Future Tau-Charm Factory 2024,

Guanzhou

November 19th, 2024

The Cylindrical Resistive WELL

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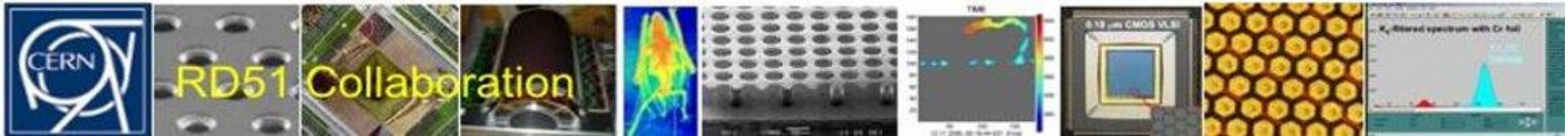
1. LNF-INFN
2. CERN
3. INFN-Fe

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072.



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WP5: Overview

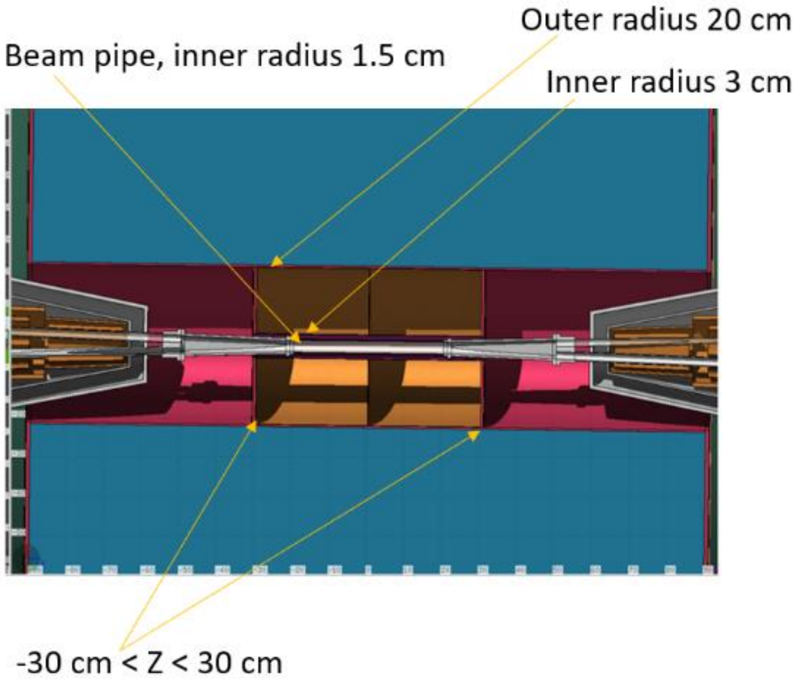
- WP5 was aimed to support developments for a Super Charm-Tau (SCT) Factory, to be build at BINP, Novosibirsk
  - Task 5.1: Internationalization and outreach for Super Charm Tau (BINP)
  - Task 5.2: Accelerator Developments for SCT (BINP, IJCLab, CERN)
  - Task 5.3: Software Developments for SCT Simulation, Reconstruction, Analysis (BINP, CERN)
  - Tasks 5.4, 5.5, 5.6: Sub-detector developments for SCT
  - Developments of different sub-detectors: Inner Tracker (BINP, INFN), Central Tracker (BINP, INFN), Cherenkov Detector (BINP, JLU)
- With the removal of BINP and the loss of focus on the (Russian) SCT, we pivoted the work package towards developments for Lepton Colliders: SCT also under development in China, FCCee, CLIC, ILC (partially aiming at much higher centre-of-mass energies)

Presented by A. Sailer at the EURIZON Final Event, Prague 17-19 January 2024

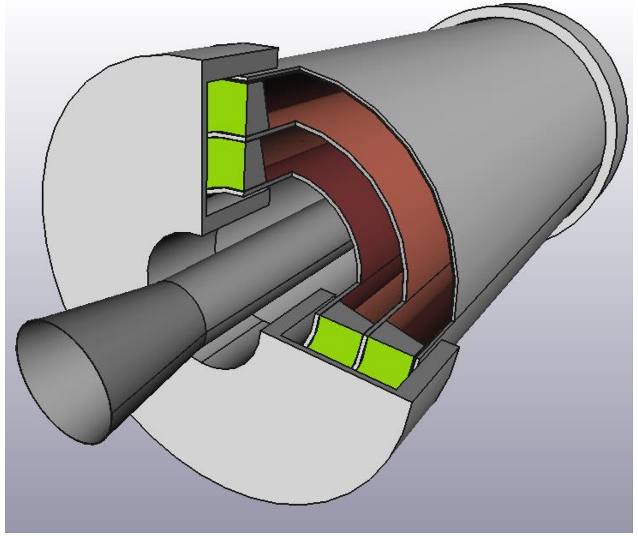
About EURIZON project

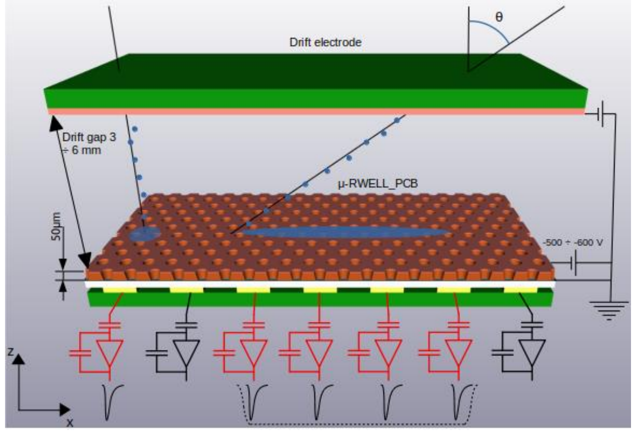
The EU funded project EURIZON supports scientific and technical collaboration in the field of research infrastructures.

TPC

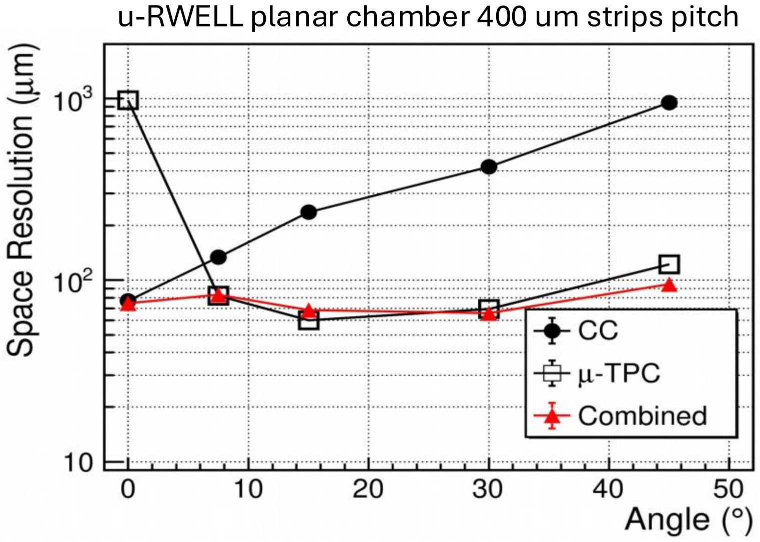


Cylindrical micro-RWELL





Operated in **uTPC mode**:
By an analog readout the delay time of the signals is recorded and, knowing the electrons $v_{drift}(E_{drift})$, the z coordinate of the clusters is reconstructed.



JINST 16 (2020) P08036.

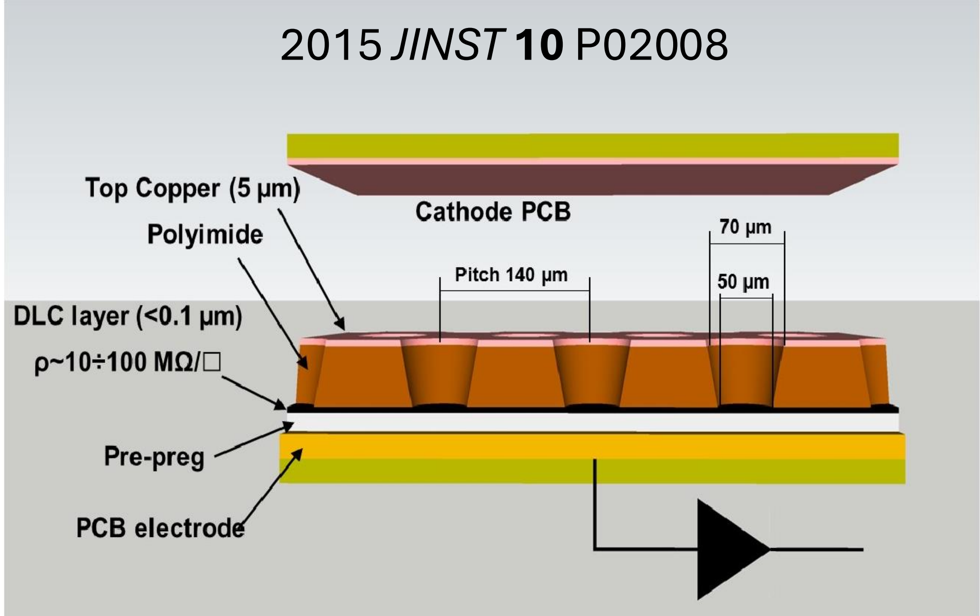
For more details: https://www.eurizon-project.eu/about/

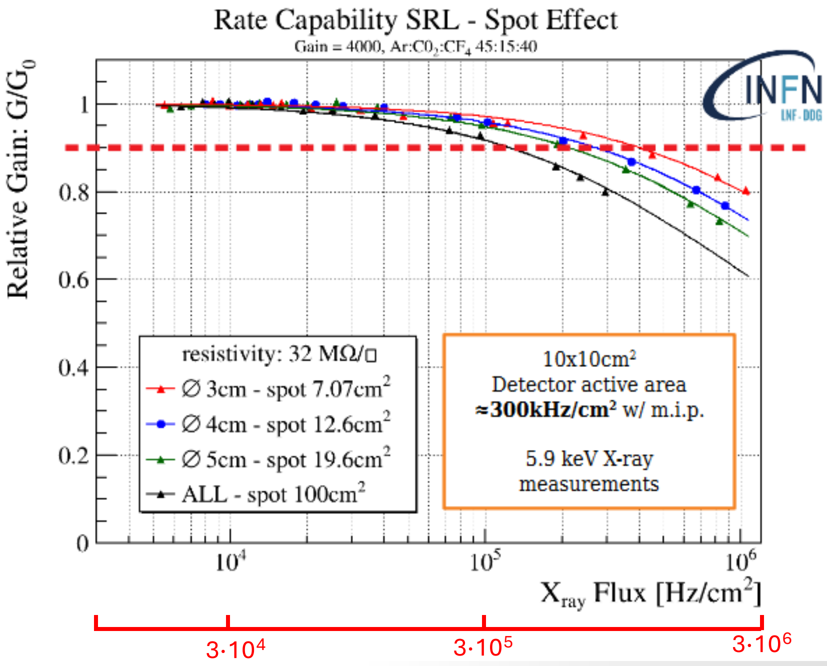
The u-RWELL technology at a glance

Developed in collaboration with CERN-EP-DT-MPT workshop
The features can be summarized:

- **Spark suppression**: presence of a resistive layer (Diamond-like Carbon) to quench sparks amplitude (like MM)
- **Compactness**: amplification stage (geometry like WELL and GEM) embedded in the PCB readout → multi-layer PCB std. industrial technology →mass production

But the resistive layer introduces a local gain drop as the rate increases





$$\frac{G}{G_0} = \frac{-1 \pm \sqrt{1 + 4p_0\varphi}}{2p_0\varphi}$$

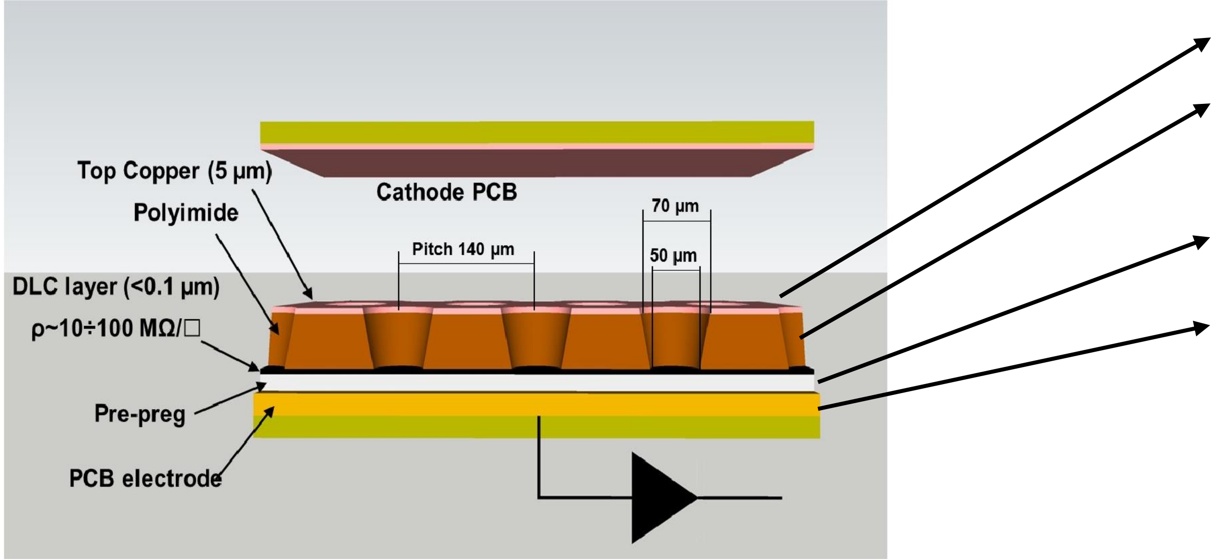
Naïf model for the **average resistance Ω** between the charge point collection and the perimetrical grounding line

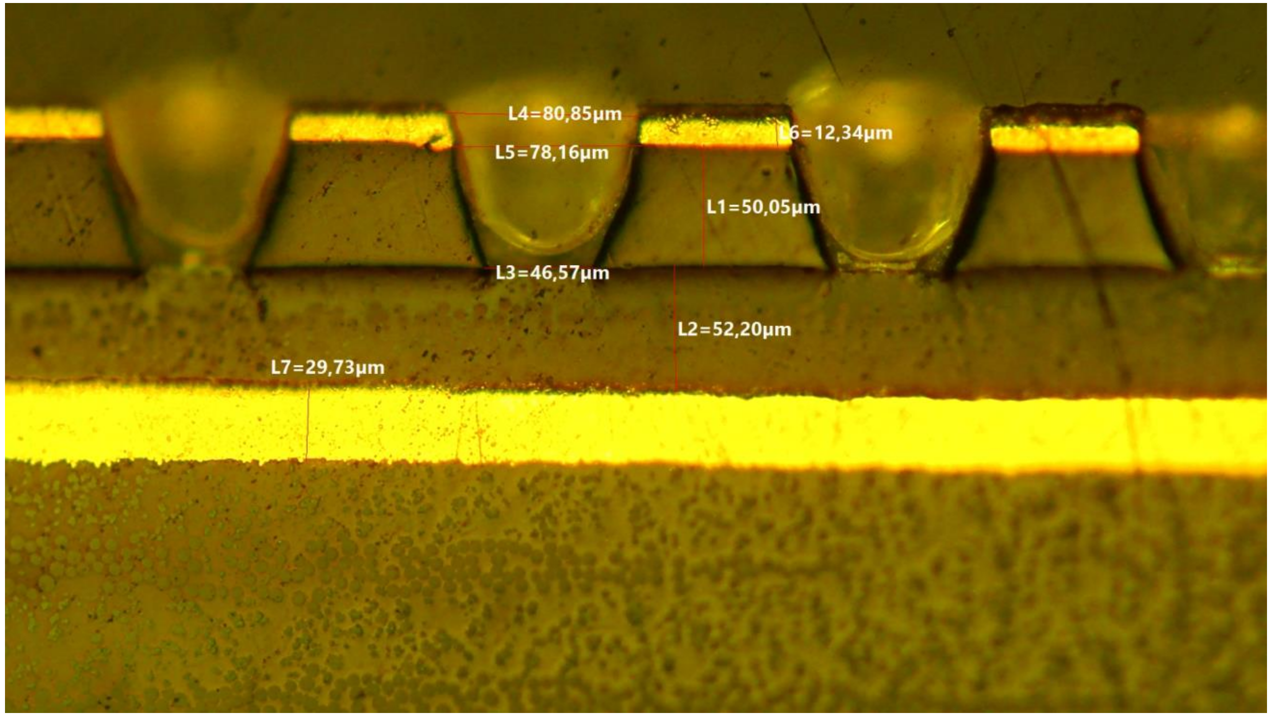
$$\Omega(r) = \frac{p_0(r)}{\alpha e N_0 G \pi r^2} = \rho_S \frac{d - \frac{r}{2}}{\pi r}$$

α from the fit to the gain vs. applied ΔV
N_0 from GARFIELD++ simulation
r radius of the X-rays spot
d average distance to the ground

The micro-Resistive WELL features

JINST 10 (2015) P02008





The **micro-RWELL technology** can be «easily» adapted to any geometry, since the base material is Kapton
This latter can be:

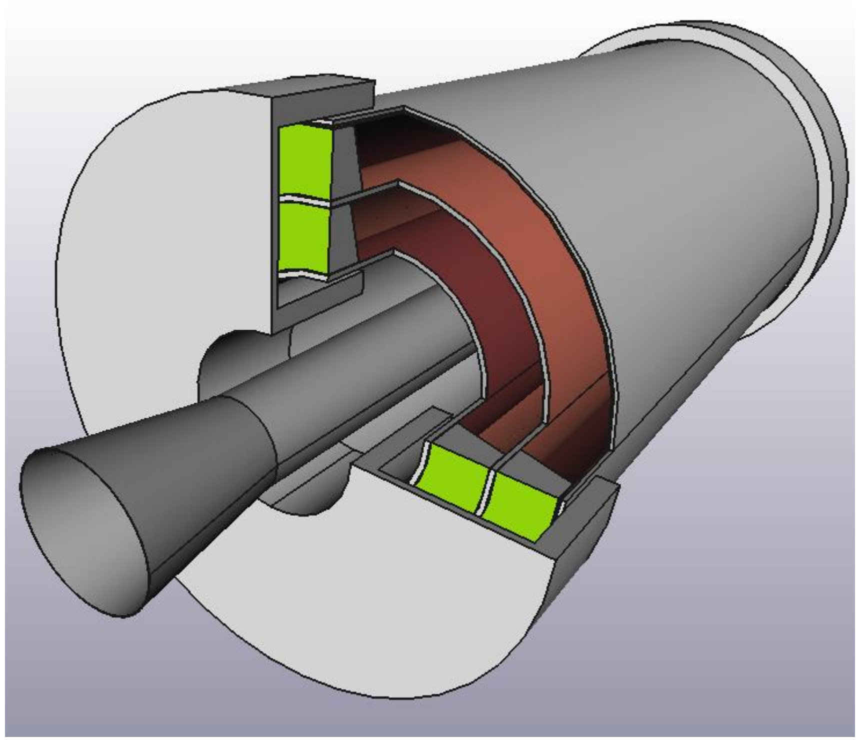
- **Shaped** according the wanted geometry
- Realized on a **flexible PCB** and then even bent

The **compactness and the ductility** of this very important part of the detector make this technology suitable for many applications, especially the ones needing a low material budget detector

A low material budget Inner Tracker

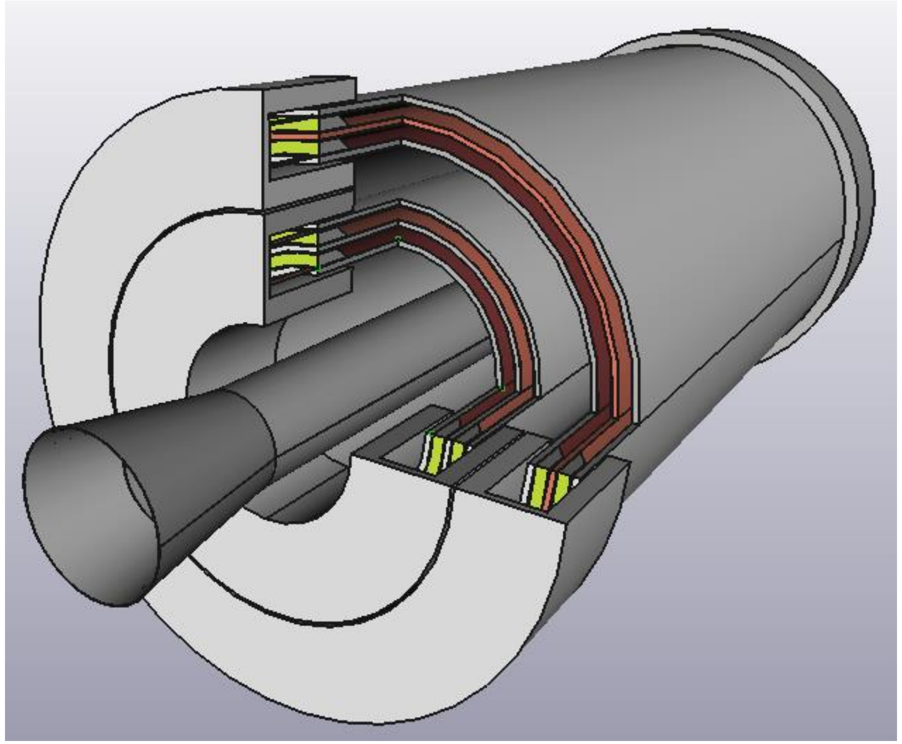
Two options for the Inner Tracker have been proposed, both exploiting the possibility to introduce a double-faced cathode between two cylindrical anodes

Option A



Global 10 cm gas sampling
0.75 ÷ 0.86% X_0
Lower material budget but longer track segment reconstruction due to a larger diffusion

Option B:



Global 4 cm gas sampling
1.46 ÷ 1.72% X_0
Larger material budget but smaller tracks segments

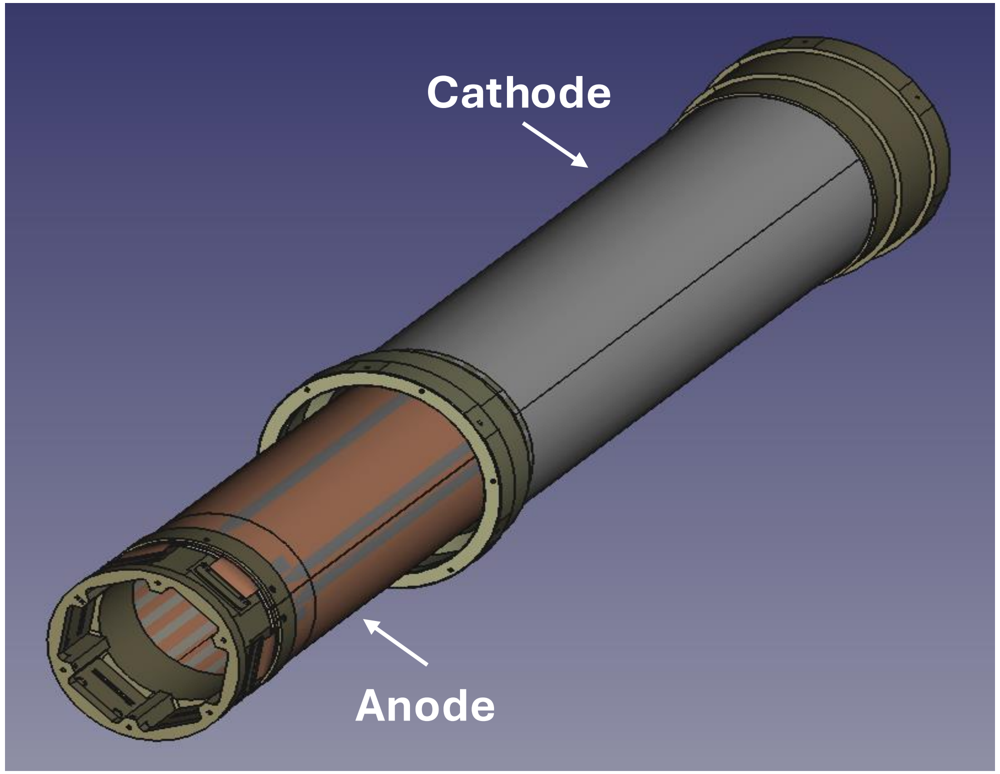
The prototype

The prototype has been built thanks to the joined efforts of CERN, **Loson S.r.l**, INFN-Fe and INFN-LNF. In particular:

- mechanics drawn by LNF and INFN-Fe and realized by LOSON
- FEE drawn by INFN-LNF
- Flexible circuits realized by CERN

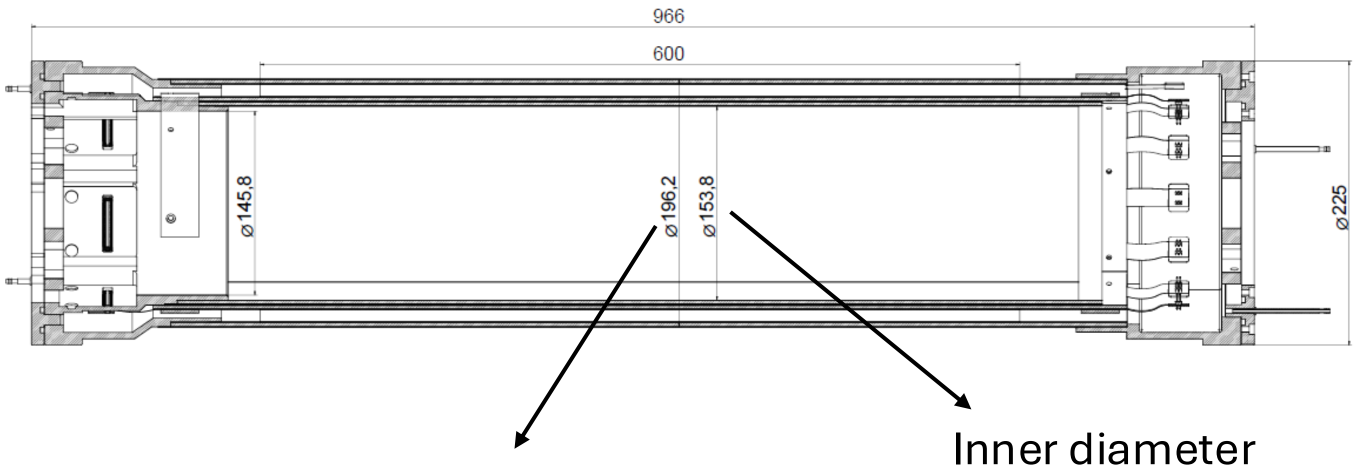
The detector is composed of **two coaxial electrodes**, where the anode is the innermost one

The detector exhibits **two** very interesting **features**: the **anode is segmented** in three modules and the sealing is performed by O-rings so that, in case of malfunctioning, the device can be re-opened and the bad module can be substituted saving the rest of the detector.



Here follow the main geometrical parameters of the detector

anode dia.	cathode dia.	drift size	active length	# HV chs	# r/out chs	strip pitch
168.5	188.5	10	600	12	768	0.68

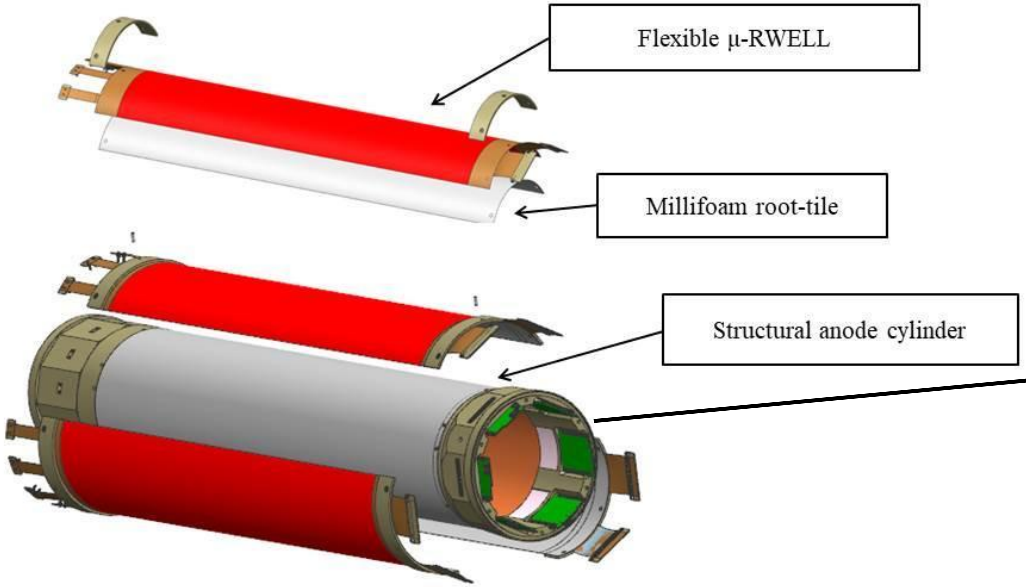


Outer diameter of the cathode

Inner diameter of the anode support

The Anode

The **active area is divided in three modules** fixed by screws to a rectified support in **Millifoam®**
Each module is a cylindrical shell (“**roof tile**”) covering approximately an angle of 120° in the r-φ plane

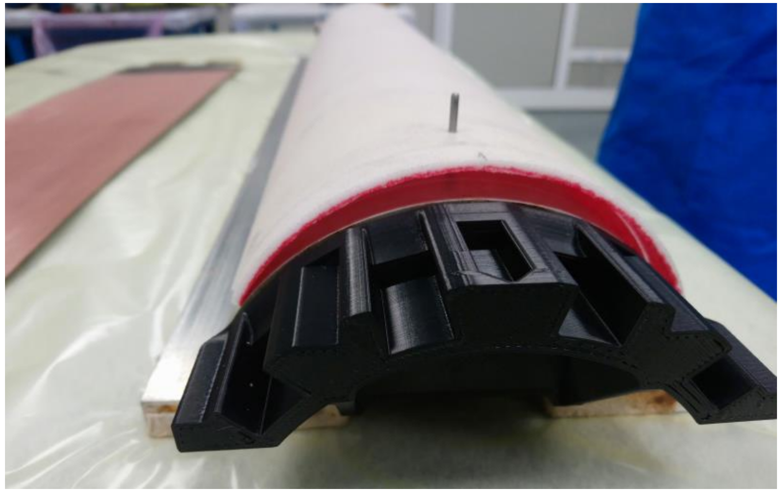


The **dead area** is about **1%** due to the separation between the tiles.
One-dimensional readout: axial strips with 0.68 mm pitch

We need a **good compromise between the rigidity of the tile**, to fit the shape of the structure, **and the request for a low material budget detector.**
Several tests have been carried out at LOSON S.r.l. to find the good recipe

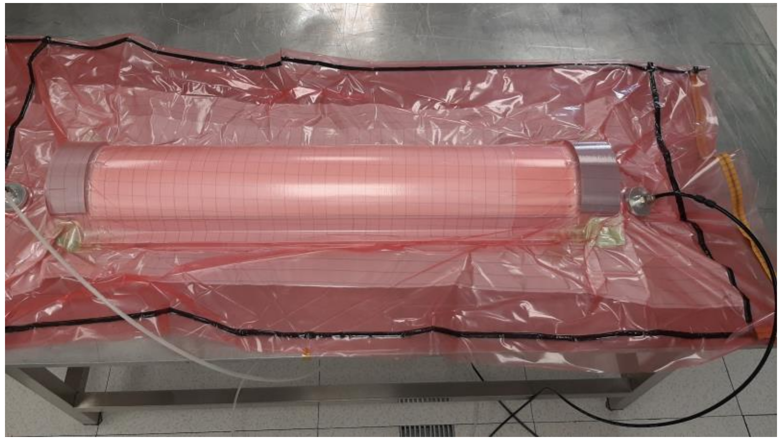
The Roof Tile

The roof tile is composed of a **Structural Adhesive Film (30 um)** coupled to **a layer of Millifoam® (2 mm)** where the flexible PCB is glued, under vacuum, with epoxy.



The roof tile Millifoam® support

Flexible Micro-RWELL PCB produced at CERN-EP-DT MPT Workshop. Each foil is divided in **four HV sectors**

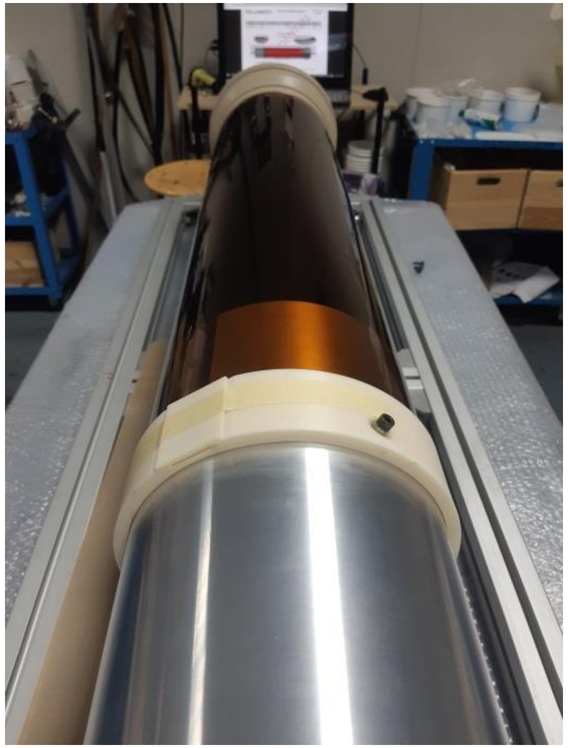


Epoxy curing cycle under vacuum

The final roof tile coupled to the anode support

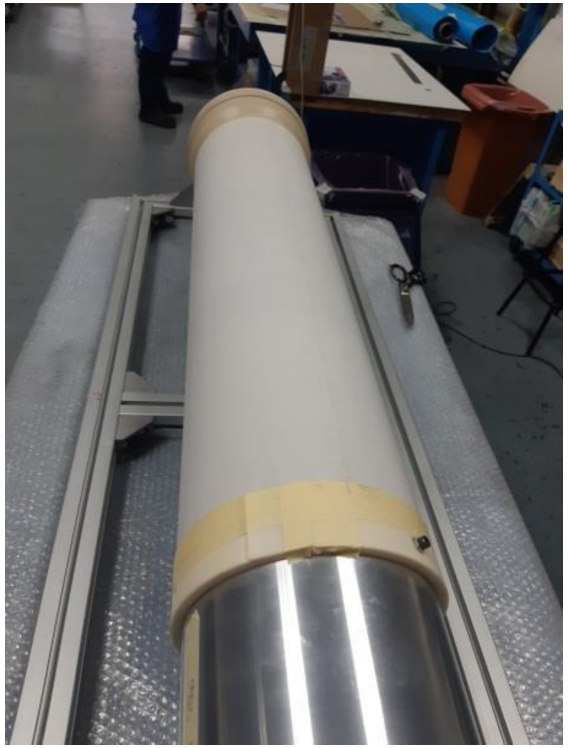
The Cathode

The **cathode** is the outermost electrode and it is made in different steps, starting from a rectified Aluminum mould. Differently from anode, it is composed of a **unique foil**.



Kapton-copper foil disposition around the mould

Fiberglass lamination

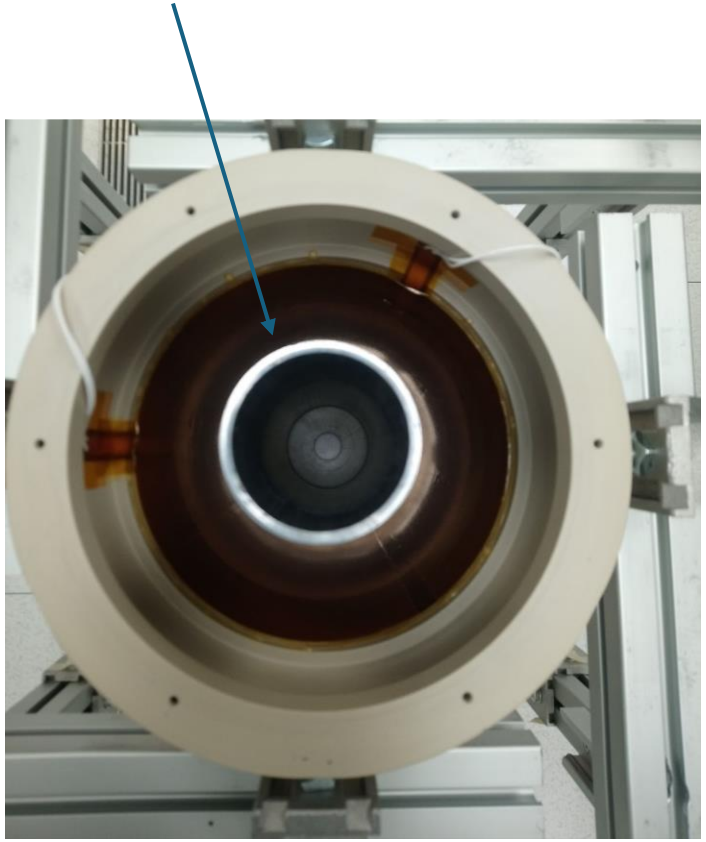


Structure reinforcement with Millifoam®

The cathode is then completed with an external kapton-copper foil, part of the Faraday cage

The final assembly

The final assembly didn't need any very sofisticated sliding machine, thanks to the large distance (10 mm) between the roof tiles and the internal surface of the cathode. **It took 10 days for the realization of the tiles and the assembly.** Anyway, to avoid any possible dangerous movement, a system based on aluminum profiles has been quickly assembled. An internal Aluminum tube led the insertion of the anode without any risk.

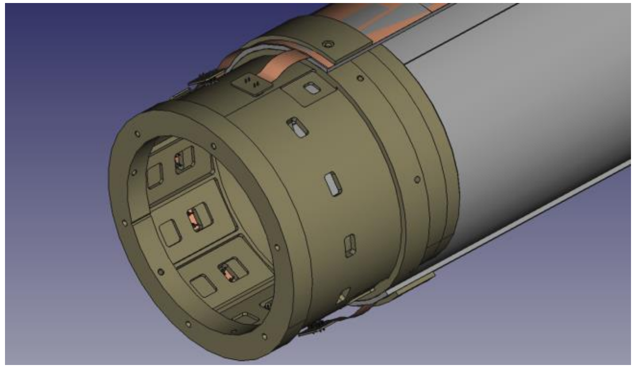


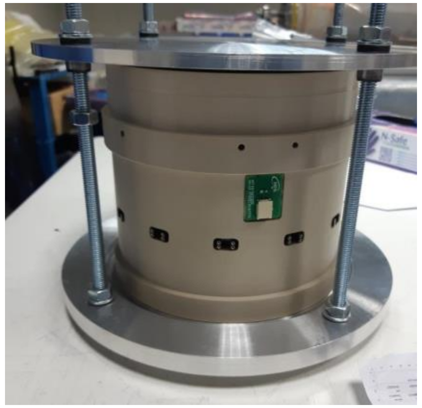
The cathode in place on the system

The assembly

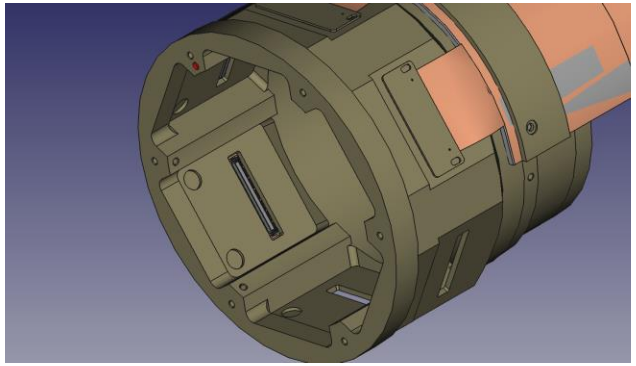
Flanges and equipment

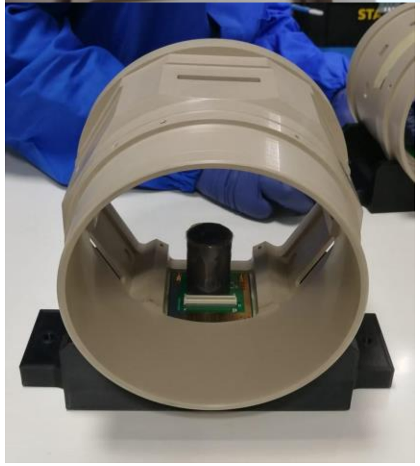
The flanges and the end-caps of the detectors are all realised in PEEK, much better than FR4 for manufacturing and cleaning.
The flanges glued on the anode host the **transition boards** for the **HV** and for the **front-end electronics**, so that all the connections are done on the internal surface of the detector.
These boards have been glued and an extensive gas tightness test has been performed with a «special tool» (rectified Aluminum disks and threaded rods).





At an overpressure of 20 mbar the system lost 1 mbar after 2 hours





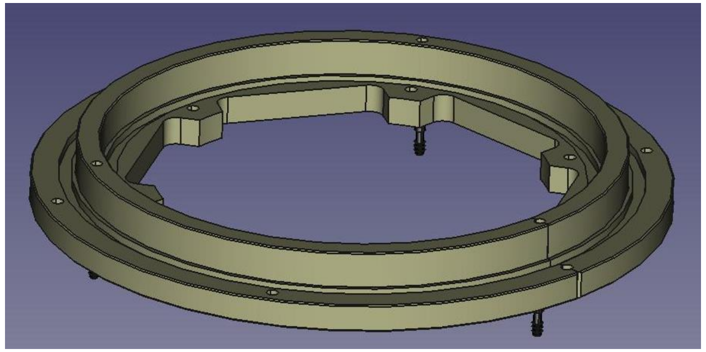
From drawings…

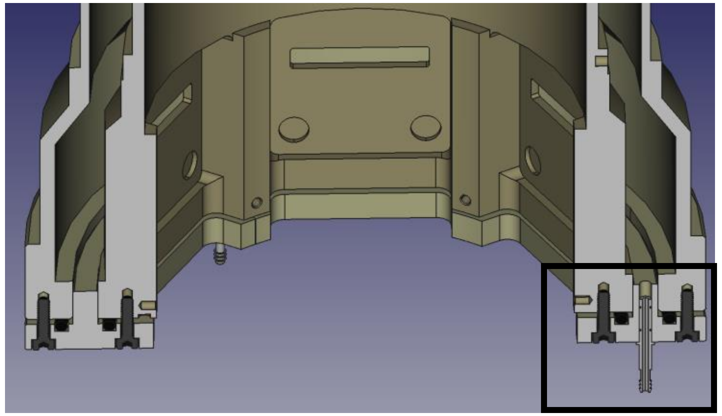
… to reality

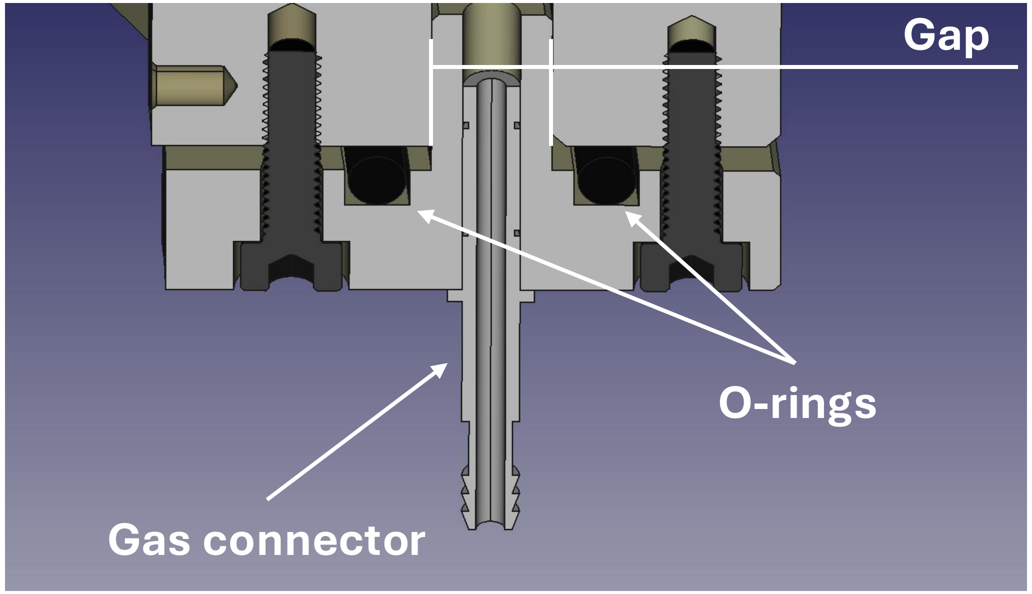
End-caps and services

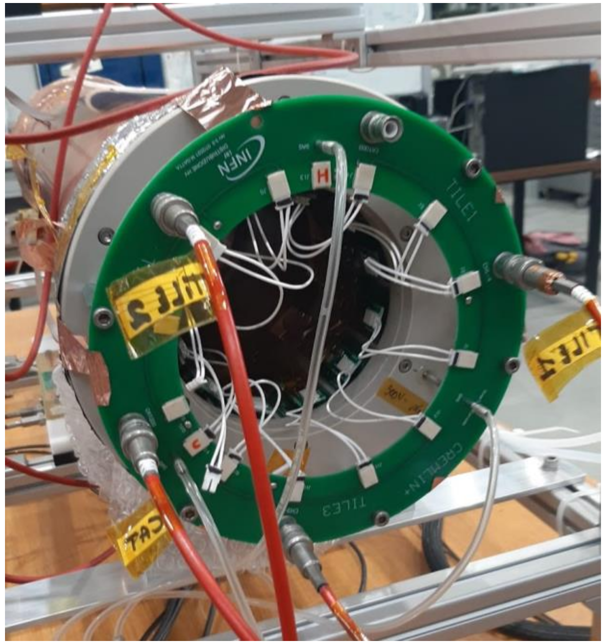
The end-caps are made in PEEK and **have three main tasks**:

- Sealing the detector, hosting two O-rings
- Maintaining the radial distance between the two flanges
- Hosting the gas connectors









The HV distribution is provided by a circular PCB.
We need just four HV channels (cathode + three u-RWELL foils)
Each micro-sector is then powered in parallel.
Moreover, in case of malfunctioning, any sector can be independently disconnected

Cosmic-rays test and results

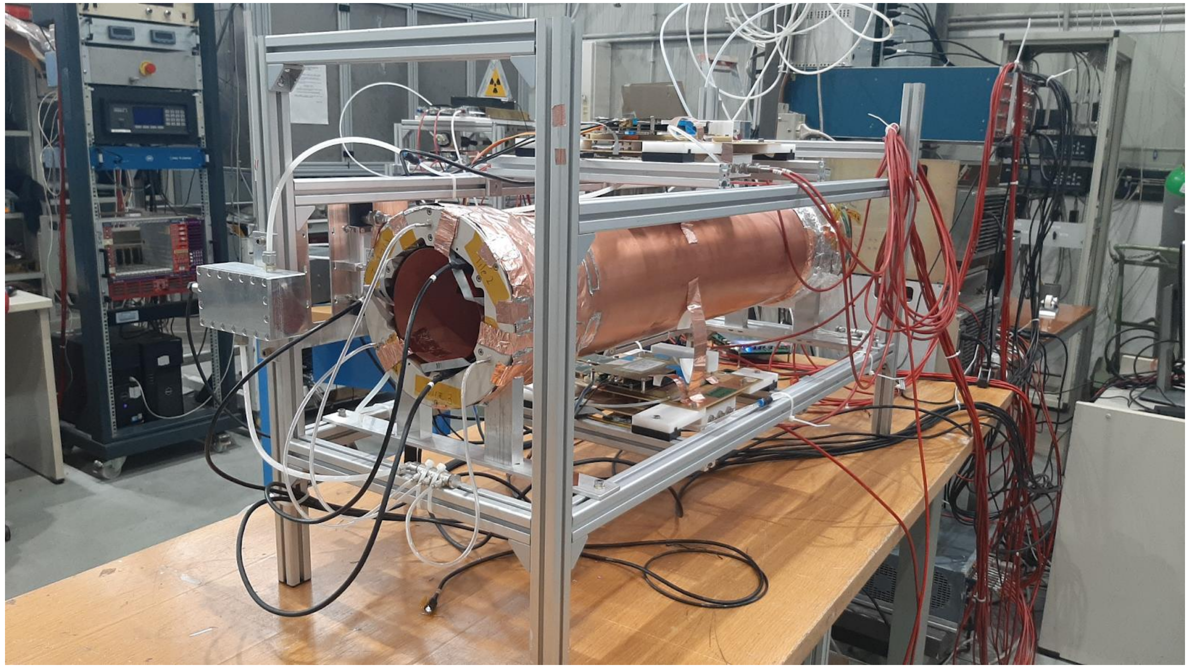
The detector has been then tested with cosmic-ray muons

We set up a **tracking system** with four one-dimensional micro-RWELL (400 um strip pitch→~70 um track. res.)

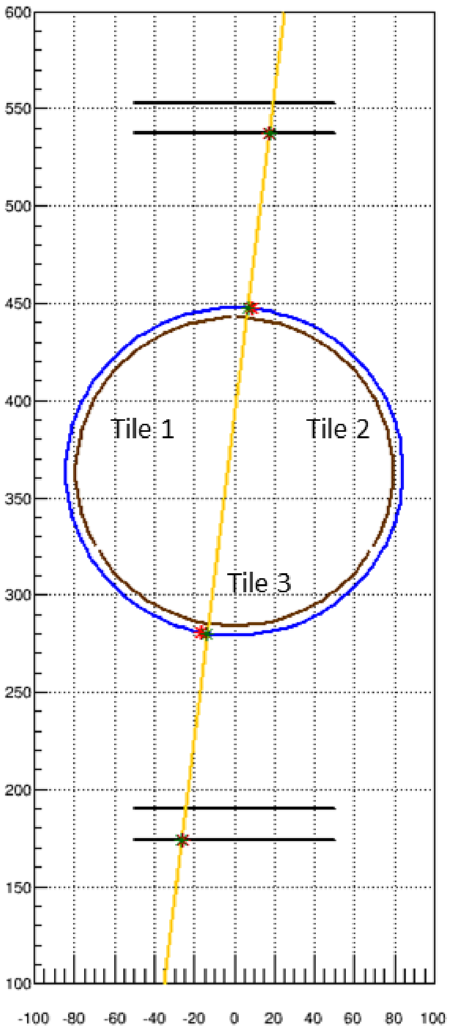
All the detectors equipped with **APV25-based boards** and flushed with **Ar:CO_2:CF_4 45:15:40**

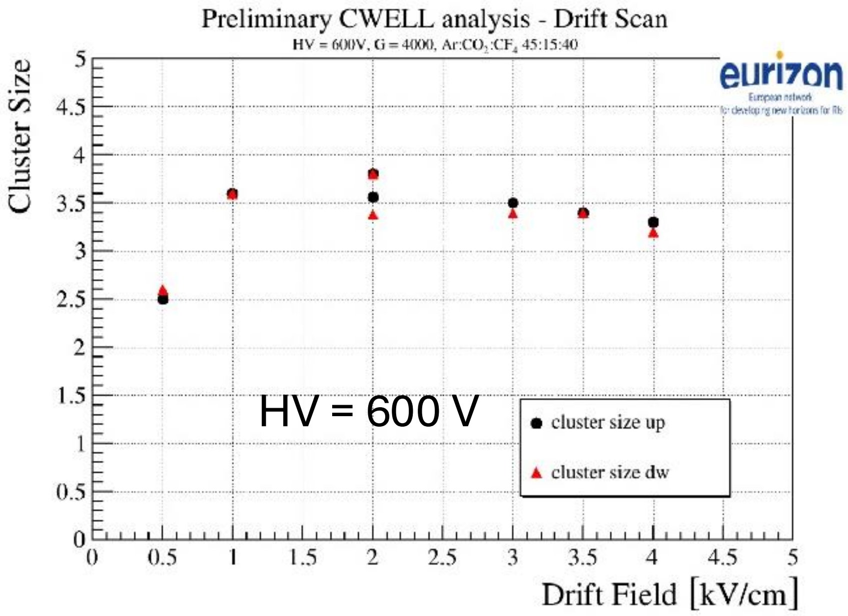
For the analysis the C-RWELL has been considered as **two halves**, divided by the orizontal plane.

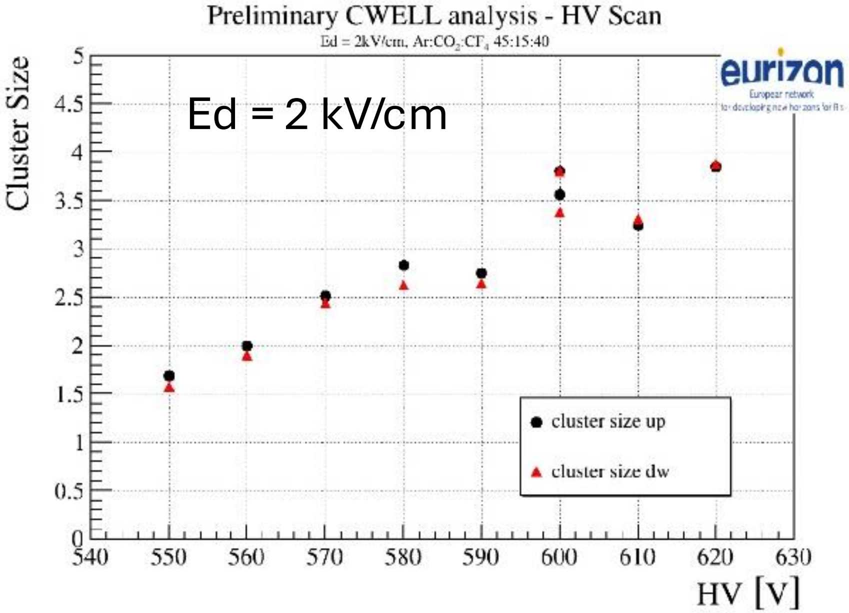
Tracks selection: one single cluster for each tracker, cl. size<5 and angular acceptance of 3° around the vertical direction



Thr. 1.5 fC







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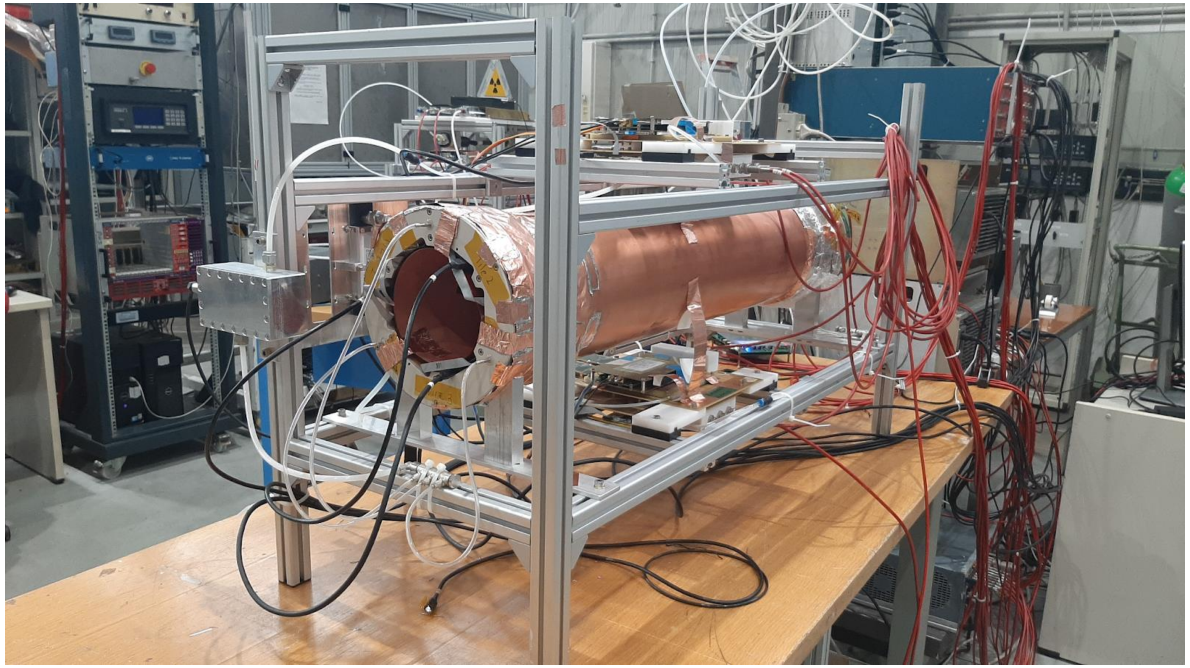
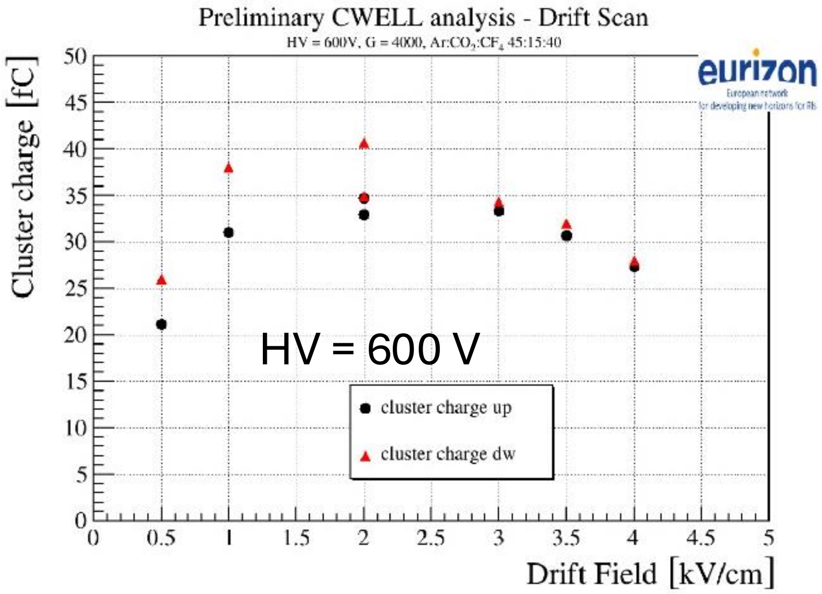
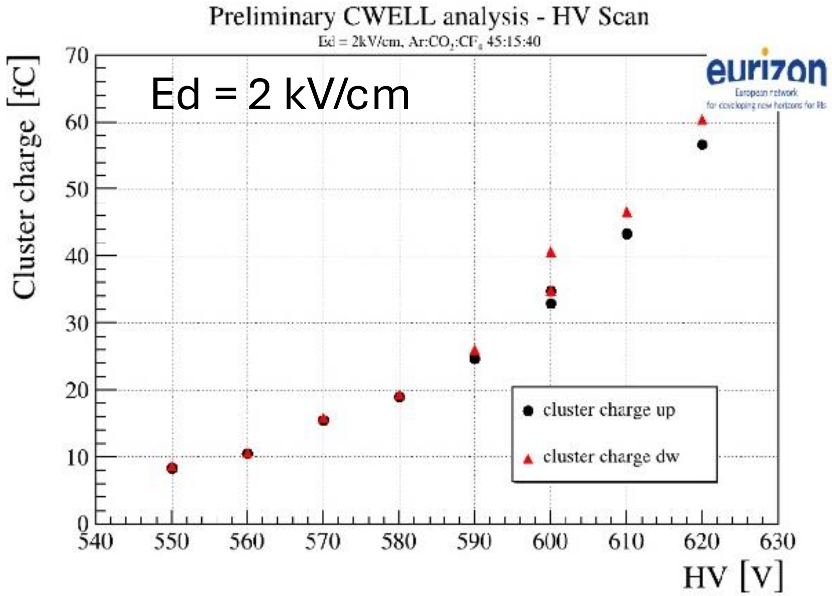
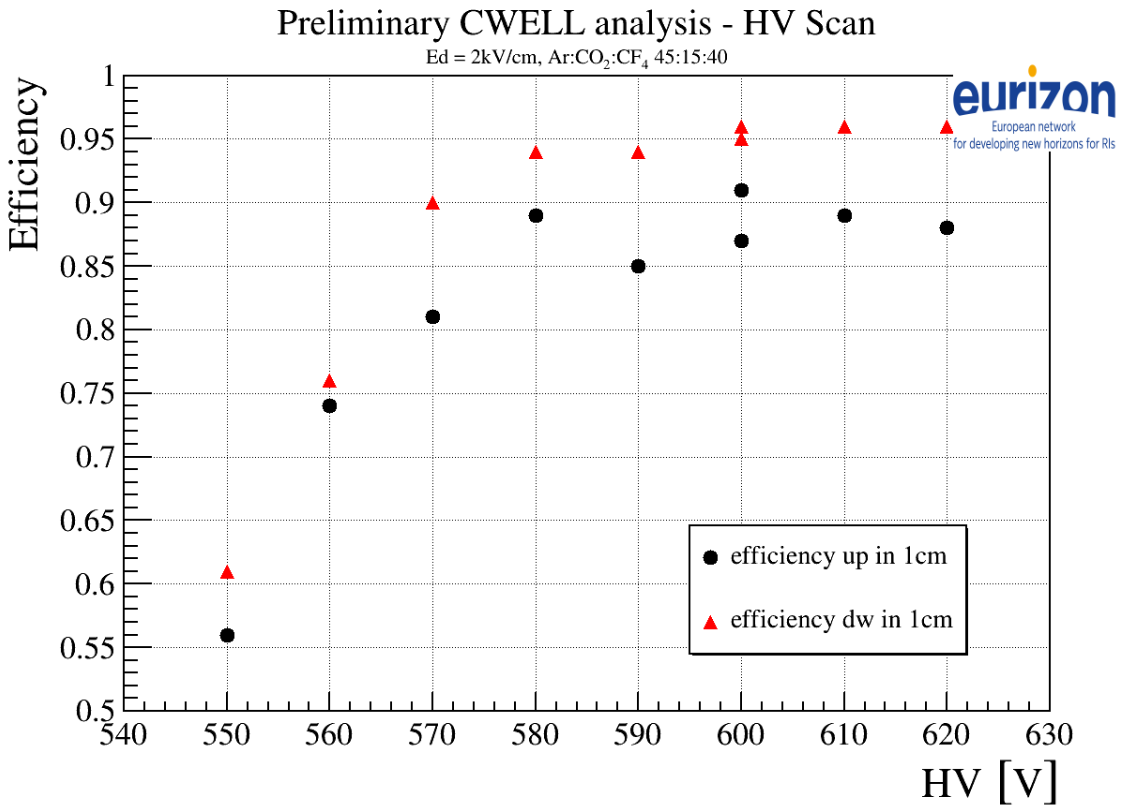


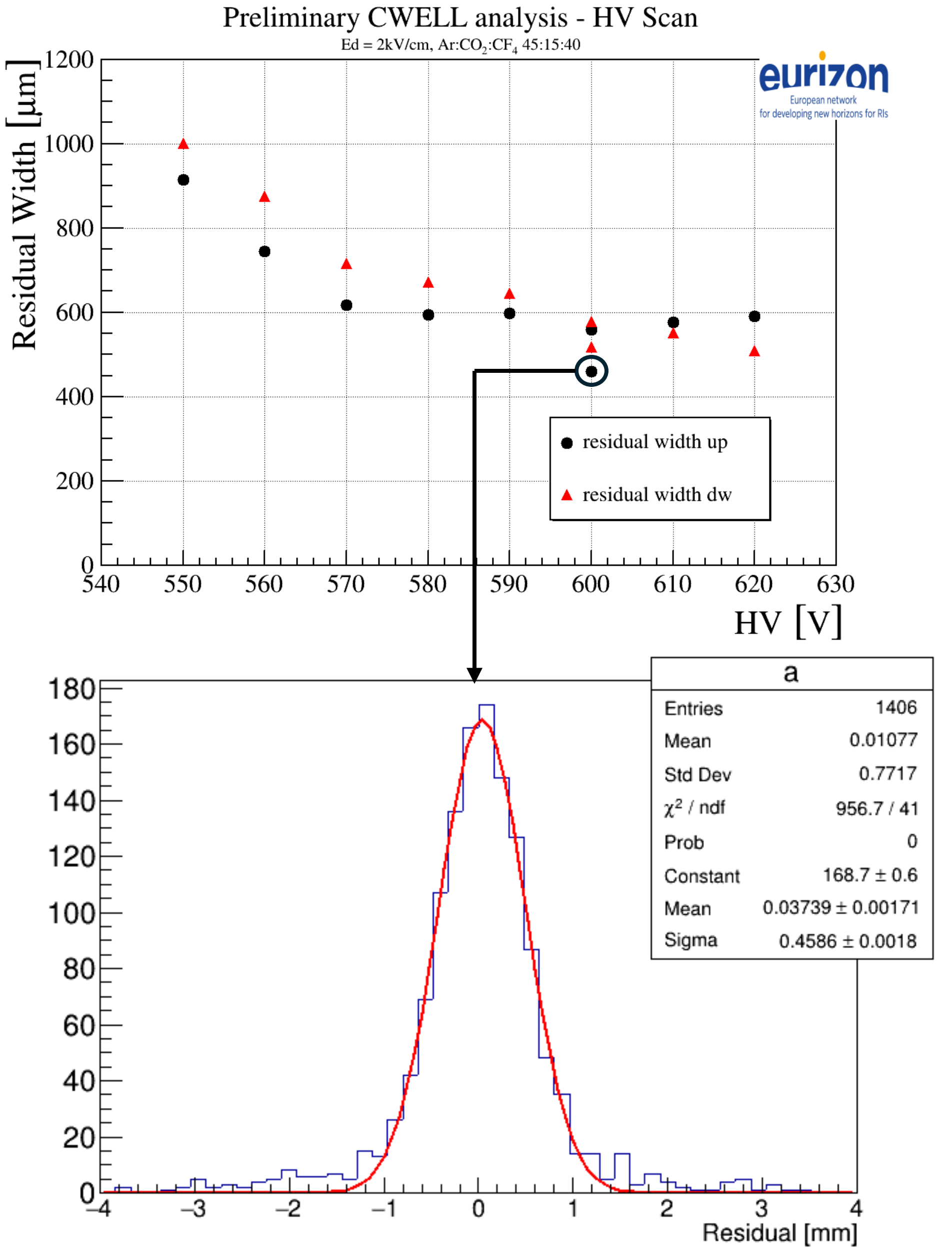




Cosmic-rays test and results

We also performed a **preliminary study of the efficiency** and space resolution, reconstructing the points with the Charge Centroid method
A FOI of 5 strips has been opened around the expected point

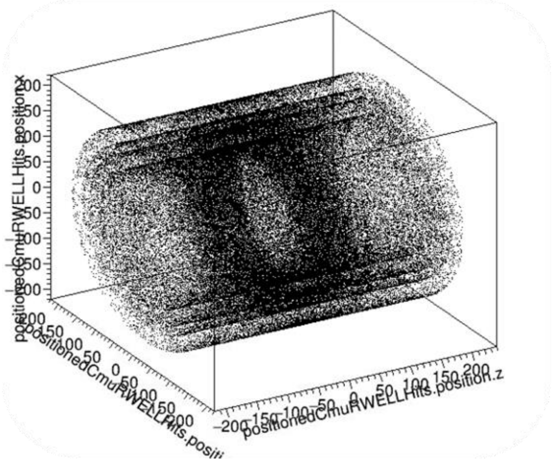




Very promising results with a pitch of 680 um!

Detector simulation

Software framework based on Gaudi
First description of 4-gaps-detector geometry implemented using DD4HEP
Detector response parametrisation based on the Parsifal code (arXiv:2005.04452), developed for the BESIII CGEM detector
Simulation integrated with resistive stage modelling describing the charge spread on the resistive layer
Validation with DATA/MC matching of known planar detector configuration studied at test beams

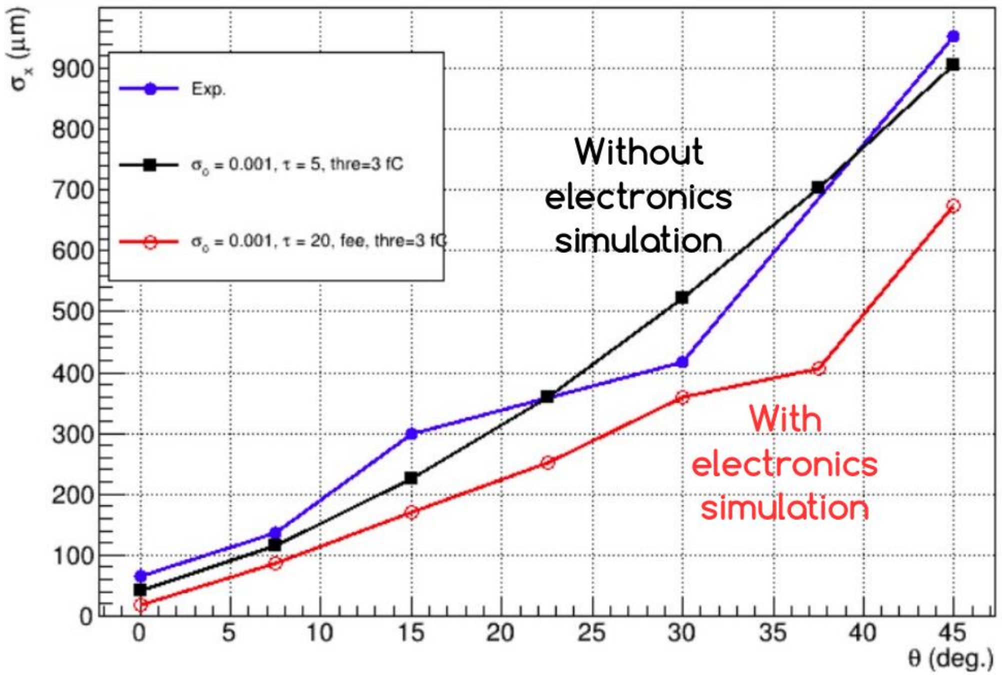


$$\rho(x,y,t) = \frac{Nq_e}{2\pi(2ht+w^2)} exp\left[-\left(x^2+y^2\right)/\left(2\left(2ht+w^2\right)\right)\right]$$

→ *M. S. Dixit, A. Rankin, NIM **A** 566 (2006) 281-285*

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

Model adapted to one-dimensional readout and with the following replacements:
h→1/τ
w→ σ
t_0 is the arrival time of the drifting electon in the amplification channel



Conclusions

- In the Working Package 5 of the EU funded project EURIZON (grant agreement n°871072) **we validated the idea of a low-mass, modular, re-openable Cylindrical RWELL**
- The construction validated the **proof of concept**
- **The assembly** has been **simple and smooth** w.r.t. other MPGD technologies
- The first tests confirmed the construction quality of the cylindrical u-RWELL
- **Simulations studies are ongoing**, but a promising model for the charge sperad on the DLC already implemented.
- «Emergency operation» still to be verified: detector opening, replacement of a «roof tile» and re-sealing to be done (data taking ended in December 2023)

Backup

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

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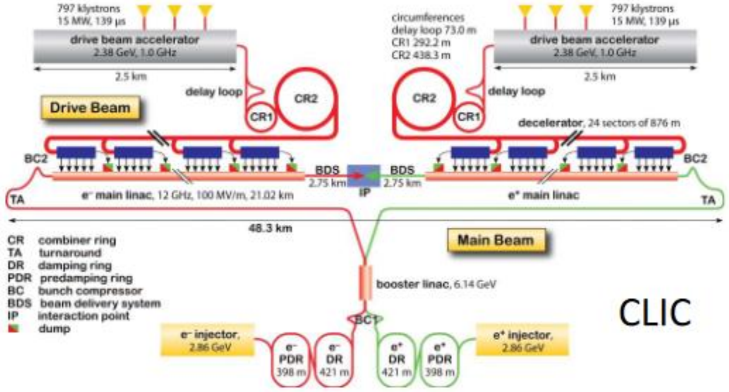
Different Lepton Collider Proposals



CLIC

ILC

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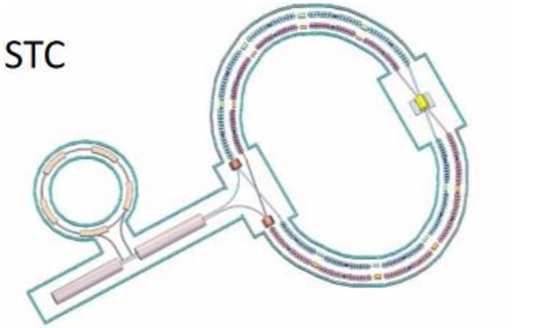
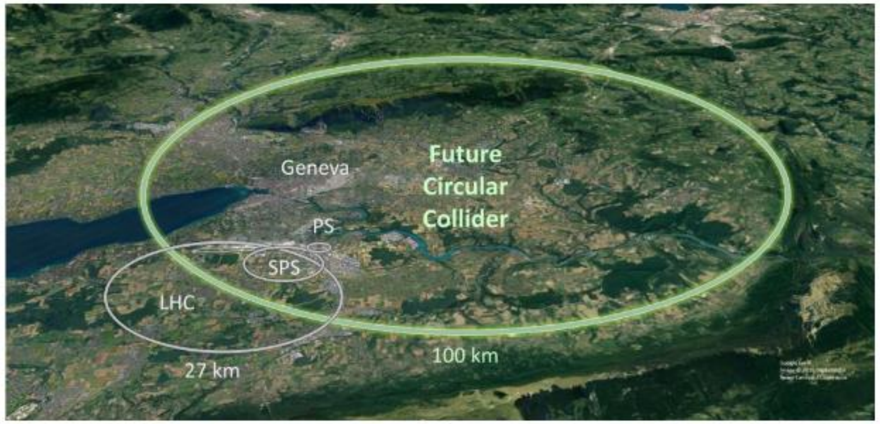
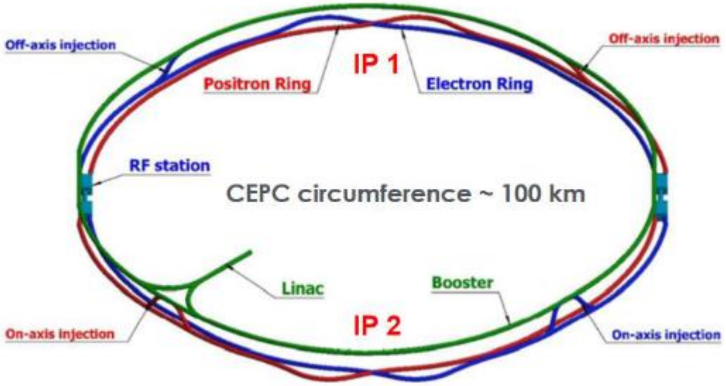


https://cicpi.ustc.edu.cn/indico/contributionDisplay.py?contribId=22&confId=2760



https://cds.cern.ch/images/OPEN-PHO-ACCEL-2019-001-2



https://indico.ihep.ac.cn/event/17020/contributions/117889/

Presented by A. Sailer at the EURIZON Final Event, Prague 17-19 January 2024

Applications

The micro-Resistive WELL is involved in

1. **LHCb RUN 5-6 muon upgrade:** partial replacement of MWPC of the LHCb muon system to cope with higher rates
2. **FCC_ee**: the muon system of the IDEA apparatus for a Future Collider
3. **CLAS12** @ 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. **URANIA-V**: a project funded by CSN5 for neutron detection, an ideal spin-off of the EU-founded ATTRACT-URANIA
6. **TACTIC @ YORK Univ.:** radial TPC for detection of nuclear reactions with astrophysical significnace
7. **UKRI:** neutron detection with pressurized ^{3}He-based gas mixtures
8. **Muon collider:** hadron calorimeter

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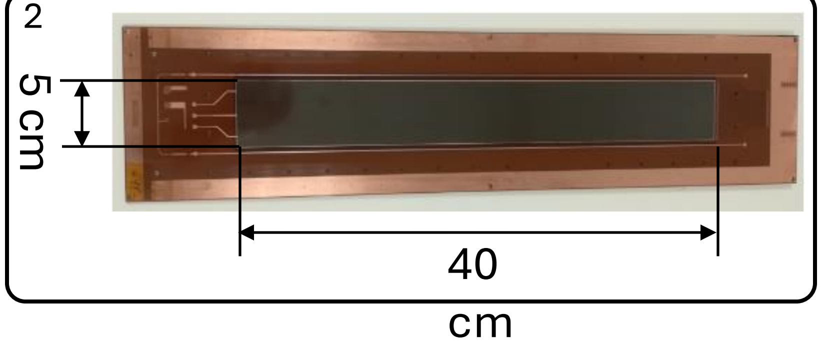

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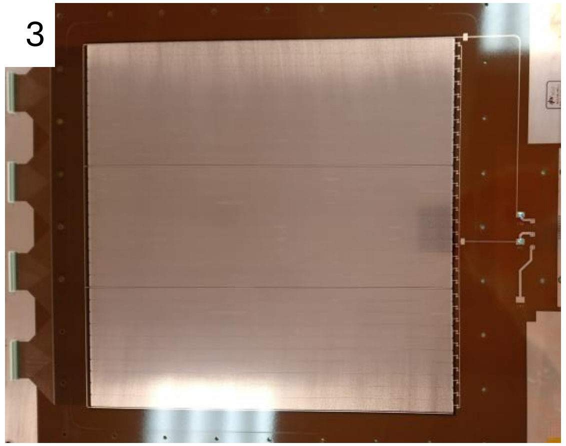

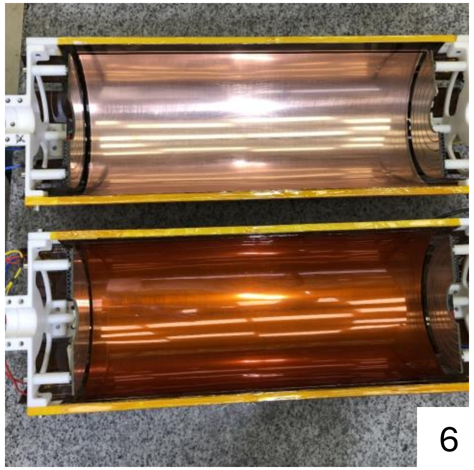

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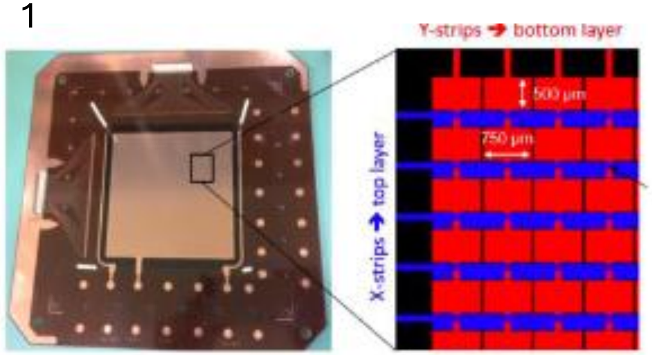
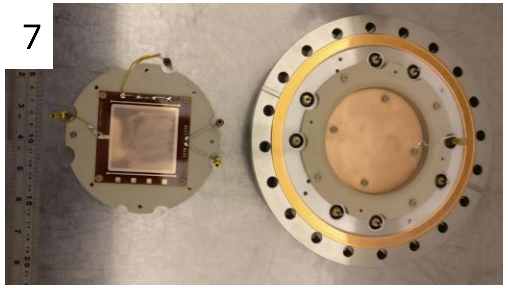
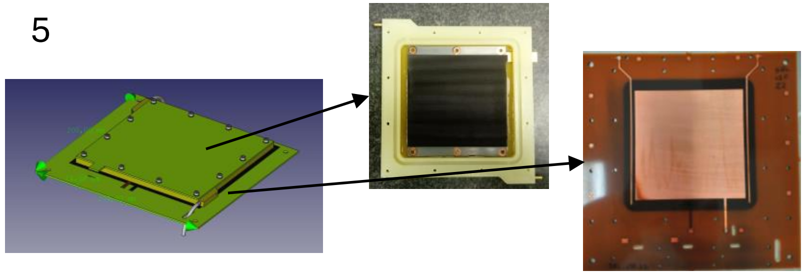


7



5



MILLIFOAM® RHC71RI is a closed-cell rigid foam based on polymethacrylimide (PMI) chemistry and contains no CFC's. The fine cell structure ensures a minimum resin uptake behaviour of approx. 50g/m², which allows the end weight of the component to remain extremely low. The foam is used for infusion components in aeronautic and aerospace applications, in sports equipment and in automotive constructions.

Polymer	PMI	Compressive Strength	1.7 MPa
Density	75 kg/m³	Shear Modulus	42 MPa
Thickness range	0.12 -1.5 mm	Sheet Size	2500 x 625 mm
Thermoform Temperature	205°C	Supplier	Evonik GmbH

Featuring an extremely fine cell structure, MILLIFOAM® RHC71RI is well suited for vacuum infusion and RTM processes where the cell fine-cell foam can also be used purely as a fly-away tool. Processing is possible at temperatures up to 130°C (266°F) and pressures up to 0.7 MPa (102 psi). The foam can be easily thermoformed or CNC machined to meet customized application requirements.

4a MANUFACTURING

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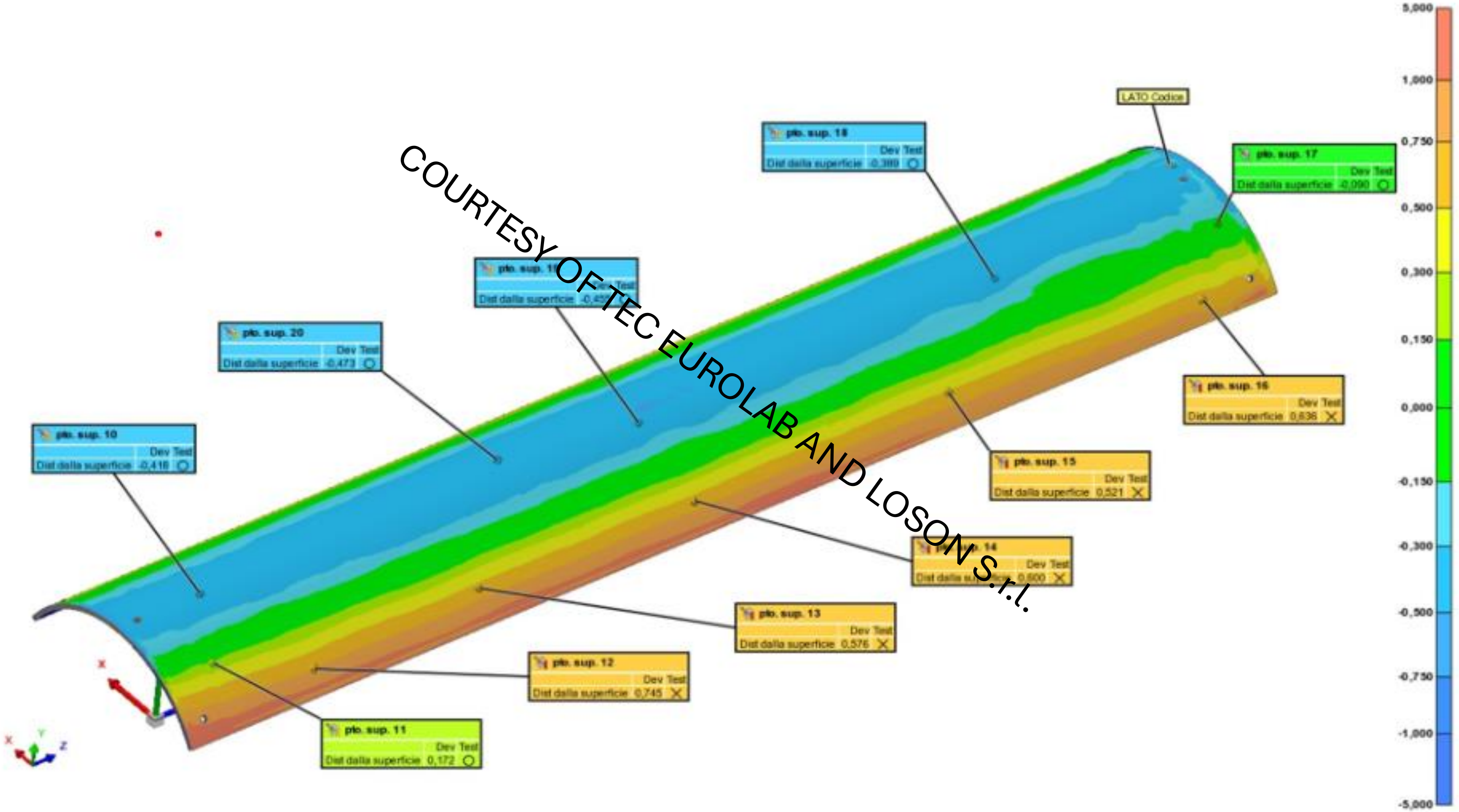
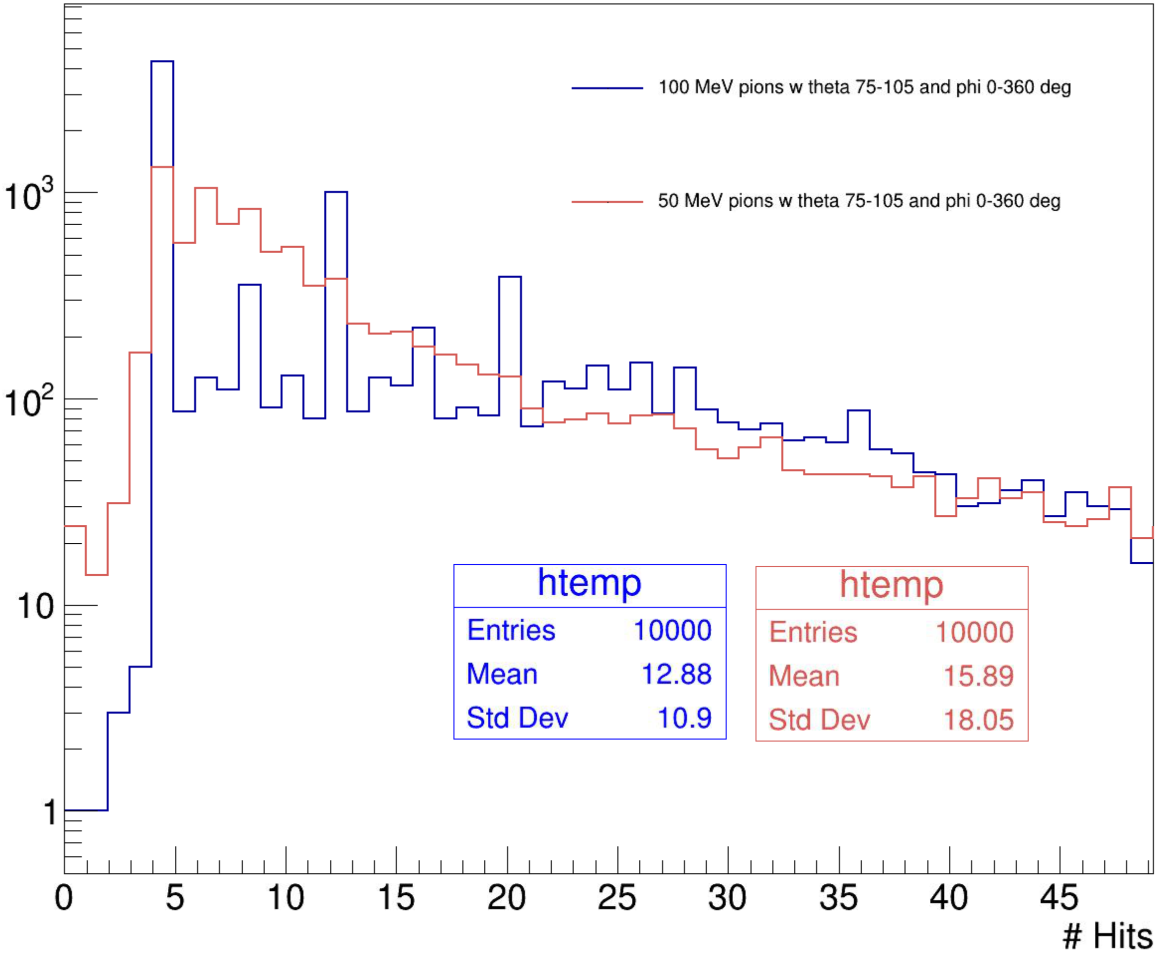
Roof tile validation

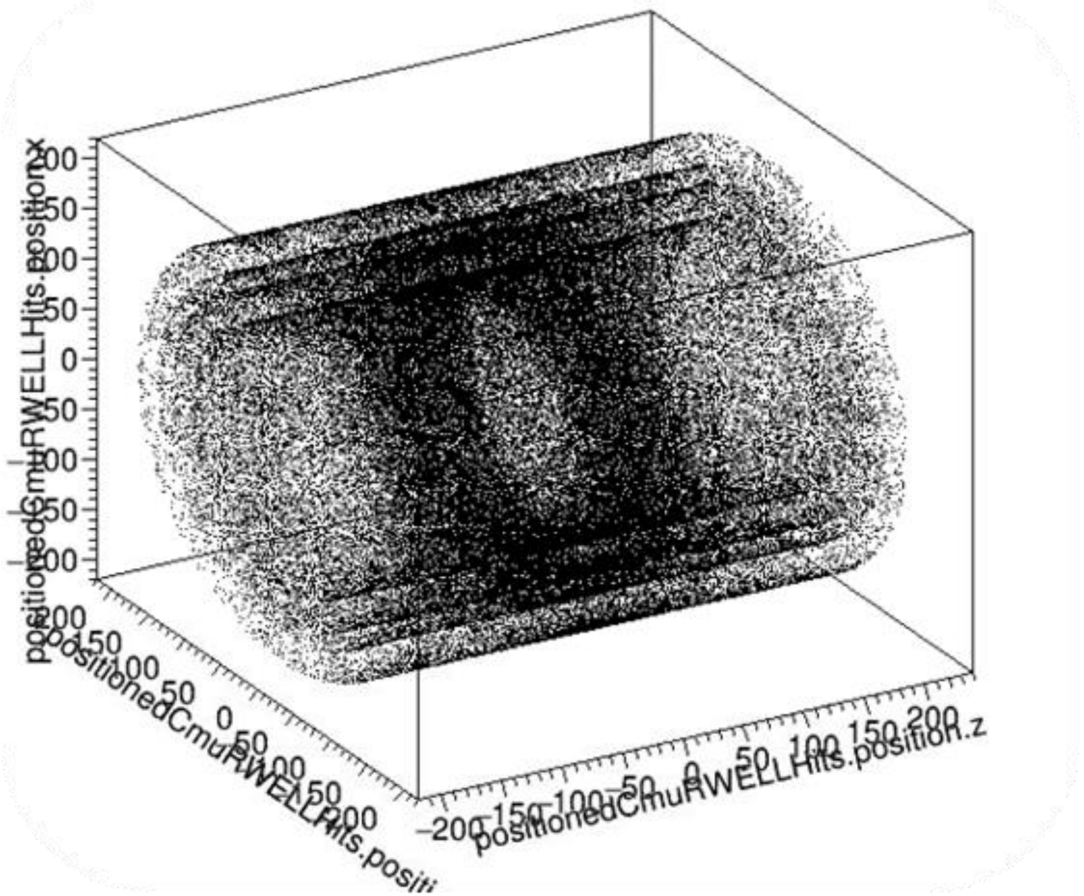


3D optical measurement (GOM technique) and report of the discrepancy between the expected values and the measured ones

Simulations



Number of hits in the detector for 100 MeV and 50 MeV pions



100 MeV pions