FCC France&Italy workshop
Lyon, 21-23 November 2022

Muon detector technology R&D

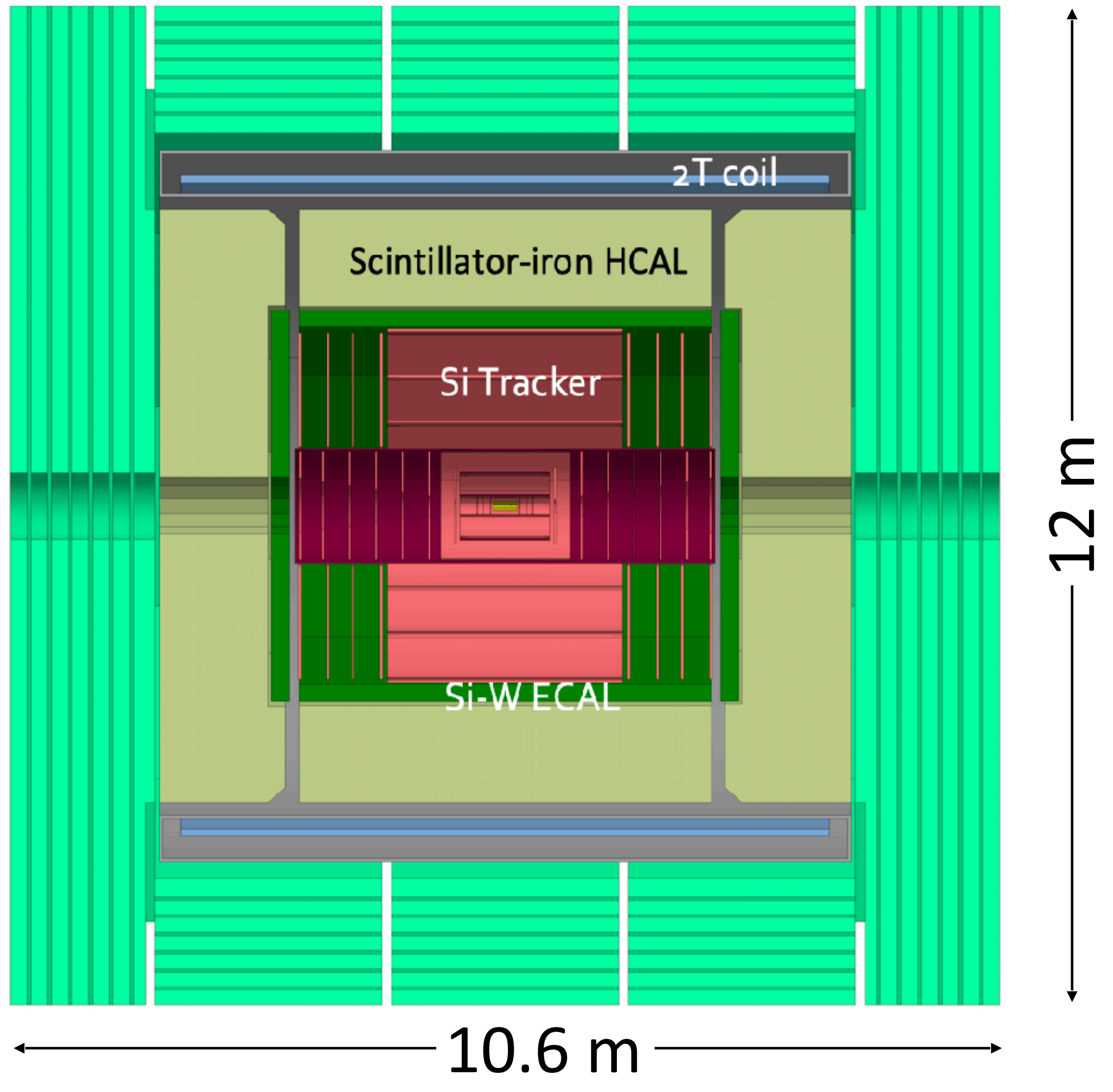
Paolo Giacomelli
INFN Bologna

FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

CDR: 2 Detector concepts

"Proof of principle concepts"
- Not necessarily matching (all) detector requirements, which are still being spelled out

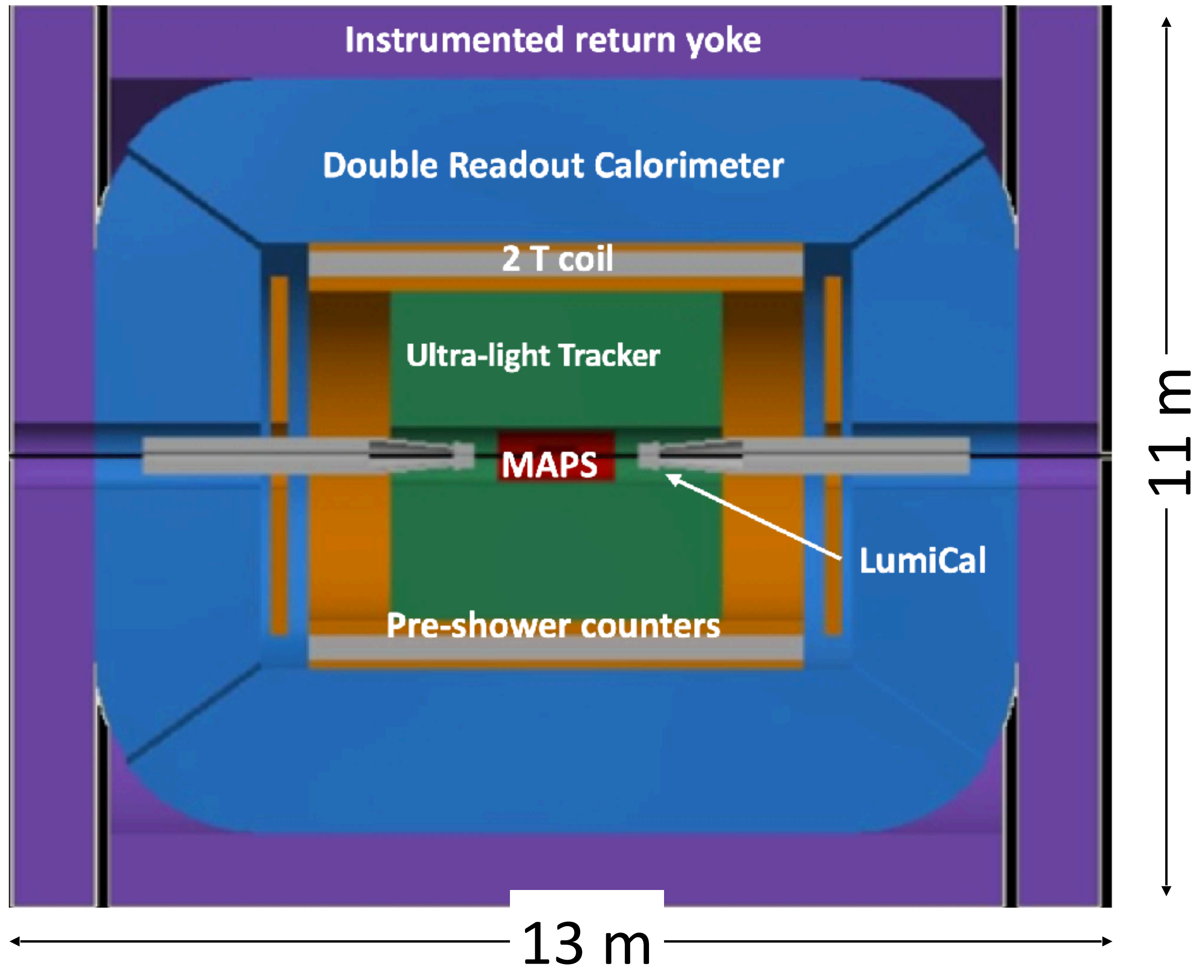
CLD



- Based on CLIC detector design; profits from technology developments carried out for LCs
  - All silicon vertex detector and tracker
  - 3D-imaging highly-granular calorimeter system
  - Coil *outside* calorimeter system
  - Muon system made of RPC layers embedded in the iron yoke

https://arxiv.org/abs/1911.12230, https://arxiv.org/abs/1905.02520

IDEA

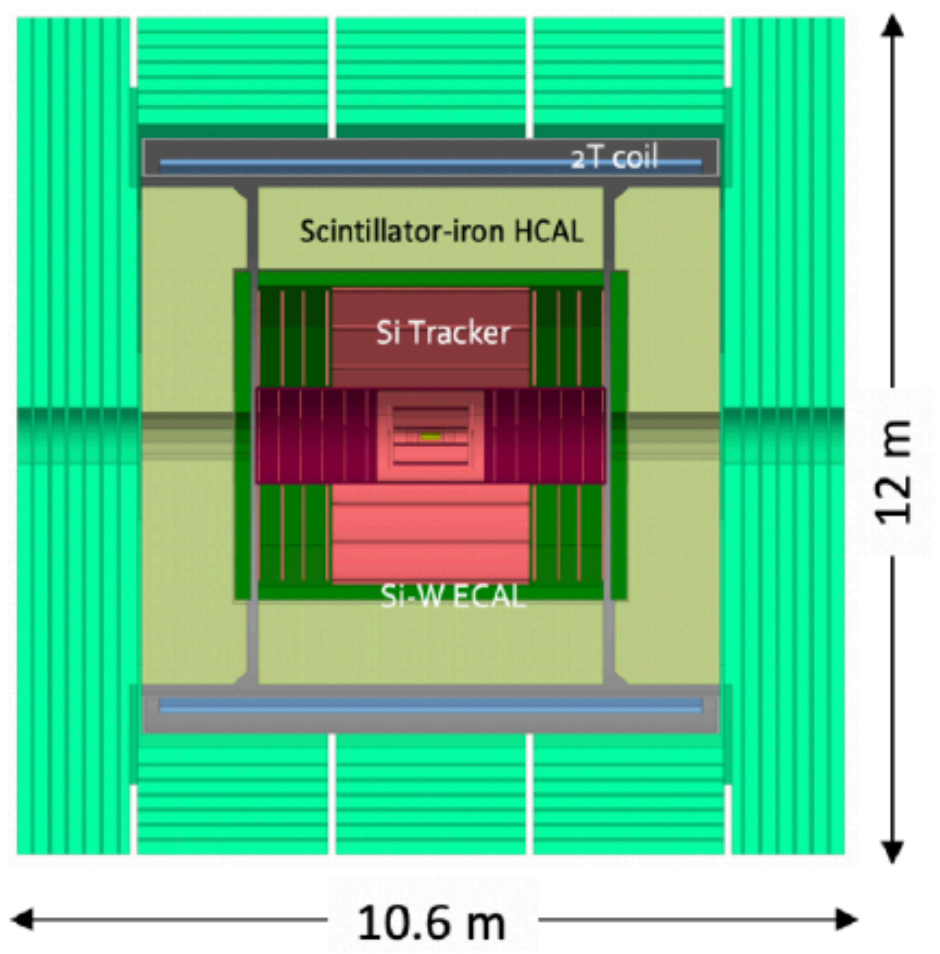


- New, innovative, possibly more cost-effective concept
  - Silicon vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil *inside* calorimeter system
  - Muon system made of 3 layers of μRWell detectors in the return yoke

https://pos.sissa.it/390/

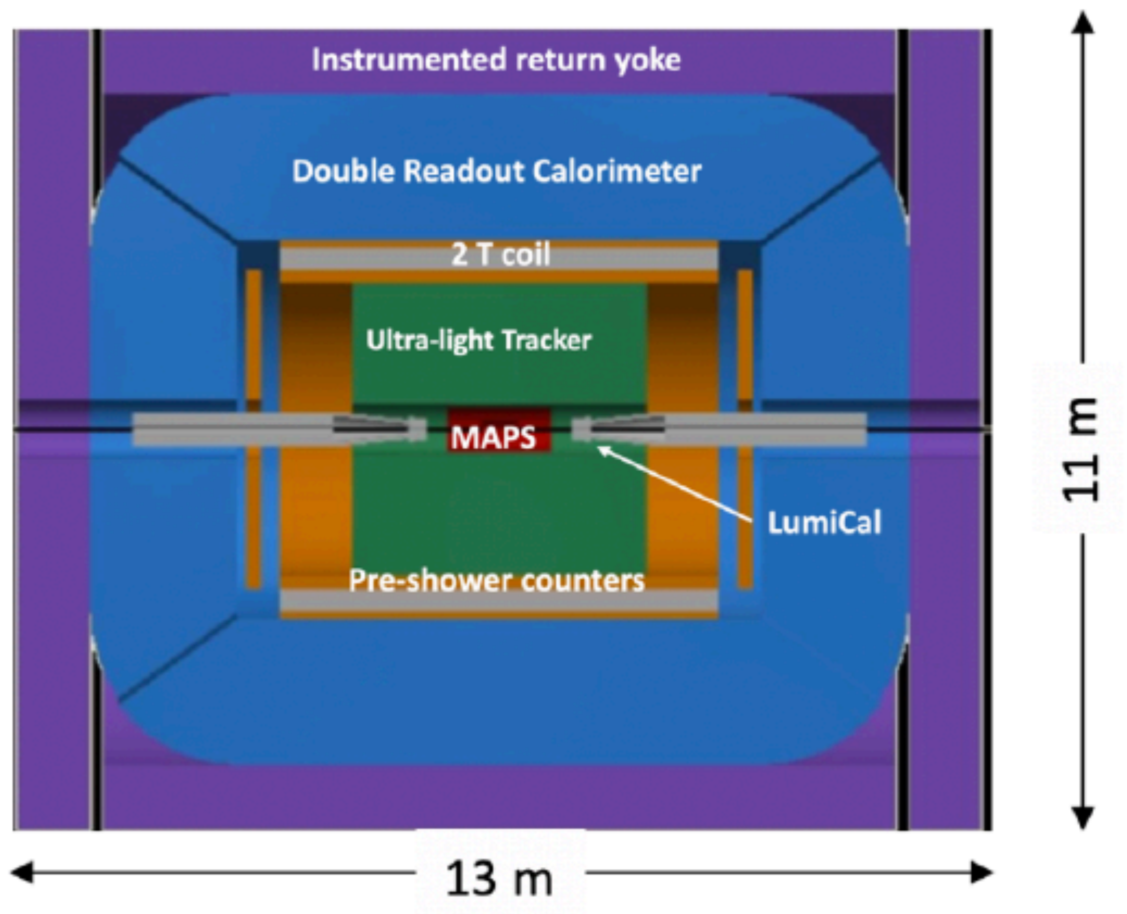
Detector concepts fast overview

CLD



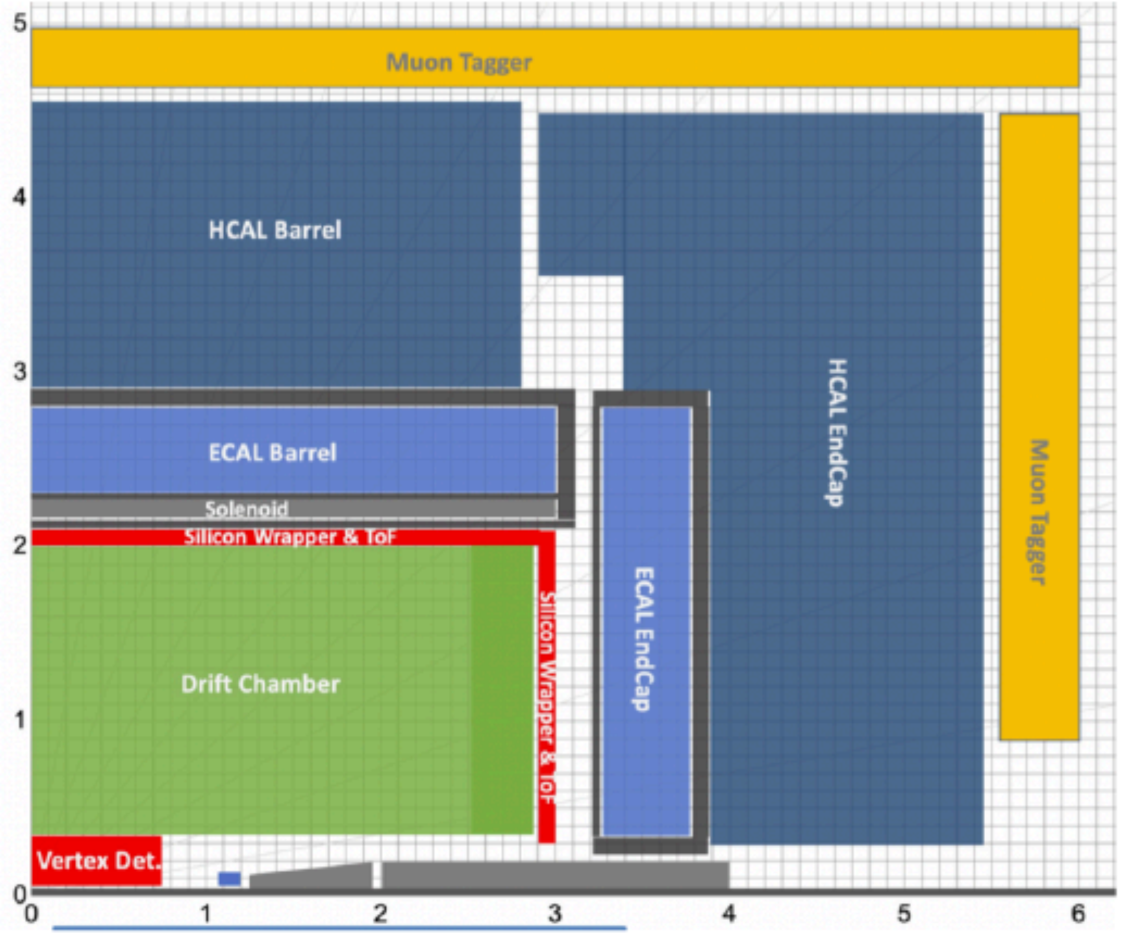
- Well established design
  - ILC -> CLIC detector -> CLD
- Engineering needed to make able to operate with continous beam (no pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations?
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?
  - …
- Robust software stack
  - Now ported (wrapped) to FCCSW

IDEA



- ~~Less~~ established design
  - But still ~15y history: 4^{th} Concept
- Developed by very active community
  - Prototype construction / test beam campaigns
  - Italy, Korea, France, Switzerland, USA, …
- Is IDEA really two concepts? Or will it be?
  - w, w/o crystals
- Software under active development
  - Being ported to FCCSW

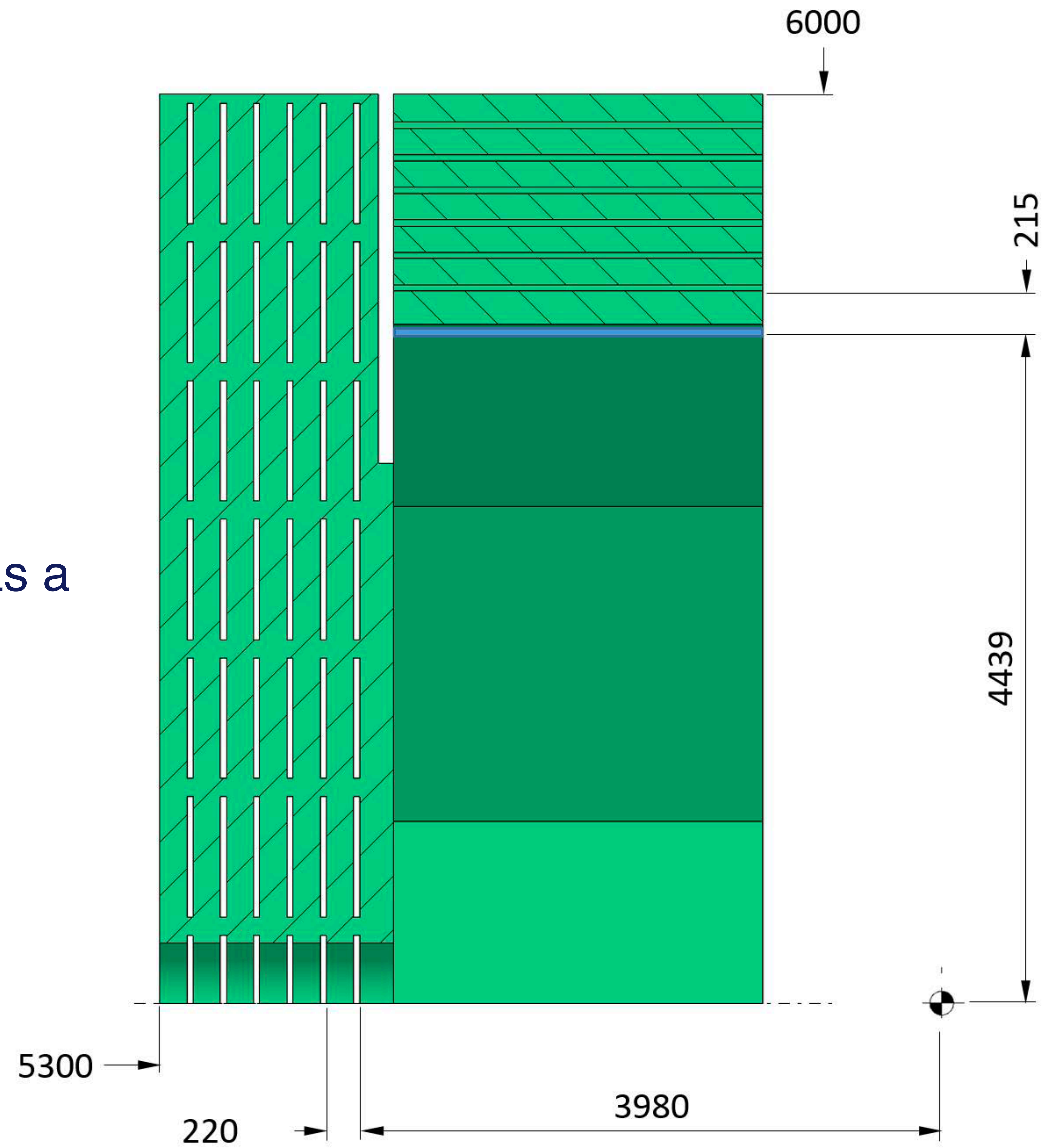
Noble Liquid ECAL based



- A design in its infancy
- High granul Noble Liquid ECAL is the core
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies
- Full simulation of ECAL available in FCCSW

CLD Muon Detector

- 2 Tesla Solenoid Field
- Return yoke contains Muon system with 6 equidistant layers
  - One additional layer after the solenoid to serve as a *tail-catcher*

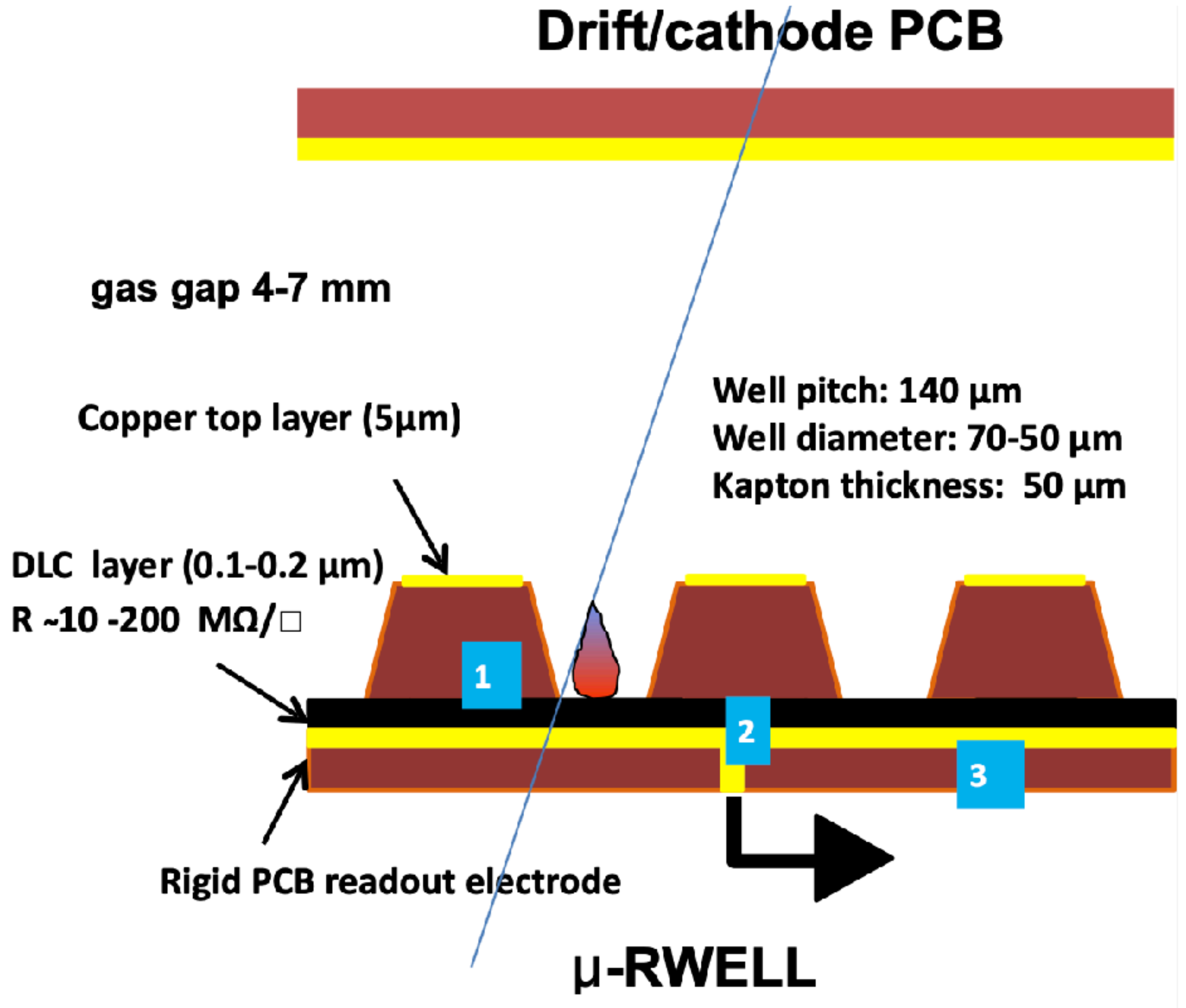


Muon detector

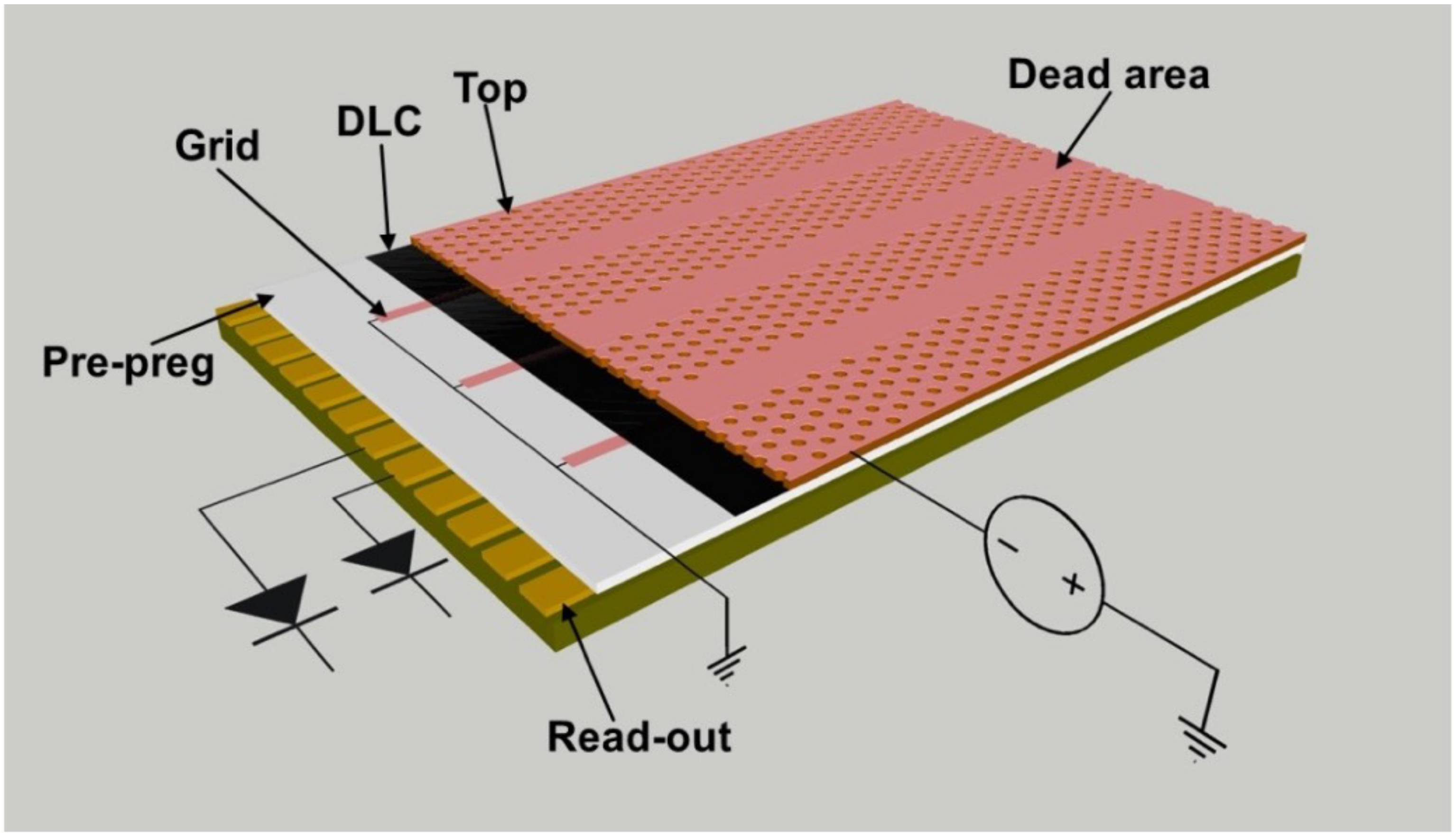
Muon system in instrumented return yoke

- 3-7 layers being considered: 3000-6000 m^2
- Proposed technologies
  - RPC (30 × 30 mm^2 cells)
  - Crossed scintillator bars
  - μ−RWell chambers (1.5 × 500 mm^2 cells)
    - Also for IDEA pre-shower detector
    - Ongoing R&D work

CLD Muon system
- 6 layers of RPC muon chambers inside yoke
  - Cell size: 30 × 30 mm^2



G. Bencivenni et al., 2015_JINST_10_P02008



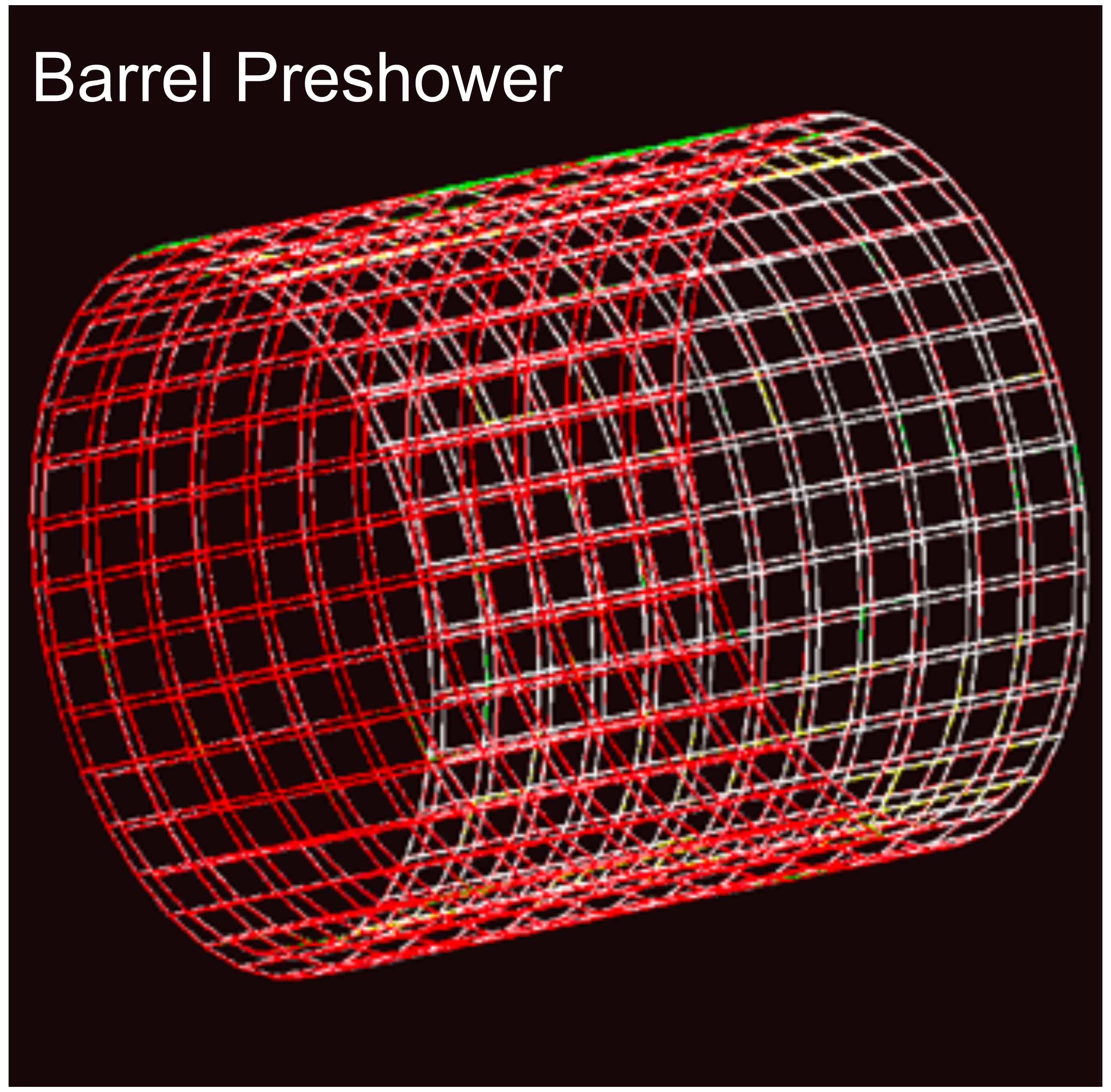
IDEA Muon system
- 3 layers of µ-RWell chambers inside yoke
  - Cell size: 1.5 × 500 mm^2
  - Detector size: 500 x 500 mm^2

IDEA: Preshower and muon detector

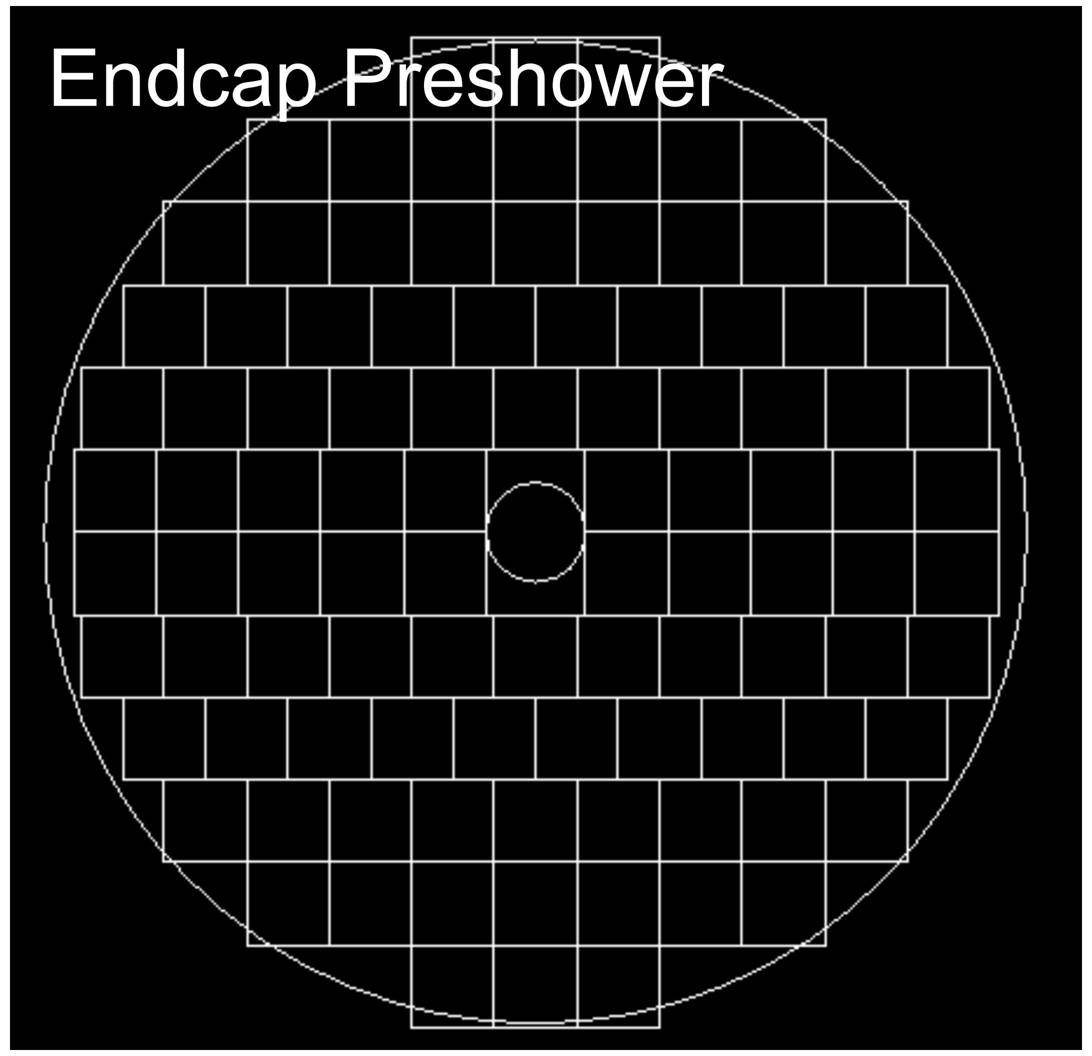
Preshower Detector

High resolution before the magnet
to improve cluster reconstruction

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



Similar design for
the Muon detector



Similar design for
the Muon detector

Muon Detector

Identify muons and search for LLPs

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

Detector technology: μ-RWELL

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

Preshower	**Muon**
pitch = 0.4 mm	pitch = 1.5 mm
FEE capacitance = 70 pF	FEE capacitance = 270 pF
1.5 million channels	5 million channels

μ-RWELL technology

INFN Istituto Nazionale di Fisica Nucleare
LNF
BOLOGNA
FERRARA
TORINO

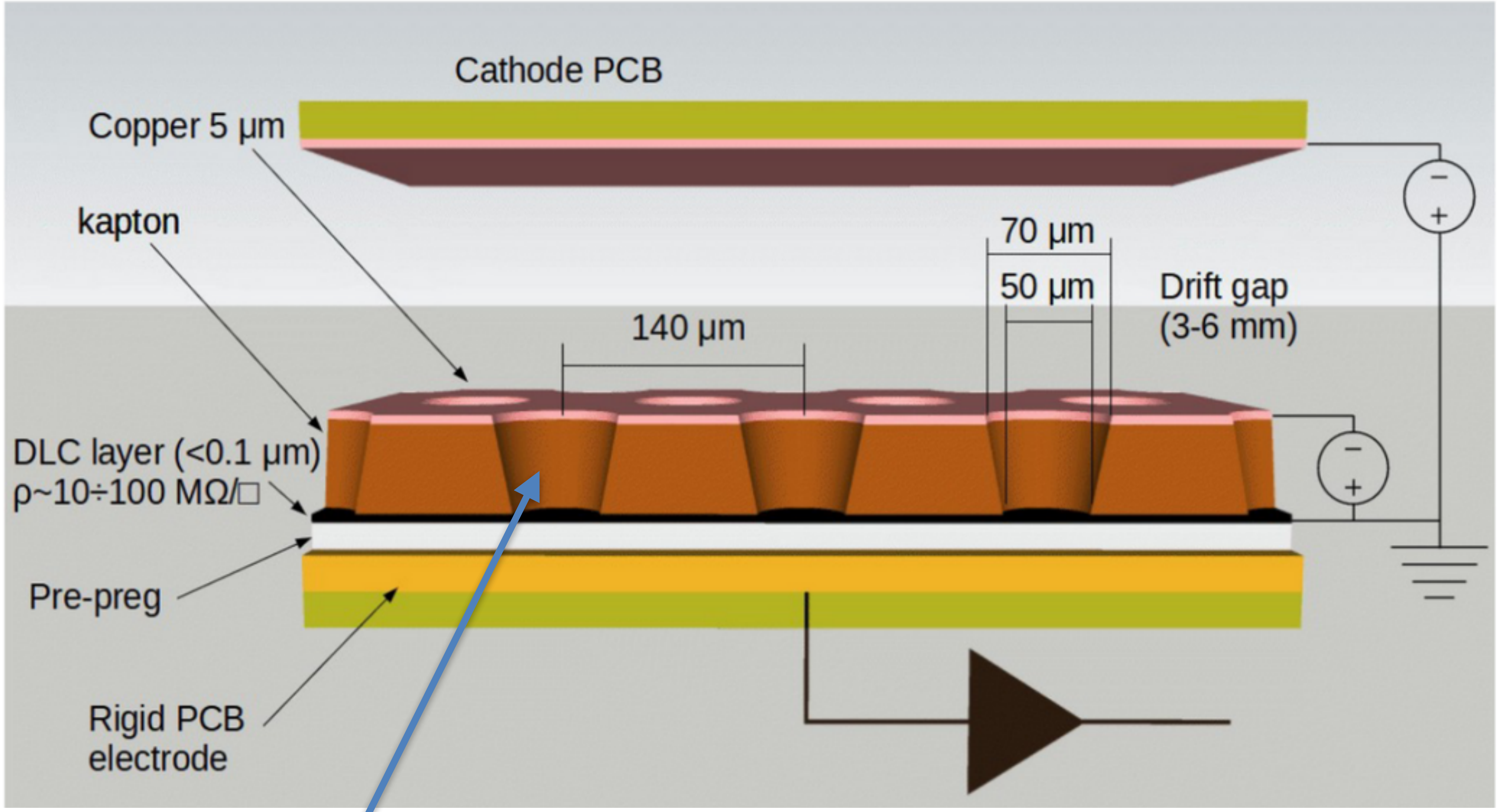
The μ-RWELL is composed of only two elements:

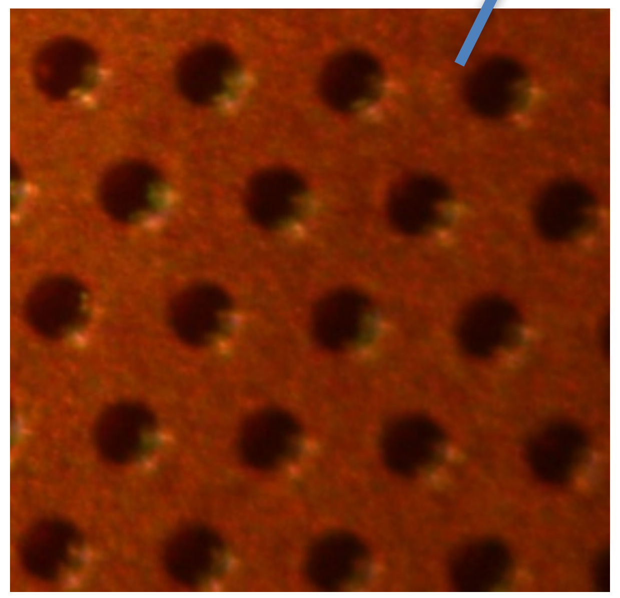
- μ-RWELL_PCB
- drift/cathode PCB defining the gas gap

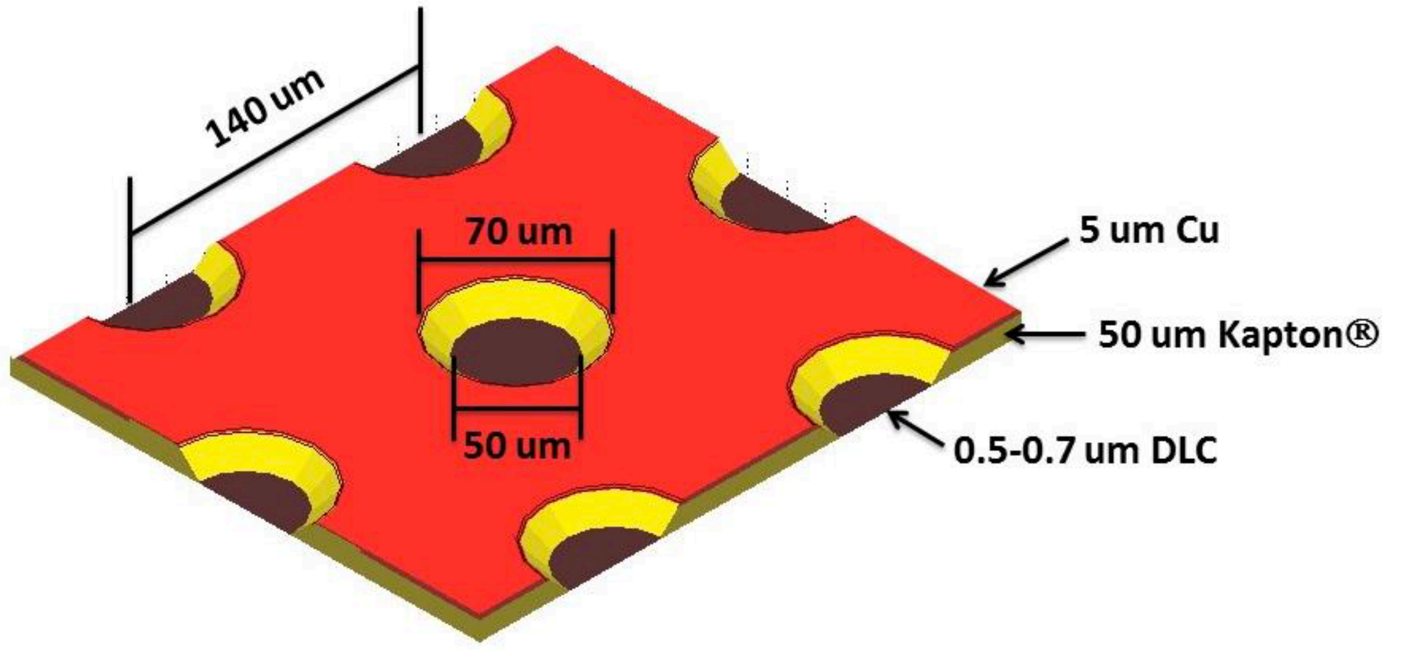
μ-RWELL_PCB = amplification-stage ⊕ resistive stage ⊕ readout PCB

μ-RWELL operation:

- A charged particle ionises the gas between the two detector elements
- Primary electrons drift towards the μ-RWELL_PCB (anode) where they are multiplied, while ions drift to the cathode
- The signal is induced capacitively, through the DLC layer, to the readout PCB
- HV is applied between the Anode and Cathode PCB electrodes
- HV is also applied to the copper layer on the top of the kapton foil, providing the amplification field







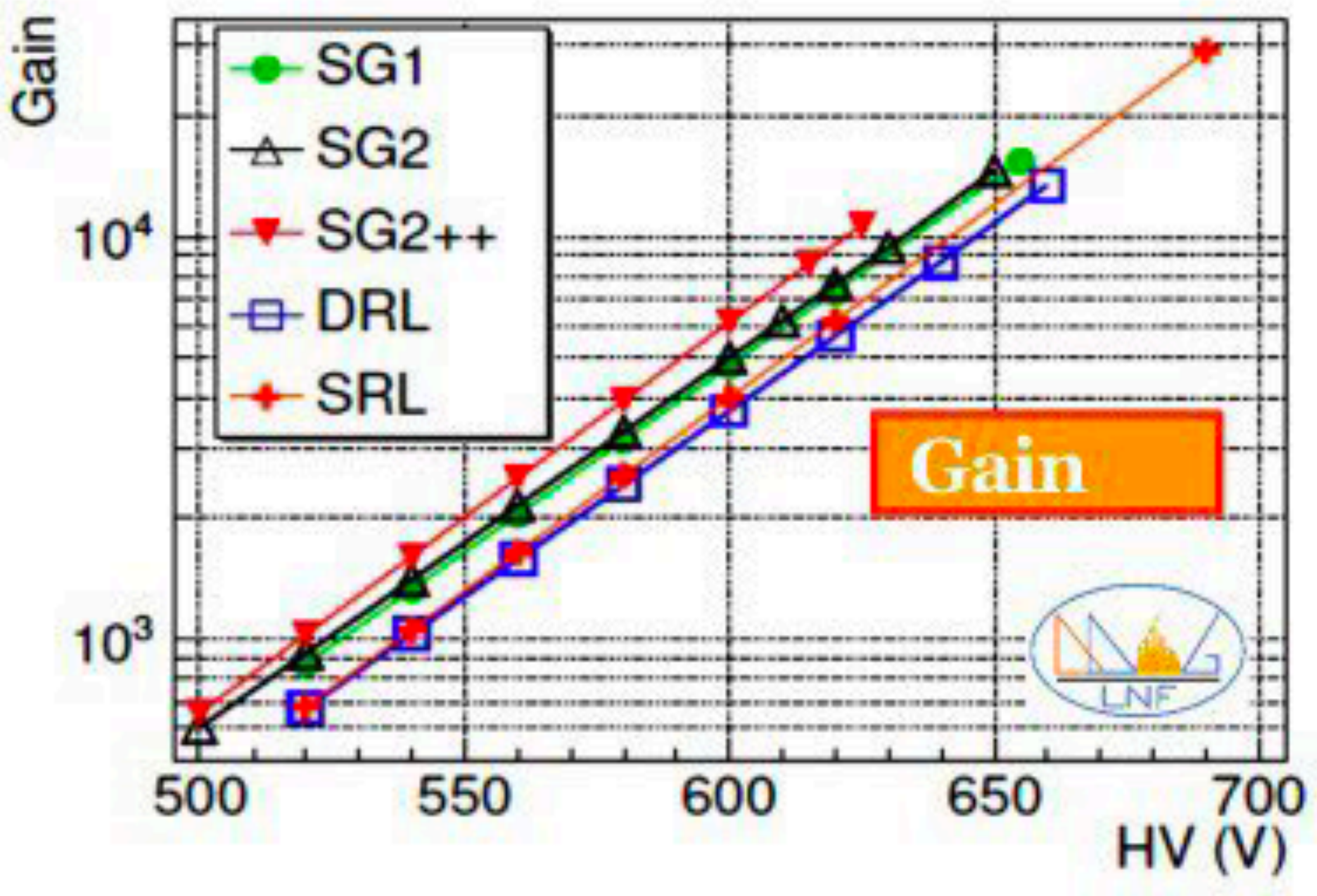
(*) G. Bencivenni et al., "The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD", 2015_JINST_10_P02008)

FUTURE CIRCULAR COLLIDER

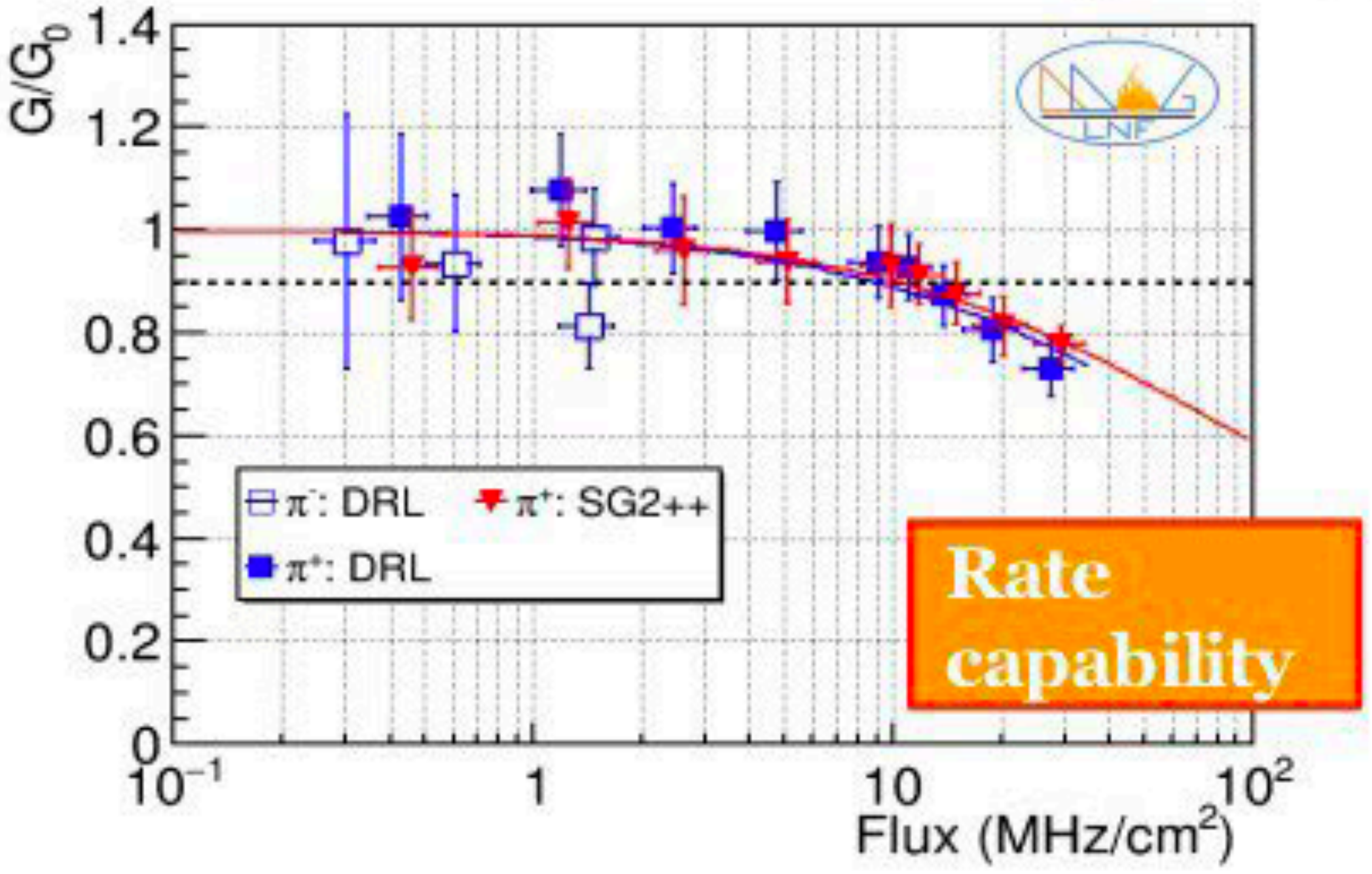
IDEA: μ-RWELL performances overview

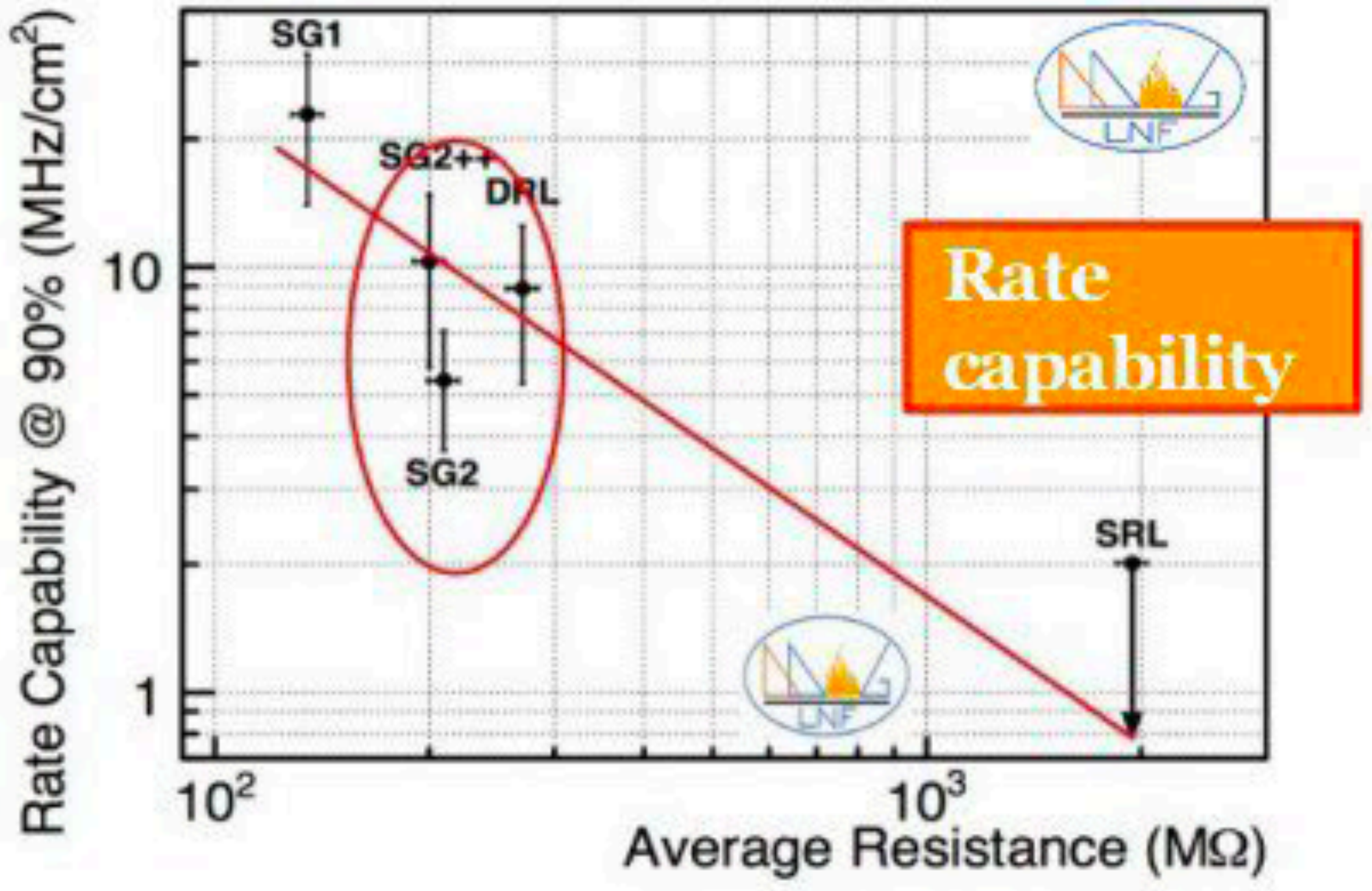
INFN Istituto Nazionale di Fisica Nucleare

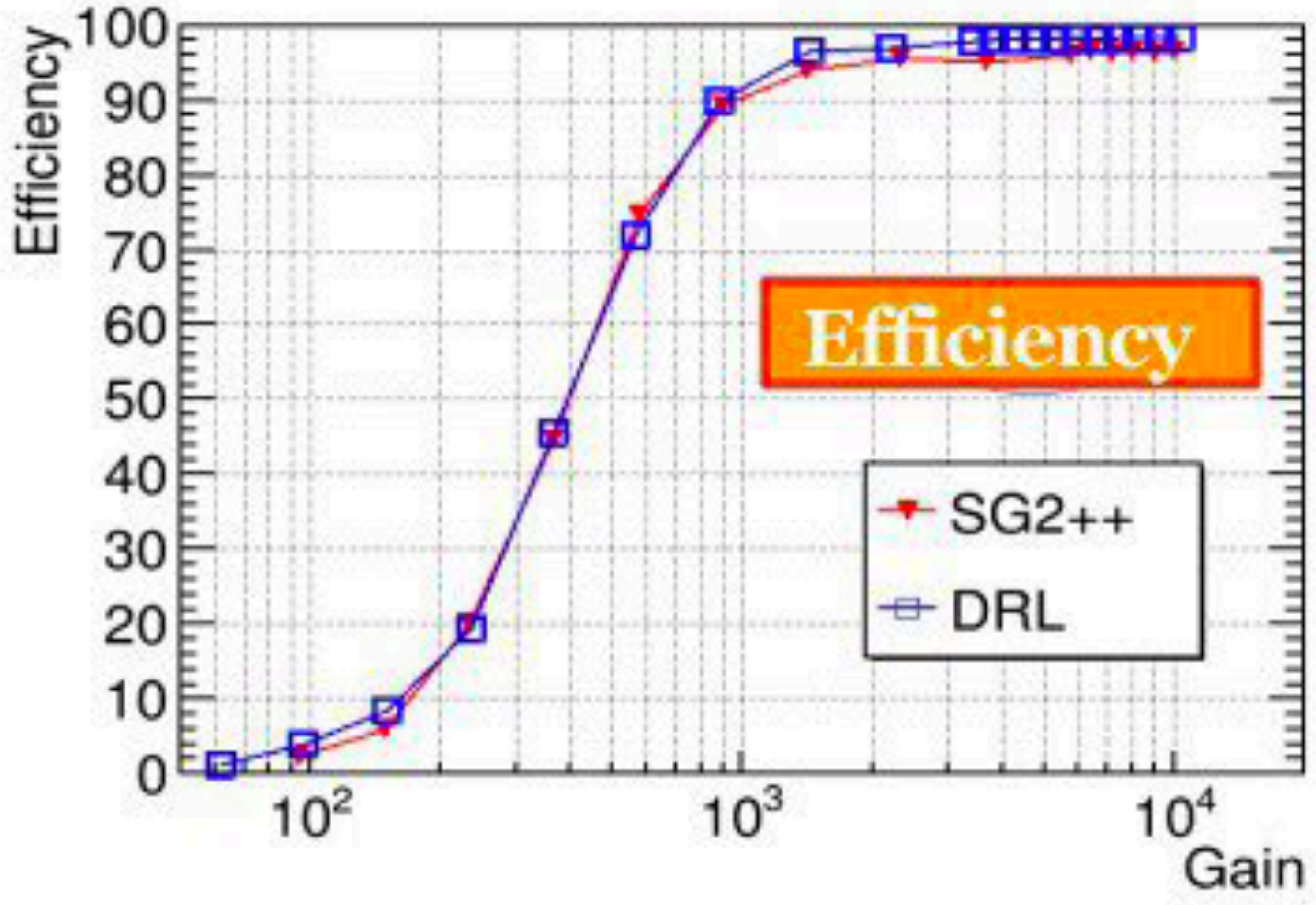
Gain up to 10^4



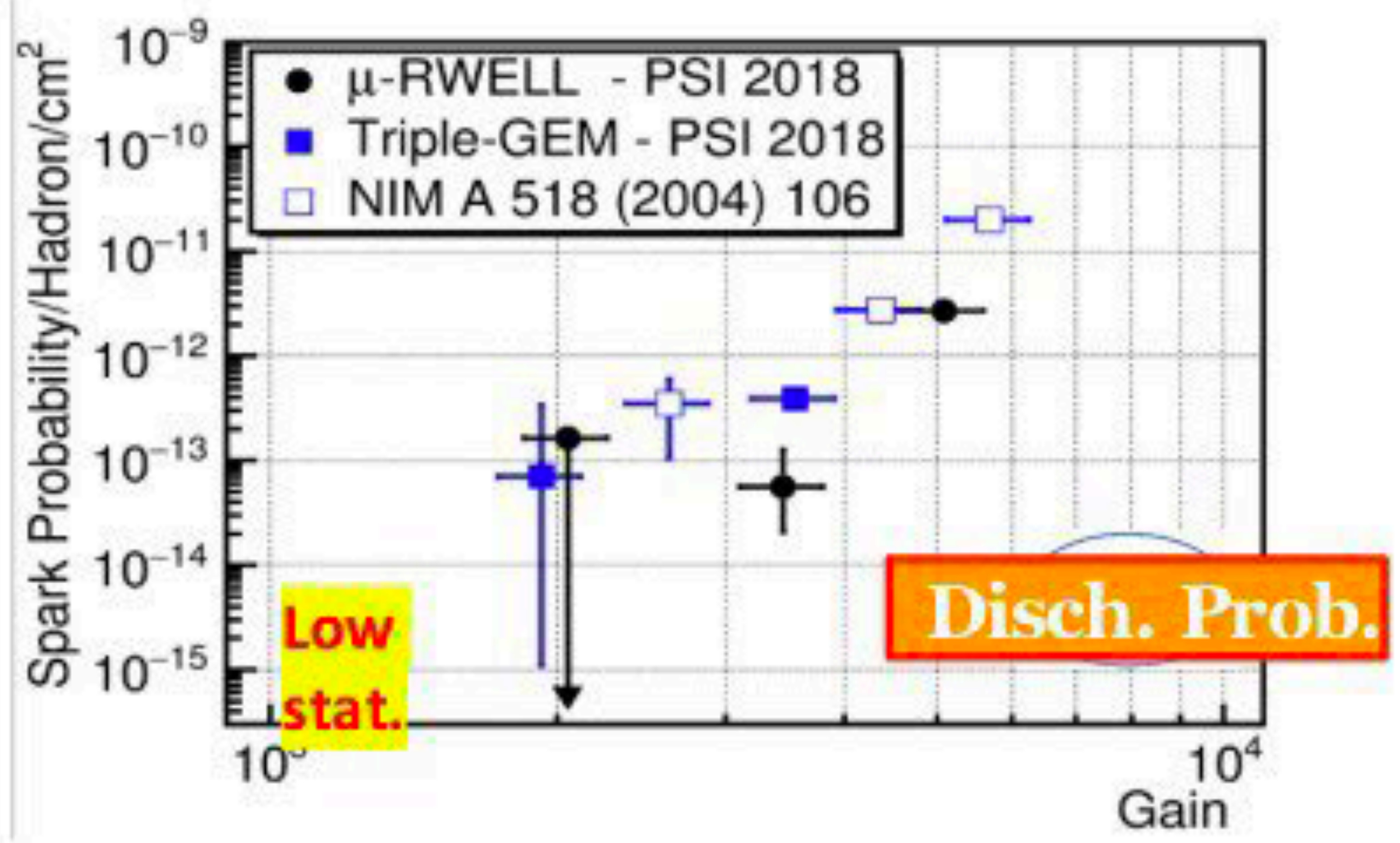
Rate Capability (@ G= 5000) ~ 5-10 MHz/cm²



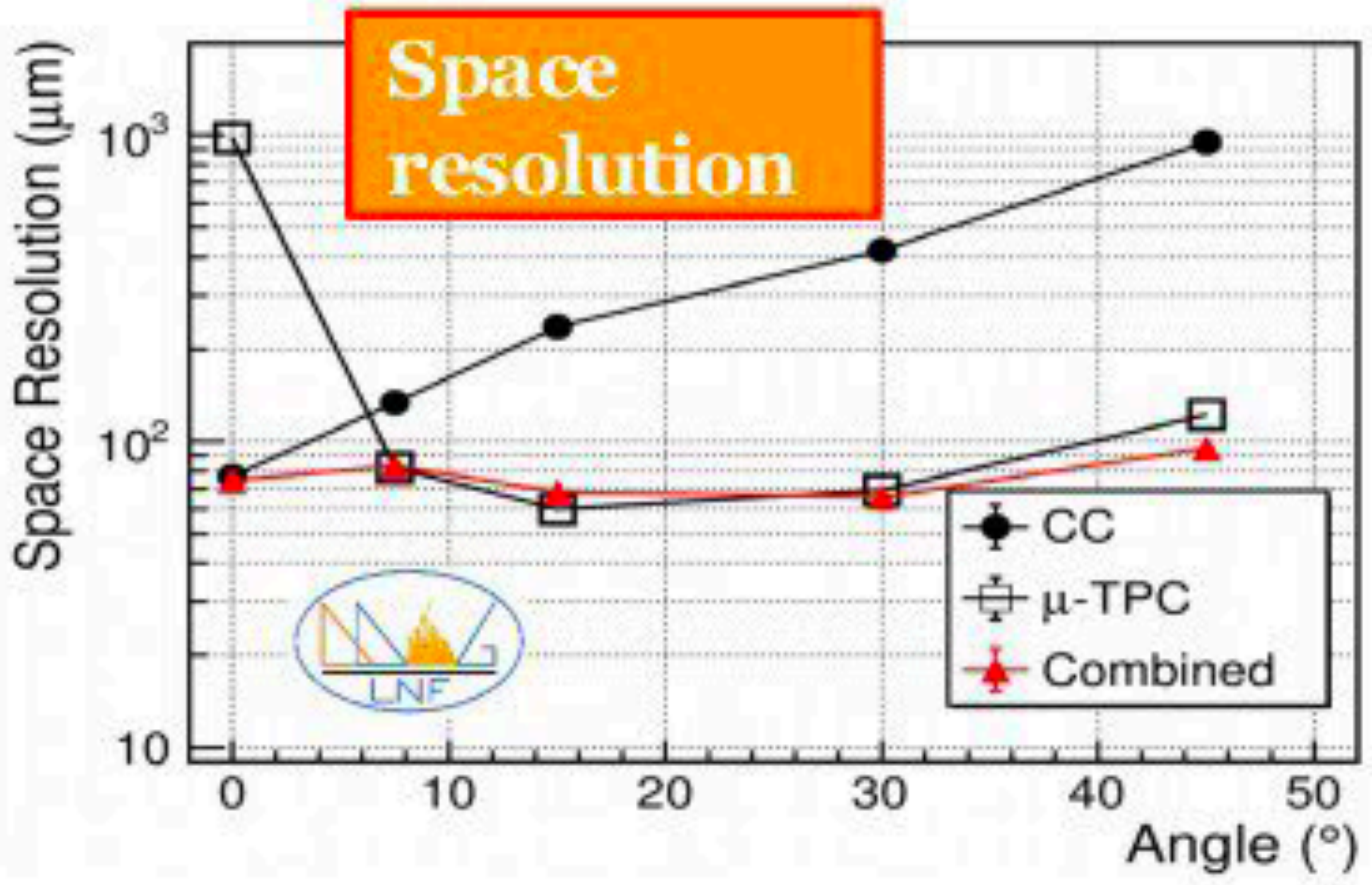




Efficiency ~ 98%

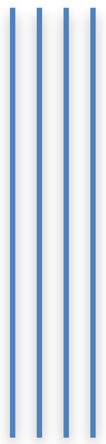


Discharge probability ~ 10^{-13} @ 4000



Space resolution ~ 100 μm

Resistivity validation

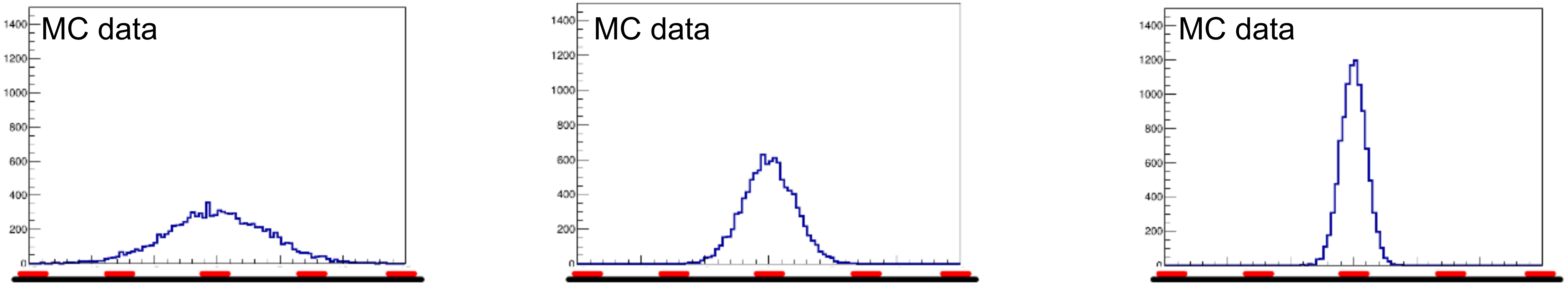


R&D to identify optimal DLC resistivity by studying spatial performance

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

Muon:15, 35 MOhm/square

Effect of resistivity on charge spread

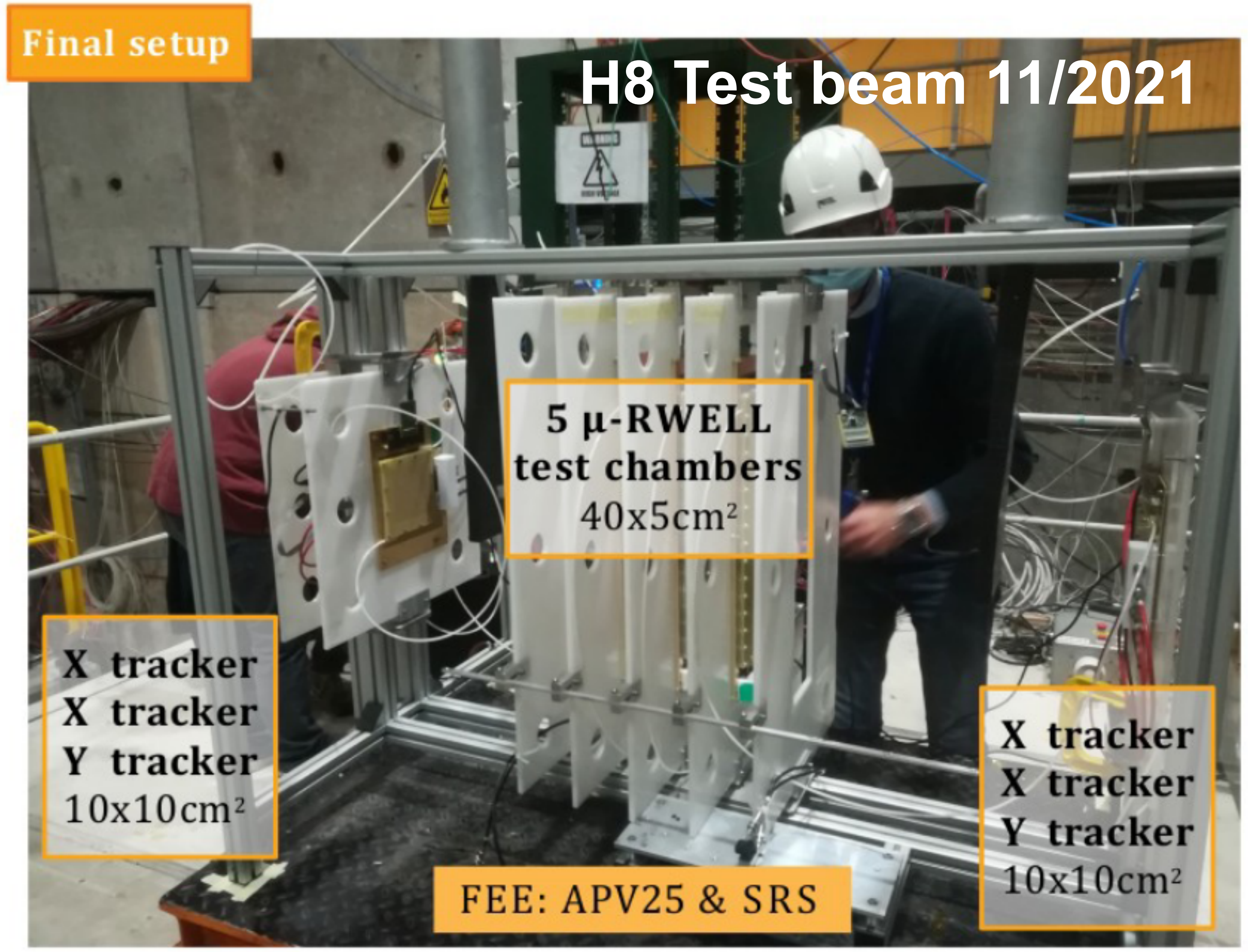


Test beam performed in October 2021 at SPS-H8 CERN line

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

G.Bencivenni et al., "Performance of μ-RWELL detector vs resistivity of the resistive stage", NIM A 886 (2018) 36

IDEA: μ-RWELL Test beam 2021



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

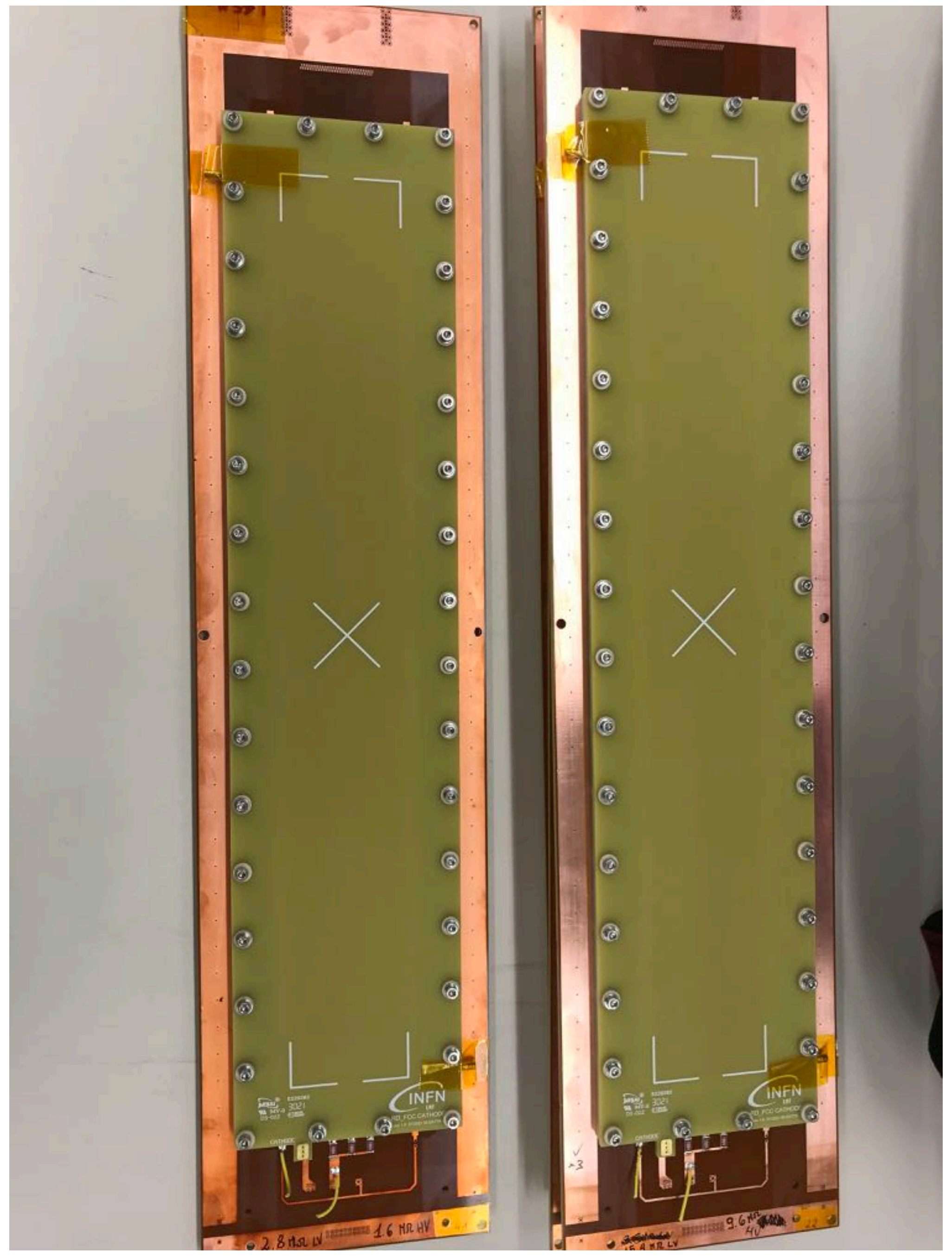
1- Signal shape
(cluster charge, cluster size)
2 - Detector performance
(efficiency, space resolution)

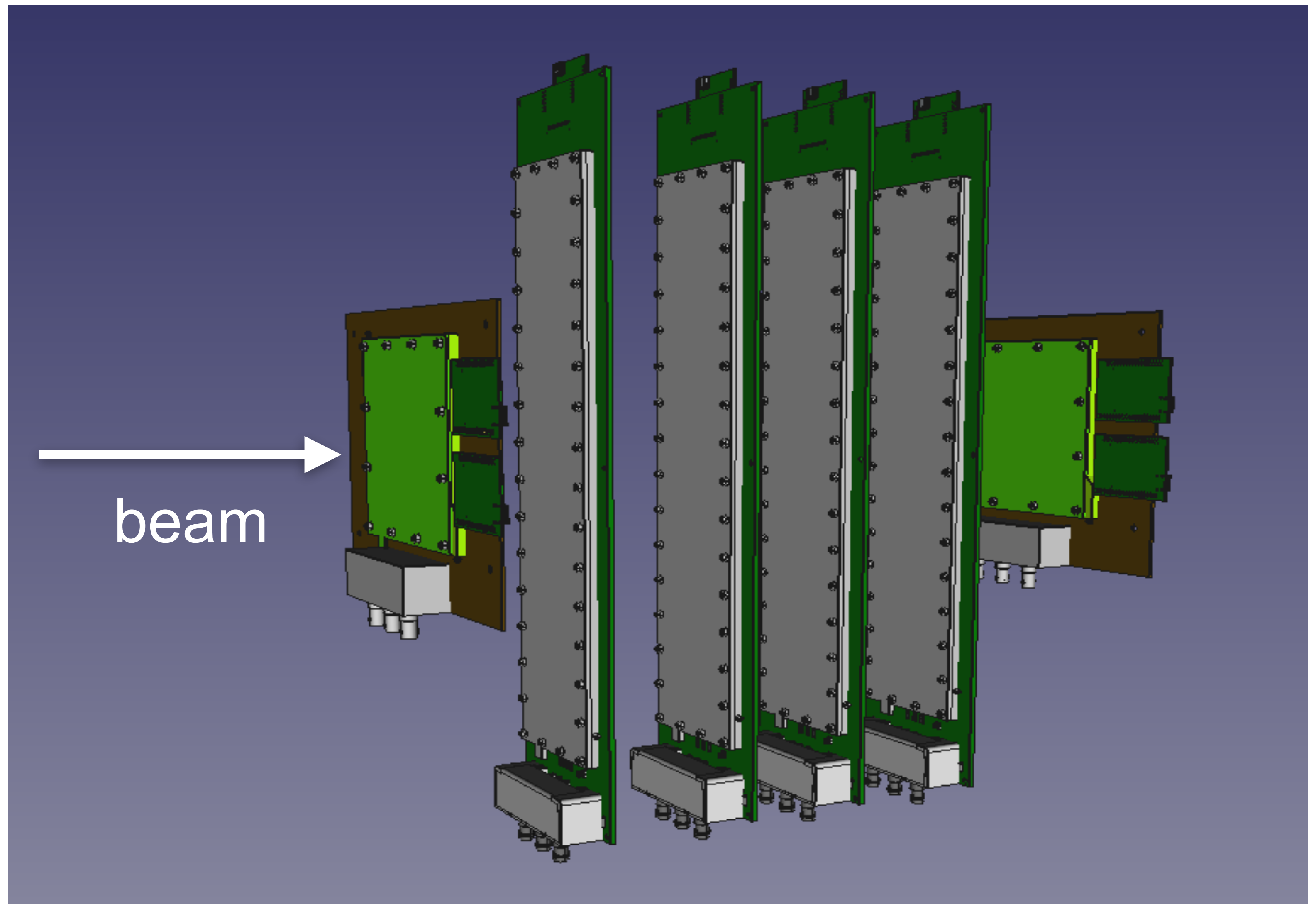
New μ-RWELL prototypes with 40 cm long strips (1D readout)

a) Design optimization:
- different HV filter applied

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

strips

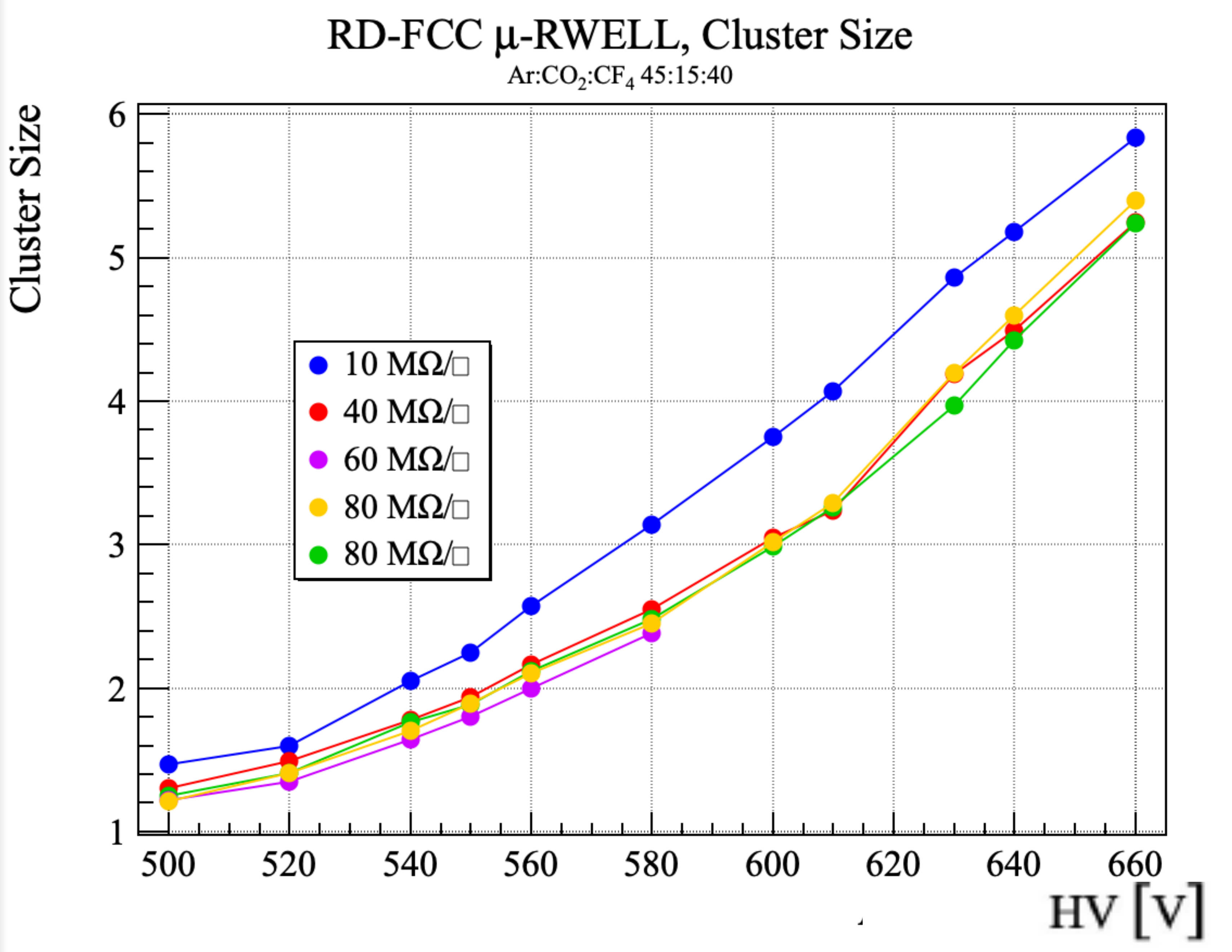


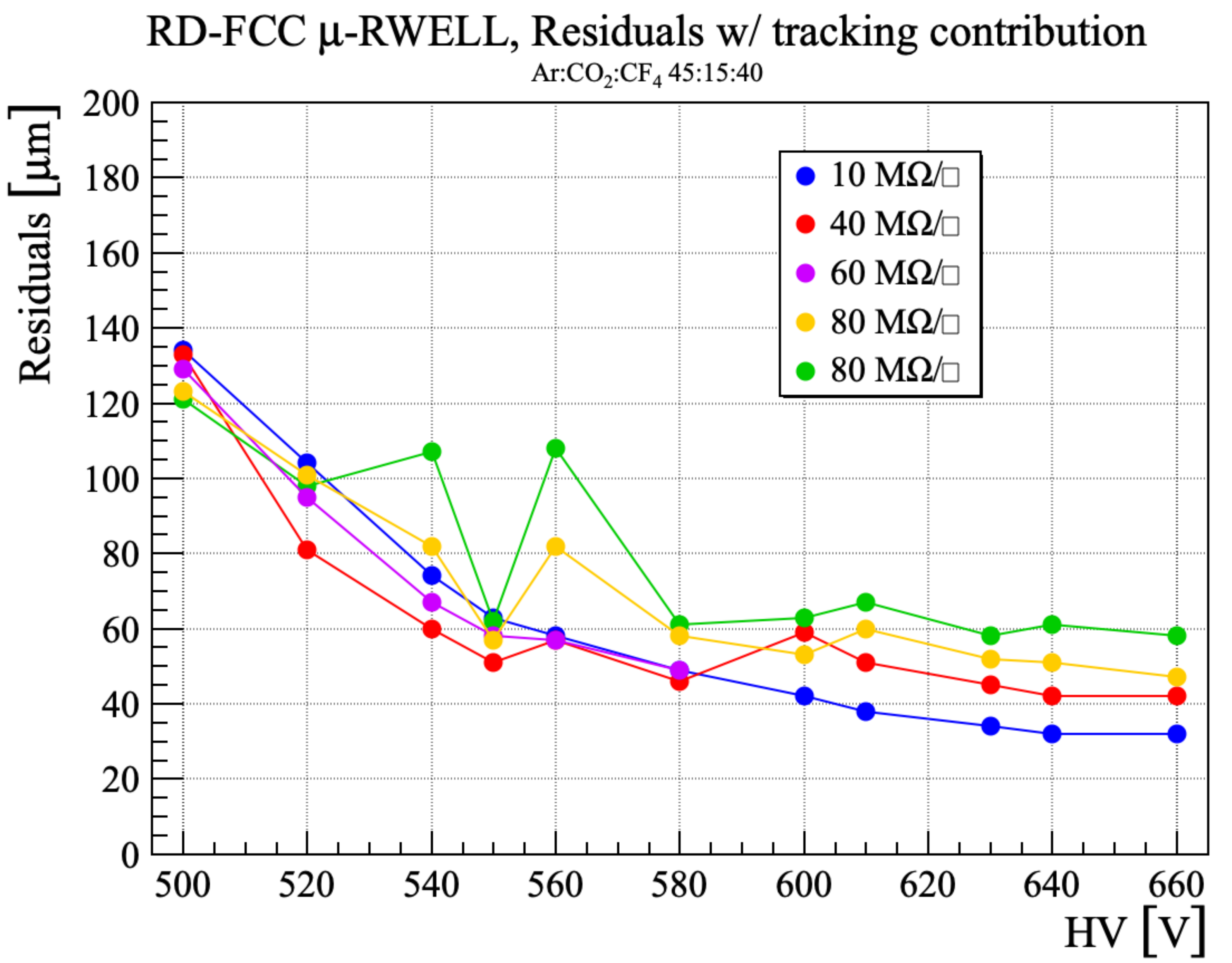


7 μ-RWELL prototypes with resistivity varying between 10 and 80 MOhm/□ will allow to define best resistivity for final 50x50 cm^2 detector

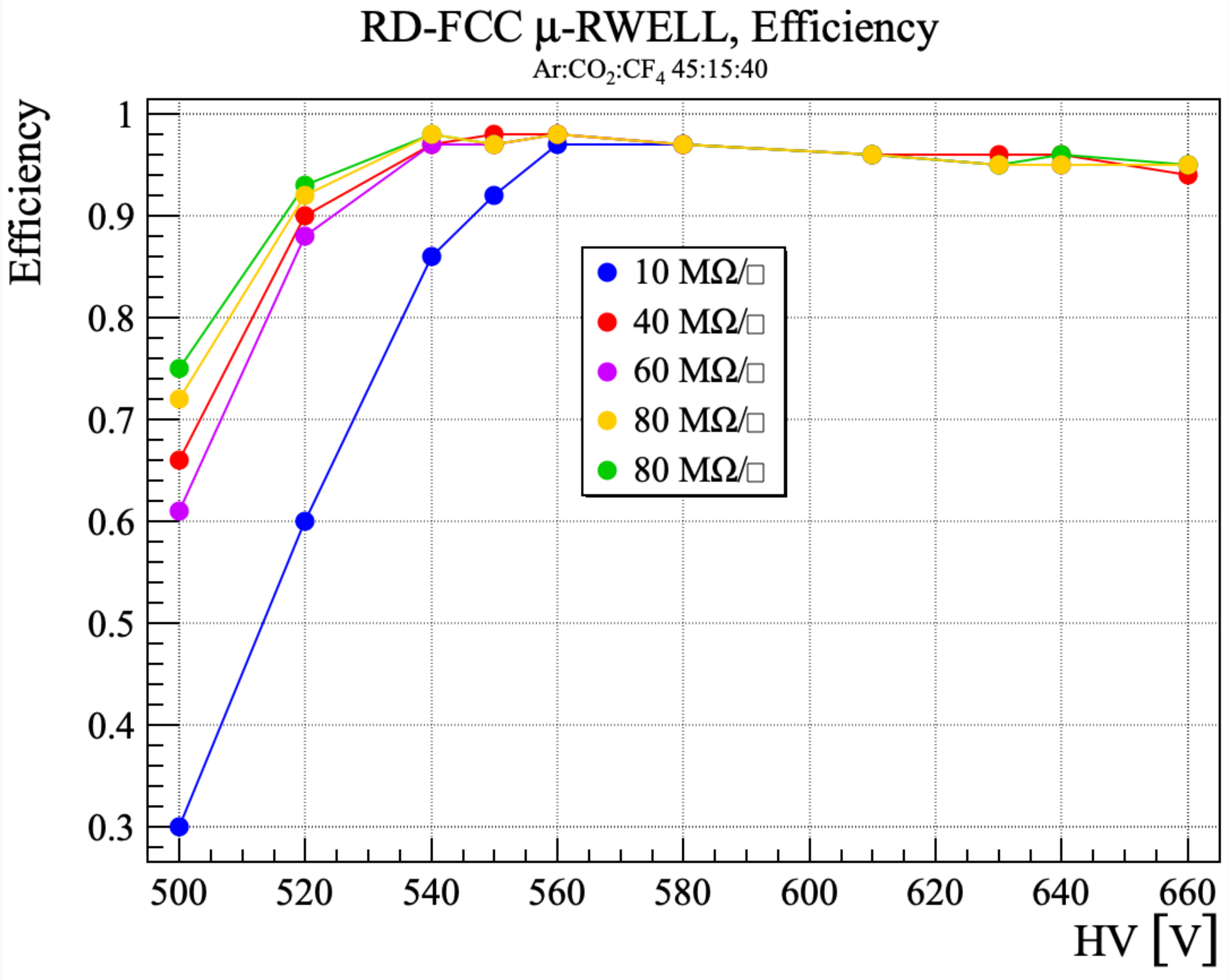
INFN BOLOGNA FERRARA LNF TORINO
Istituto Nazionale di Fisica Nucleare

Test beam 2021 preliminary results





A residual below 100 μm has been measured for all surface resistivities

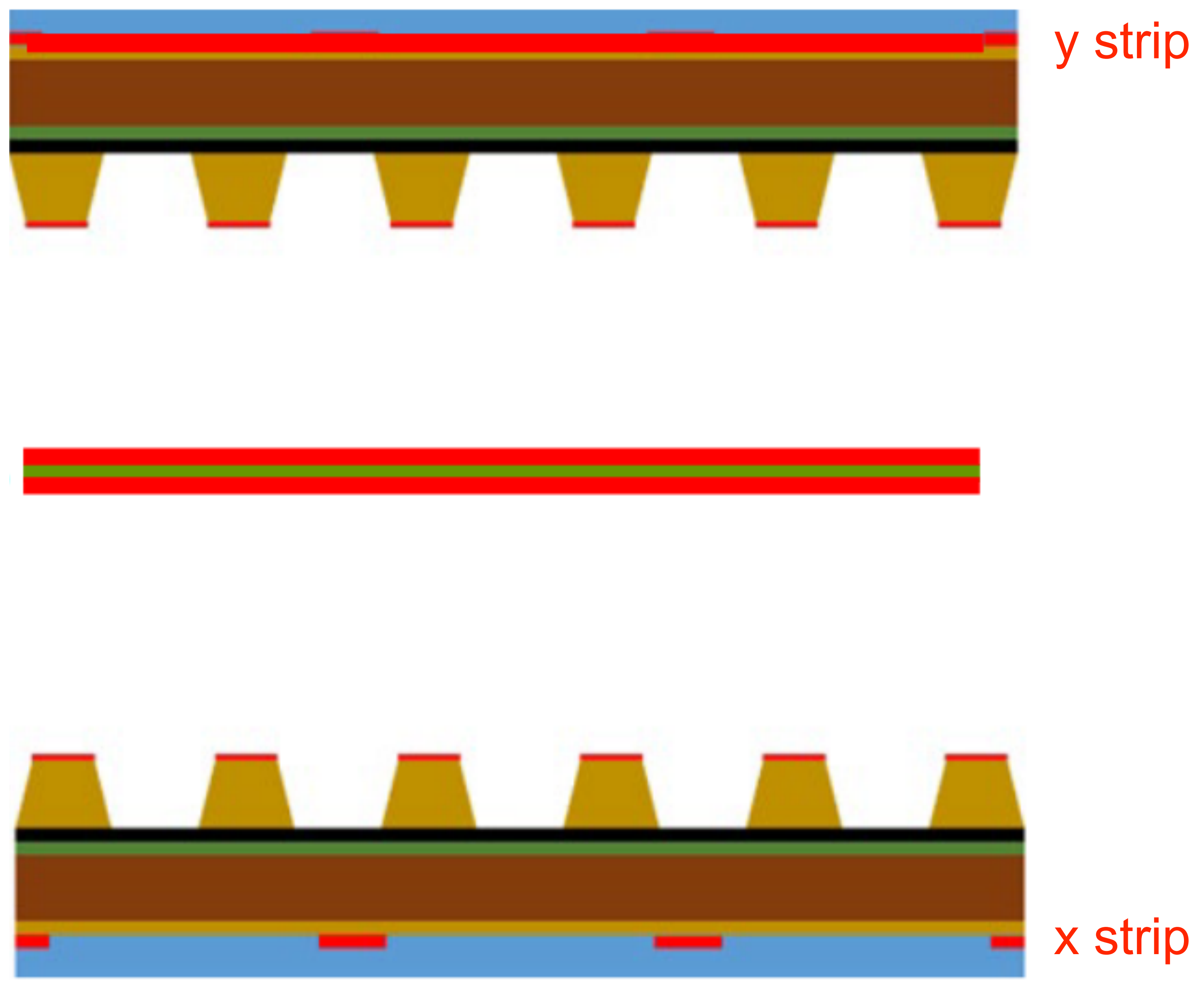


A large eff. plateau (> 100 V) measured

2D μ-RWELL R&D for 2022-2023

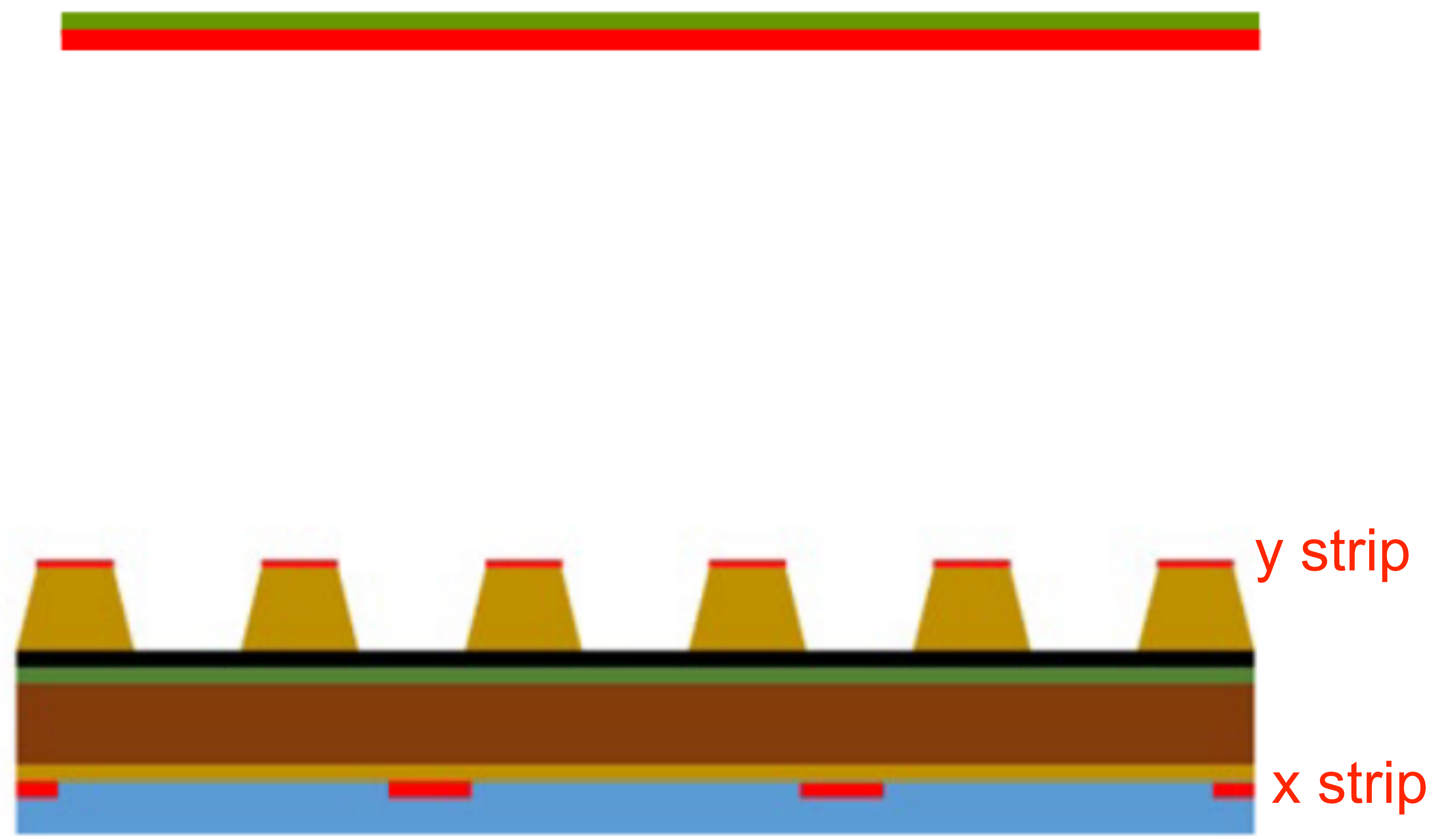
2 stacked 1D μ-RWELL

1 view per μ-RWELL



μ-RWELL with strips on top and anode

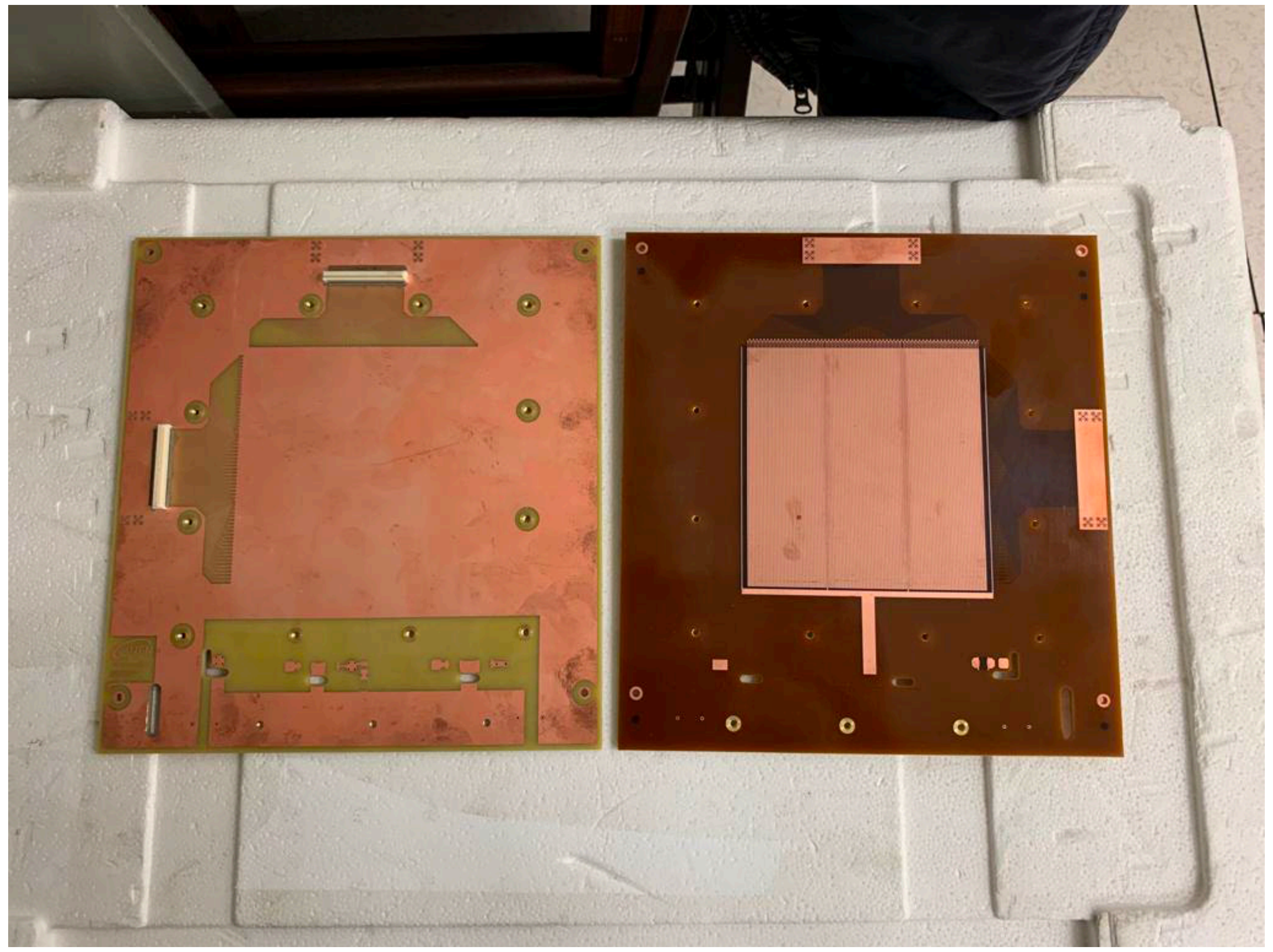
HV on DLC,
TOP to ground

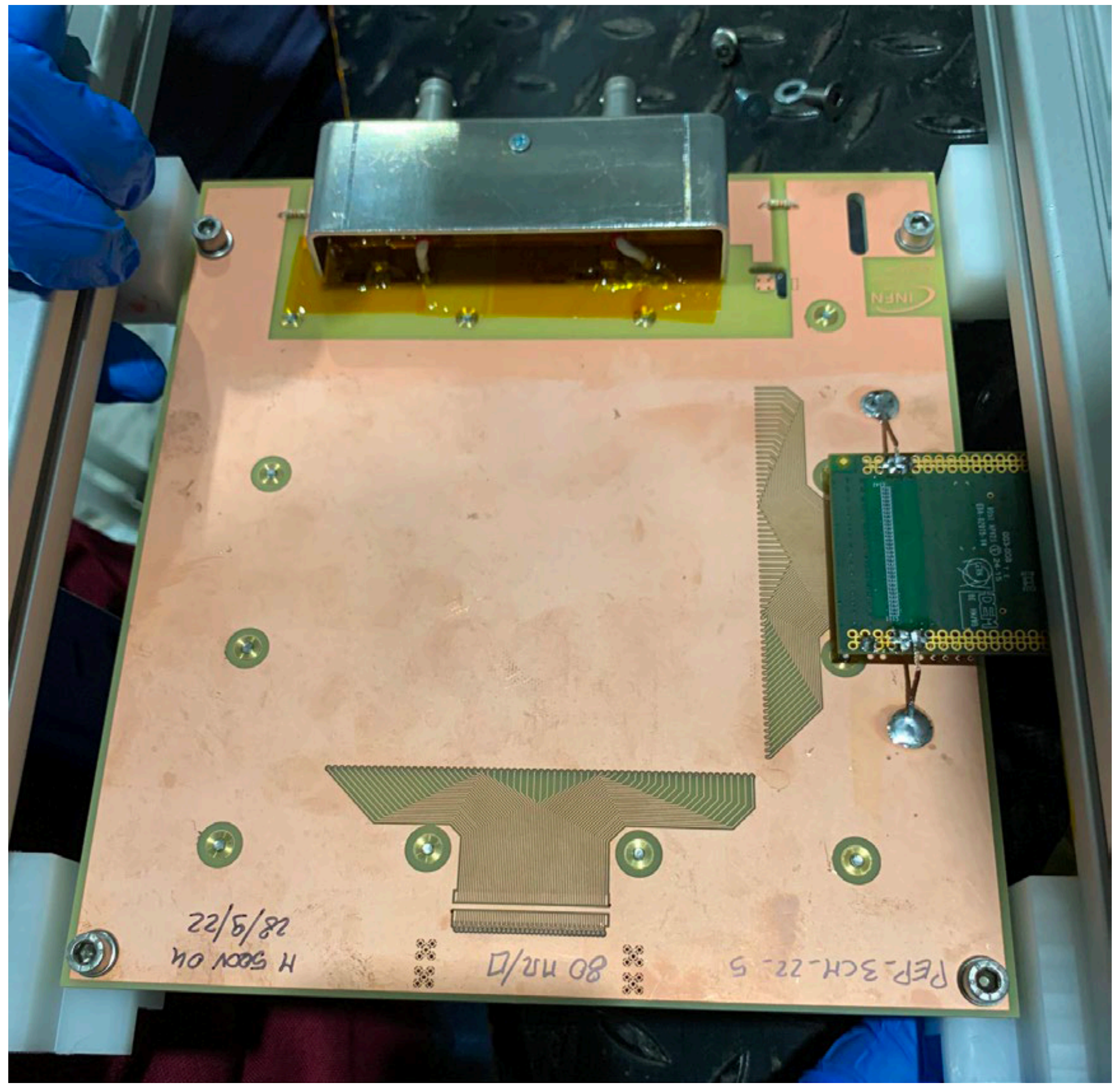


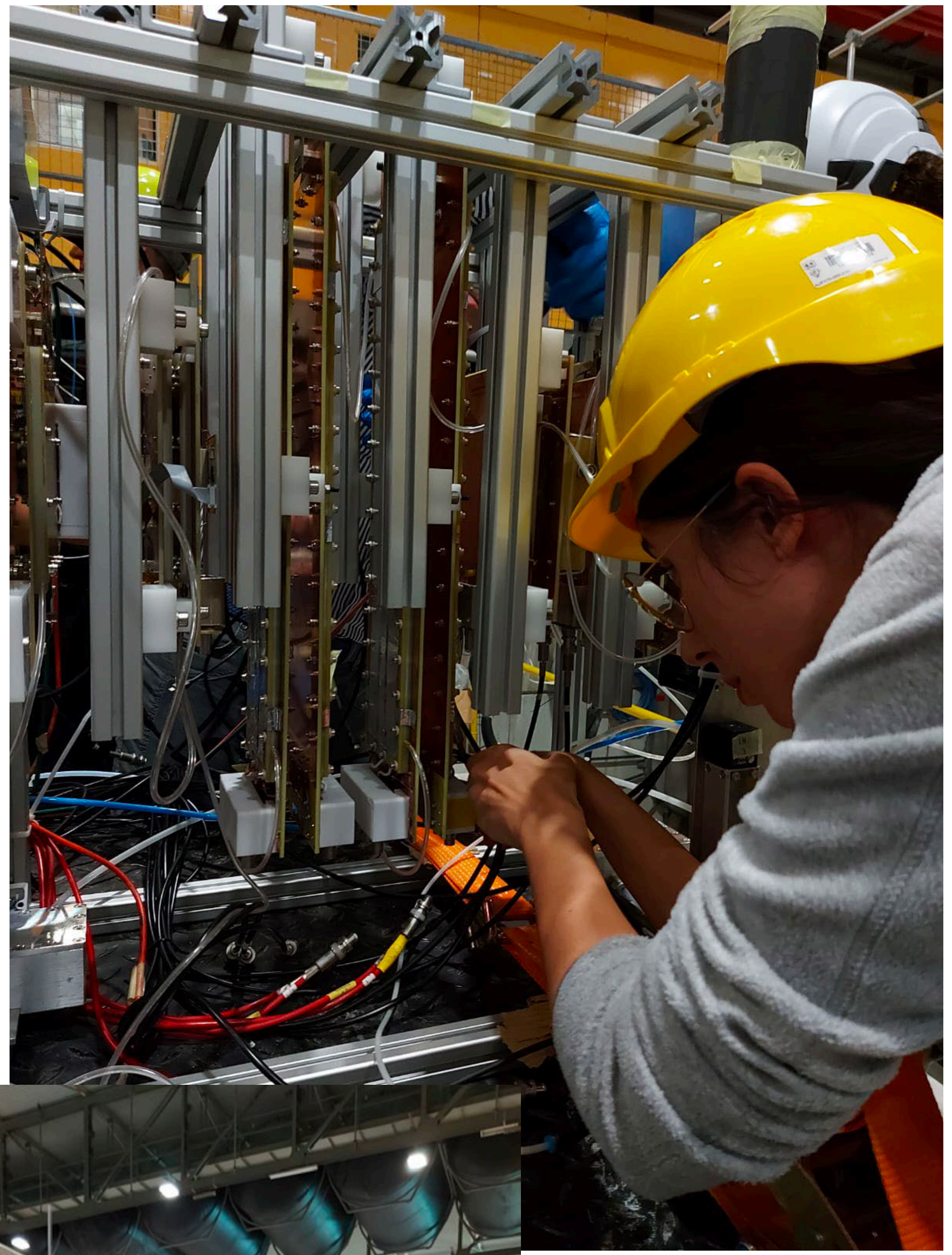
Y coordinate on TOP of the amplification stage

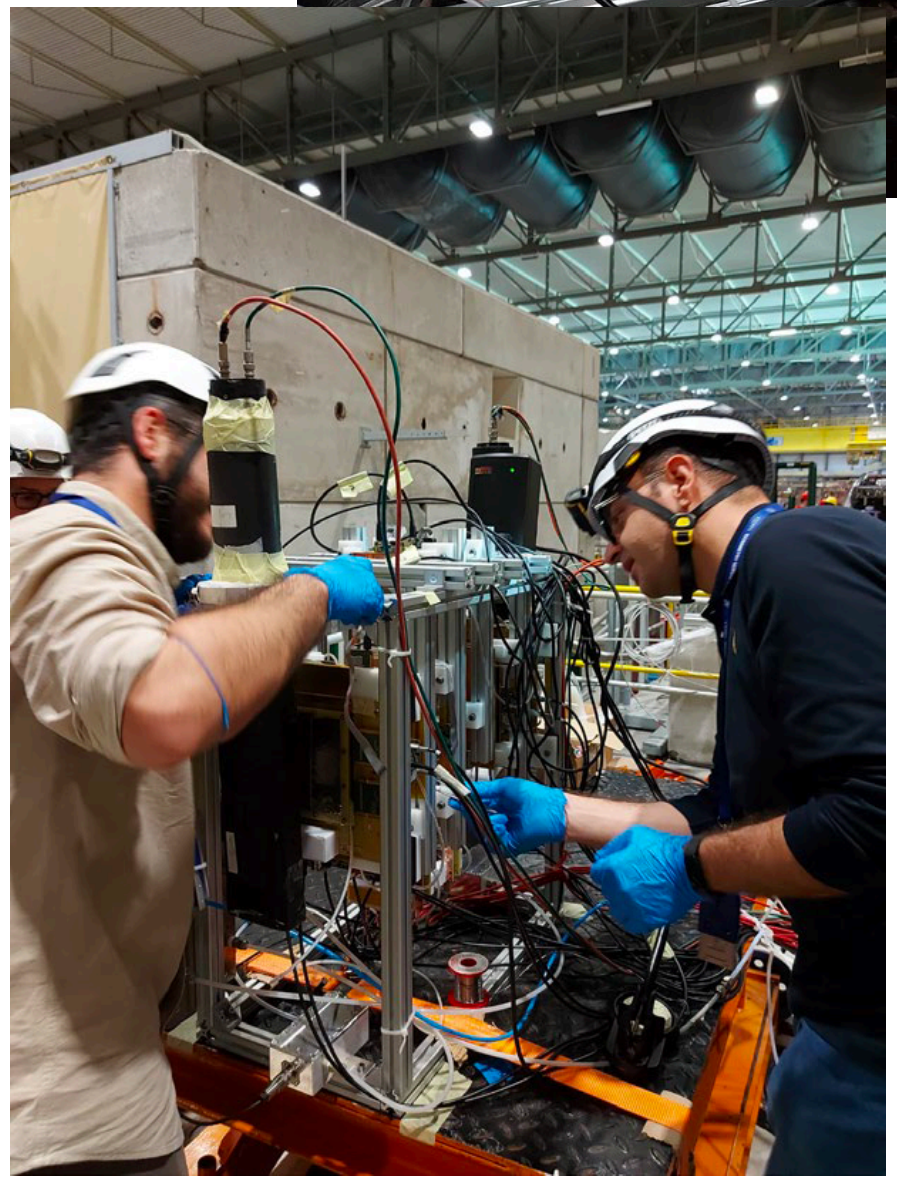
Easy production technology for both layout
2D space resolution to be measured with beam test

μ-RWELL R&D 2022-2023 preliminary results

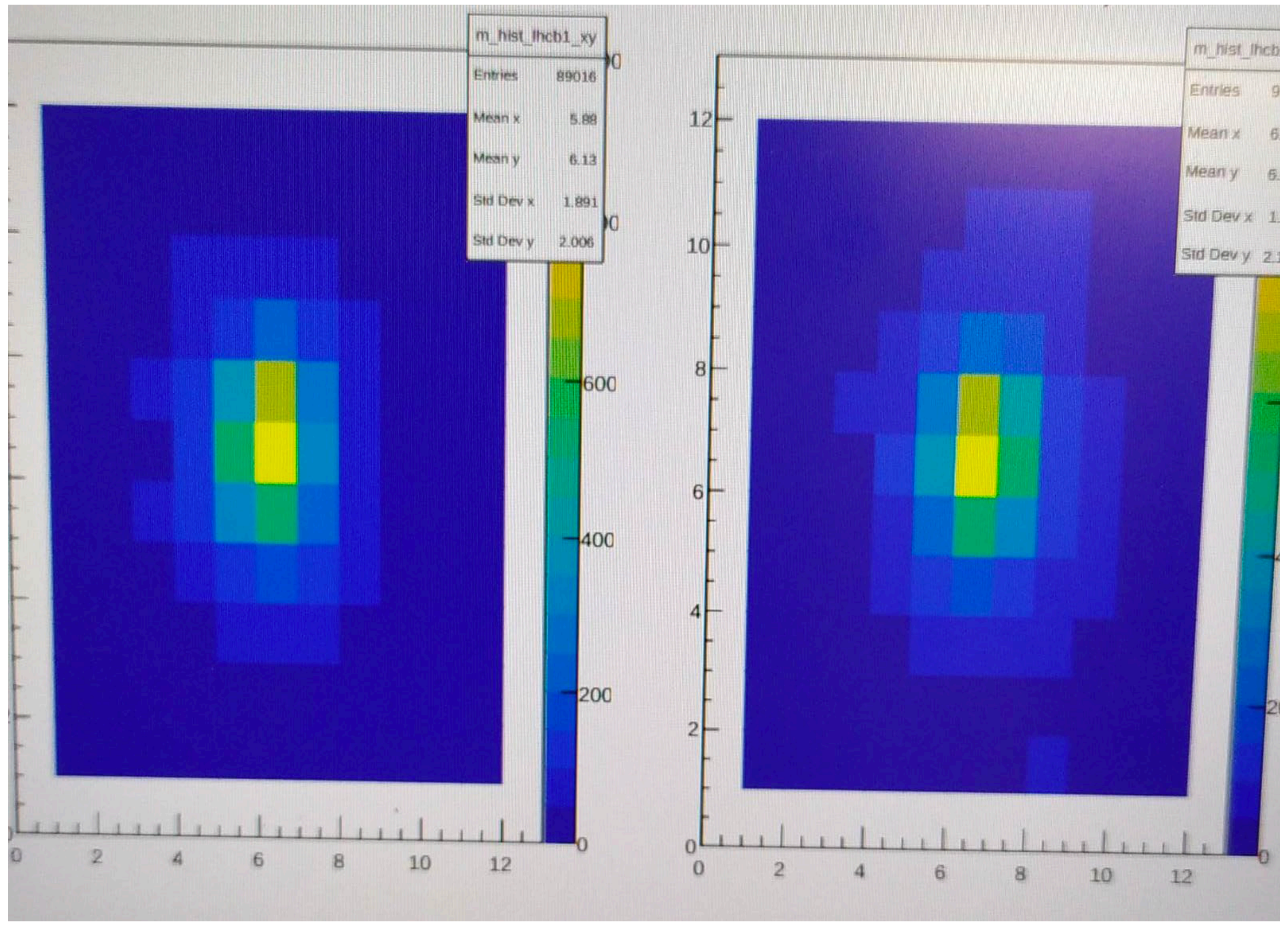




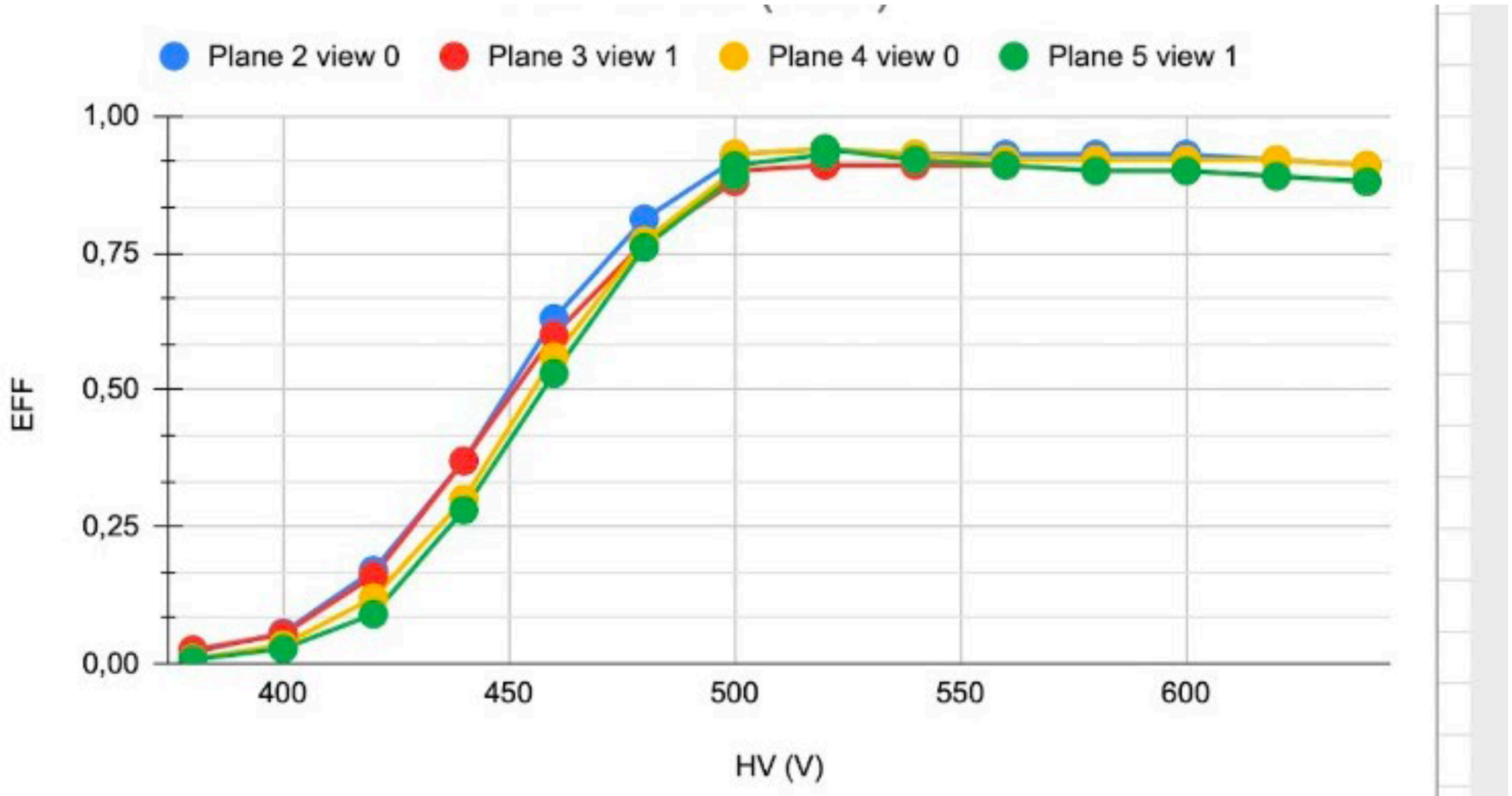




2D beam spot

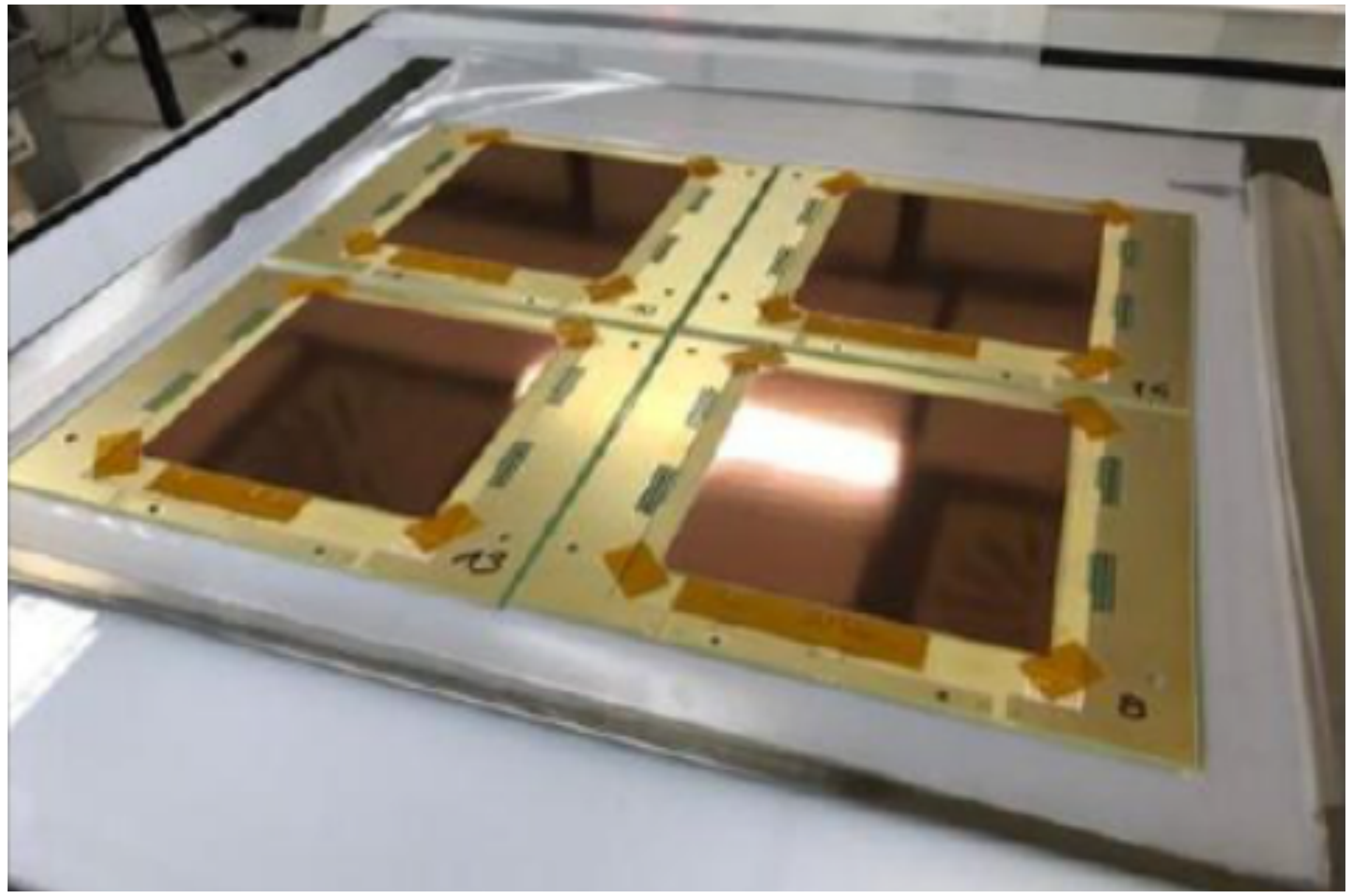


Efficiency



Technology transfer with ELTOS

DLC sputtering with new INFN-CERN machine @ CERN



Step 1: producing μ-RWELL_PCB

- 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 μm thick) (already used in ELTOS)
- pre-smoothing + 106-prepreg (~50 μm thick)
- single 1080-prepreg (~75 μm thick)

Step 4: top copper patterning

Step 5: Kapton etching on small PCB

Finalization

Detector @ CERN for final preparation

IDEA: Test with TIGER electronics

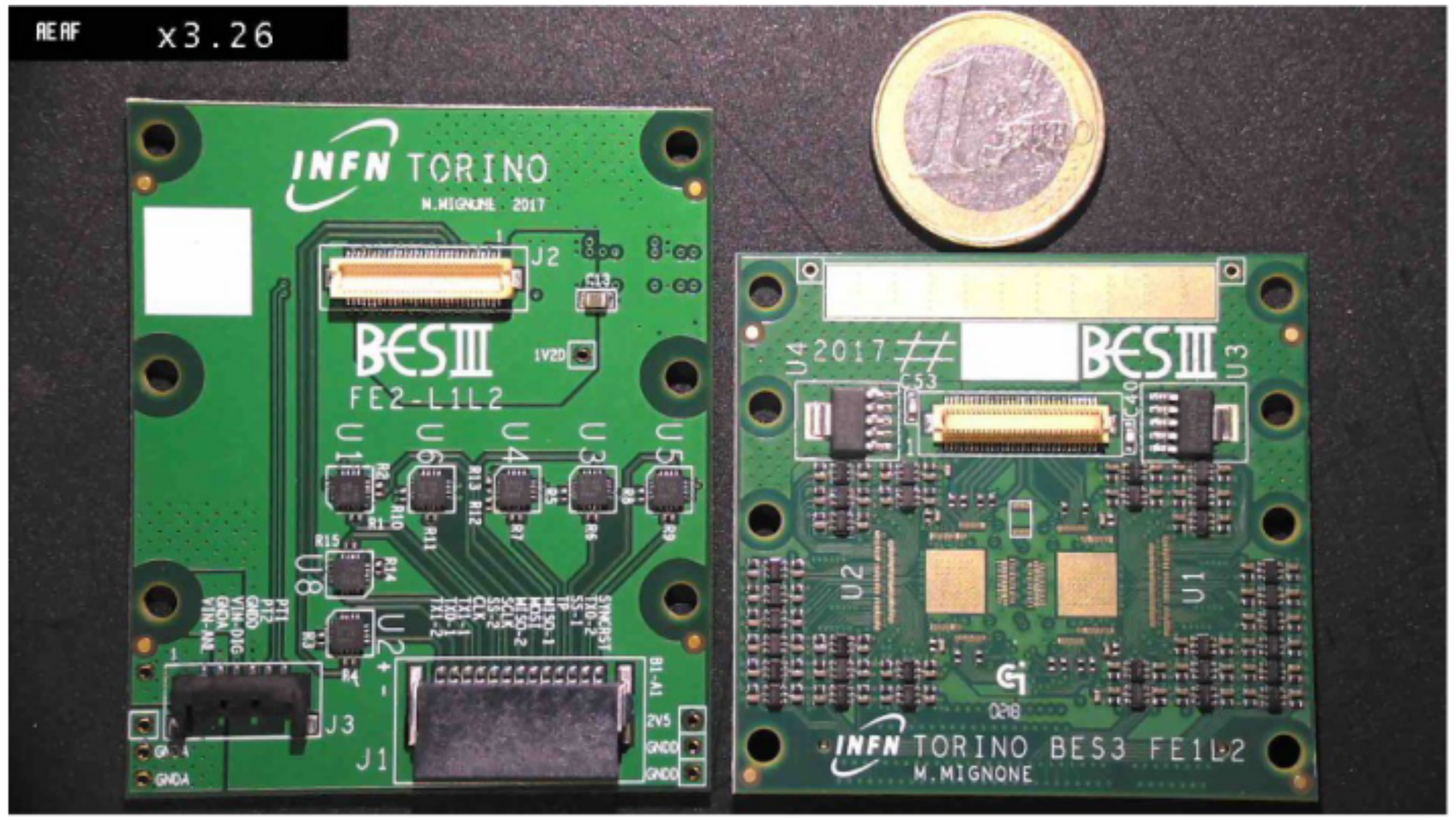


Table 2
Measured performance of the TIGER ASIC.

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)

Aim

Develop dedicated ASIC for μ-RWELL (AIDAinnova task 11.3)

Conclusions

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision μ−RWell detectors

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision μ−RWell detectors
    - Each station is made of a mosaic of hundreds of 50x50 cm^2 μ−RWells

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision μ−RWell detectors
    - Each station is made of a mosaic of hundreds of 50x50 cm^2 μ−RWells
    - Significant R&D is ongoing since 4-5 years, foresee another 3-4 years to finalise the design

FUTURE CIRCULAR COLLIDER

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision μ−RWell detectors
    - Each station is made of a mosaic of hundreds of 50x50 cm^2 μ−RWells
    - Significant R&D is ongoing since 4-5 years, foresee another 3-4 years to finalise the design
  - CLD foresees a muon detector made of 6 stations of RPC detectors

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision μ–RWell detectors
    - Each station is made of a mosaic of hundreds of 50x50 cm^2 μ–RWells
    - Significant R&D is ongoing since 4-5 years, foresee another 3-4 years to finalise the design
  - CLD foresees a muon detector made of 6 stations of RPC detectors
    - Unfortunately no R&D is ongoing on this design

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision μ−RWell detectors
    - Each station is made of a mosaic of hundreds of 50x50 cm^2 μ−RWells
    - Significant R&D is ongoing since 4-5 years, foresee another 3-4 years to finalise the design
  - CLD foresees a muon detector made of 6 stations of RPC detectors
    - Unfortunately no R&D is ongoing on this design
  - LAs-based detector concept has not yet made clear plans of their muon system

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision $\mu-$RWell detectors
    - Each station is made of a mosaic of hundreds of 50x50 cm^2 $\mu-$RWells
    - Significant R&D is ongoing since 4-5 years, foresee another 3-4 years to finalise the design
  - CLD foresees a muon detector made of 6 stations of RPC detectors
    - Unfortunately no R&D is ongoing on this design
  - LAs-based detector concept has not yet made clear plans of their muon system
    - Could be a RPC-based or a scintillator-based system. No R&D activity at the moment

Conclusions

- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision μ−RWell detectors
    - Each station is made of a mosaic of hundreds of 50x50 cm^2 μ−RWells
    - Significant R&D is ongoing since 4-5 years, foresee another 3-4 years to finalise the design
  - CLD foresees a muon detector made of 6 stations of RPC detectors
    - Unfortunately no R&D is ongoing on this design
  - LAs-based detector concept has not yet made clear plans of their muon system
    - Could be a RPC-based or a scintillator-based system. No R&D activity at the moment
  - For the time being IDEA is the most active on hardware studies and developments

Conclusions

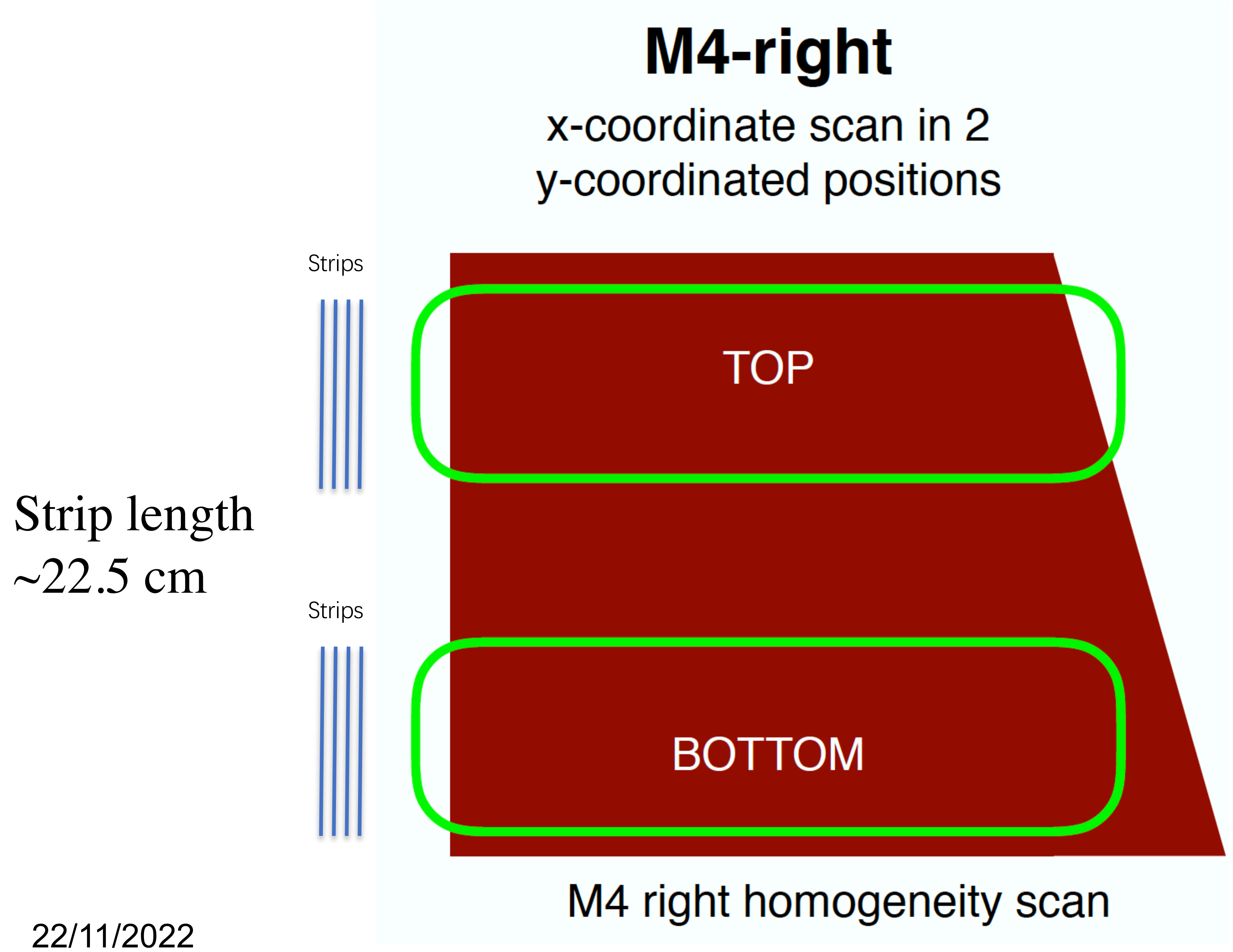
- **FCC-ee** will be a fascinating machine, allowing to achieve unprecedented precision on **EW measurements** and **Higgs couplings**
  - For the time being 3 detector concepts have been presented
    - CLD, IDEA and a LAr-based detector
  - IDEA proposes a muon detector made of three stations of high precision μ−RWell detectors
    - Each station is made of a mosaic of hundreds of 50x50 cm^2 μ−RWells
    - Significant R&D is ongoing since 4-5 years, foresee another 3-4 years to finalise the design
  - CLD foresees a muon detector made of 6 stations of RPC detectors
    - Unfortunately no R&D is ongoing on this design
  - LAs-based detector concept has not yet made clear plans of their muon system
    - Could be a RPC-based or a scintillator-based system. No R&D activity at the moment
  - For the time being IDEA is the most active on hardware studies and developments
    - Profiting from several national funding schemes, EU projects (AIDAinnova, EURO-LABS), etc.

Backup

μ−RWELL-based detectors

2022-2024 R&D program

- Define the best resistivity of the DLC for both μRWELL fundamental tiles and build the 50×50 cm^2 prototypes for the pre-shower and muon systems.
- Optimize the engineering mass construction process together with the ELTOS industry.
- Develop a custom-made ASIC for the μRWELL with the experience obtained from the TIGER chip and to test the μRWELL prototypes.
- Develop a new reconstruction algorithm, ML-based, to improve the resolution of μRWELL.
- Simulation of the CEPC decay channels of interest to optimize the detector design with special emphasis on Long Lived Particles to show the impact of a performing tracked in the muon system instead of a tagger.



Development of a new ASIC

- Two large microRWell chambers M4 in Bologna;
- Ferrara has procured the Tiger electronics;
- Plan to start equipping the M4s with the TIGER next spring;
- Use a cosmic telescope to characterize the detector and the electronics and later to expose the chamber with the TIGER electronics to a test beam;
- Funding received to develop a new ASIC starting from the experience of the TIGER.