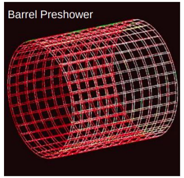
SECOND • ECFA • WORKSHOP
on e^+e^- Higgs / Electroweak / Top Factories

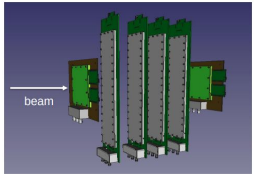
R&D on muon detectors for the IDEA experiment

R. Farinelli
on behalf of INFN-RD_FCC Muon group

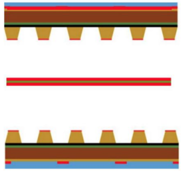
Outline



IDEA, pre-shower and muon chamber



μ-RWELL technology and and its spread in the HEP



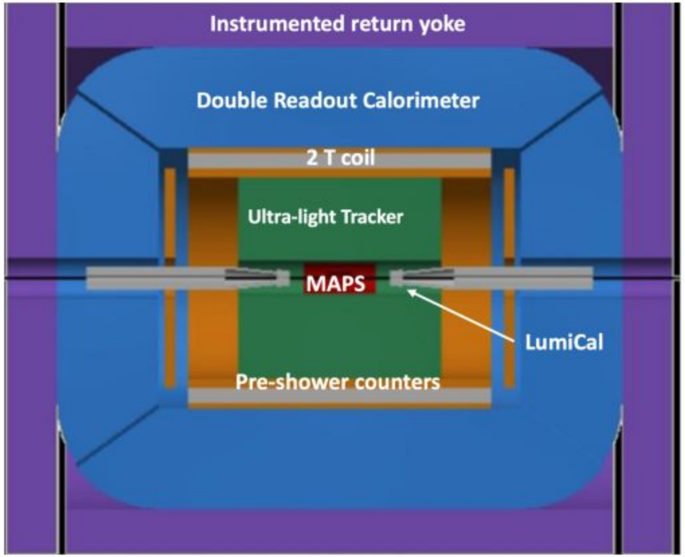
Optimization for IDEA

IDEA detector

Innovative **D**etector for **E**lectron-positron **A**ccelerators

Combining novel elements with past and present lepton colliders, the FCC-ee design achieves outstandingly high luminosity.

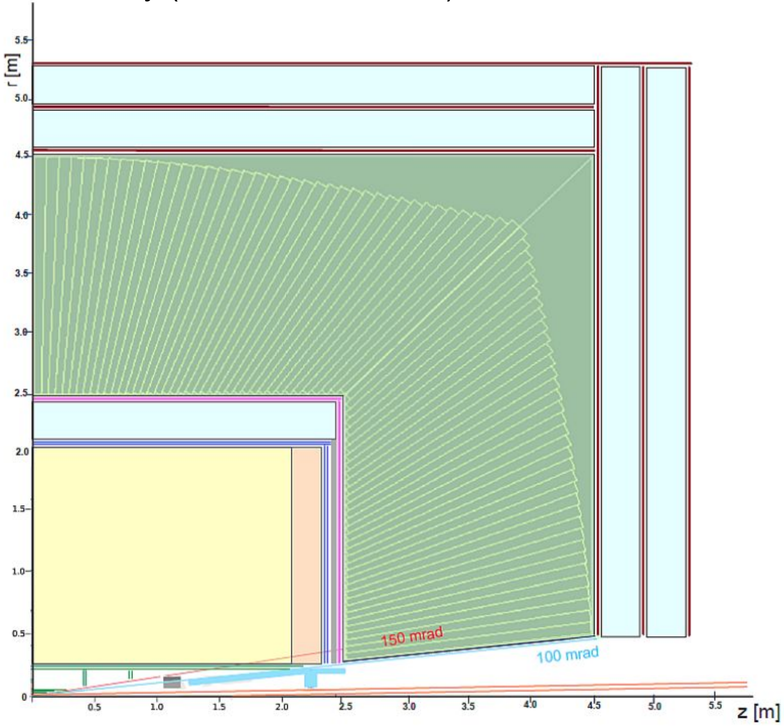
This will make the FCC-ee an instrument to study the heaviest known particles (Z, W and H bosons and the top quark) to improve the precision measurement in literature and the sensitivity to new physics.



IDEA baseline detector concept

Here is shown the original concept but some update/upgrade are under study (i.e. EM calorimeter)

- drift chamber
- drift chamber service area
- magnet and iron return yoke
- calorimeter
- Si pixels: 20μm×20μm (inner barrel layers), 50μm×1mm (outer barrel layers), 50μm×50μm (forward disks)
- Si strips double stereo layer 50μm×10cm
- μRwell double layer 0.4mm×50cm
- μRwell double layer 1.5mm×50cm
- absorber (lead)
- luminometer
- steel simulating compensating and shielding solenoids
- vacuum tube



The IDEA pre-shower

R. Aly, et., Nucl.Instrum.Meth.A 958 (2020) 162088

High resolution after the magnet to improve cluster reconstruction

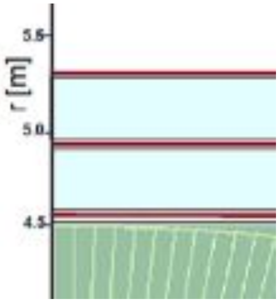
Efficiency > 98%
Space Resolution < 100 μm
Mass production
Optimization of FEE channels/cost

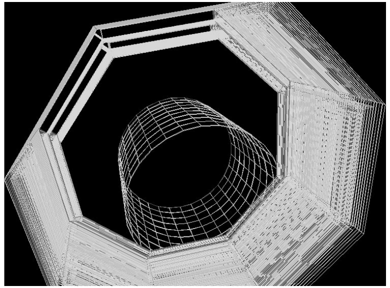
50x50 cm^2 2D tiles
to cover about **130 m^2**

pitch = 0.4 mm
FEE capacitance = 70 pF
1.3 million channels

A first testbeam to explore the interplay between preshower and calorimeter

The IDEA muon detector





Reconstruct and tag the muon with three layers in between the iron return yoke

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

50x50 cm^2 2D tiles
to cover about **1525 m^2**

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

µ-RWELL technology and its spread in the HEP

μ-RWELL technology

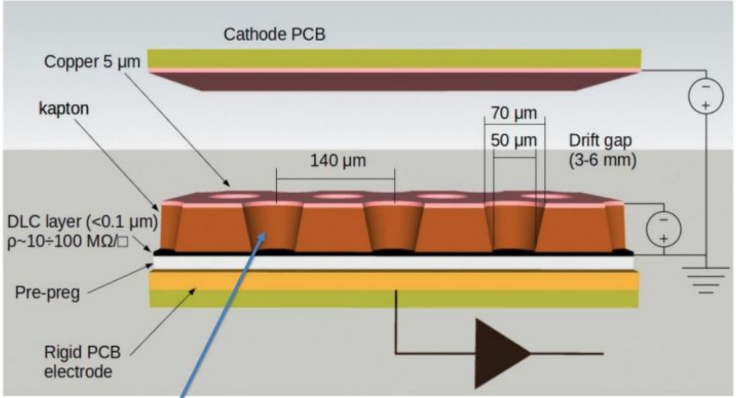
G. Bencivenni et al., 2015 JINST 10 P02008

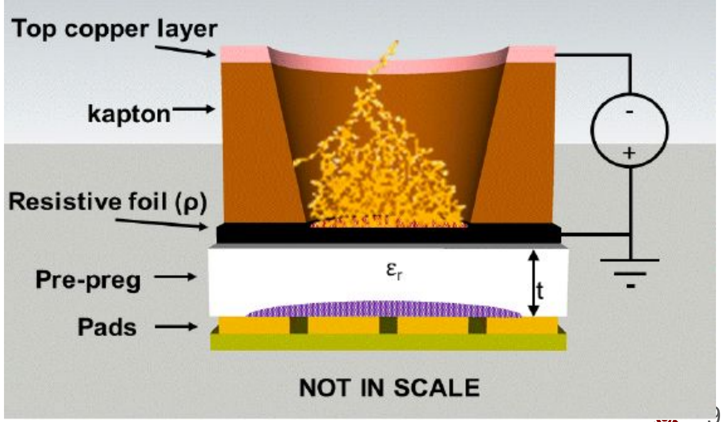
The μ-RWELL is composed of only **two elements**:

- **μ-RWELL_PCB** = amplification-stage ⊕ resistive stage ⊕ readout PCB
- **cathode** defining the gas gap

μ-RWELL **operation**:

1. A charged particle **ionizes** the gas between the two detector elements
2. Primary electrons **drift** towards the μ -RWELL_PCB (anode) where they are **multiplied**, while ions drift to the cathode or to the PCB TOP
3. The signal is **induced** capacitively, through the DLC layer, to the readout PCB
4. only two HV for the drift region (cathode-drift wrt PCB TOP) and the amplification region (PCB TOP wrt resistive stage)



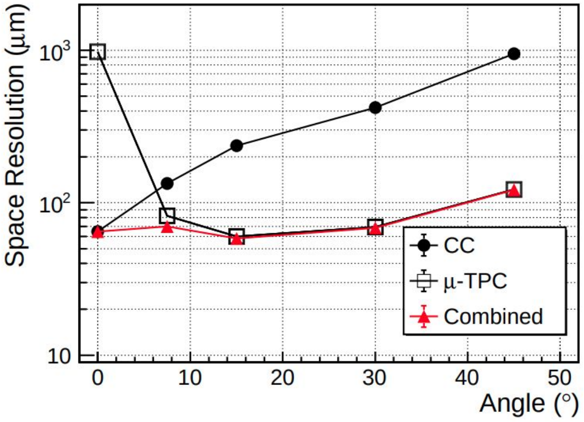


μ-RWELL technology

G. Bencivenni et al., JINST 16 (2021) 08, P08036

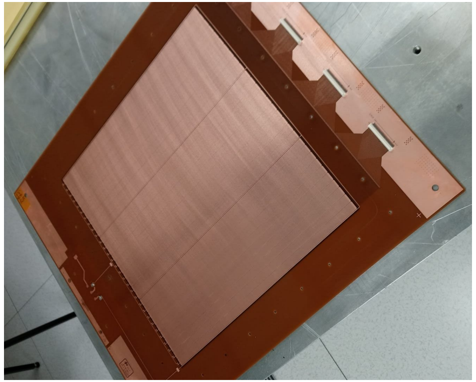
Well **known performance** on prototypes 10x10 cm^2 active area:

efficiency > 98%
spatial resolution < 100μm
rate capability ~ 1-10 MHz/cm^2



The detector is build up by two "pieces" only.
This simplifies the construction, the assembly and the HV operation wrt MicroMegas and triple-GEM

The μRWELL technology fully compatible with standard PCB building procedures **allows an easy Technological Transfer** to industry, opening the way towards industrial **mass production**.

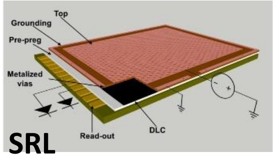


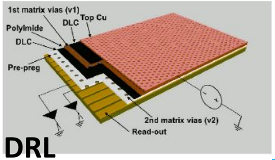
μ.RWELL R&D history

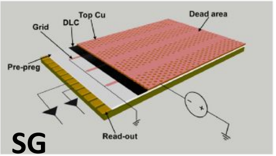
R&D on low-rate layout

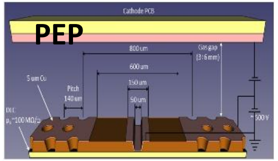
R&D on high-rate layout

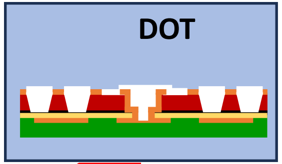
New μ-RWELL ideas (in collaboration with RD51)







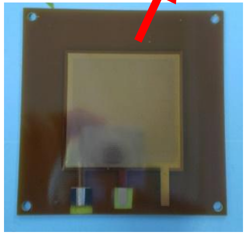




R&D start

TT @ ELTOS

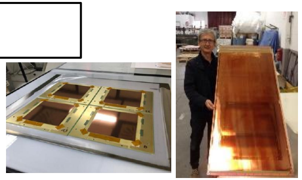
2009 — 2014 — 2015 — 2016 — 2017 — 2018 — 2019 — 2020 — 2021 — 2022 — 2023



TB @ CERN

TB @ high rate @ PSI

TB @ CERN

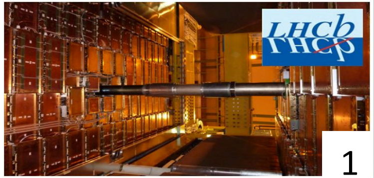


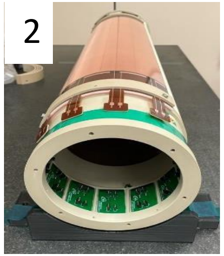
TT @ ELTOS

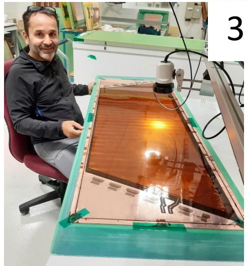
μ-RWELL technology spread

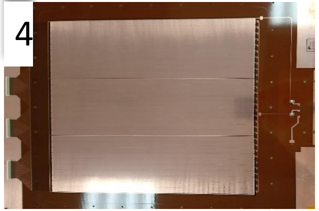
The micro-Resistive WELL is involved in

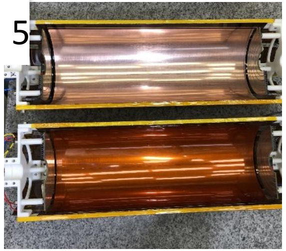
1. **LHCb @ CERN:** the upgrade of the muon system
2. **EURIZON project for Super Charm Tau factory:** low material budget inner tracker
3. **CLASS12 @ JLAB:** the upgrade of the muon spectrometer
4. **X17 @ n_TOF EAR2**: for the amplification stage of a TPC dedicated to the detection of the X17 boson
5. **TACTIC @ YORK Univ.:** radial TPC for detection of nuclear reactions with astrophysical significance
6. **Muon collider:** hadron calorimeter
7. **CMD3:** uRWELL Disk for the upgrade of the tracking system
8. **URANIA-V**: a project funded by CSN5 for neutron detection, an ideal spin-off of the EU-founded ATTRACT-URANIA
9. **UKRI:** neutron detection with pressurized ^{3}He-based gas mixtures
10. **EIC @ Brookhaven Nat. Lab:** detector tracker stations

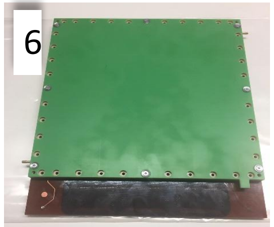

1

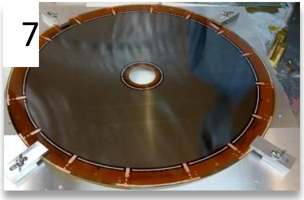

2

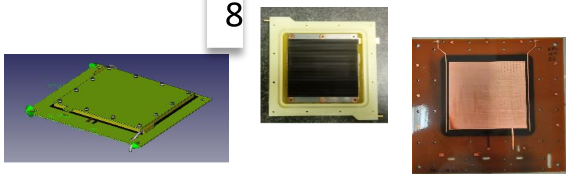

3

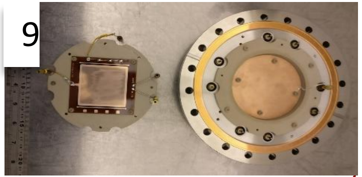

4


5


6

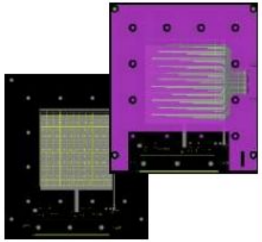

7


8


9

µ-RWELL Technology Transfer

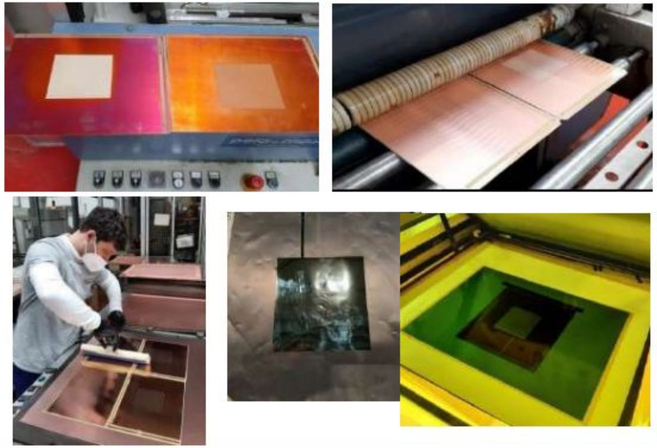
LAYOUT design



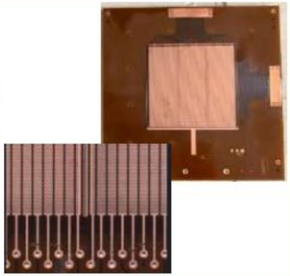
Feedback from tests

synergic

PCB production



Final detector manufacturing



DLC foil production (*)

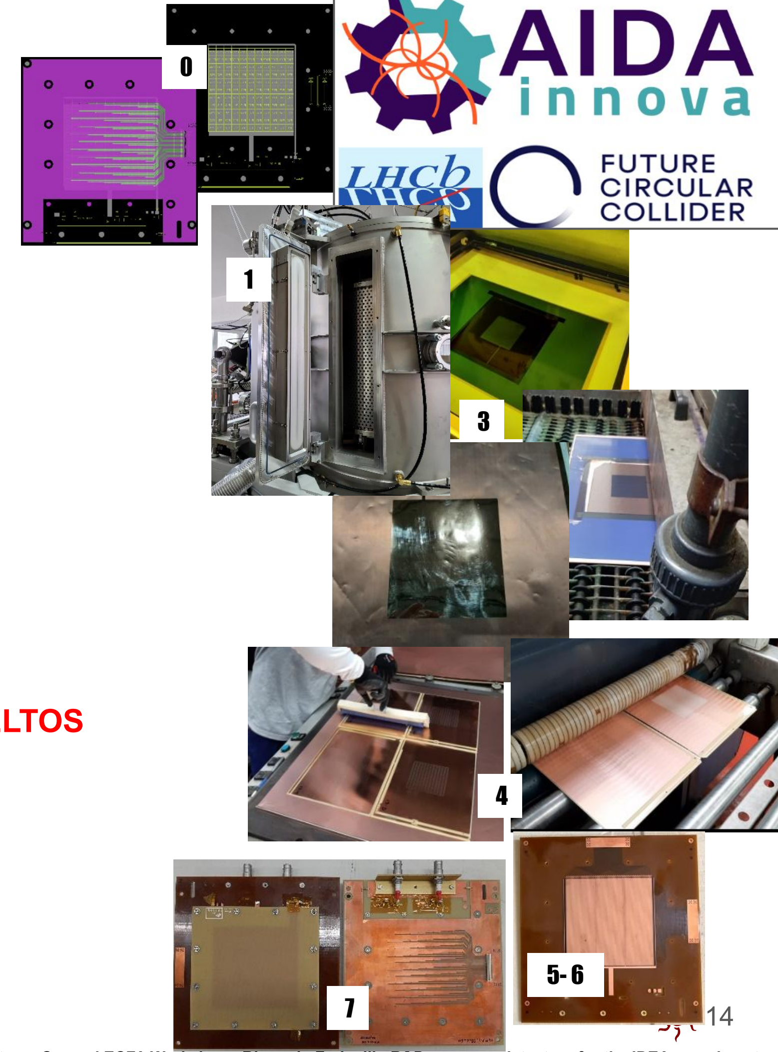
*DLC Magnetron Sputtering machine
co-funded by INFN- CSN1
R&D by INFN LNF, RM3, NA

R&D by INFN-LNF
AIDAinnova Task 7.3.2

μ-RWELL Technology Transfer

Step 0 - Detector PCB design	LNF
Step 1 - DLC sputtering machine	CERN (+INFN)
Step 2- Producing readout PCB	ELTOS
Step 3 - DLC patterning	CERN → ELTOS
Step 4 - DLC foil gluing on PCB	CERN → ELTOS
Step 5 - Top copper patterning	CERN → ELTOS
Step 6 - Amplification stage patterning	CERN
Step 7 – Electrical cleaning and closing	CERN

today

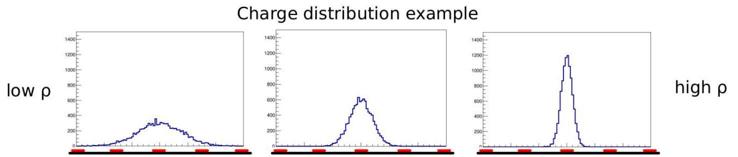


INFN

μ-RWELL R&D

- optimization of 1D cell segmentation
- optimization of DLC resistivity
- test of 2D layout

Detector optimization - Resistivity



The use of **low resistivity** increases the charge spread (cluster size) on the readout strips and then spatial resolution is affected by the electronic noise.

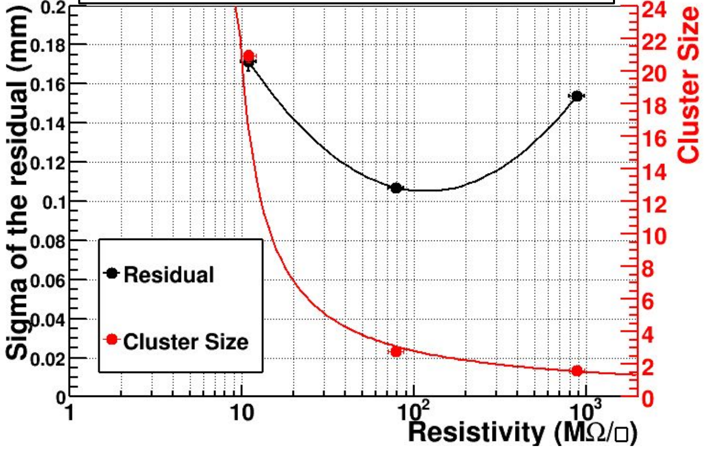
At **high resistivity** the charge spread is too small (Cl.size ~1) then the Charge Centroid method becomes no more effective (σ~ pitch/12).

Preshower -> reduce the resistivity to reduce the cluster size, keeping the same spatial resolution

Muon chamber -> reduce the number of channel matching the cluster size (resistivity) with a larger pitch (1.5 mm)

The collected measurement have been used to tune the detector simulation.

G. Bencivenni et al., NIM A 886 (2018) 36



Experimental measurements - Resistivity

Goal:

Characterize the μ-RWELL signal shape (charge and multiplicity) as a function of the resistivity

Resistivity range under test: 10-80 MΩ/□

Setup:

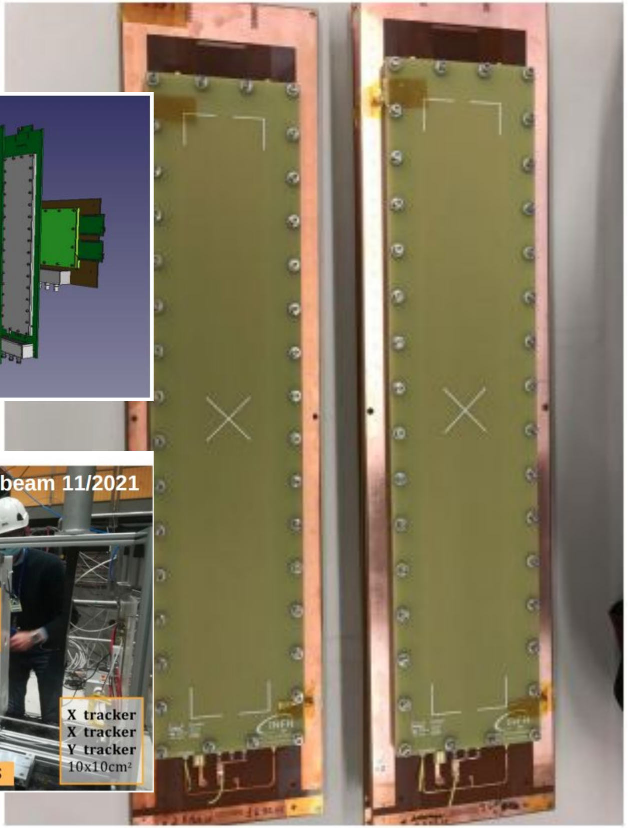
Active area: 5 x 40 cm2
Strip length: 40 cm (close to 50cm)
FEE capacitance ~ 50 pF
6 detector for tracking, event selection and alignments
5 DUTs

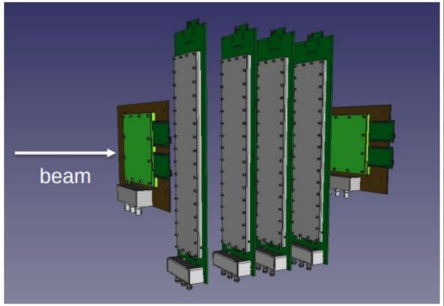
Settings:

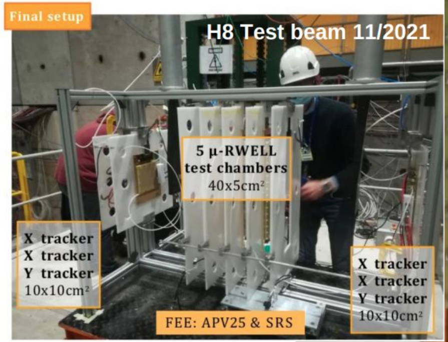
Gas mixtures: Ar/CO2/CF4 (45:15:40)
Electronics: APV25 + SRS
Beam: muons w/ 140-180 GeV/c

Measurements:

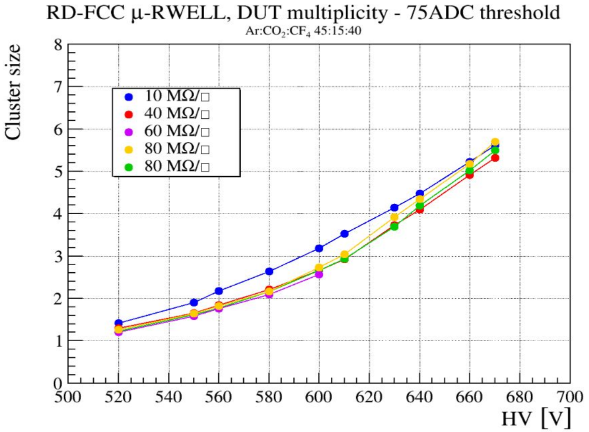
1. HV scan
2. Impinging angle scan
3. Drift field scan

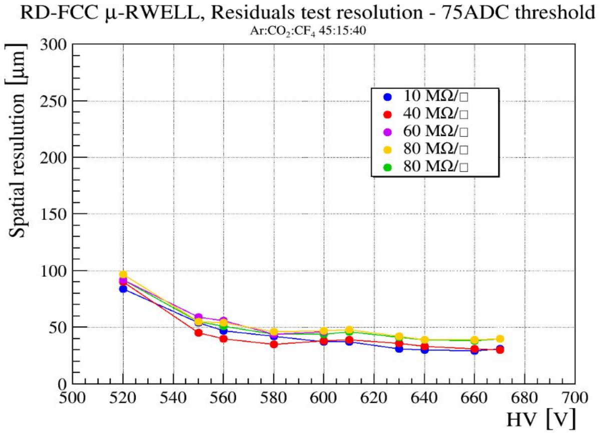


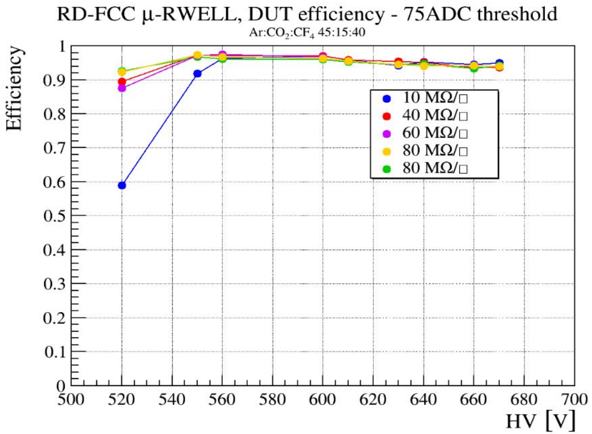




Scan results - Resistivity







An **HV scan** shows a large range of operability with a cluster size range [1-5].
The core spatial resolution is better than 50 μm with a strip pitch of 400 μm and center of gravity algorithm.

The **dependence** on the DLC **resistivity** is smaller in the range 40-80 MΩ/□ for cluster charge and cluster size, while the major dependency are observed in the efficiency.

Experimental measurements - Strip pitch

Goal:

Characterize the μ-RWELL signal shape (charge and multiplicity) as a function of the pitch

Strip pitch range under test: 0.4-1.6 mm

Setup:

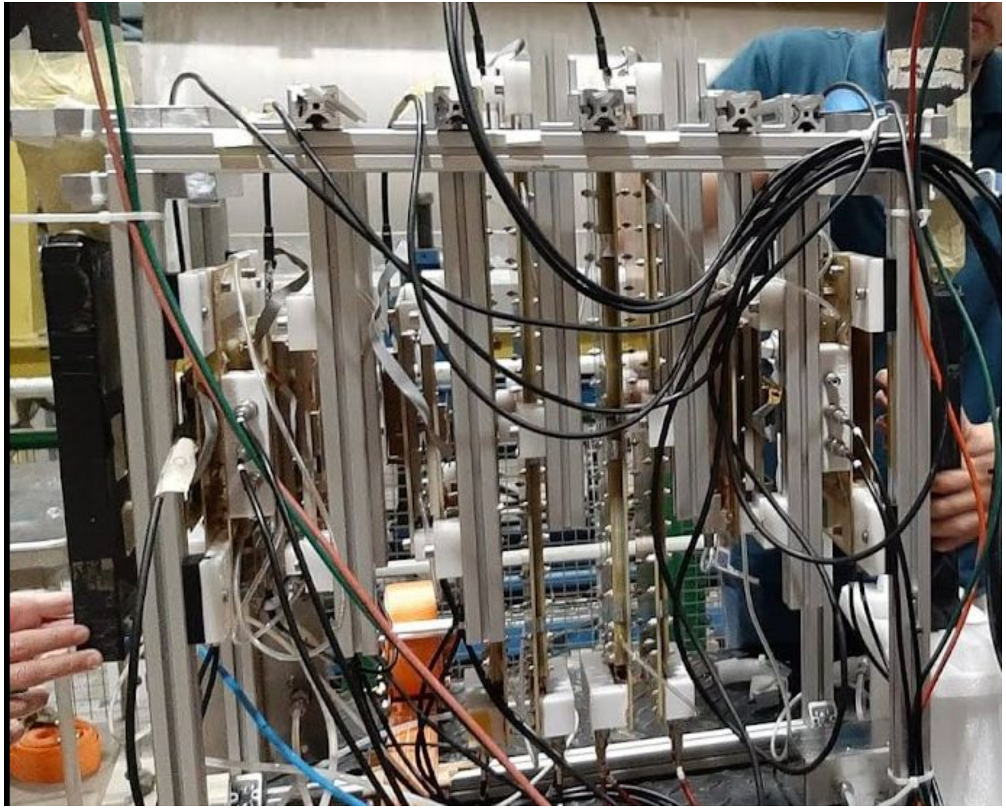
Active area: 10 x 10 cm2
4 detector for tracking, event selection and alignments
4 DUTs X with strip pitch from 400μm to 1.6 mm

Settings:

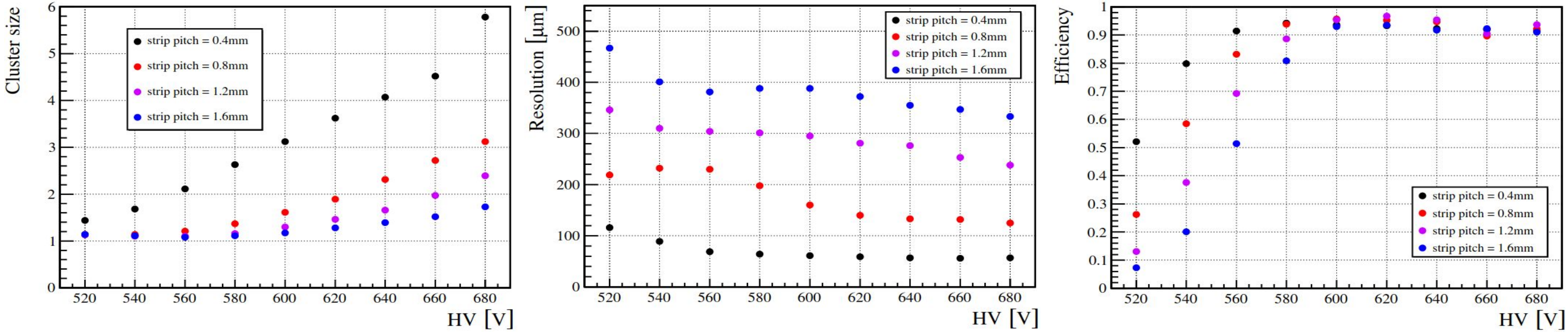
Gas mixtures: Ar/CO_2/CF_4 (45:15:40)
Electronics: APV25 + SRS
Beam: muons w/ 140-180 GeV/c

Measurements:

1. HV scan
2. Drift field scan



Scan results - Strip pitch



An **HV scan** shows a large impact of the strip pitch in the detector performance.
The smaller is the pitch, the better is the position reconstruction.
The larger is the pitch, the smaller is the number of readout channels then the detector cost
but the strip capacitance increases then its noise too.

A spatial resolution better than 400 μm is granted in each configuration studied.

Experimental measurements - 2D readout

Goal:

Characterize the μ-RWELL with bi-dimension readout

Setup:

Active area: 10 x 10 cm2

4 detector for tracking, event selection and alignments

1 DUTs XY “TOP readout”

2 DUT XY “charge sharing readout”

Settings:

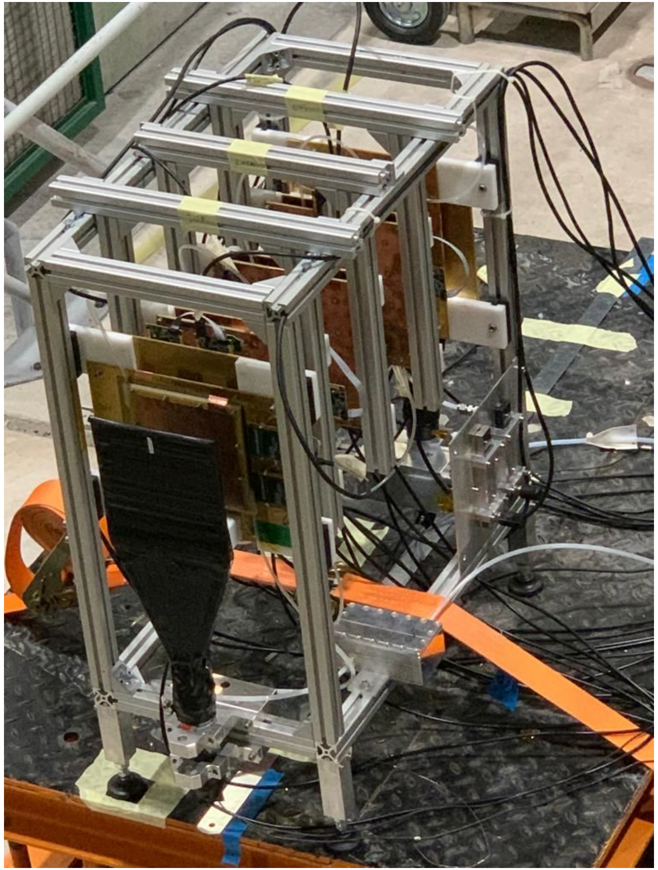
Gas mixtures: Ar/CO2/CF4 (45:15:40)

Electronics: APV25 + SRS

Beam: muons w/ 140-180 GeV/c

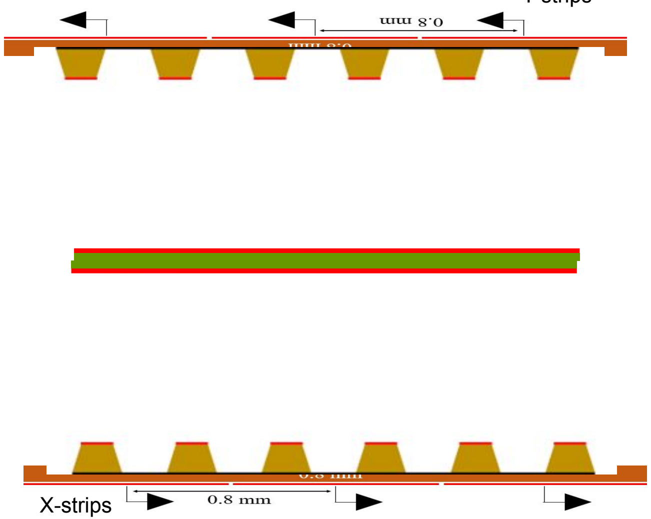
Measurements:

1. HV scan
2. Drift field scan

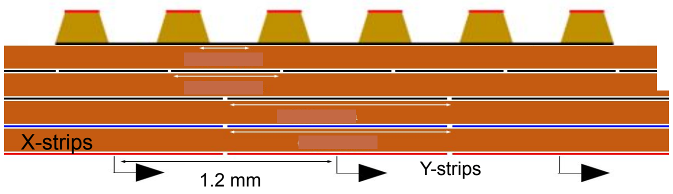


Experimental measurements - 2D readout

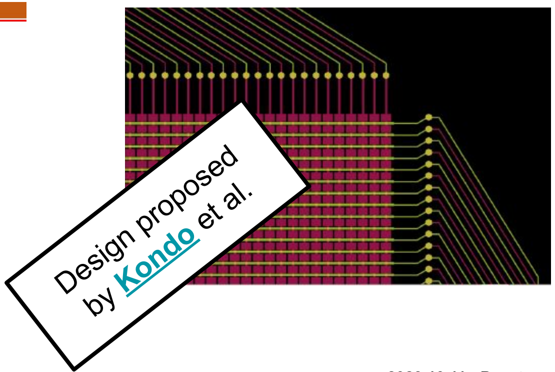
μ-RWELL 2x1D



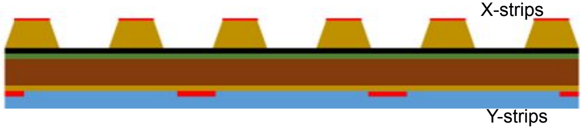
μ-RWELL 2D (Charge Sharing r/o)



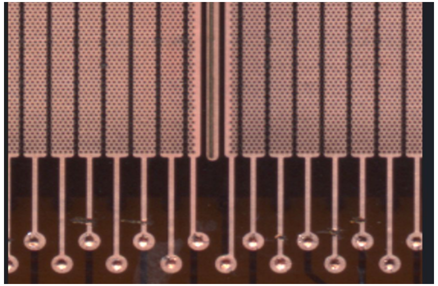
CS Readout board



μ-RWELL 2D (TOP r/o)



X coordinate on the TOP of the amplification stage



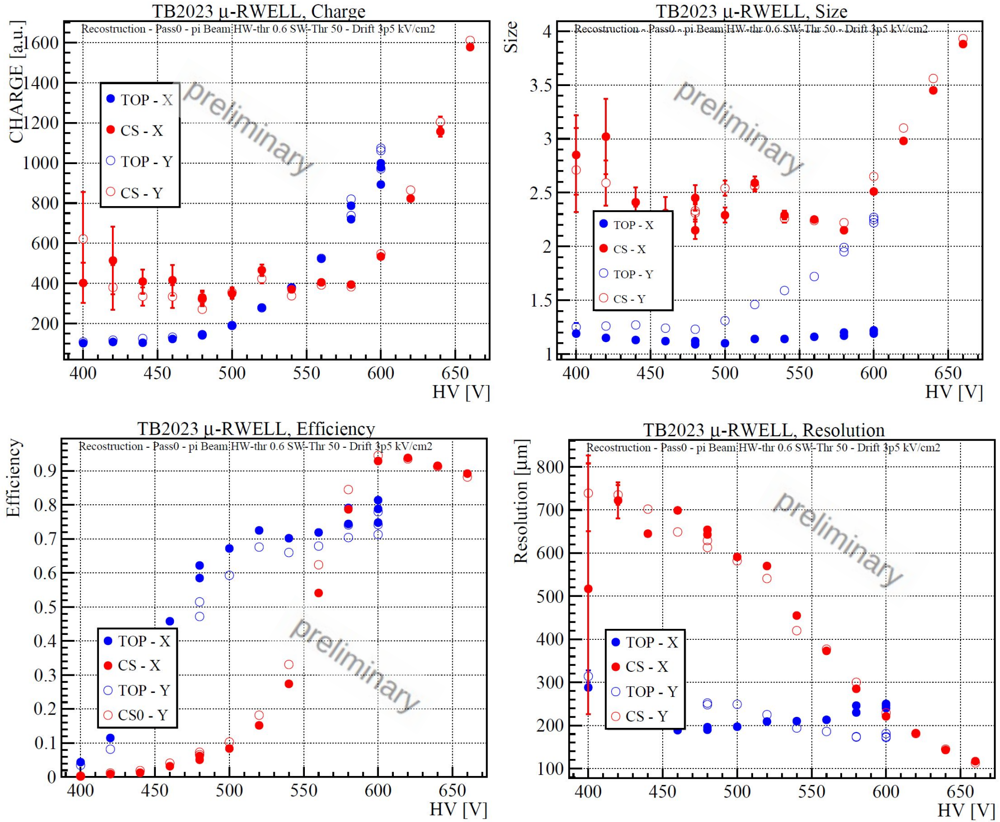
Scan results - 2D readout

TOP r/o does not share the signal charge between X and Y. On the X (TOP) its cluster size is fixed and the spatial resolution is digital; while on the Y it has a standard behavior and thanks to the charge diffusion (DLC) the spatial resolution improves with the gain.

TOP r/o reaches the efficiency plateau at lower HV values but it is affected by the segmentation of the TOP.

CS r/o shares the signal charge between X and Y. The charge sharing mechanics works properly and it increases the cluster size up o 4; this improves the spatial resolution up to 100 µm.

CS r/o reaches the efficiency > 95%.



Further activities

Parametrization of a μ-RWELL

Dixit et al.

- Ionization
- Electron Drift
- Amplification
- **Resistive**
- Induction
- Readout
- Reco

Reading from the webpage https://garfieldpp.web.cern.ch

is a toolkit for the **detailed simulation of detectors which use gases** or semi-conductors as sensitive medium.

the main area of application is currently in **micropattern gaseous detectors.**

Ionisation → Heed generates ionisation patterns of fast charged particles

Electric fields → interfaces with the finite element programs (Ansys, Elmer, Comsol and CST) which can compute approximate fields in nearly arbitrary 3D configurations with dielectrics and conductors

Transport of electrons → Magboltz is used for computing electron transport and avalanches in nearly arbitrary gas mixtures

GARFIELD++ capabilities

+

More speed

Parametrization!

Simulation results

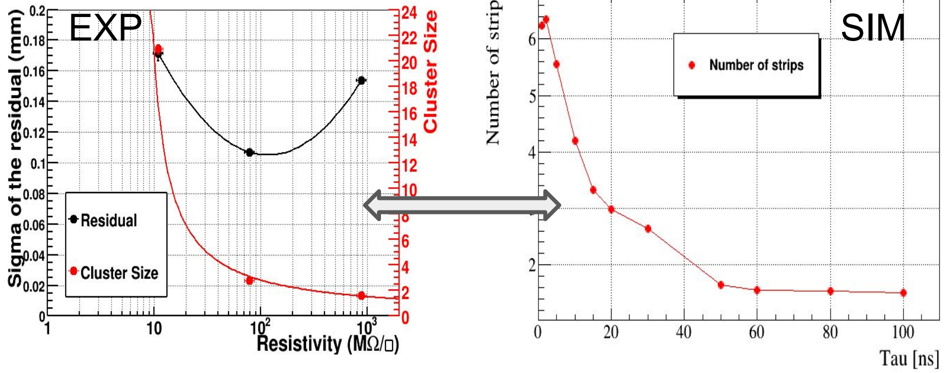
Thanks to a detector parametrization,
it is possible to reproduce the **µ-RWELL signal**.

Different **configuration** (resistivity, angle, etc…) can be tested

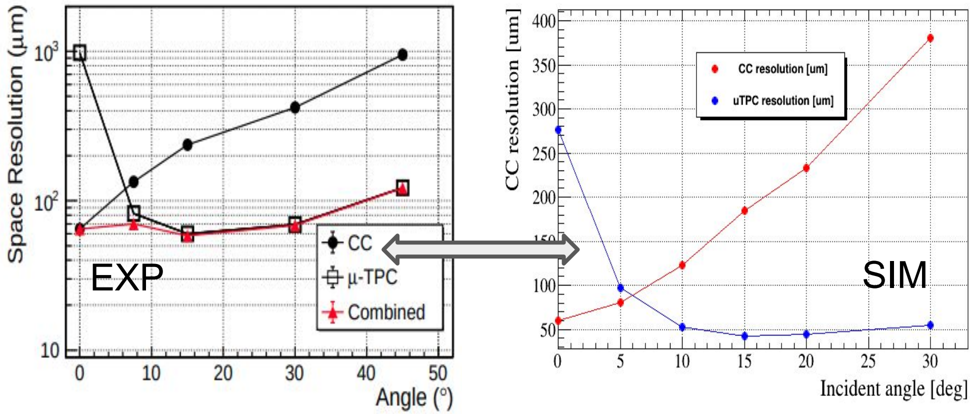
Results shows a good agreement with the experimental.

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

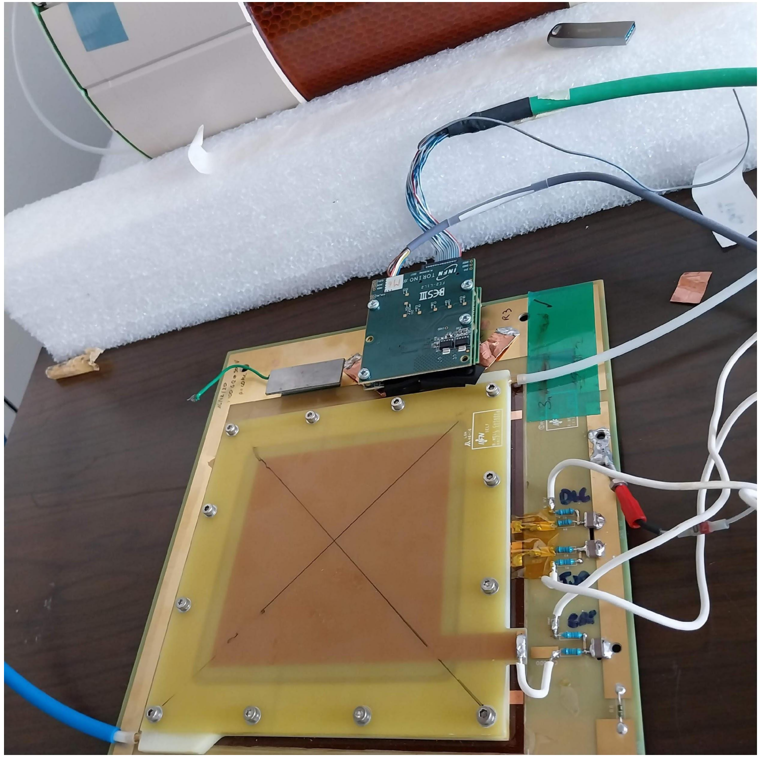
G. Bencivenni et al., NIM A 886 (2018) 36



G. Bencivenni et al., JINST 16 (2021) 08, P08036

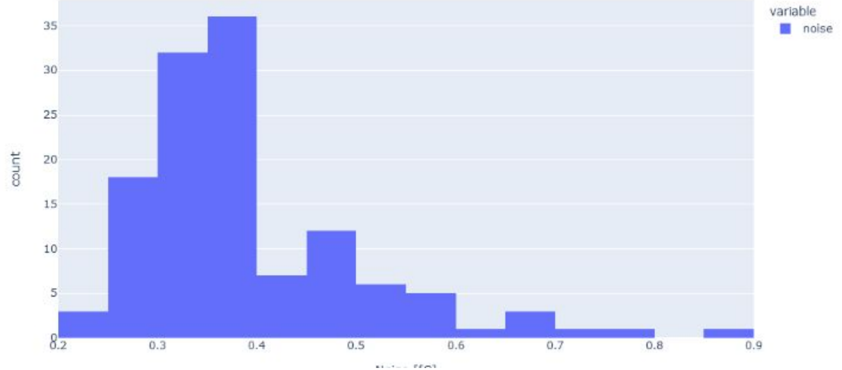


Integration μ-RWELL and TIGER



- First working setup of TIGER/GEMROC readout installed and tested with a 10x10 cm2 μ-RWELL prototype.
- Noise level very low (~1 fC)
- Cosmic setup ready

Distribution of thresholds of an entire chip (64 channels)



Conclusion

The μ-RWELL technology is under **optimization** (resistivity and pitch)
to match the IDEA **requirements** (performance and budget)

A new R&D on the **2D readout** is ongoing,
and the preliminary results suggests further investigation.

At the moment **the best 2D performance** are granted by two 1D detectors: efficiency plateau reached at lower HV values, high efficiency and stability and a spatial resolution better than 400μm as requested from IDEA.

Technological transfer of the manufacturers with external industries will open to large scale and low cost production.

F**ast simulation** of the detector and
integration with the **electronics** are ongoing.

Thank You

Bibliography

L. Pezzotti et al., Dual-Readout Calorimetry for Future Experiments Probing Fundamental Physics, FERMILAB-PUB-22-233-PPD-SCD

R.Aly et al., First test-beam results obtained with IDEA, a detector concept designed for future lepton colliders, Nucl.Instrum.Meth.A 958 (2020), 162088

G. Bencivenni et al., The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD, JINST 10 (2015) 02, P02008

G. Bencivenni et al., On the space resolution of the μ-RWELL, JINST 16 (2021) 08, P08036

G. Bencivenni et al., Performance of μ-RWELL detector vs resistivity of the resistive stage, Nucl.Instrum.Meth.A 886 (2018), 36-39

M. Giovanetti et al., AidaInnova Task 7.3.2: Industrial engineering of high-rate μ-RWELLs

A. Amoroso et al., PARSIFAL: a toolkit for triple-GEM parametrized simulation, arXiv:2005.04452

A. Amoroso et al., The CGEM-IT readout chain, JINST 16 P08065

M. Dixit et al., Simulating the charge dispersion phenomena in Micro Pattern Gas Detectors with a resistive anode, Nucl.Instrum.Meth.A 566 (2006) 281-285