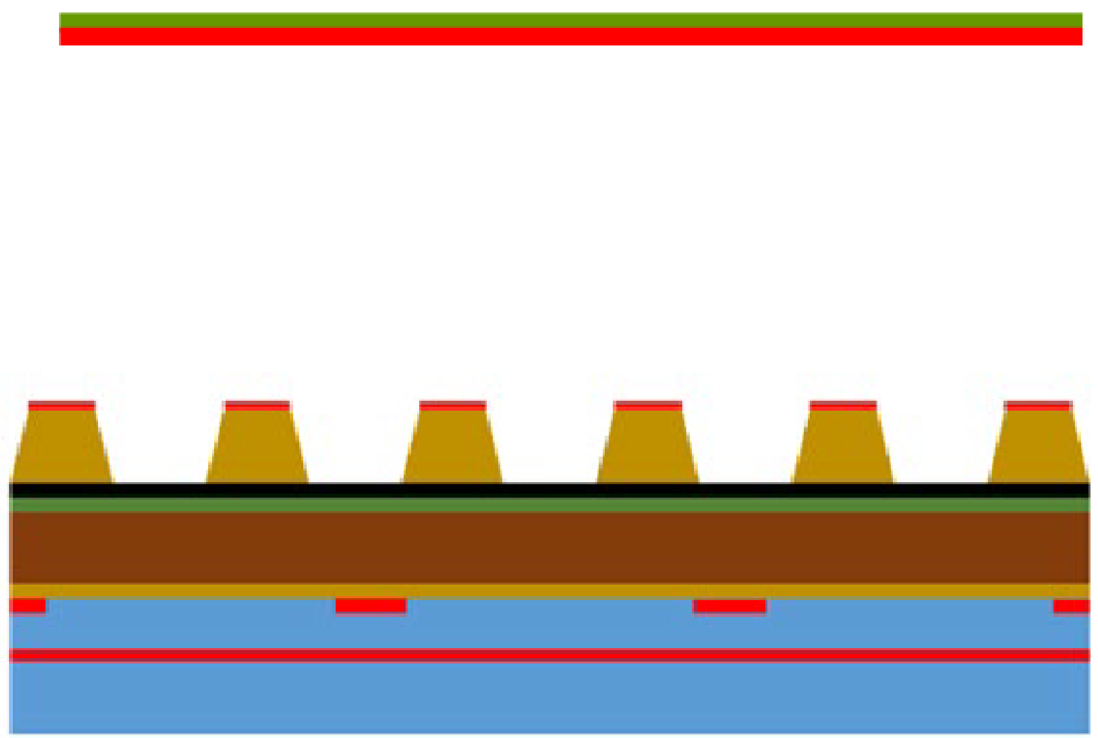


# 2D readout R&D ideas

**micro-RWELL with 2D anode readout**

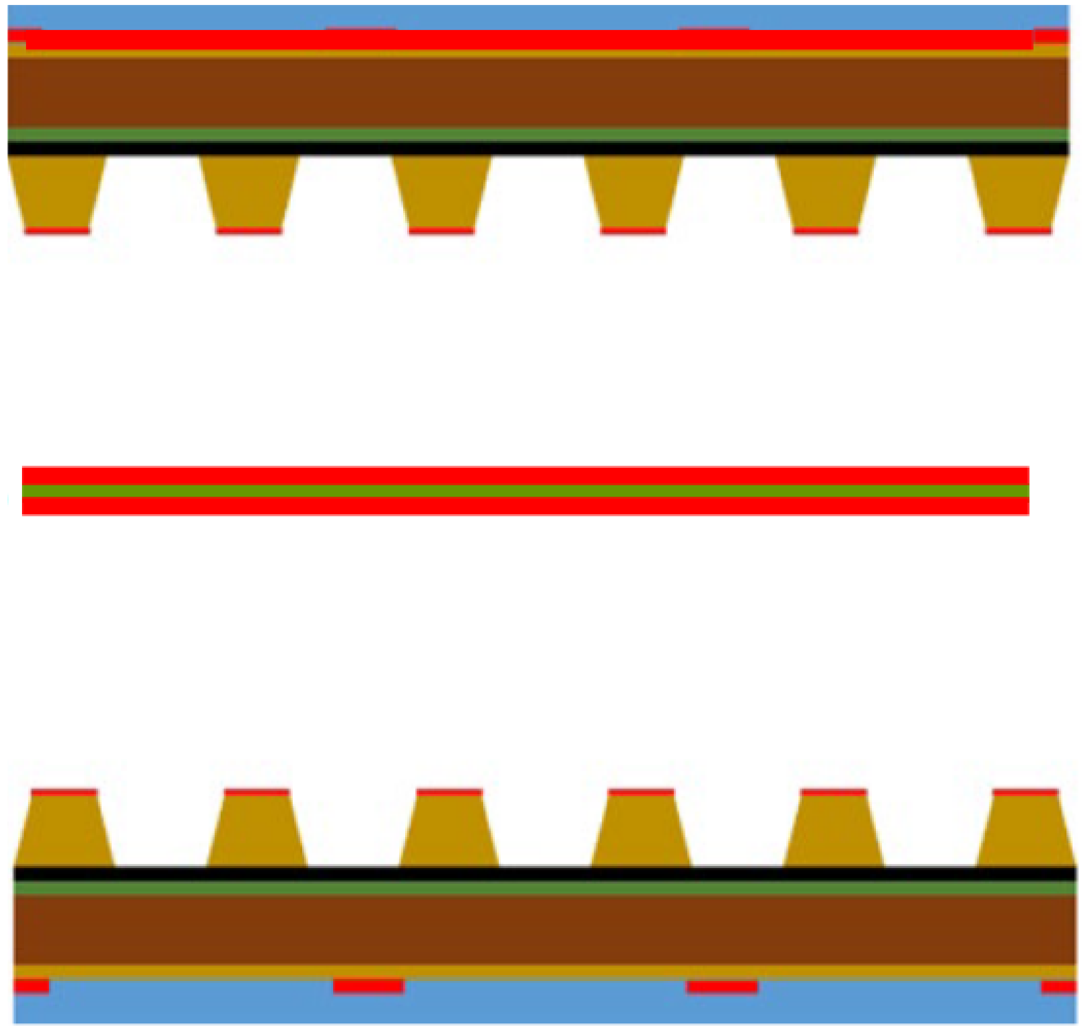
Good performance
but need higher gain wrt to 1D micro-RWELL

More complex PCB construction



**2 1D micro-RWELL stacked**

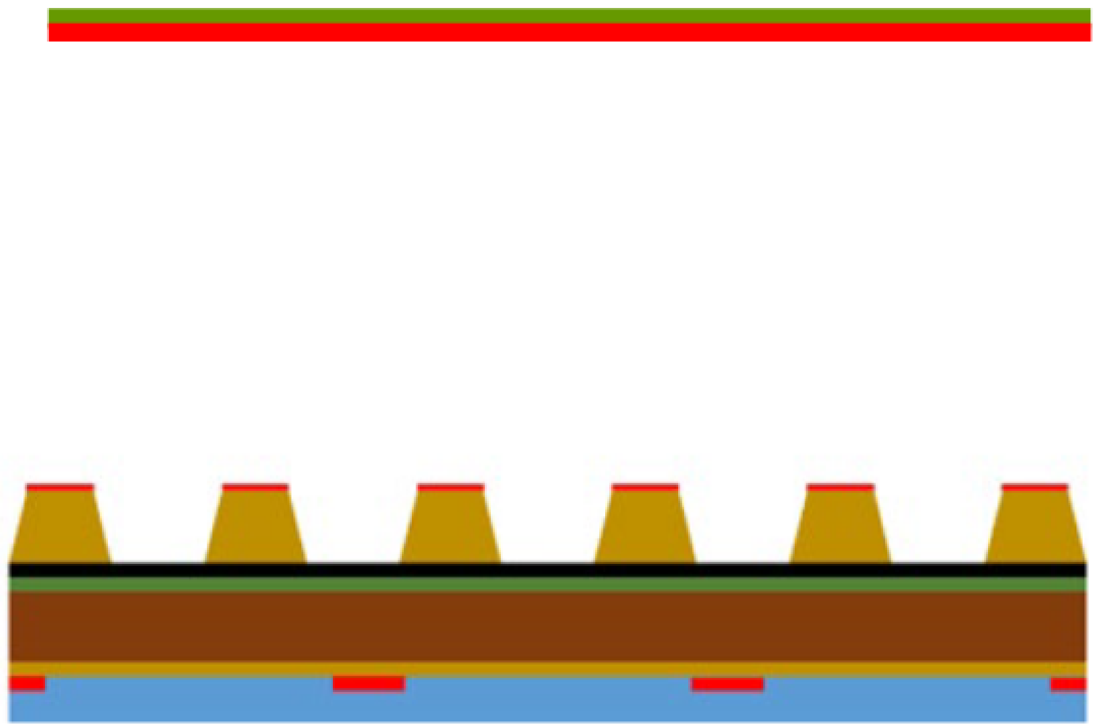
1 view per micro-RWELL easy PCB construction
2D performance to be measured



**micro-RWELL with strips on top and anode**

HV on DLC,
TOP to ground

2D performance to be measured



Preparation

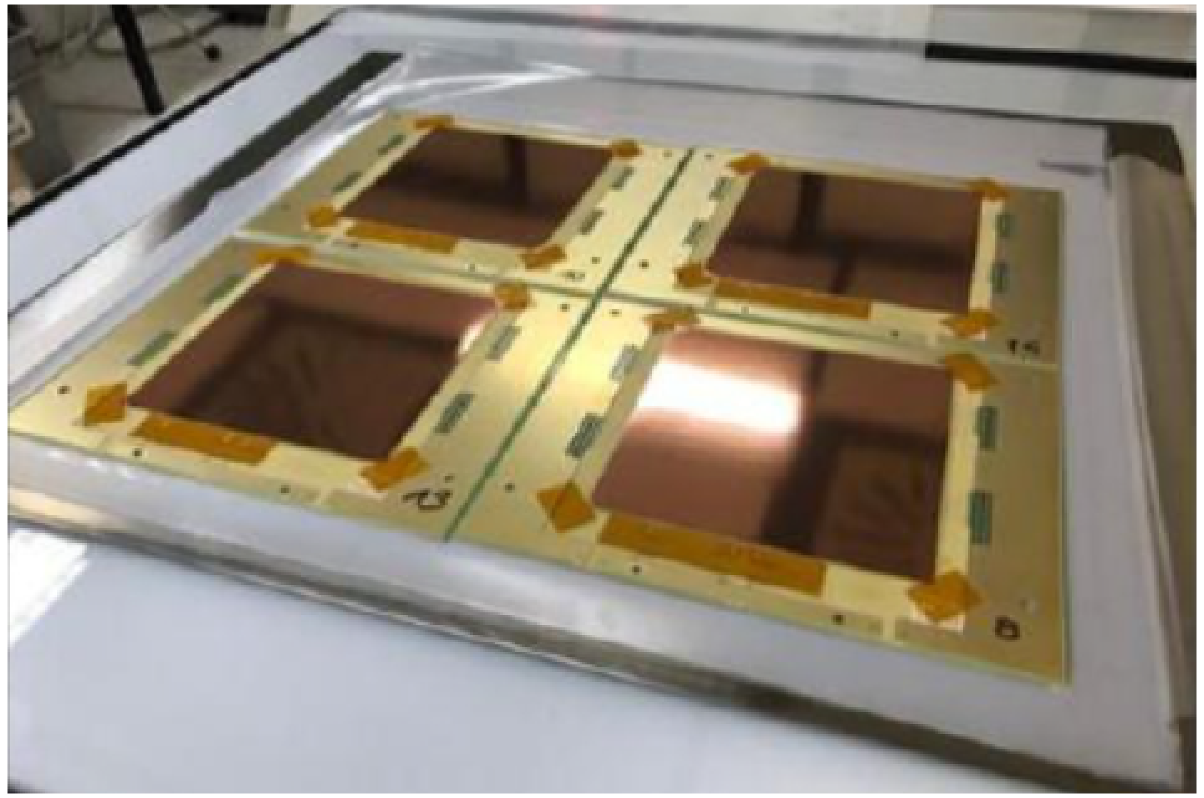
DLC sputtering with new INFN-CERN machine @ CERN

# Technology transfer at ELTOS

AIDA innova

## Step 1: producing u-RWELL_PCB (1D 10x10 $cm^2$)

- with top patterned (pad/strip)
- without bottom patterned



## Step 2: DLC patterning

- in ELTOS with BRUSHING-machine

## Step 3: DLC foil gluing on PCB

- double 106-prepreg (~2x50 um thick) (already used in ELTOS)
- pre-smoothing + 106-prepreg (~50 um thick)
- single 1080-prepreg (~75 um thick)

## Step 4: top copper patterning

## Step 5: Kapton etching on small PCB

Finalization

Detector @ CERN for final preparation

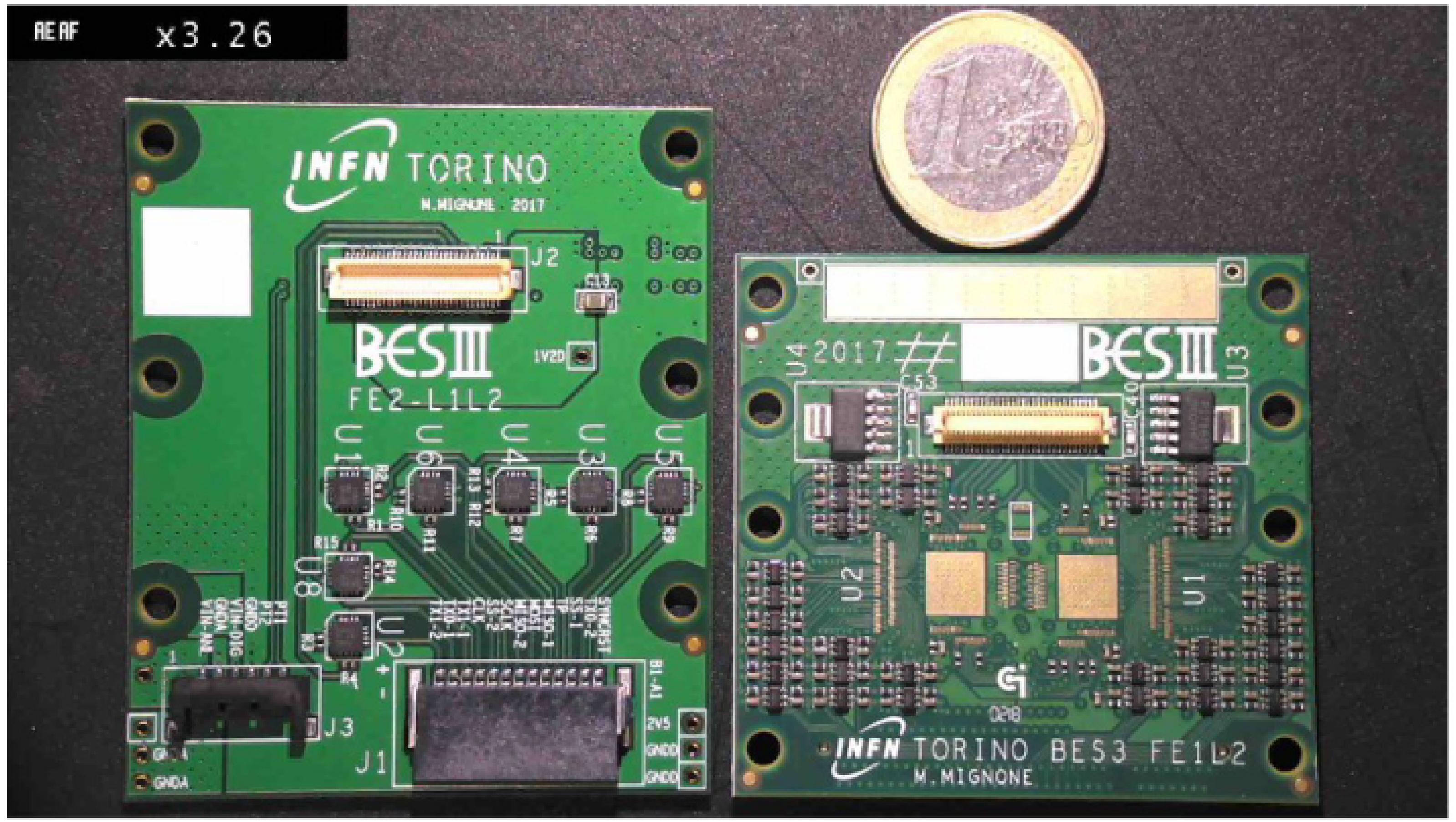



**Table 2**
Measured performance of the TIGER ASIC.

| Parameters | Values |
|---|---|
| Input charge | 5-55 fC |
| TDC resolution | 30 ps RMS |
| Time-walk (5-55 fC range) | 12 ns |
| Average gain | 10.75 mV/fC |
| Nonlinearity (5-55 fC range) | 0.5% |
| RMS gain dispersion | 3.5% |
| Noise floor (ENC) | 1500 $e^-$ |
| Noise slope | 10 $e^-$/pF |
| Maximum power consumption | 12 mW/ch |

# Test with TIGER ASIC

Developed for BESIII CGEM-IT

Prepare new readout card based on System On Modules (SOM)

# Summary and outlook

## Plenty of activities on-going

Contribution to full detector simulation to perform more detailed physics case studies

More results from 2021 test beam coming soon

Another test beam is planned to continue the 2D prototype characterization

Test of the TIGER ASIC with micro-RWELL prototype

Continue partnership with ELTOS (preparation) and CERN (finalization) to complete technology transfer

# Thank you!

**Working group:**

A. Amoroso, I. Balossino, G. Bencivenni, V. Cafaro, G. Cibinetto, E. De Lucia, D. Domenici, R. Farinelli, G. Felici, I. Garzia, M. Gatta, P. Giacomelli, M. Giovannetti, S. Gramigna, L. Lavezzi, M. Melchiorri, GM, G. Morello, G. Papalino, M. Poli Lener, M. Scodeggio, S. Sosio

# Selected bibliography


01 JINST 10 (2015) 02, P02008

02 Nucl.Instrum.Meth.A 886 (2018) 36-39

03 Nucl.Instrum.Meth.A 924 (2019) 181-186

04 JINST 15 (2020) 09, C09034

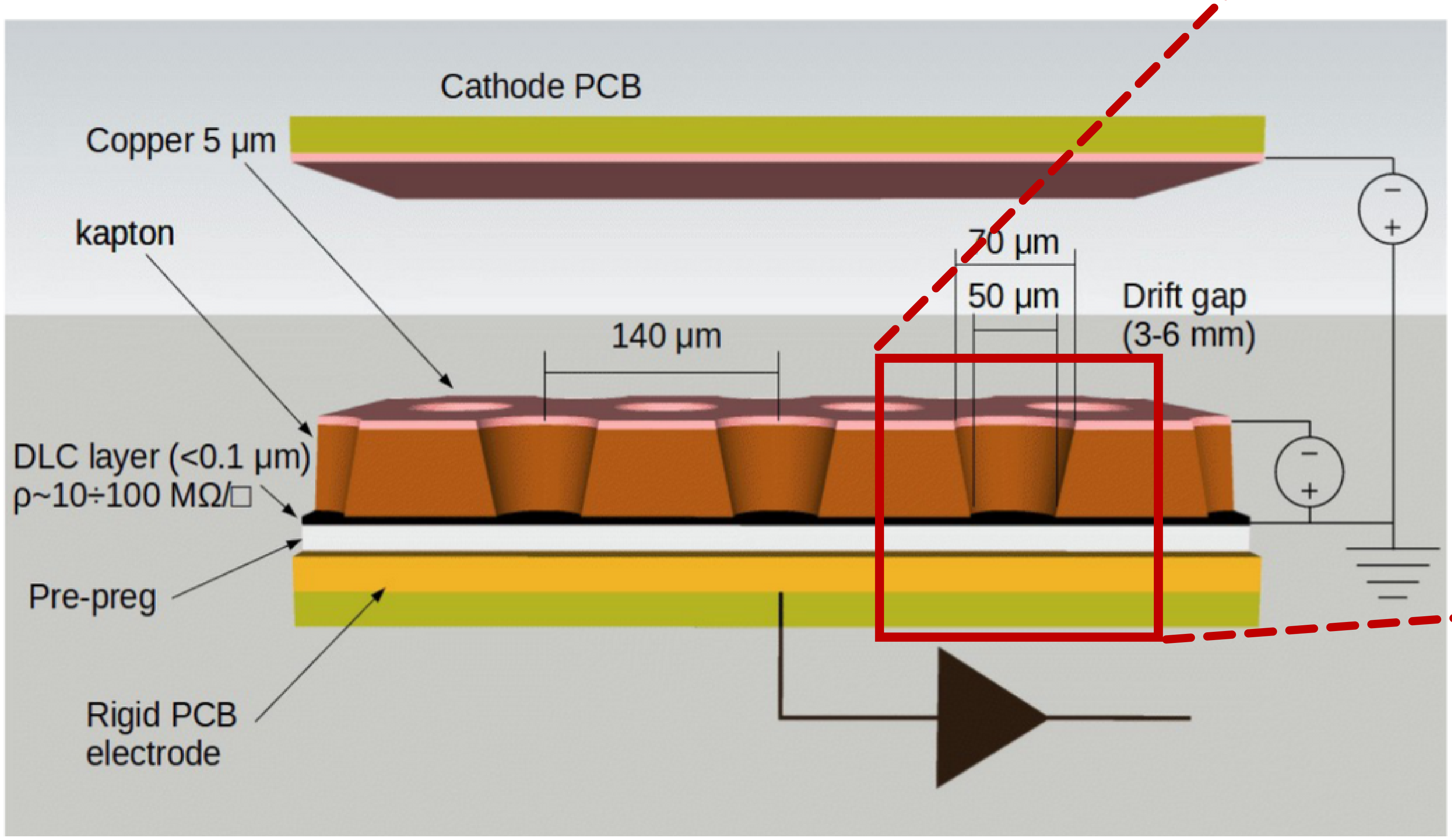
05 JINST 16 (2021) 08, P08036

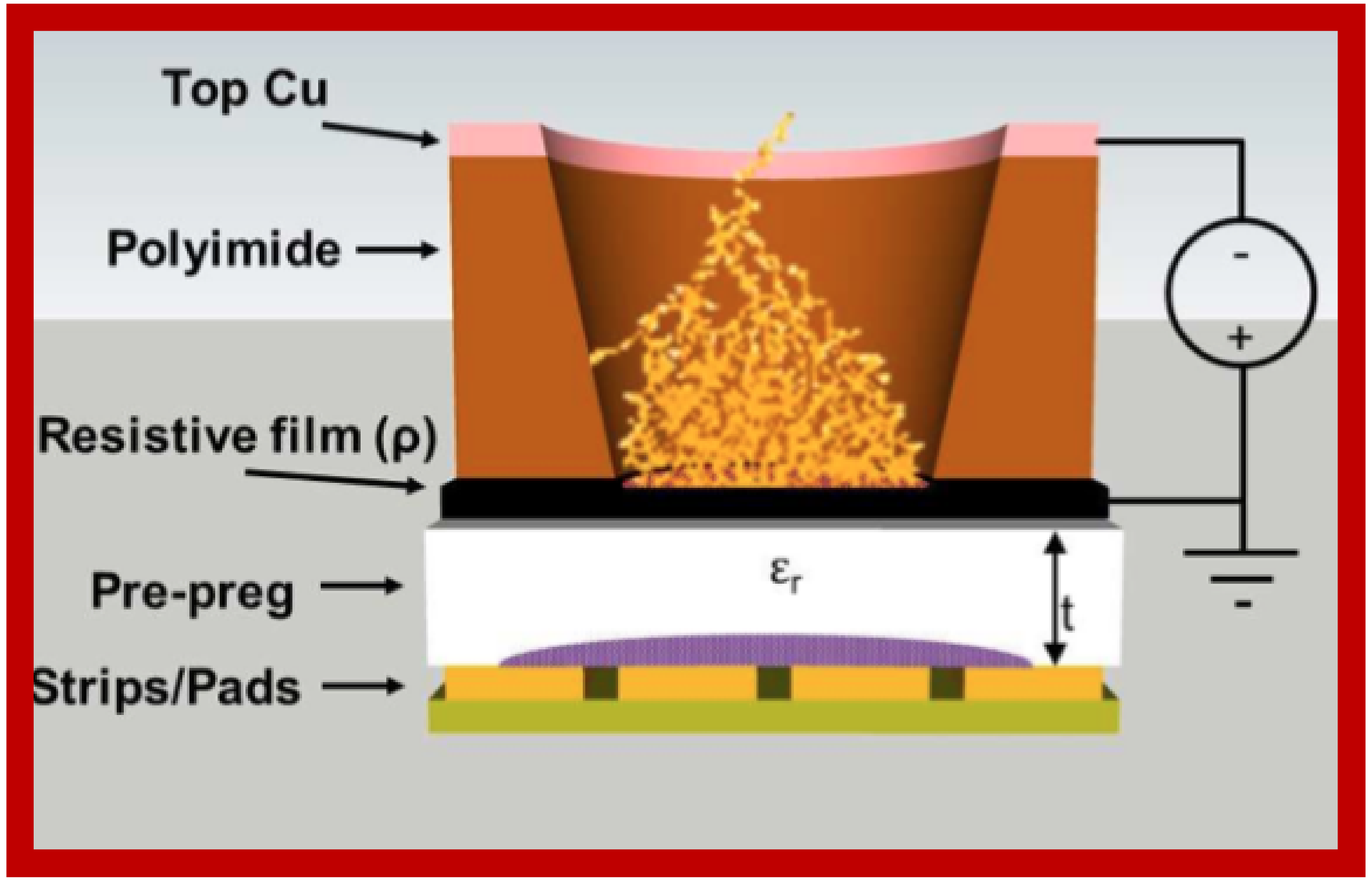
06 Eur.Phys.J.Plus 136 (2021) 11, 1143

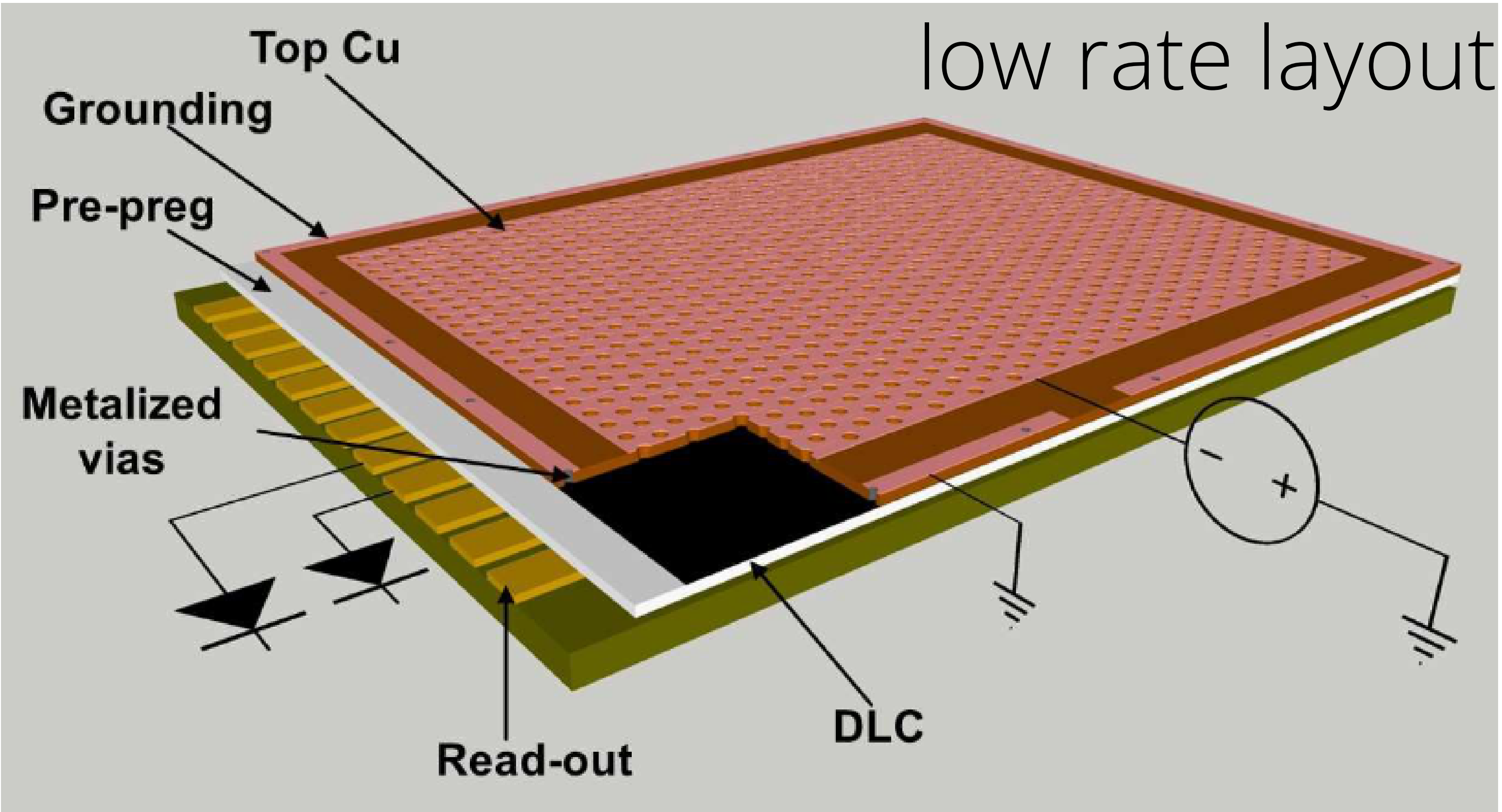
# Additional material

# micro-RWELL

A SHORT INTRODUCTION



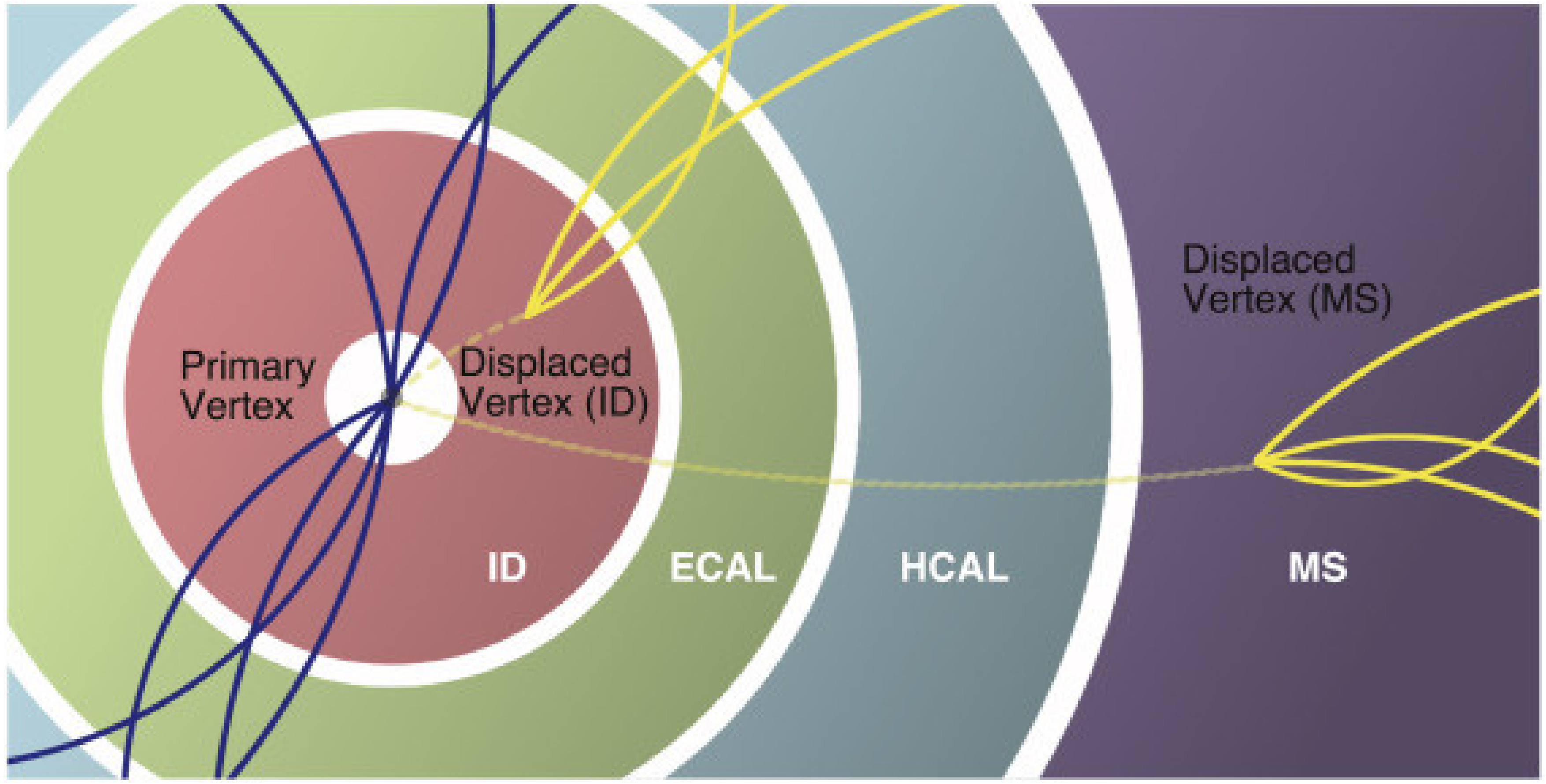




Single stage resistive Micro Pattern Gas Detector firstly designed by G. Bencivenni in 2007

# Long Lived Particles (LLP)

Category of BSM particles that, due to feeble interaction, decay far away from the primary vertex

Signatures of different BSM models similar




**neutral LLP channels**

| Production \ Decay | $\gamma\gamma(+\text{inv.})$ | $\gamma + \text{inv.}$ | $jj(+\text{inv.})$ | $jj\ell$ | $\ell^+\ell^-(+\text{inv.})$ | $\ell^+_\alpha \ell^-_{\beta\neq\alpha}(+\text{inv.})$ |
|---|---|---|---|---|---|---|
| DPP: sneutrino pair | † | SUSY | SUSY | SUSY | SUSY | SUSY |
| HP: squark pair, $\tilde{q} \to jX$ or gluino pair $\tilde{g} \to jjX$ | † | SUSY | SUSY | SUSY | SUSY | SUSY |
| HP: slepton pair, $\tilde{\ell} \to \ell X$ or chargino pair, $\tilde{\chi} \to WX$ | † | SUSY | SUSY | SUSY | SUSY | SUSY |
| HIG: $h \to XX$ or $\to XX + \text{inv.}$ | Higgs, DM* | † | Higgs, DM* | RH$\nu$ | Higgs, DM* RH$\nu$* | RH$\nu$* |
| HIG: $h \to X + \text{inv.}$ | DM*, RH$\nu$ | † | DM* | RH$\nu$ | DM* | † |
| RES: $Z(Z') \to XX$ or $\to XX + \text{inv.}$ | $Z'$, DM* | † | $Z'$, DM* | RH$\nu$ | $Z'$, DM* | † |
| RES: $Z(Z') \to X + \text{inv.}$ | DM | † | DM | RH$\nu$ | DM | † |
| CC: $W(W') \to \ell X$ | † | † | RH$\nu$* | RH$\nu$ | RH$\nu$* | RH$\nu$* |

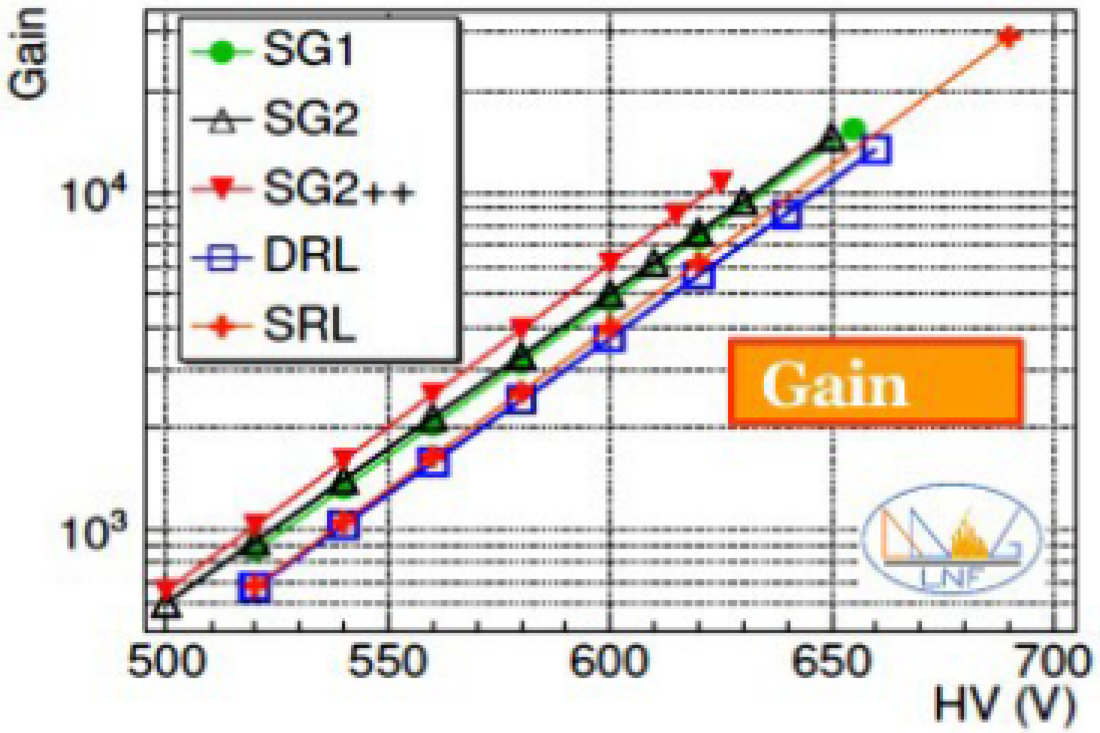
https://indico.cern.ch/event/714087/contributions/2985914/attachments/1650488/2641192/LHC-LLP_Shuve.pdf

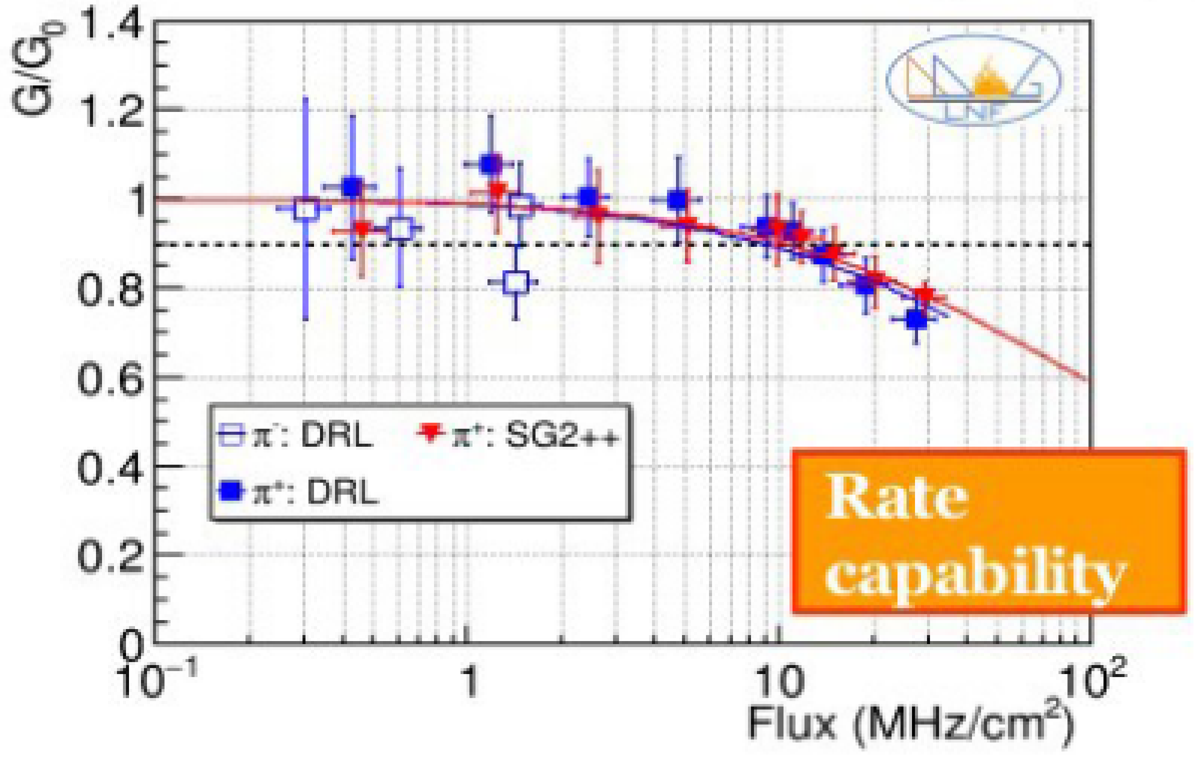
Muon detector with high spatial resolution can be used to measure very long displaced vertexes!

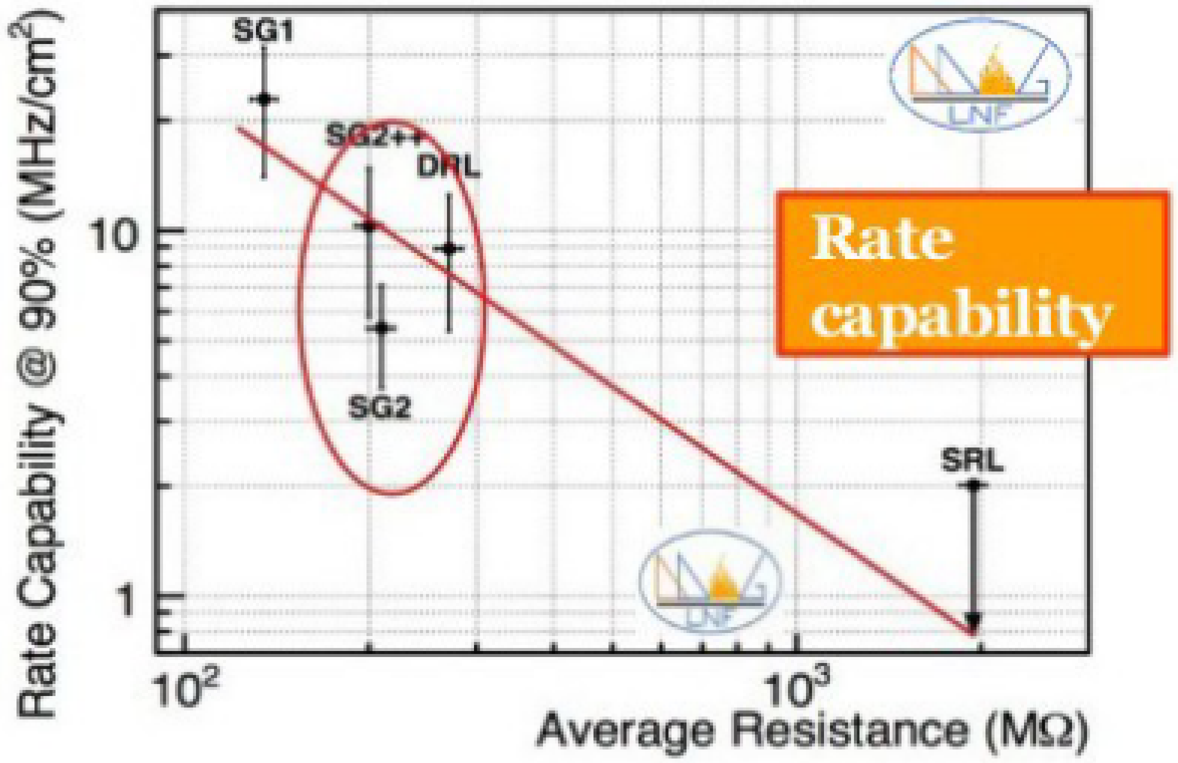
# μ-RWELL performance overview

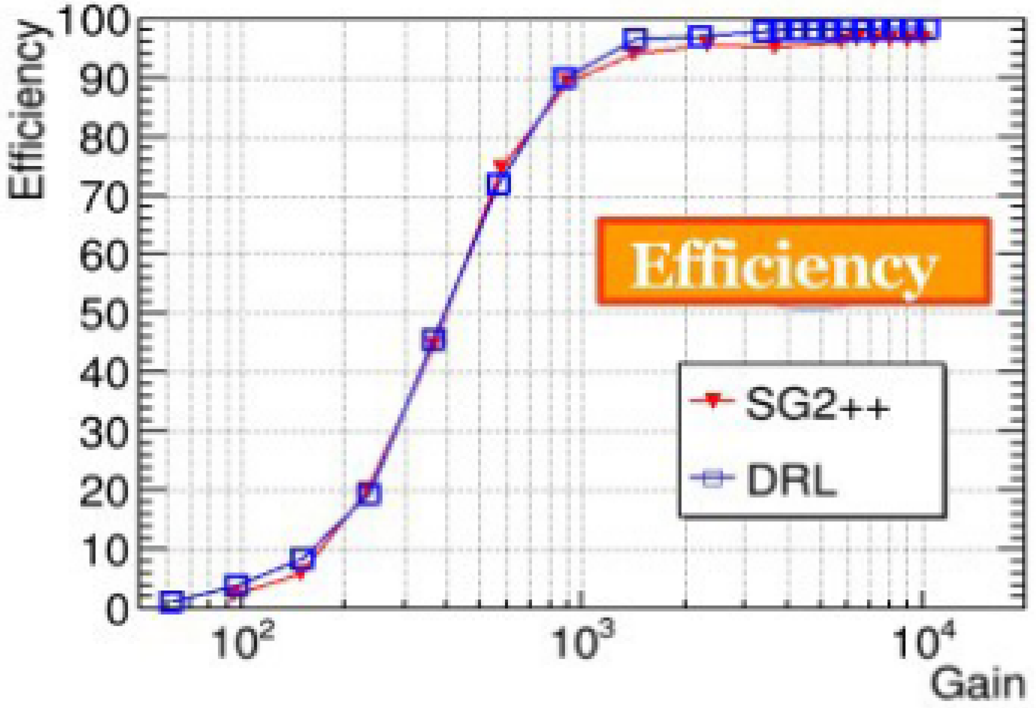
Gain up to $10^4$

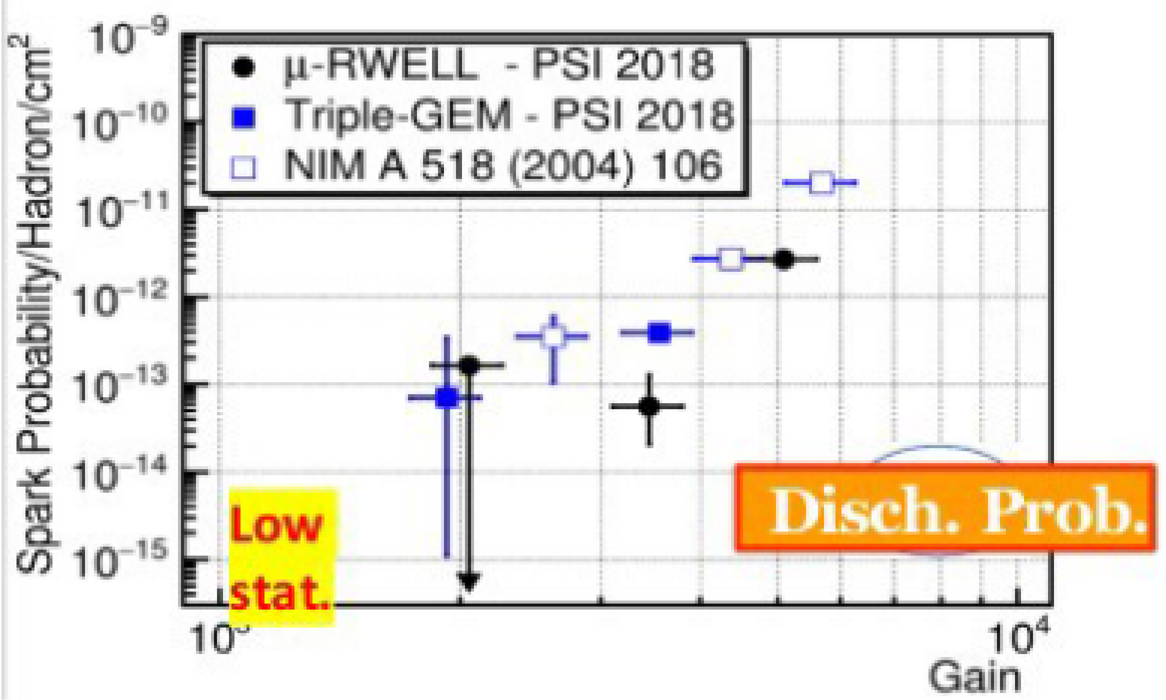
Rate Capability (@ G= 5000) ~ 5-10 MHz/cm$^2$

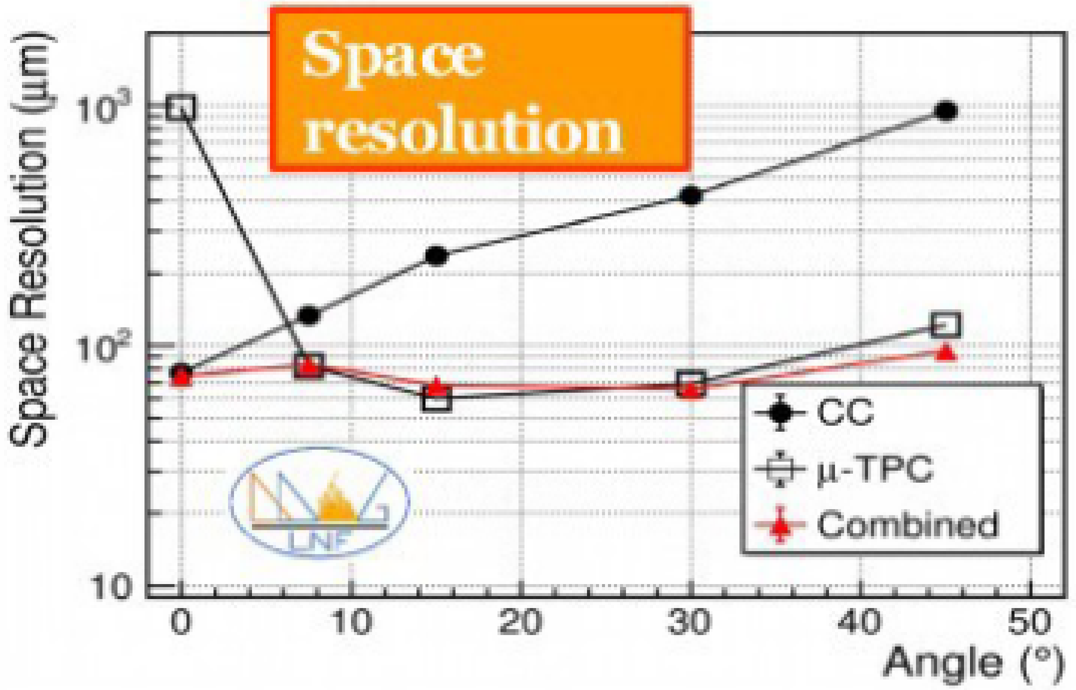


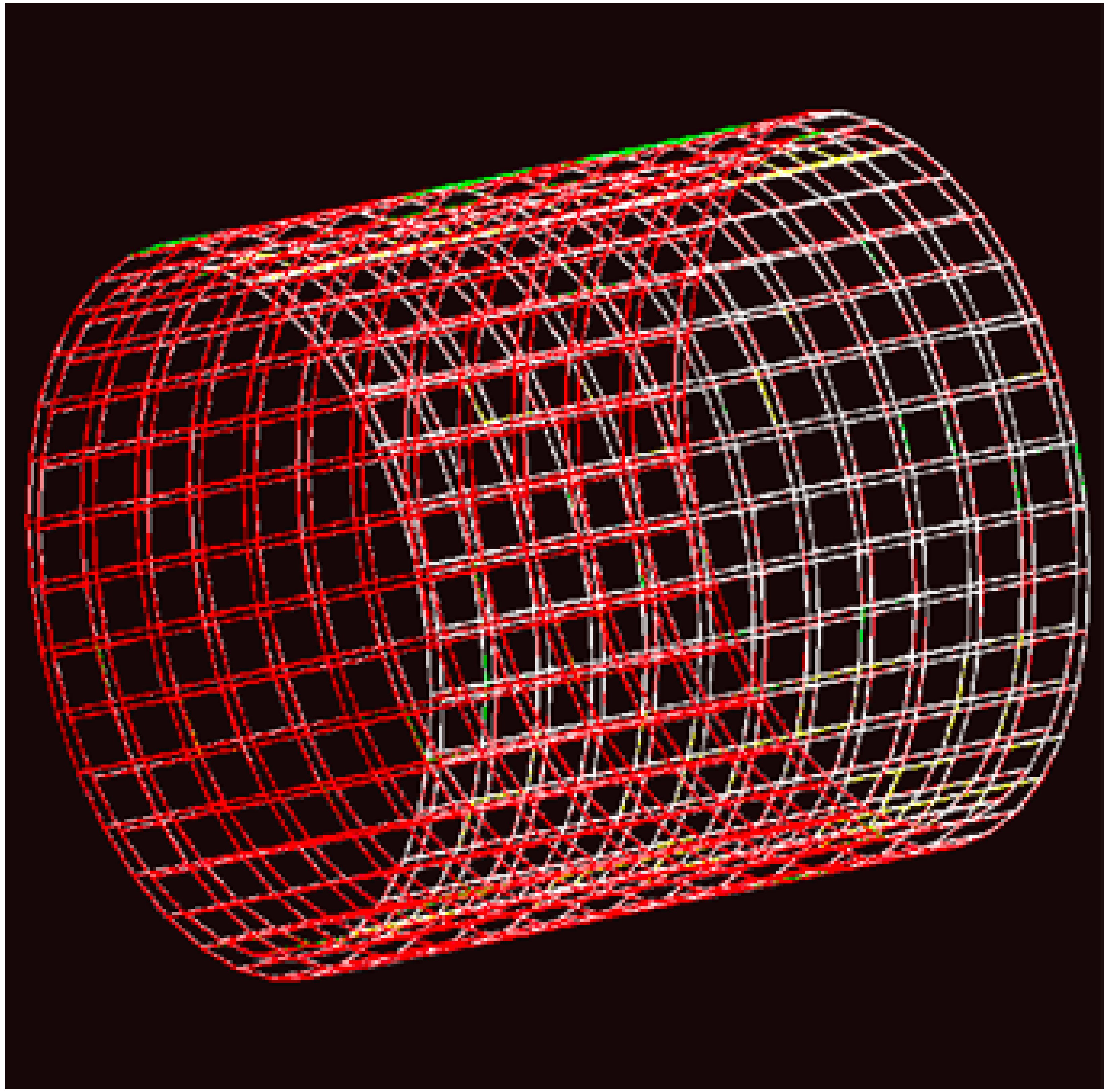




Efficiency ~ 98%

Discharge probability ~ $10^{-13}$ @ 4000

Space resolution ~ 100 μm



**Barrel Preshower layout**

**GEANT4 Simulation by E. Fontanesi, PhD**

**Muon detector similar, but larger**

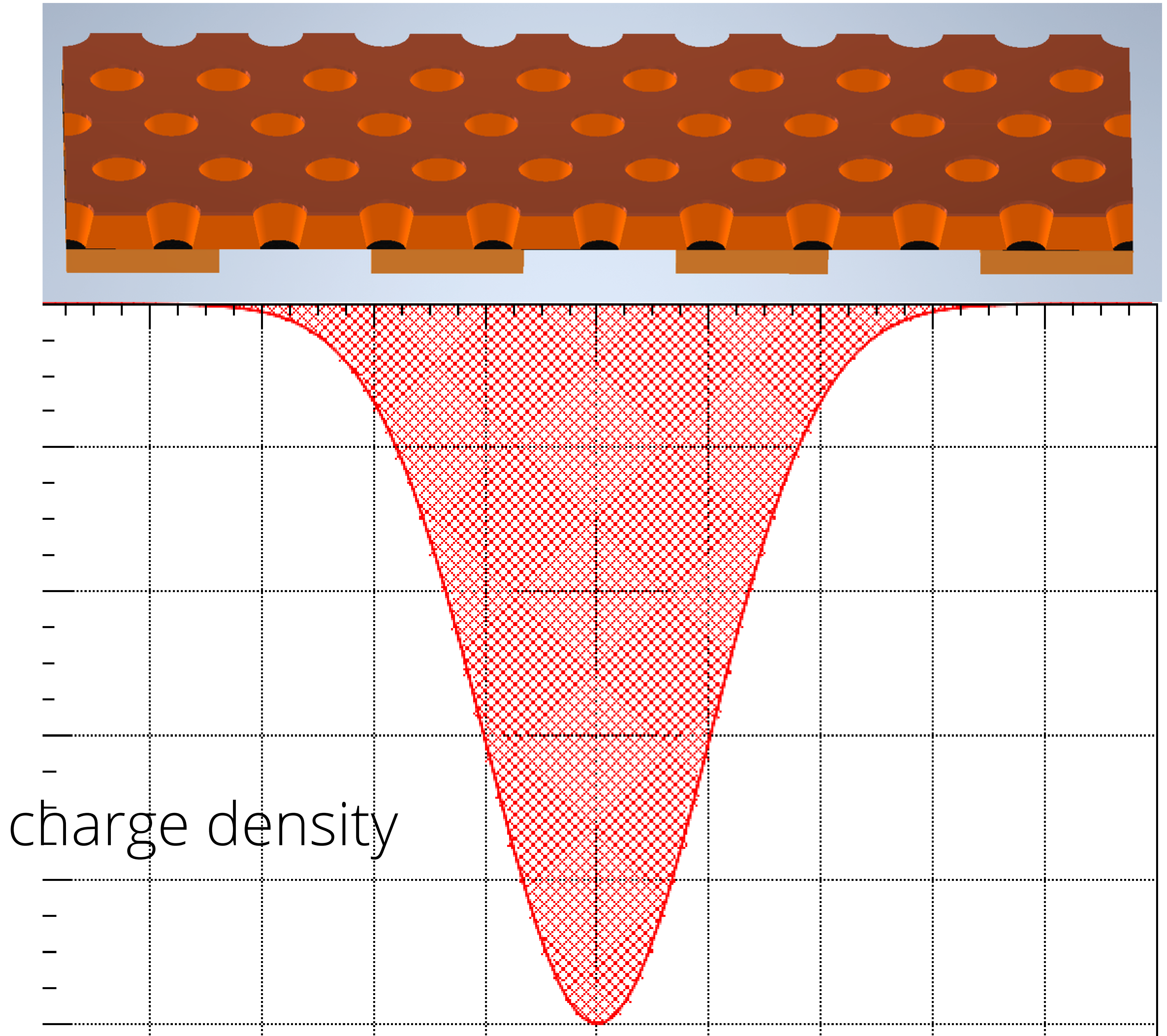
Optimization on-going on reducing input strip capacitance

Few Options:

- pitch to 1-1.2mm but an increasing number of channels -> to keep low-cost necessary TIGER ASIC

- narrower strips but to understand the charge collection -> to see signals low threshold TIGER ASIC

The spread of the charge on the resistive layer has been described by M. S. Dixit, A. Rankin, NIM A 518 (2004) 721-727, NIM A 566 (2006) 281-285




$$\rho(x,y,t) = \frac{Nq_e}{2\pi\left(2ht + w^2\right)} exp\left[-\left(x^2+y^2\right)/\left(2\left(2ht+w^2\right)\right)\right]$$

$$\rho(x,t) = \frac{q}{\sqrt{2\pi}\left[\sigma_0\left(1+\frac{t-t_0}{\tau}\right)\right]} exp\left[-\frac{\left(x-x_0\right)^2}{2\sigma_0^2\left(1+\frac{t-t_0}{\tau}\right)^2}\right]\Theta\left(t-t_0\right)$$

- q the charge produced in an avalanche
- x0 the position of the primary electron entering the amplification stage
- σ0 a theoretical charge space extension of the avalanche
- t0 the starting time of the track
- τ the decay time of the charge density due to the electrons movement towards the ground on the resistive surface.

τ is the parameter to be tuned

# TB full dataset

Optimization S/N vs HV resistor filter

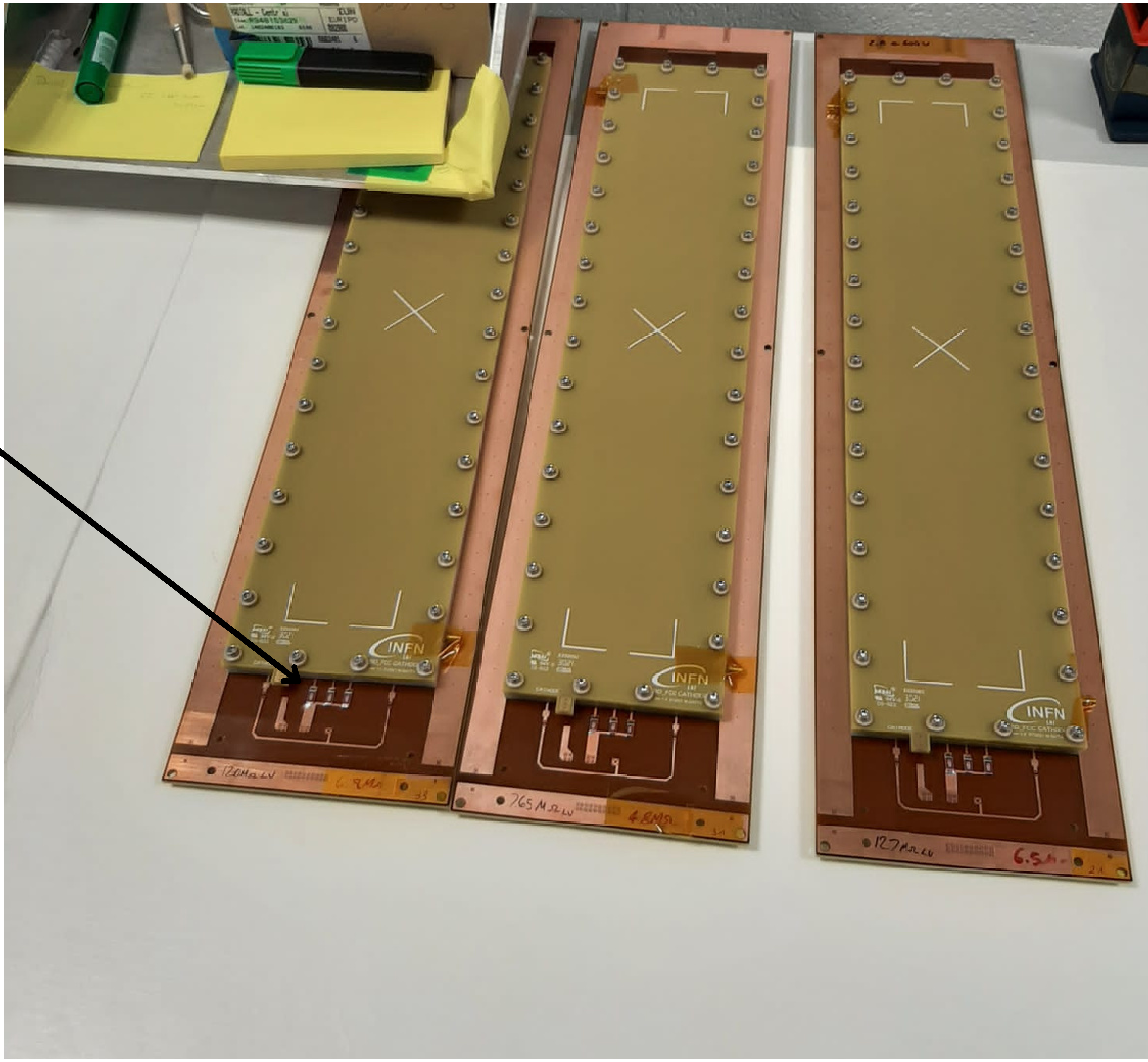
HV scan 0° - for trackers & test chambers

HV Scan 40° for test chambers

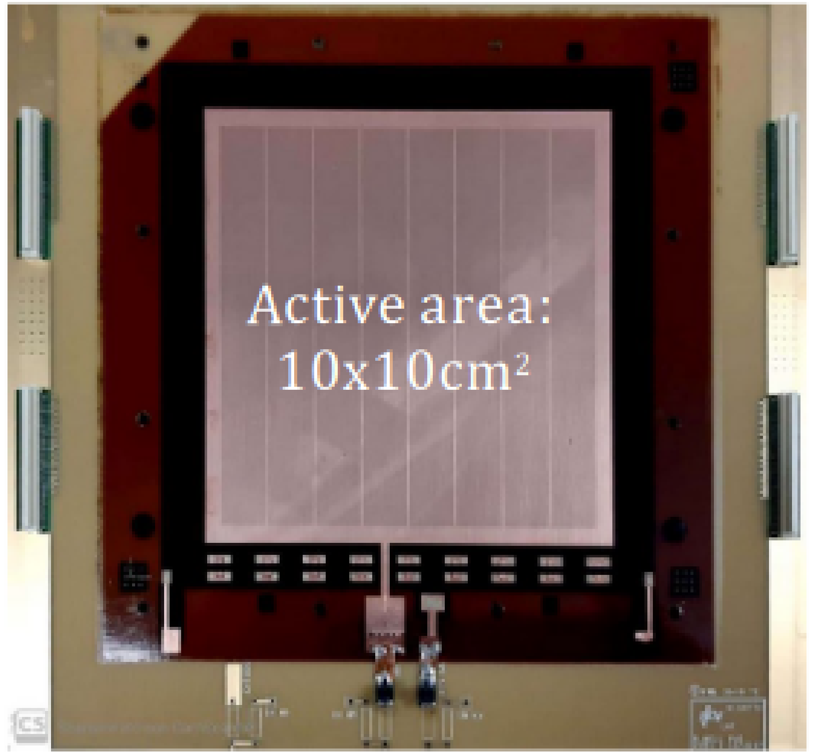
Angle scan [ 0,10,20,30,40 ]° test chambers

Drift filed 0.5 kV, HV and angle scan

Drift field scan 0°



# Detector Comparison





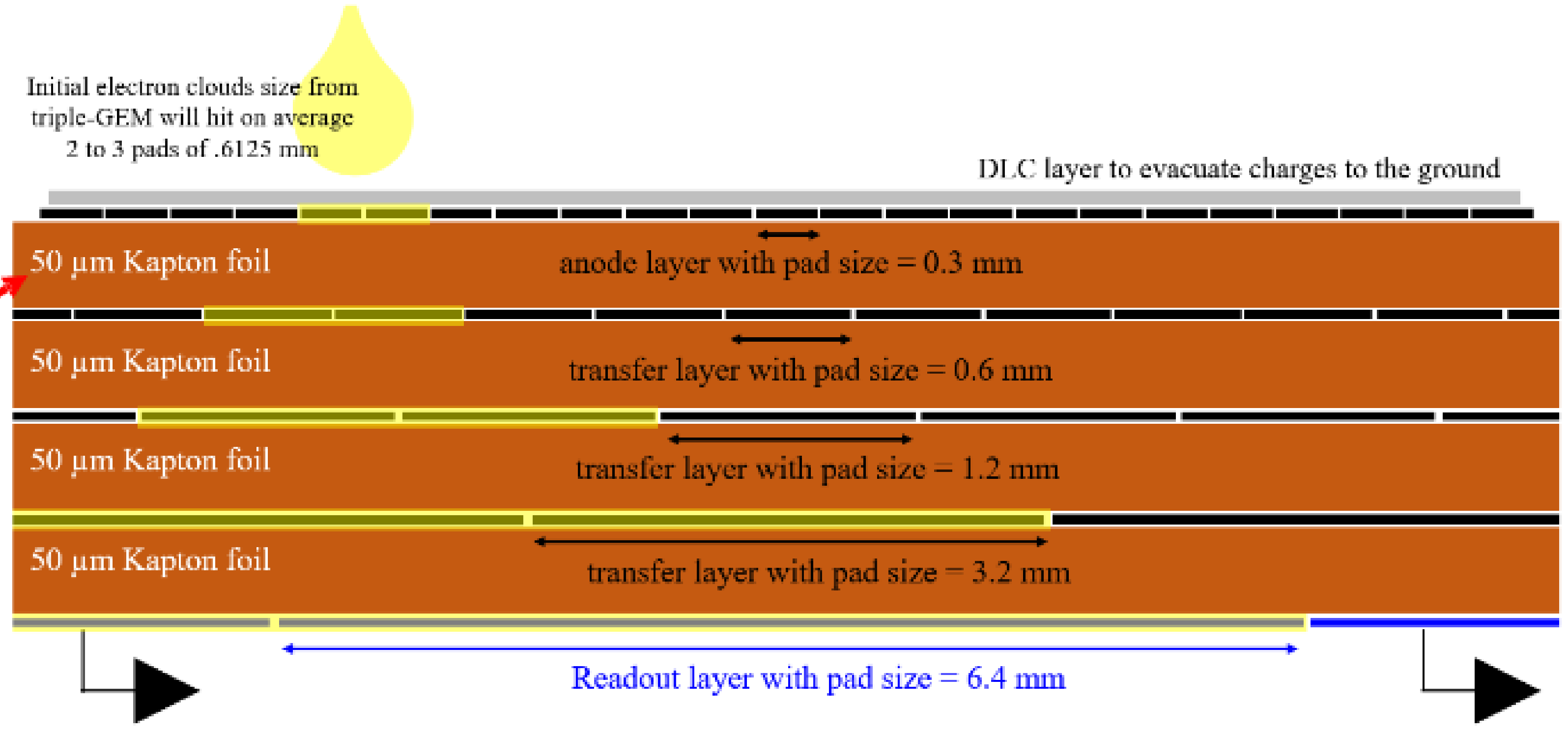
| μ-RWELL trackers | | μ-RWELL test | FEE signal |
|---|---|---|---|
| $10x10cm^2$ | Active area | $5x40cm^2$ | |
| 300μm / 400μm / 10cm | Strip width/pitch/lenght | 150μm / 400μm / 40cm | ÷ 2 |
| 100μm | Strip distance from DLC | 50μm | × 2 |
| Standard (70μm) | Amplification WELL diameter | Larger (to be measured) | ÷ ? |
| 30÷40MΩ/□ | DLC surface resistivity | 10÷80MΩ/□ | |

# Capacitive-sharing readout: Principe & Motivation (K.GNAVO)

**Principe of capacitive-sharing readout structures:**

- Vertical stack of pads layers ⇨ Transfer of charge from MPGD via **capacitive coupling**
- A given arrangement of the pads position from one layer to the layer underneath as well as the doubling in size of the pad pitch allows:
  - Transverse sharing of the charges between neighboring pads of the layer (i+1) from vertical charged transfer from layer (i) through capacitive coupling
  - Principle of transverse charge-sharing through capacitive coupling i.e., **capacitive- sharing** is illustrated on the cross-section sketch on the left
- The scheme preserves of the position information i.e. spatial resolution with large readout strips or pads: Goal 50 µm for 1-mm strip r/o and 150 µm for 1 $cm^2$ pad r/o
- Basic proof of concept established with **800 µm** X-Y strip

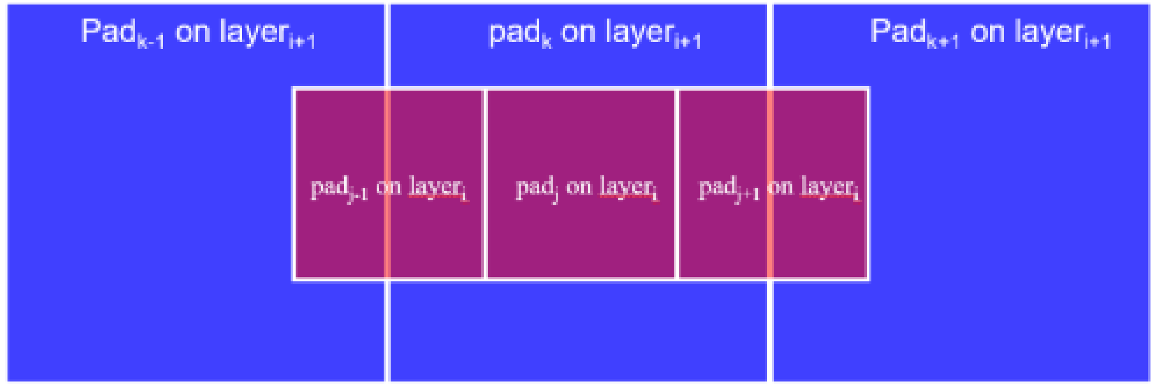
**Cross section of capacitive-sharing pad readout with 6.4 mm × 6.4 mm pads**




**Motivation & some key facts of capacitive-sharing readout:**

- Develop high performance & low channel count readout structures for MPGDs:
- Reduce the number of readout electronic channels for large area MPGDs
- Low-cost technology for large area ⇨ standard PCB fabrication techniques

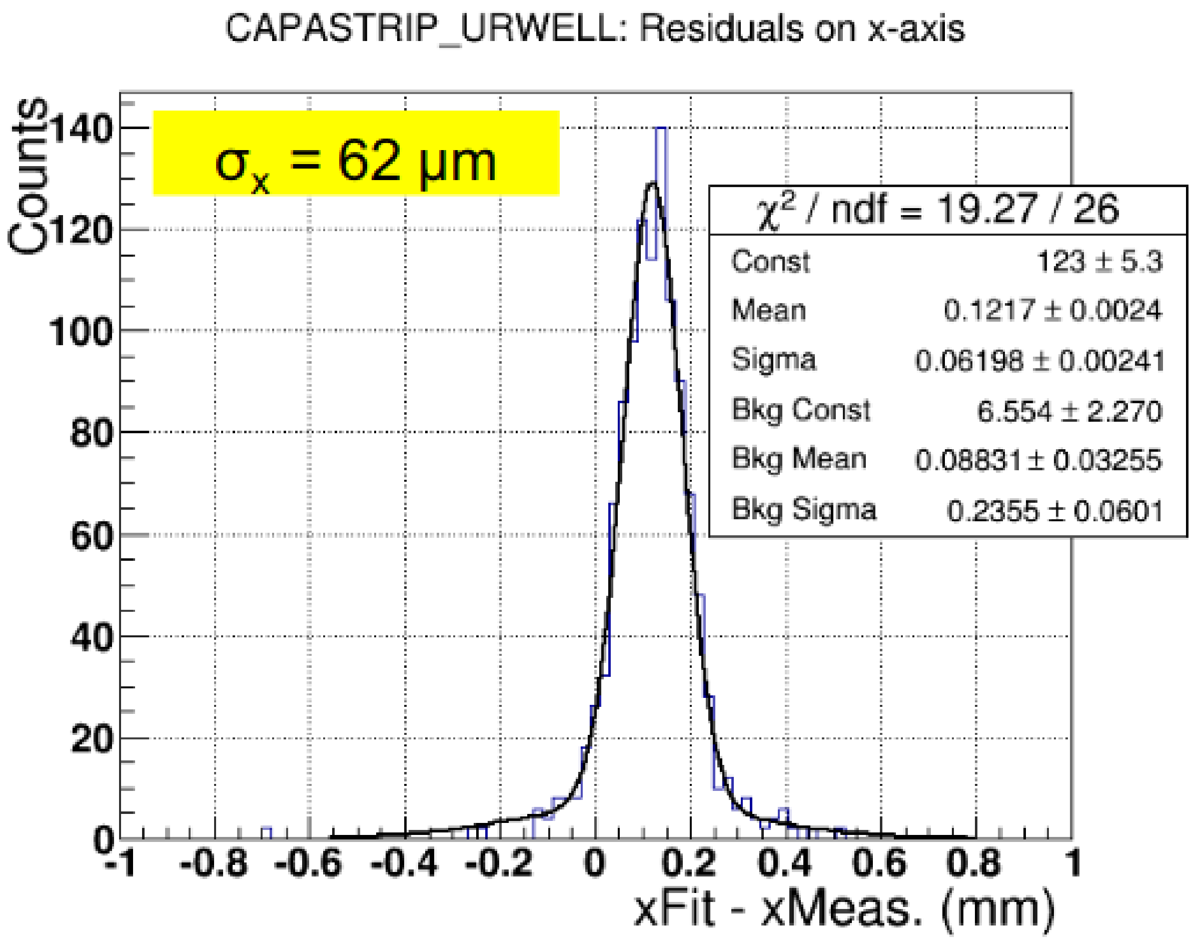
**Top view of two pad-sharing layers**

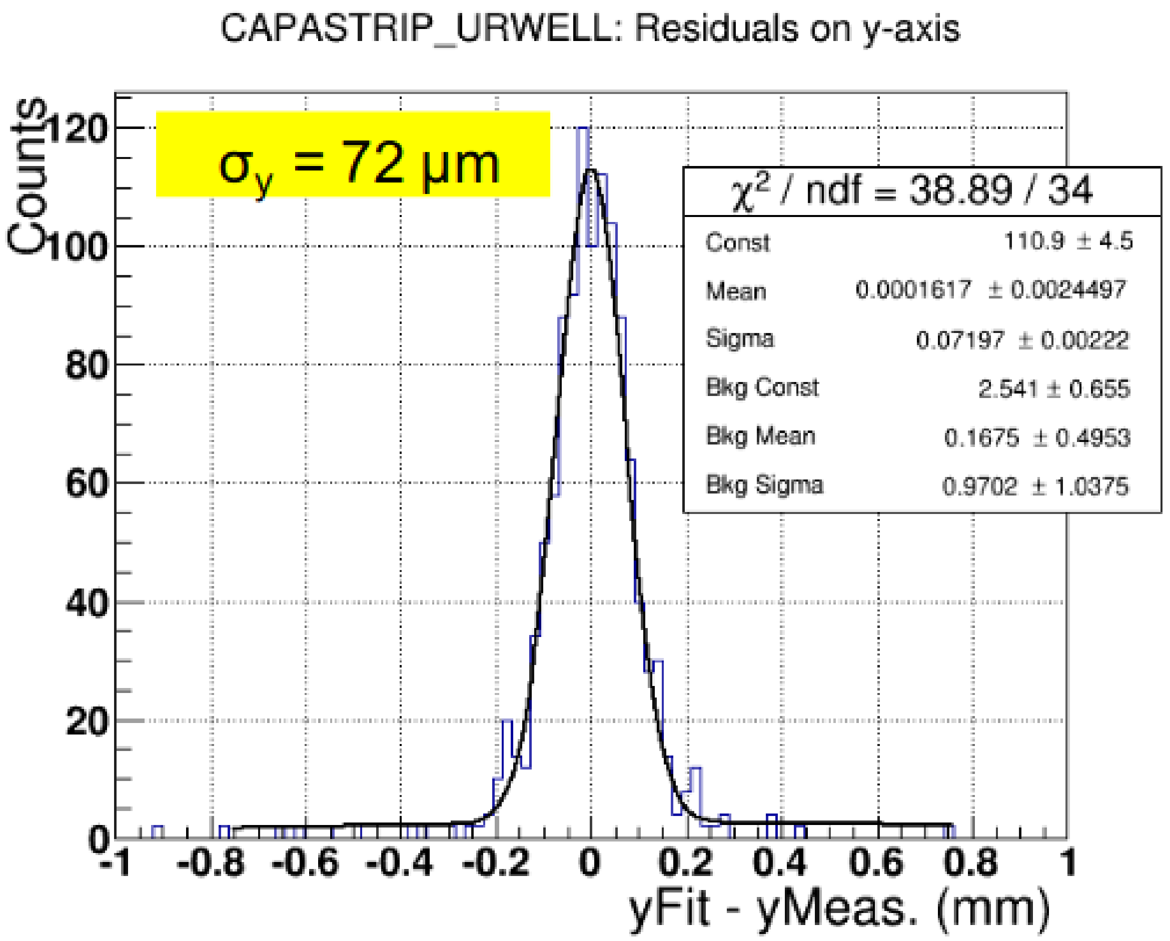


# Capacitive-sharing **X-Y strip** readout: µRWELL prototype

10 cm × 10 cm µRWELL with capacitive-sharing 2D strip readout

- Pitch is 800 µm ➔ twice COMPASS readout strip design
- X-strip and Y-strips on two separate layers with No connecting vias ➔ Easy fabrication for large area, low-mass capability
- Strip parameters: top strip (y-strips) = 250 µm, bot strip (x-strips): 750 um × 500 µm ➔ require tuning for equal charge sharing
  - Top and bottom strip area overlap minimized by design to minimize cross talk and capacitance etc …
- 3 capacitive-sharing pad layers with: 200 µm, 400 µm and 800 µm pad size respectively
- Tested in electron beam in Hall D @ JLab (Sept-Oct 2021)




capaSh-XY-Strip uRWELL