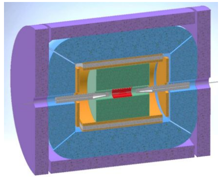
First DRD1 Collaboration Meeting
WG2: Application

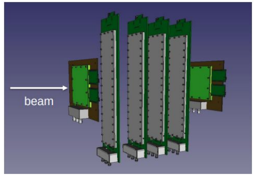
IDEA FCC Muon system with µRWELL

R. Farinelli, on behalf of INFN Bologna/Ferrara/Frascati

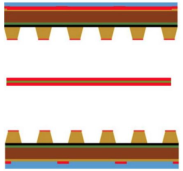
Outline



IDEA, pre-shower and muon chamber



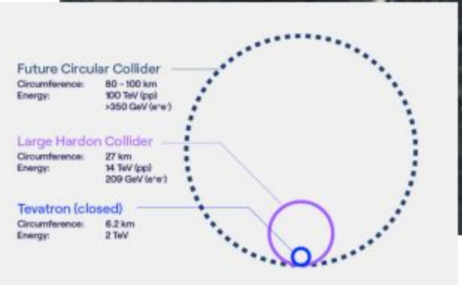
The μ-RWELL technology, measurements and **optimization**



Technological **T**ransfer and future plans

IDEA detector

Future Circular Collider @ CERN

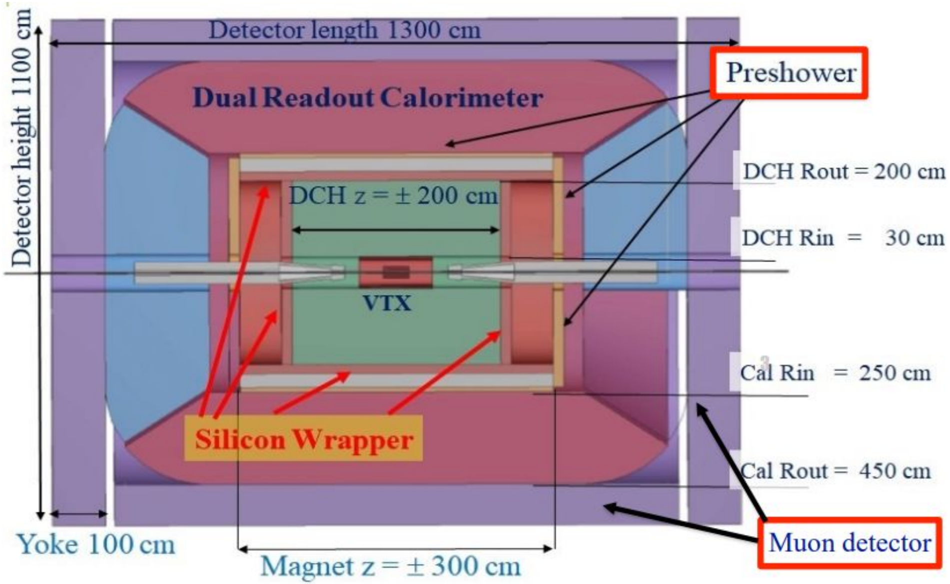


International **D**etector for **E**lectron-positron **A**ccelerators

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.

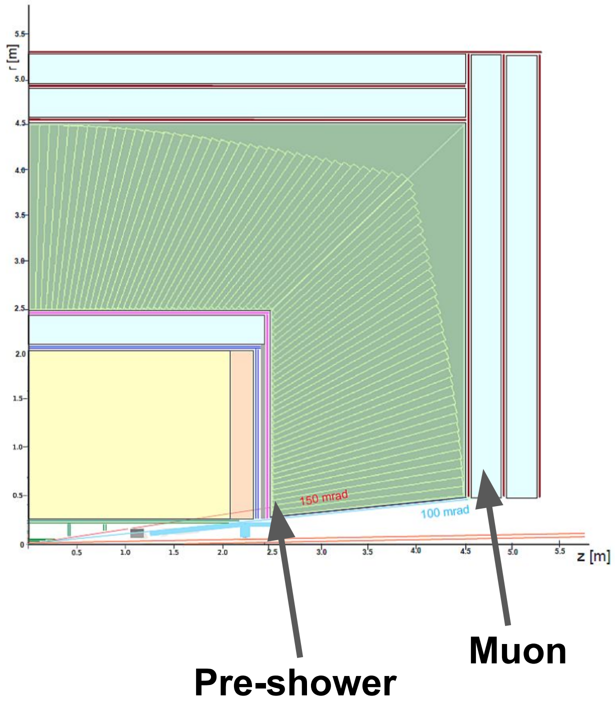
IDEA innovative, cost-effective **concept**:
- ➔ Silicon vertex detector
- ➔ Short-drift, ultra-light wire chamber
- ➔ Dual-readout calorimeter
- ➔ Thin solenoid coil inside calorimeter system
- ➔ Muon system made of 3 layers of μRWELL detectors in the return yoke



μRWELL for pre-shower and muon apparatus

Pre-shower & Muon requirements:

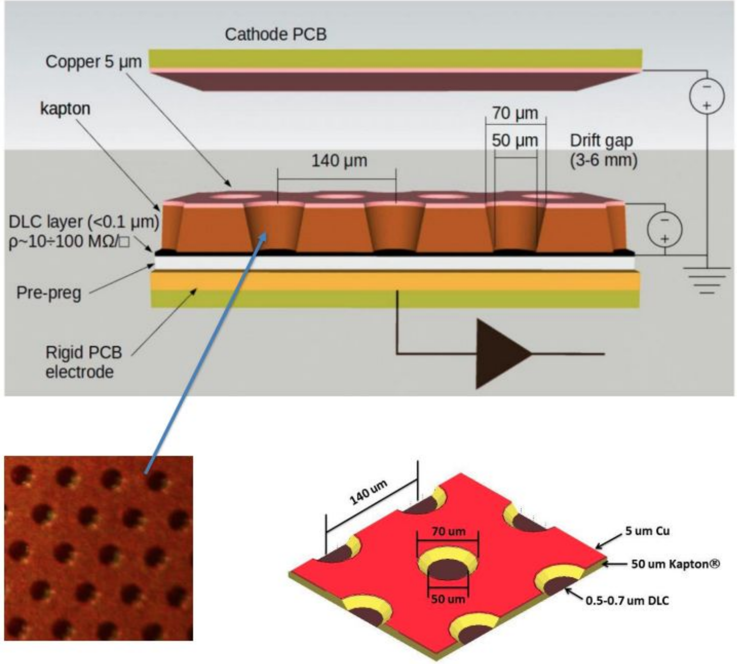
- ➔ Detector dimension: 50x50 cm^2 with X-Y readout
- ➔ Efficiency: 98%
- ➔ Space resolution:
  - ≤ 100 μm (Pre-shower)
  - ≤ 400 μm (Muon)
- ➔ Instrumented Surface/FEE:
  - 130 m2, 520 det., 3×10^5 ch. (0.4 mm strip pitch)
  - 1500 m2,1520 det., 5×10^6 ch. (1.2 mm strip pitch)
- ➔ Mass production with Technology Transfer to Industry
- ➔ FEE Cost reduction: custom made ASIC (TIGER)



μ-RWELL technology and optimization

µRWELL technology

G. Bencivenni et al., 2015 JINST 10 P02008



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

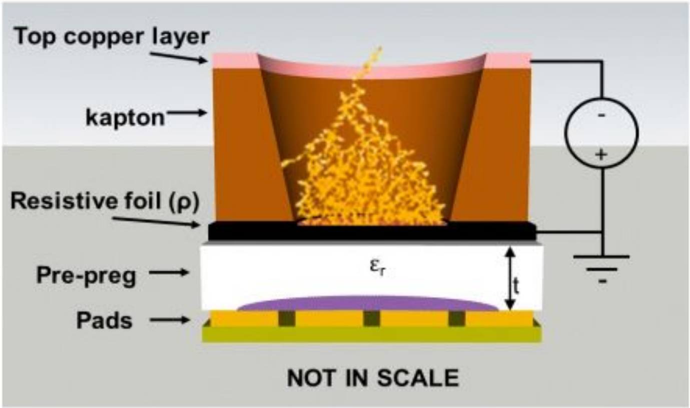
- **µ-RWELL_PCB** = amplification-stage ⊕ resistive stage ⊕ readout PCB
- **cathode** defining the gas gap

µ-RWELL **operation**:

1. A charged particle **ionises** 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 copper layer on the top of the kapton foil (TOP)
3. The signal is **induced** capacitively, through the DLC layer, to the readout PCB
4. HV is applied between the TOP and the cathode to collect the primary electrons
5. HV is also applied between the resistive stage and the copper layer on the top of the kapton foil, providing the amplification field

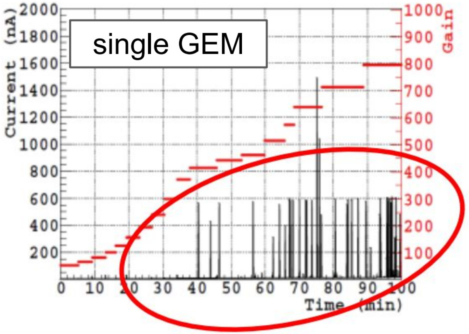
µRWELL technology

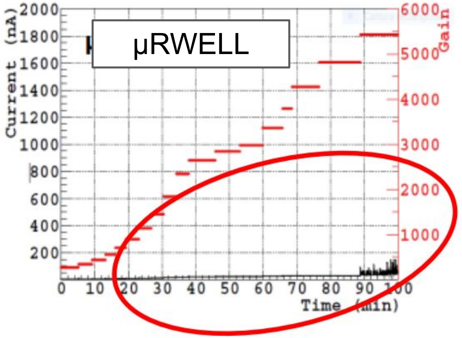
G. Bencivenni et al., 2015 JINST 10 P02008



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

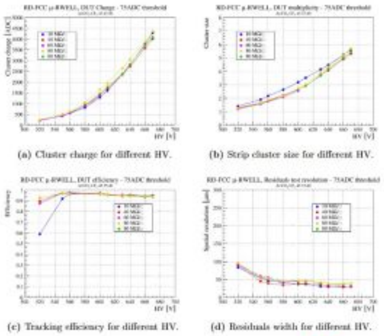
The **resistive stage** ensures the **spark amplitude quenching**.

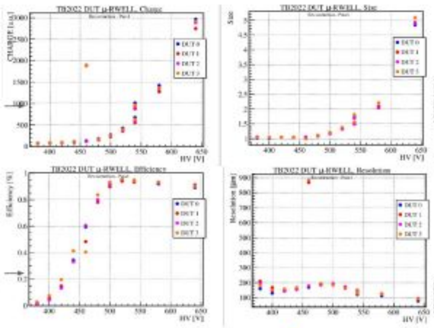


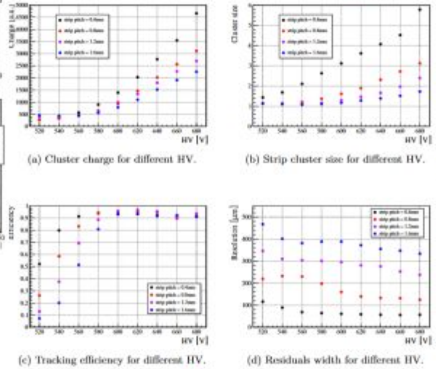


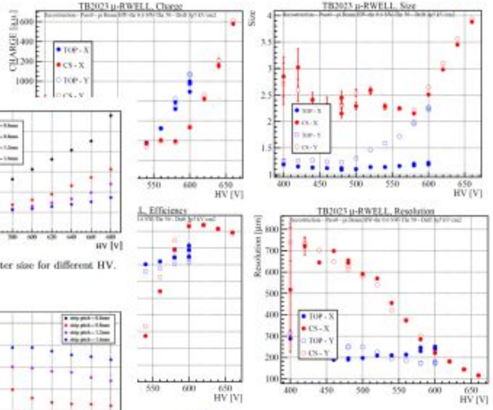
R&D for FCC

TB with DC + pre-shower + CALO+ Muon









1D PERFORMANCE

2D performance

2020

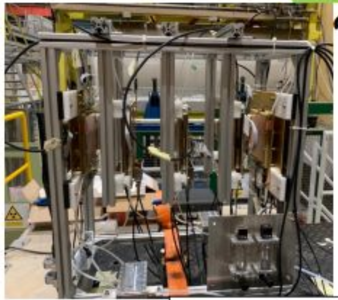
2021

2022

2023

Resistivity Scan @ fixed pitch

Pitch Scan @ fixed resistivity & 2x1D performance

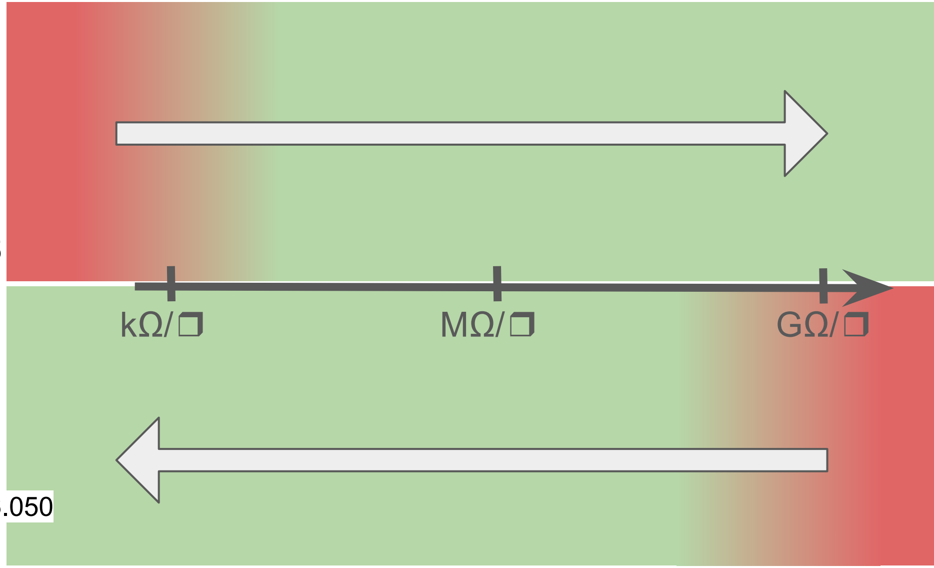


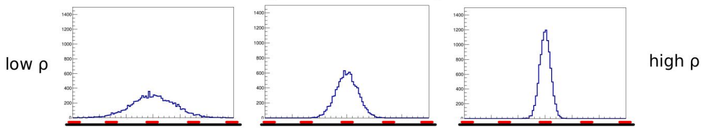
2D layouts

Resistivity Optimization

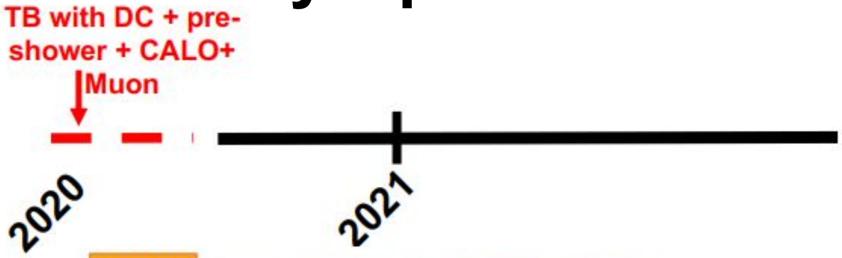
Resistivity

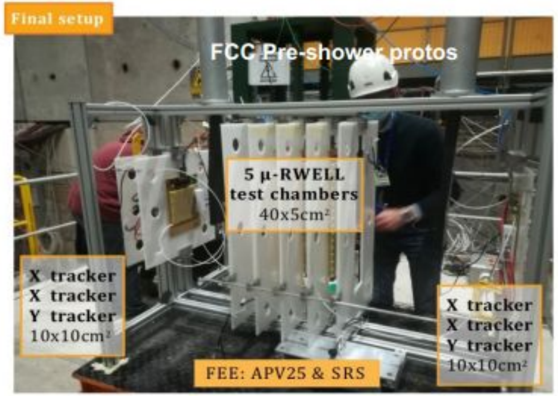
- Stability operation
  - G. Bencivenni et al., 2015 JINST 10 P02008
  - T. Alexopoulos et al., 2011 NIMA 2011.03.025
- Charge dispersion
  - M.S. Dixit et al., 2004 NIMA 2003.09.051
  - M.S. Dixit and A. Rankin, 2006 NIMA 2006.06.050





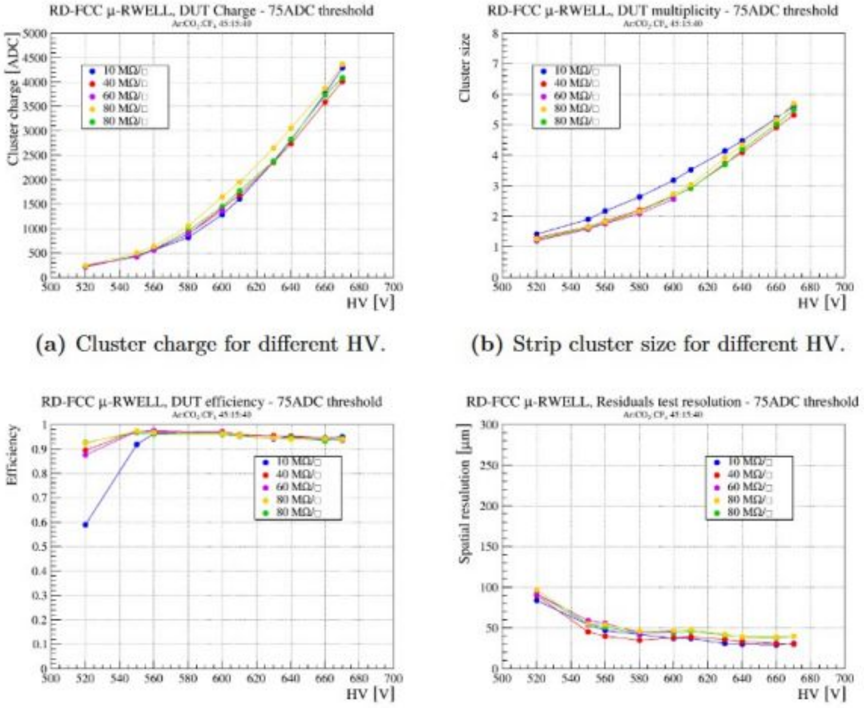
Resistivity Optimization





Active area= 400x50 mm2
Pre-preg thickness= 50 um
Resistivity= 10 ÷80 MΩ/
Strip pitch= 0.4 mm
Strip width = 0.150 mm
Ratio p/w= 2.66

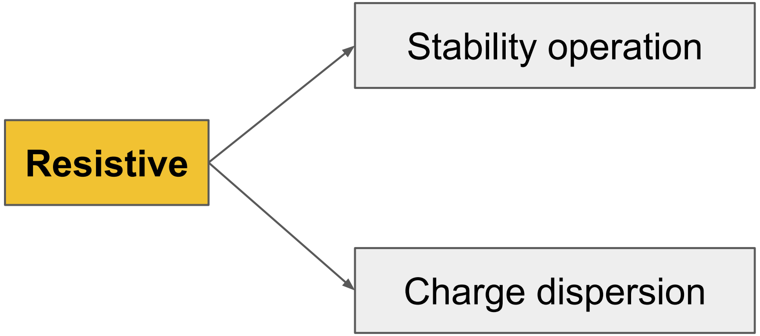
Resistivity Scan @ fixed pitch

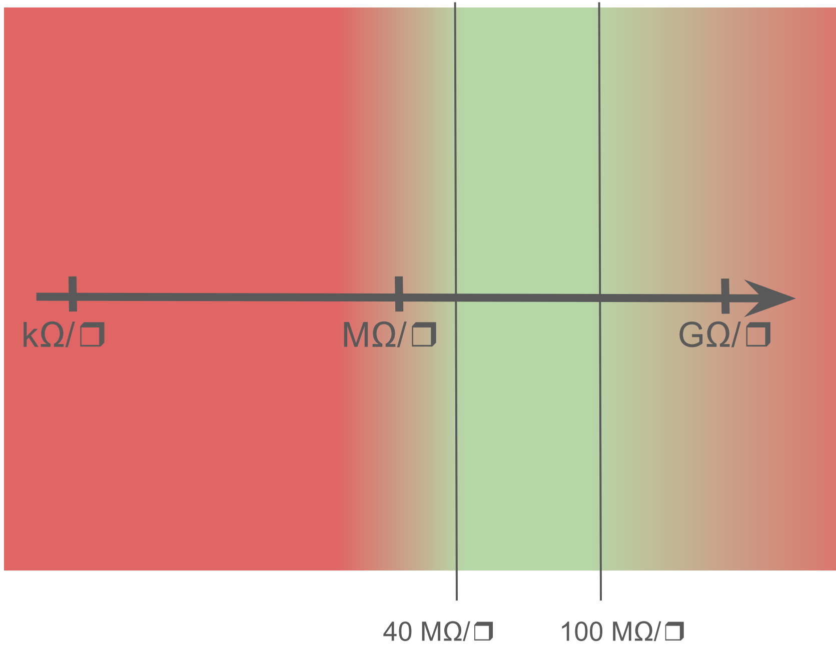


(a) Cluster charge for different HV.
(b) Strip cluster size for different HV.
(c) Tracking efficiency for different HV.
(d) Residuals width for different HV.

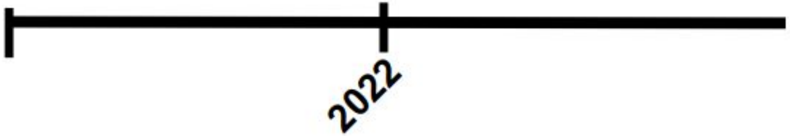
Same performance except the **10 MΩ/ proto**
Efficiency knee @ 550 V, σ_x < 100 um

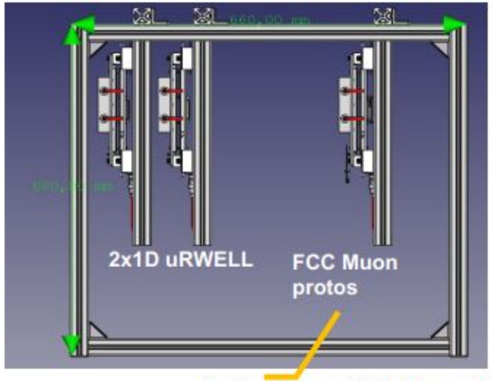
Resistivity Optimization





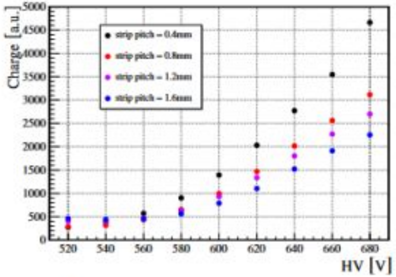
1D R/out strip pitch



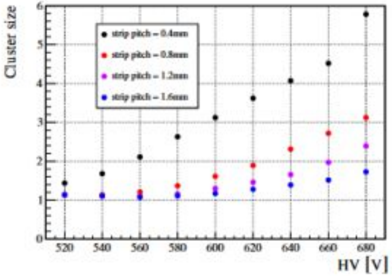


Active area= 400x50 mm2
Pre-preg thickness= 50 um
Resistivity= 30 MΩ/
Strip pitch= 0.4-1.6 mm
Strip width = 0.15 mm
p/w ratio= 2.66 – 10.66

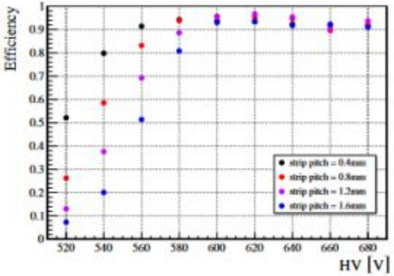
R/O pitch scan @ fixed resistivity



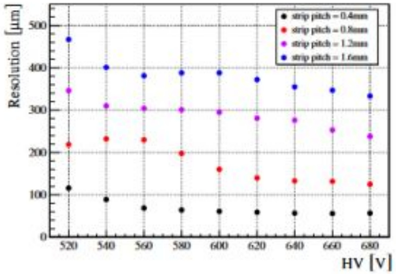
(a) Cluster charge for different HV.



(b) Strip cluster size for different HV.



(c) Tracking efficiency for different HV.



(d) Residuals width for different HV.

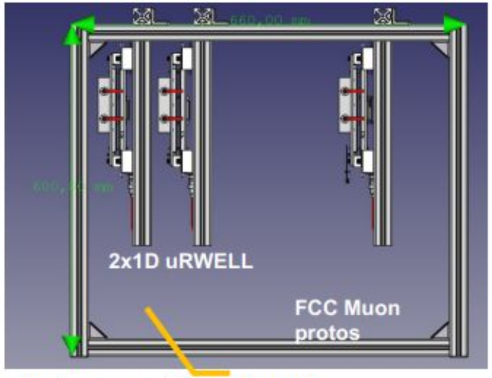
Larger is the strip pitch, lower is the charge signal requiring a higher gain to reach full efficiency.

Efficiency knee @ 600 V & σ_x < 400 um for a strip pitch = 1.6 mm

A high p/w ratio implies a worsening of the detector performance

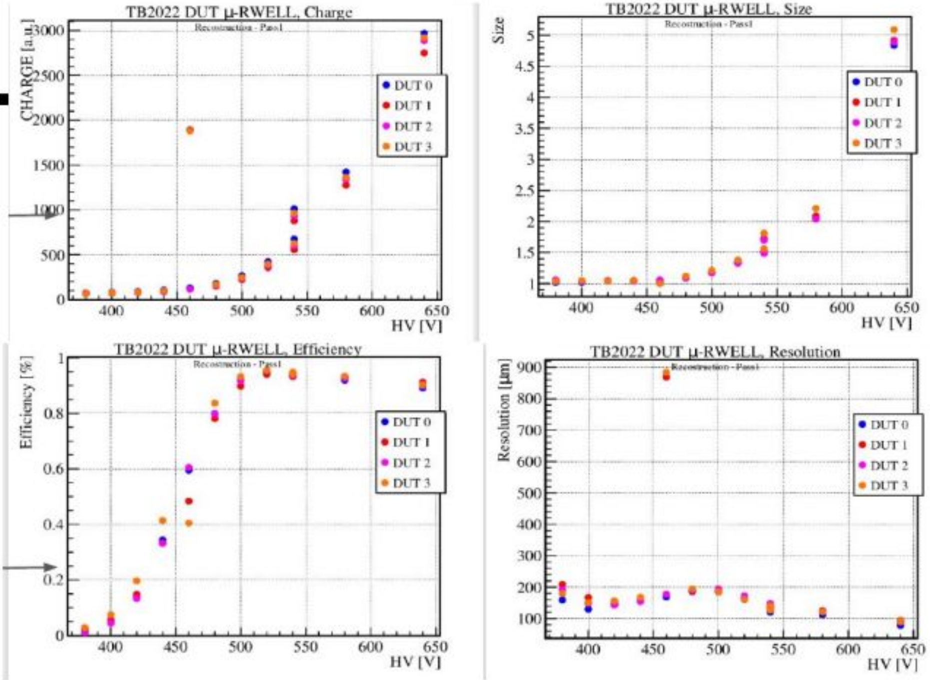
2x1D R/out

2022



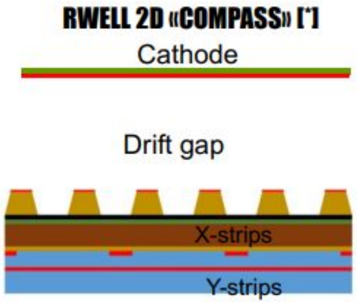
Active area= 100x100 mm2
Pre-preg thickness= 20 um
Resistivity= 50 MΩ/
Strip pitch= 0.76 mm
Strip width = 0.3 mm
Ratio p/w= 2.53

2x1D performance



The 1D proto show very good performace @ 500 V to be compared with 2D ones (TB 2023)
Efficiency knee @ 500 V & σx < 200 um for a strip pitch ~ 0.8 mm

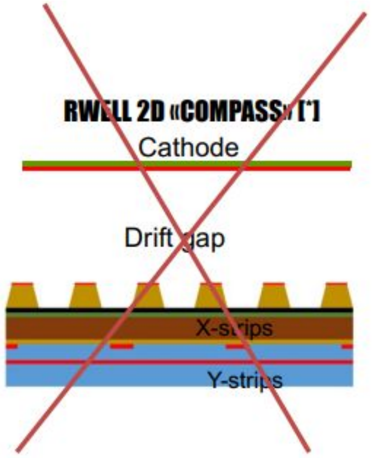
Possible 2D R/out layout



The «COMPASS» R/out requires higher gas gain due to the coupling of the X and Y R/out strips.
Good perfomance
No easy optimization of the charge sharing on X-Y views

(*) Y. Zhou et al. NIMA 927 (2019) 31

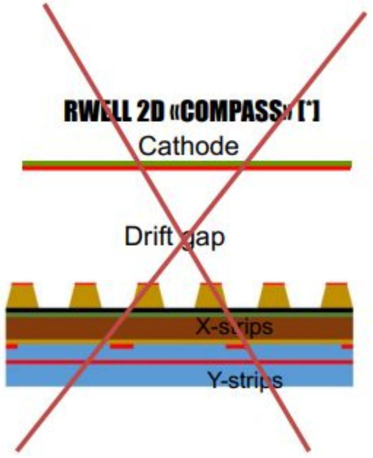
Possible 2D R/out layout

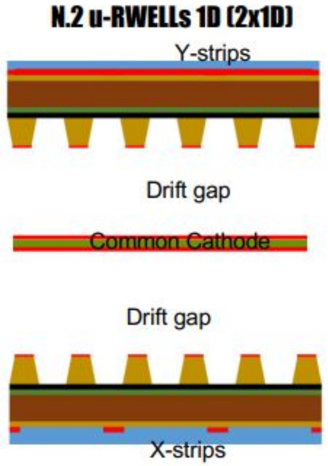


The «COMPASS» R/out requires higher gas gain due to the coupling of the X and Y R/out strips
Good perfomance
No easy optimization of the charge sharing on X-Y views

(*) Y. Zhou et al. NIMA 927 (2019) 31

Possible 2D R/out layout



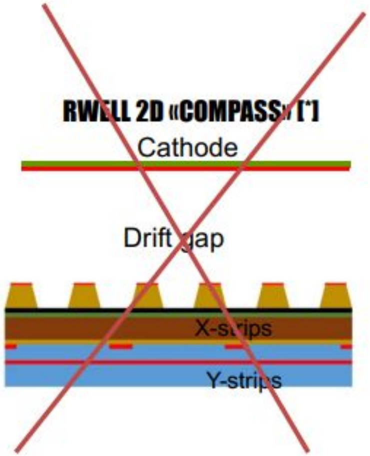


The «COMPASS» R/out requires higher gas gain due to the coupling of the X and Y R/out strips
Good perfomance
No easy optimization of the charge sharing on X-Y views

(*) Y. Zhou et al. NIMA 927 (2019) 31

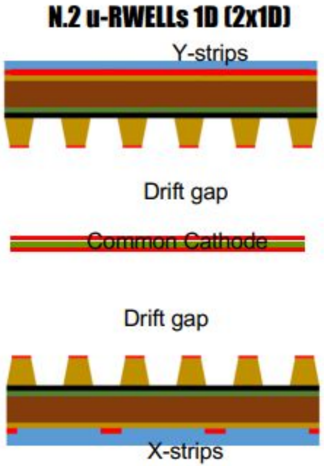
This option centainly allows to work at **lower gas gain** wrt the «COMPASS» R/out (X-Y r/out are decoupled)
→ **TB2022 results:**
- **IDEA pre-shower:** Efficiency knee @ 550 V, σ_x < 100 um with 0.4 mm strip pitch for the
- **IDEA Muon:** Efficiency knee @ 600 V & σ_x < 400 um for a strip pitch = 1.6 mm

Possible 2D R/out layout

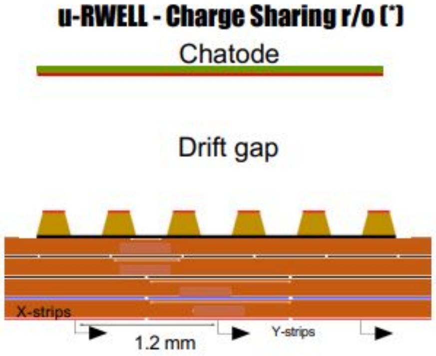


The «COMPASS» R/out requires higher gas gain due to the coupling of the X and Y R/out strips
Good perfomance
No easy optimization of the charge sharing on X-Y views

(*) Y. Zhou et al. NIMA 927 (2019) 31



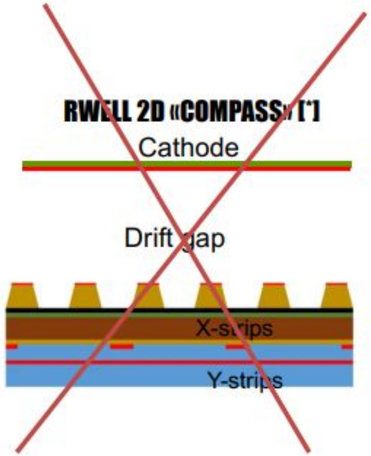
This option centainly allows to work at **lower gas gain** wrt the «COMPASS» R/out (X-Y r/out are decoupled)
→ **TB2022 results:**
- **IDEA pre-shower:** Efficiency knee @ 550 V, σ_x < 100 um with 0.4 mm strip pitch for the
- **IDEA Muon:** Efficiency knee @ 600 V & σ_x < 400 um for a strip pitch = 1.6 mm



The charge sharing structures: the **charge transfer** and **charge sharing** using **capacitive coupling between a stack of layers** of pads and **the r/out board.**
This technique offers the possibility **to reduce the FEE channels**, but the **total charge is divided between the X & Y r/out** (similar to the «COMPASS» R/out)

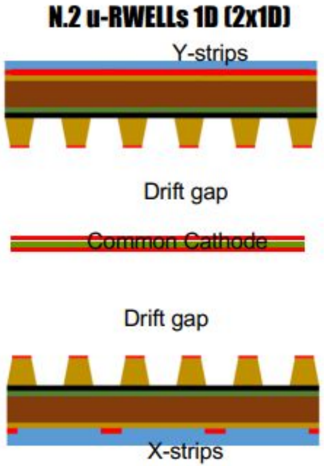
(*) K. Gnanvo et al. NIMA 1047 (2023) 167782

Possible 2D R/out layout

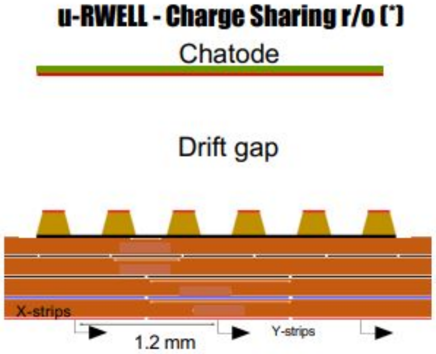


The «COMPASS» R/out requires higher gas gain due to the coupling of the X and Y R/out strips
Good perfomance
No easy optimization of the charge sharing on X-Y views

(*) Y. Zhou et al. NIMA 927 (2019) 31

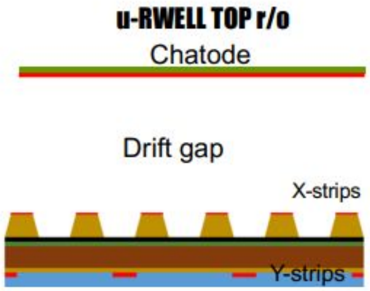


This option centainly allows to work at **lower gas gain** wrt the «COMPASS» R/out (X-Y r/out are decoupled)
→ **TB2022 results:**
- **IDEA pre-shower:** Efficiency knee @ 550 V, σ_x < 100 um with 0.4 mm strip pitch for the
- **IDEA Muon:** Efficiency knee @ 600 V & σ_x < 400 um for a strip pitch = 1.6 mm



The charge sharing structures: the **charge transfer** and **charge sharing** using **capacitive coupling between a stack of layers** of pads and **the r/out board.**
This technique offers the possibility **to reduce the FEE channels**, but the **total charge is divided between the X & Y r/out** (similar to the «COMPASS» R/out)

(*) K. Gnanvo et al. NIMA 1047 (2023) 167782

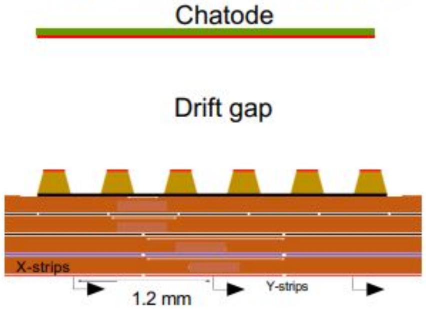


The **TOP layout** centainly allows to work at **lower gas gain** wrt the «COMPASS» r/out (X-Y r/out are decoupled)

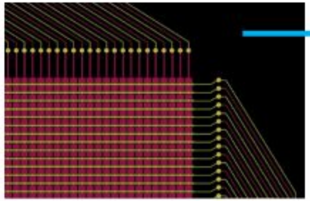
→ X coordinate on the TOP of the amplification stage introduces same **dead zone in the active area**

2D R/out layout: Charge Sharing and TOP r/out

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

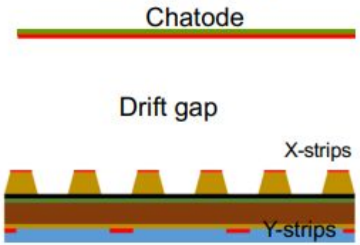


CS Readout board

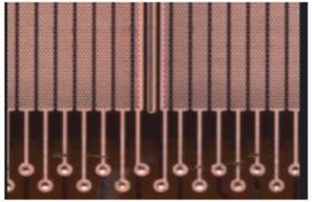


Active area= 100x100 mm2
Resistivity= 50 MΩ/
Strip pitch= 1.2 mm
Strip width = 1.1 mm
Several layer between DLC and R/out

u-RWELL TOP r/o



X coordinate on the TOP of the amplification stage

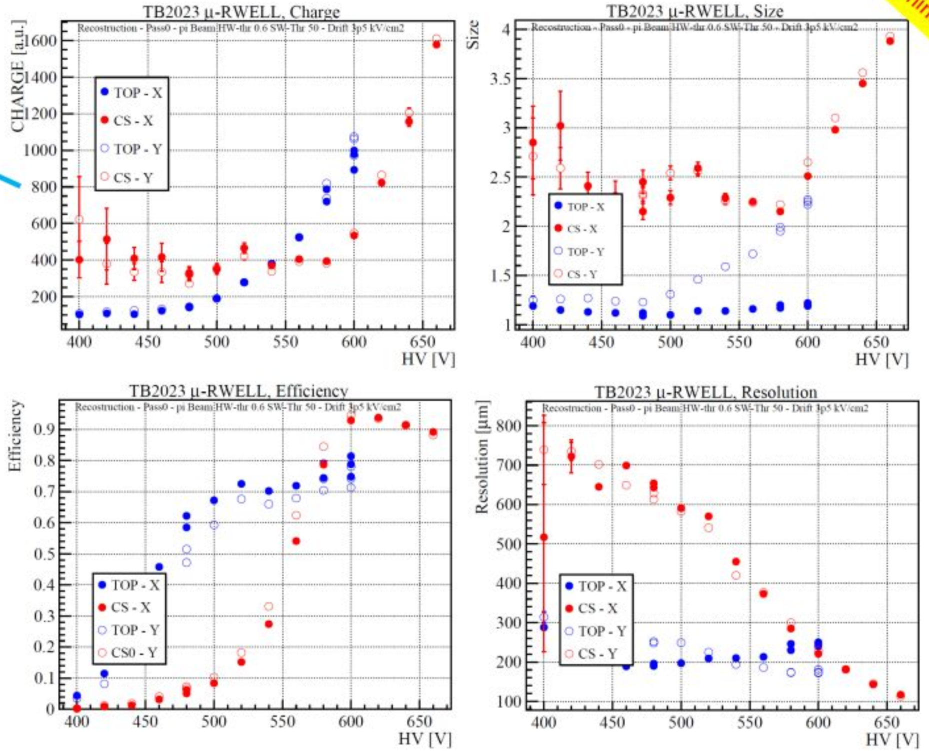


Active area= 100x100 mm2
Resistivity= 50 MΩ/
Strip pitch= 0.8 mm
Strip width = 0.7 mm
Dead zone (TOP) ~ 15%
Pre-preg thickness= 70 um

Possible 2D R/out layout

An ugual charge sharing on the X-Y coordinates is shown for both 2D r/out

preliminary

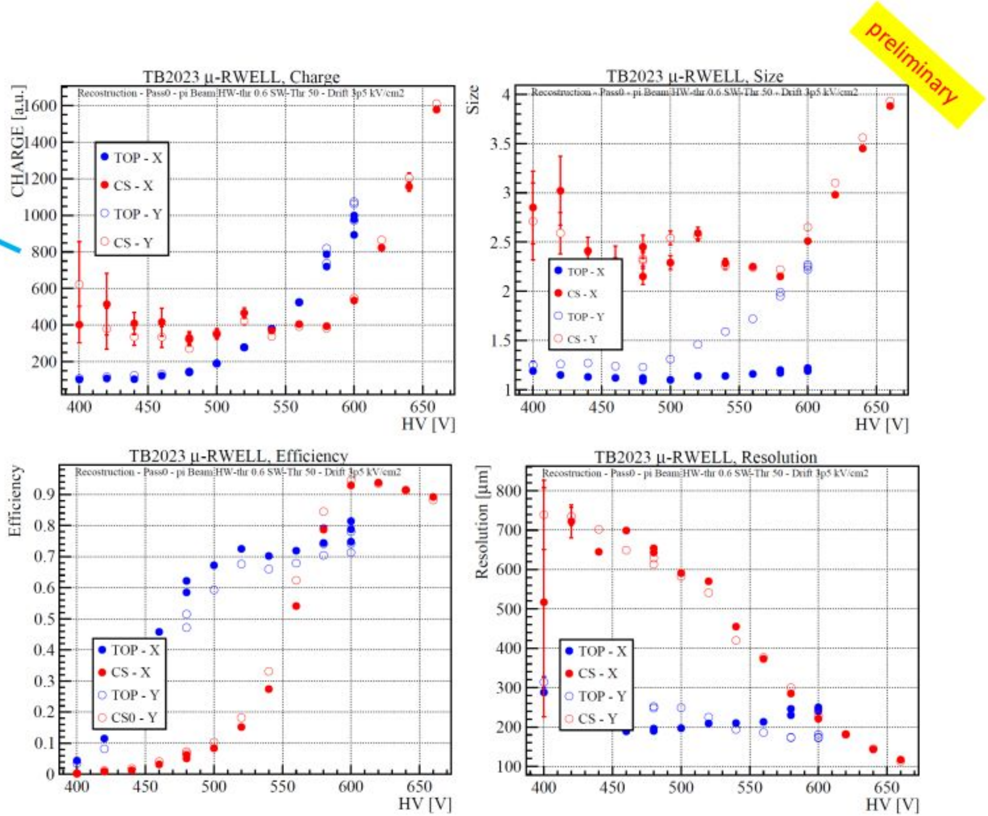


2D R/out layout: TOP r/o (blue)

An ugual charge sharing on the X-Y coordinates is shown for both 2D r/out

TOP r/o:

- **The total charge isn't divided between X & Y view;**
- **Efficiency knee @ 500 V** (such as 1D proto);
- **Low efficiency plateau (~70%) due to dead zone**
- Cluster Size does not change on X (TOP layer), while changing on the Y (due to the DLC spread);
- **Digital spatial resolution** on the X (Strip size ~ 1.5), strip Size>, improving on the Y (due to DLC spread)



2D R/out layout: Charge Sharing (red)

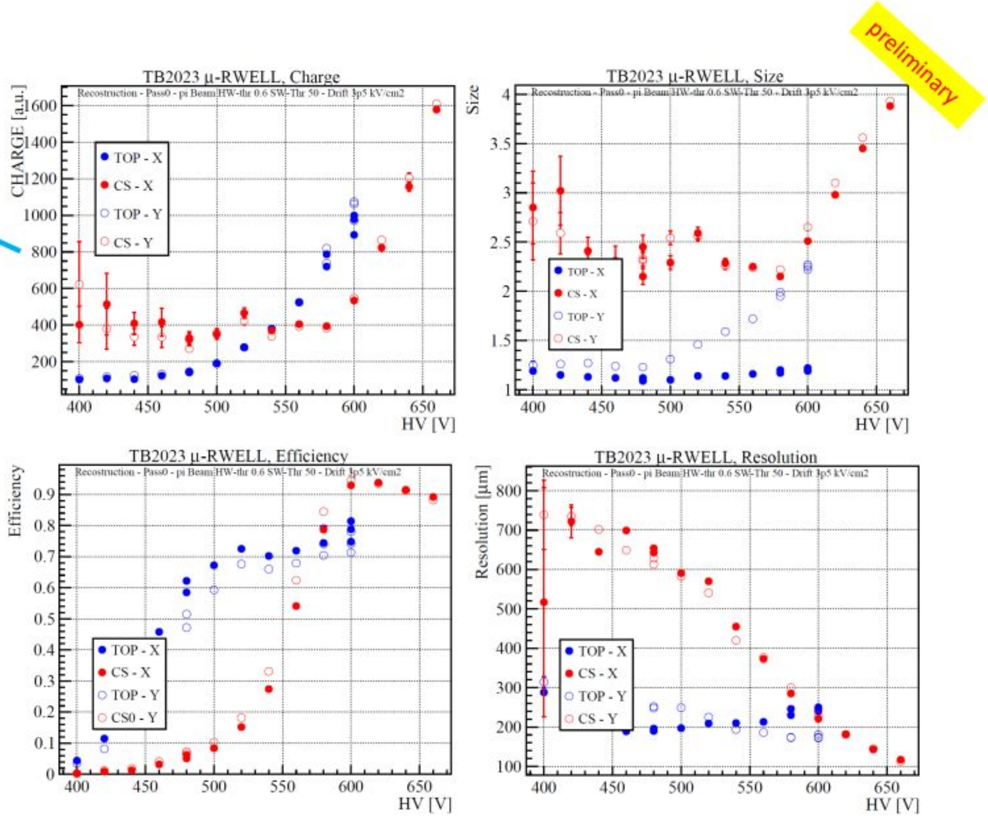
An ugual charge sharing on the X-Y coordinates is shown for both 2D r/out

TOP r/o:

- **The total charge isn't divided between X & Y view;**
- **Efficiency knee @ 500 V** (such as 1D proto);
- **Low efficiency plateau (~70%) due to dead zone**
- Cluster Size does not change on X (TOP layer), while changing on the Y (due to the DLC spread);
- **Digital spatial resolution** on the X (Strip size ~ 1.5), strip Size>, improving on the Y (due to DLC spread)

CS r/o:

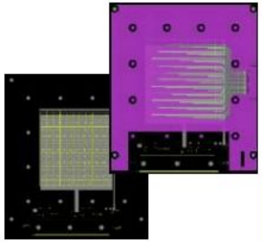
- **The total charge is divided between X & Y view;**
- **Efficiency knee @ 600 V;**
- **High efficiency plateau (~95%)**
- Cluster size increase to 4 strips (Charge Sharing mechanism work)
- **Spatial resolution** improves at higher gain reaching **150 um with a strip pitch of 1.2 mm**



Technological transfer

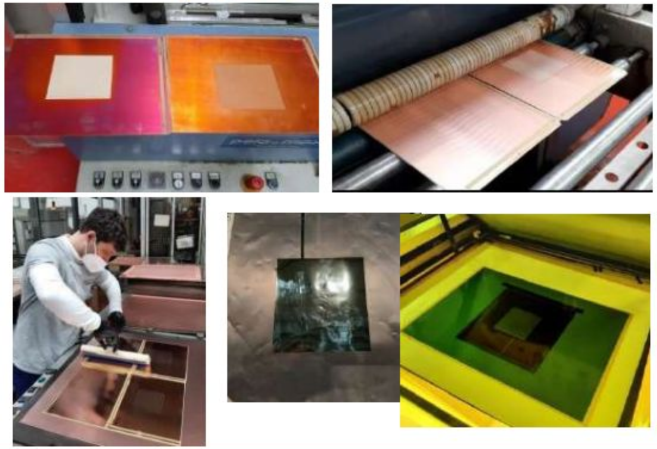
Flow-chart technological transfer

LAYOUT design



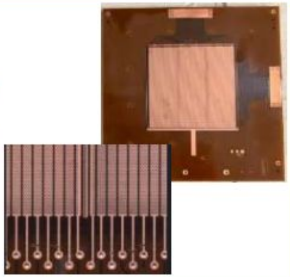
DLC foil production (*)

PCB production



Feedback from tests

Final detector manufacturing



*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

Future plans

2024 program

The 2024 program will be foreseen the following items:

1. TB analysis finalization for the 2D layouts and perform a complete comparison between the studied layouts

2. Study **gas gain optimization with different geometry** of the amplification stage (pitch well, external/internal well diameters) with 100x100 mm2 prototypes. These studies have been performed with GEM detector but never with µRWELL with a reduction of the well pitch from 140 µm to 90 µm, a possible increase of the gas gain of about 2 is foreseen

4. **Production of 500x500 mm2 prototypes** (second half of 2024): the choice of 2D layout will be based on the results obtained in the previous test. Test @LNF with X-ray & cosmic (with tracking system) will be performed.

5. Continuation of testing of the **µRWELL production** processes at ELTOS /CERN and DLC machine at CERN

6. Integration studies with **TIGER electronics** with a TB

7. **Simulation** of the pre-shower and muon systems within IDEA detector

Conclusion

The μ-RWELL is becoming a mature device, also thanks to the technology spread that is giving an important boost to its development. It is also considered for an upgrade of the LHCb Muon apparatus and for the spectrometer of CLAS12 Jlab (White paper for Snowmass), EIC, X17 @nTOF

Preshower and **muon detectors** designed with the μ-RWELL technology

- ★ Studies aimed at defining the best **DLC resistivity** and **strip pitch** for the requested spatial resolution for preshower and muon system
- ★ Good **2D μ -RWELL prototype** performance has been measured and layout optimization has been adopted
- ★ Production of the μ-RWELL layouts with the **final active area** (500x500 mm2)
- ★ Continue partnership with ELTOS (preparation) and CERN (finalization) to **complete technology transfer**

Ready for the final design for next FCC-ee descriptive document (2025-2027)