TREX-DM: a time projection chamber for low mass WIMPs detection

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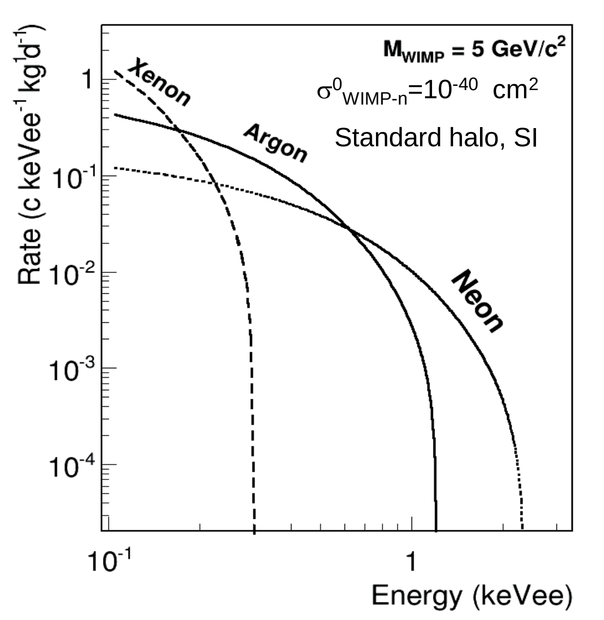
Motivation and goals

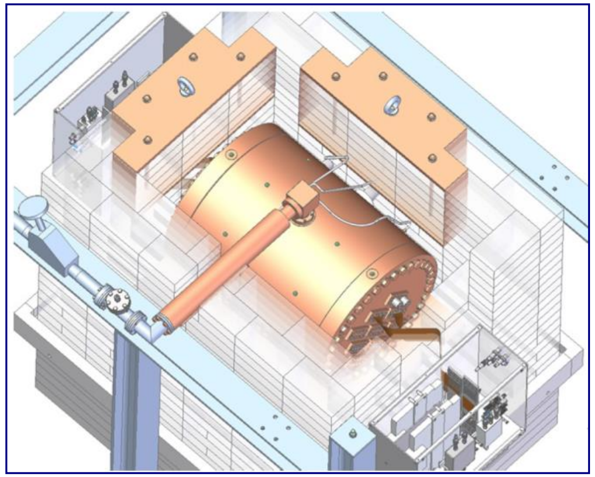
Requirements to search for low mass WIMPs**:**

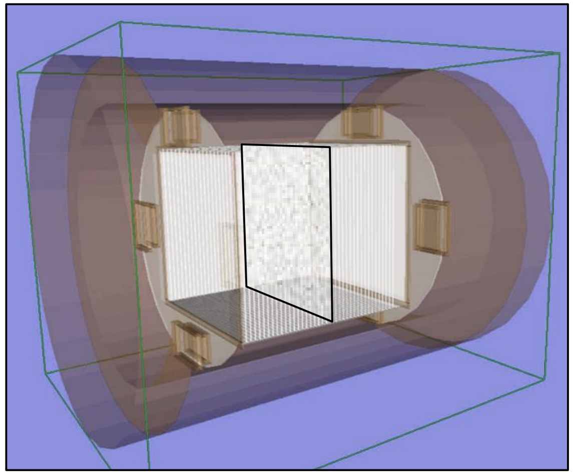
- Very low energy **threshold** (<1 keV_{ee})
- Light elements as target
- Radio-pure components to reduce **background**

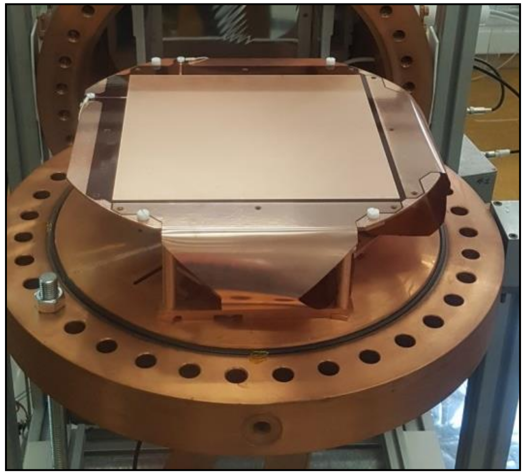


TREX-DM (*TPC for Rare Event eXperiments - Dark Matter*) conceived to

- look for **low mass WIMPs**
- using a **gas Time Projection Chamber** holding
- ~**20 liters** of pressurized gas (flexible target: **~0.3 kg Ar, ~0.16 kg Ne** at **10 bar**)
- equipped with novel micromesh gas structures (**Micromegas**) readouts
- at the **Canfranc Underground Laboratory** (LSC) in Spain

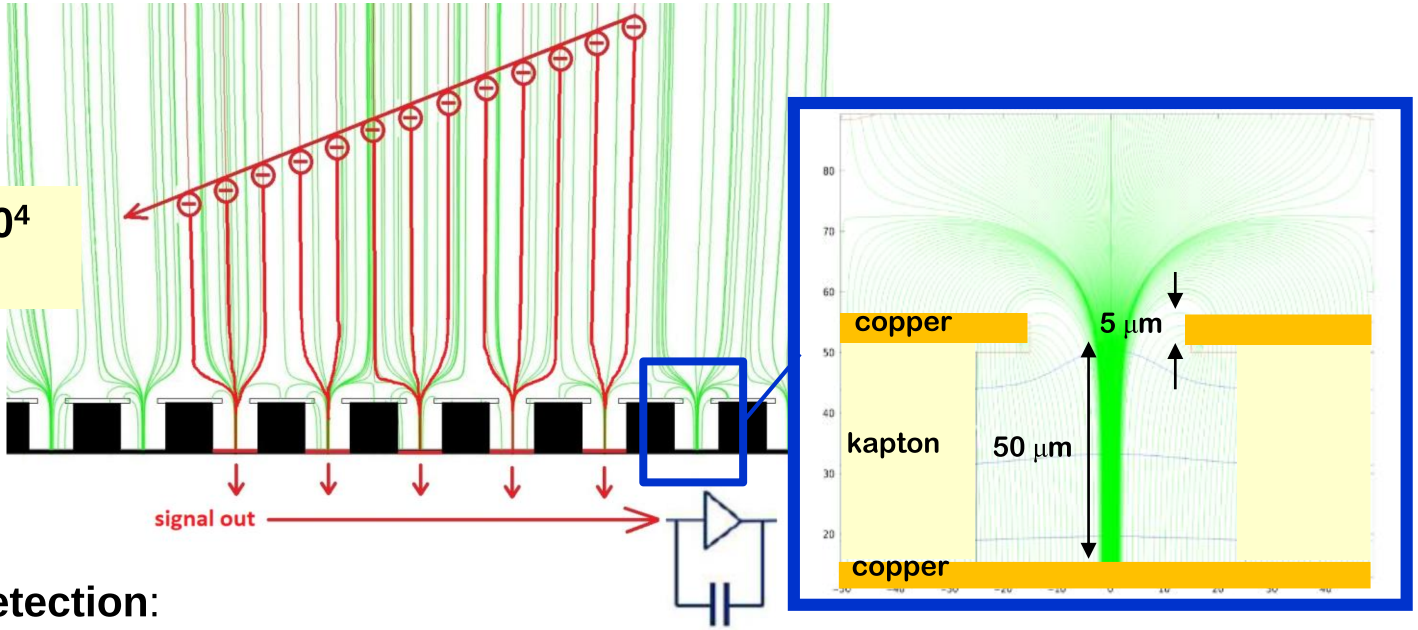






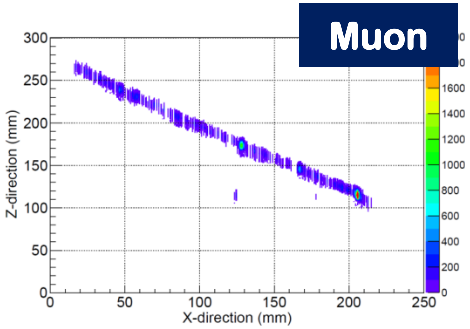
Micromegas technology as readout plane

- **Electron multiplication factor: ~10^3 ~10^4**
- **Energy resolution: 10% – 20%**



- Important **advantages for rare events detection**:
  - **Topological information**: to discriminate backgrounds from expected signal
  - **Low intrinsic radioactivity:** made of kapton and copper, potentially very clean
  - **Scaling-up**

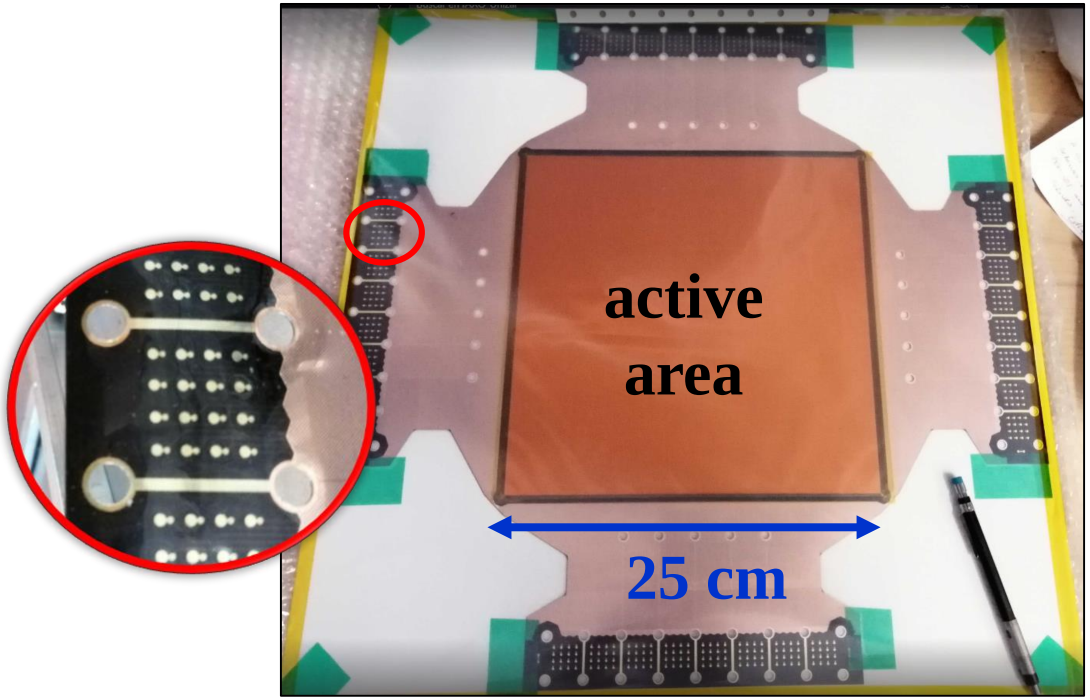
25 x 25 cm^2
TREX-DM fabricated at CERN

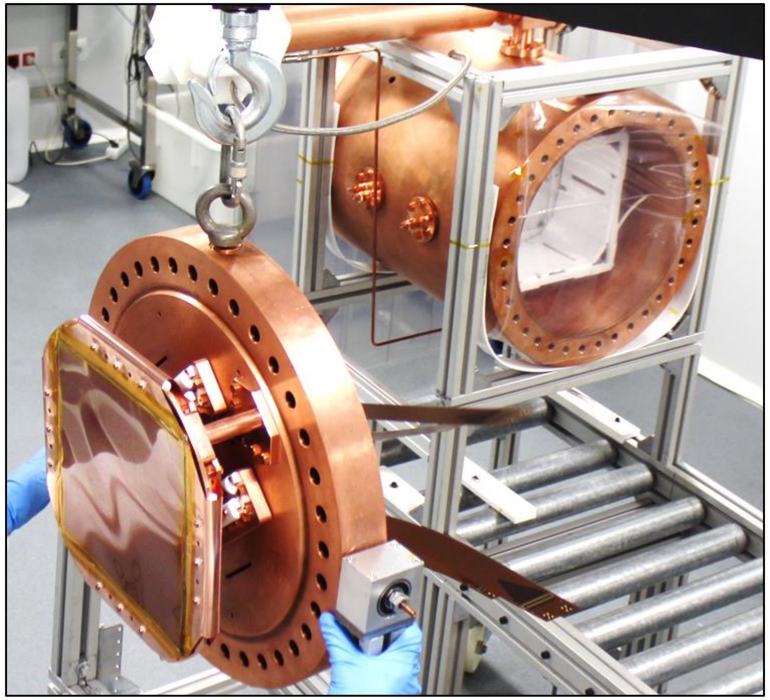


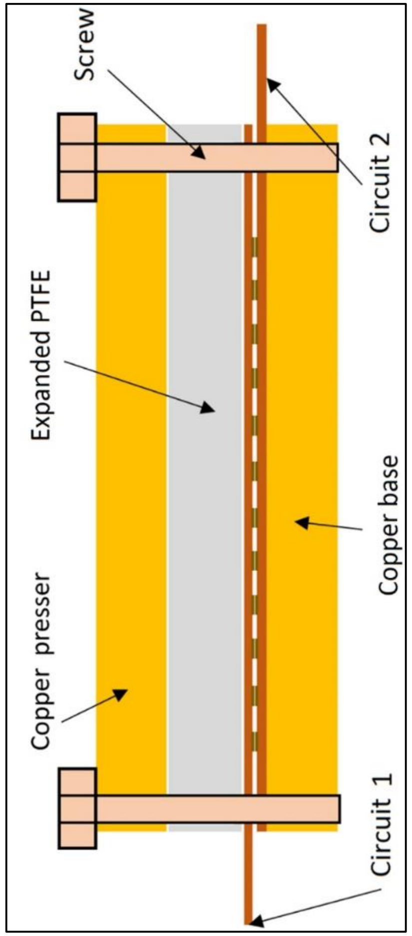
Micromegas technology as readout plane

The largest surface (~25x25 cm^2) ever produced with the *Microbulk* technology.

- Two planes (both end-caps) manufactured at CERN: **256 X strips, 256 Y strips, ~1 mm pitch**
- **Flat cables** take the strips signals out the chamber.
- **FaceToFace:** A custom made radio-pure connections



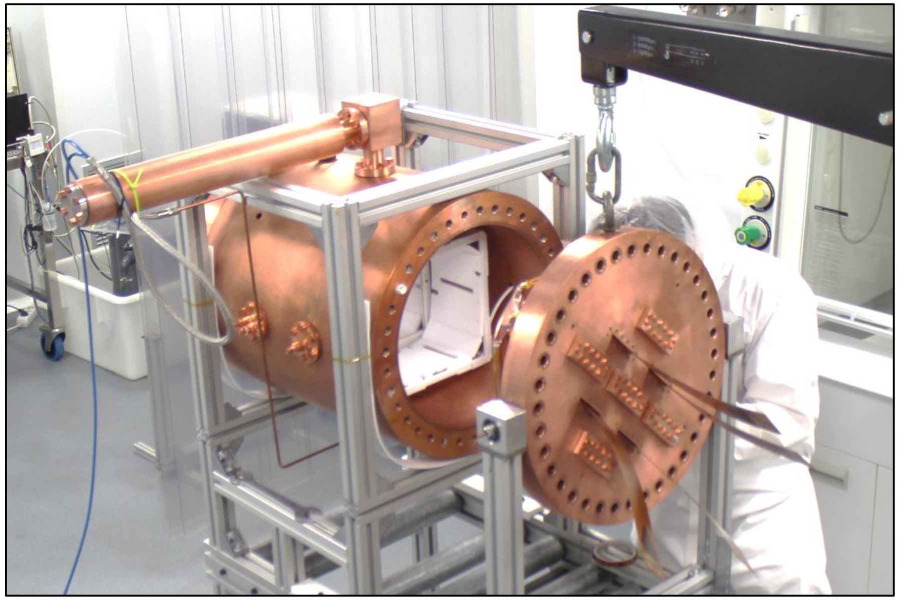


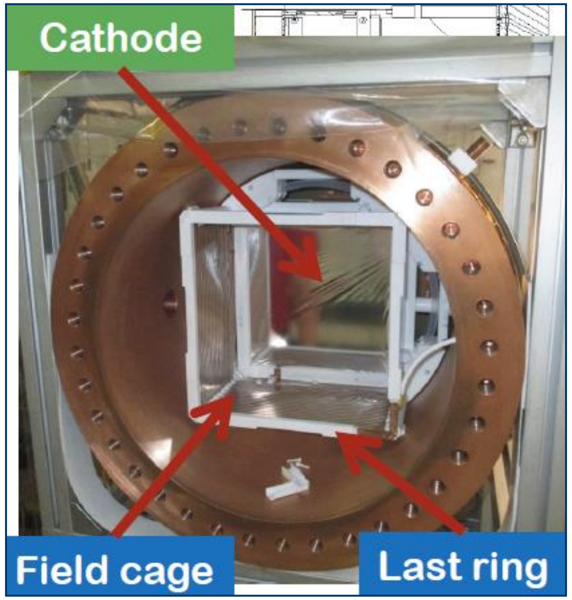


Vessel & gas system

Vessel:

- Designed to operate safely at 10 bar, **certified** as pressure equipment before installation at LSC
- Vessel pieces **cleaned** with nitric acid and demineralized water and **passivated** with citric acid



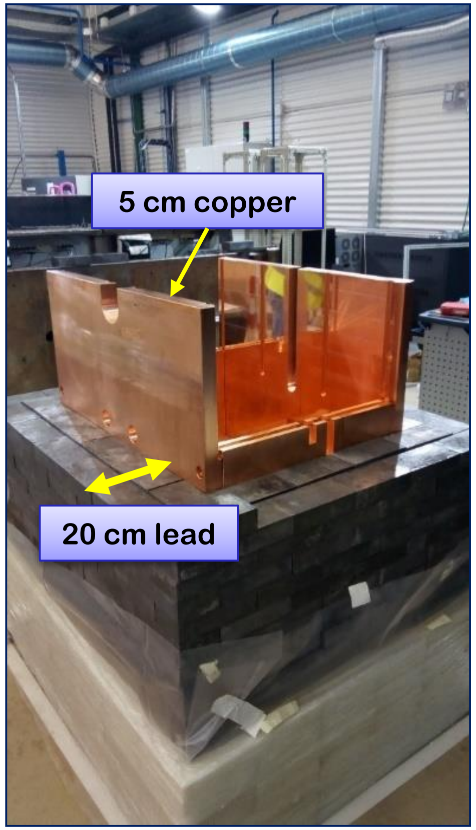


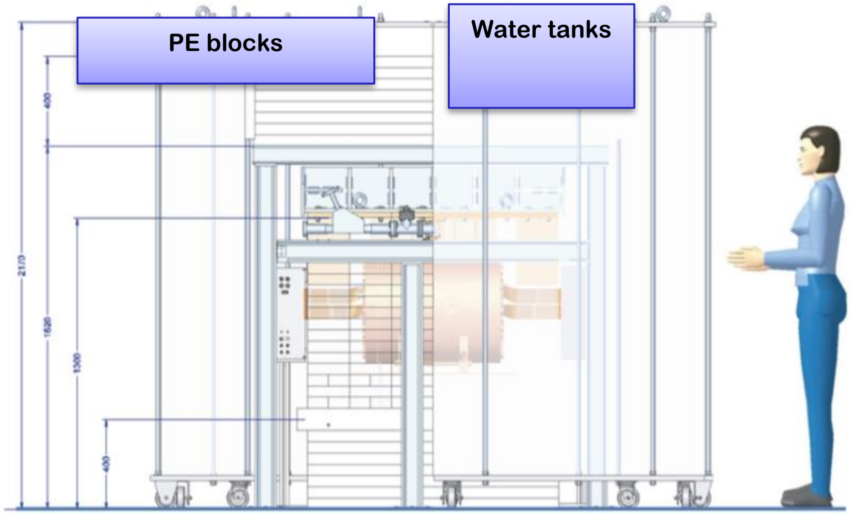
Gas system:

- Consisting of recirculation part + purification branch + gas recovery system (for depleted Ar)

Shielding

- 5 cm copper + 20 cm lead
- DAQ electronics outside the shielding
- N_2 or Rn-free air is flushed into the plastic cover
- Neutron shielding foreseen: polyethylene ceiling + water tanks



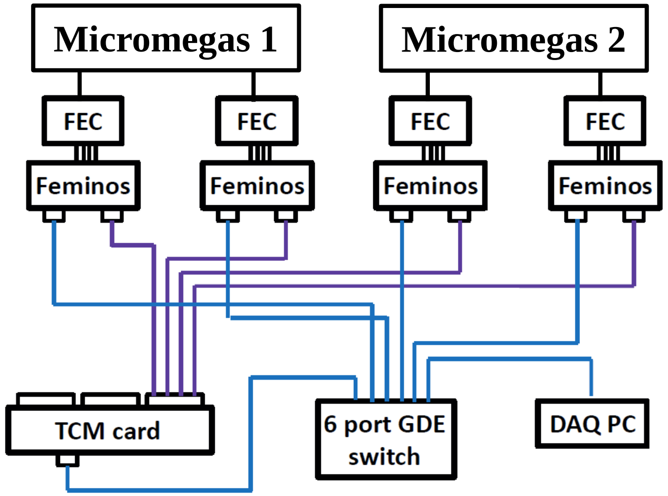


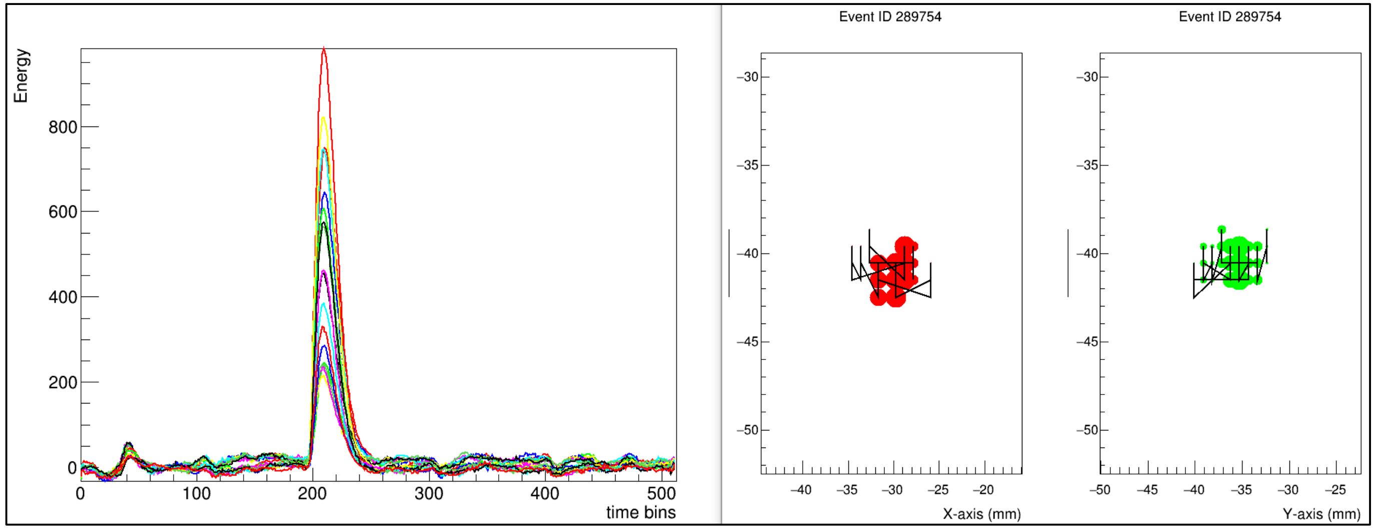
Readout electronics

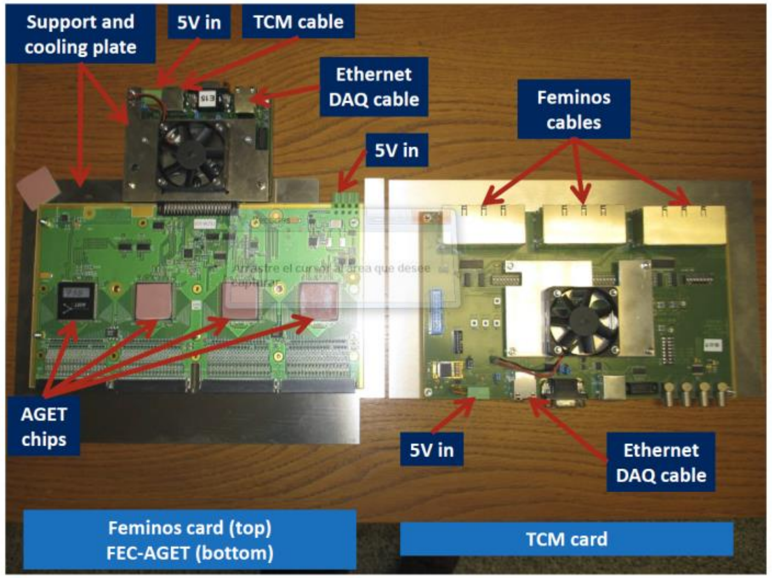
- **AGET-based system**: **self-trigger**, allowing to trigger the acquisition from the strips signals

- Two **Front End Cards (FEC), with 4 AGET chips** each, read out the 2 x 256 channels of each micromegas detector. Each FEC is connected to one **Feminos** card (FPGA)

- Employing more than one FEC-Feminos requires the use of a synchronization board **(Trigger Clock Module, TCM**). The TCM distributes a common 100 MHz reference clock and the trigger to all the FECs

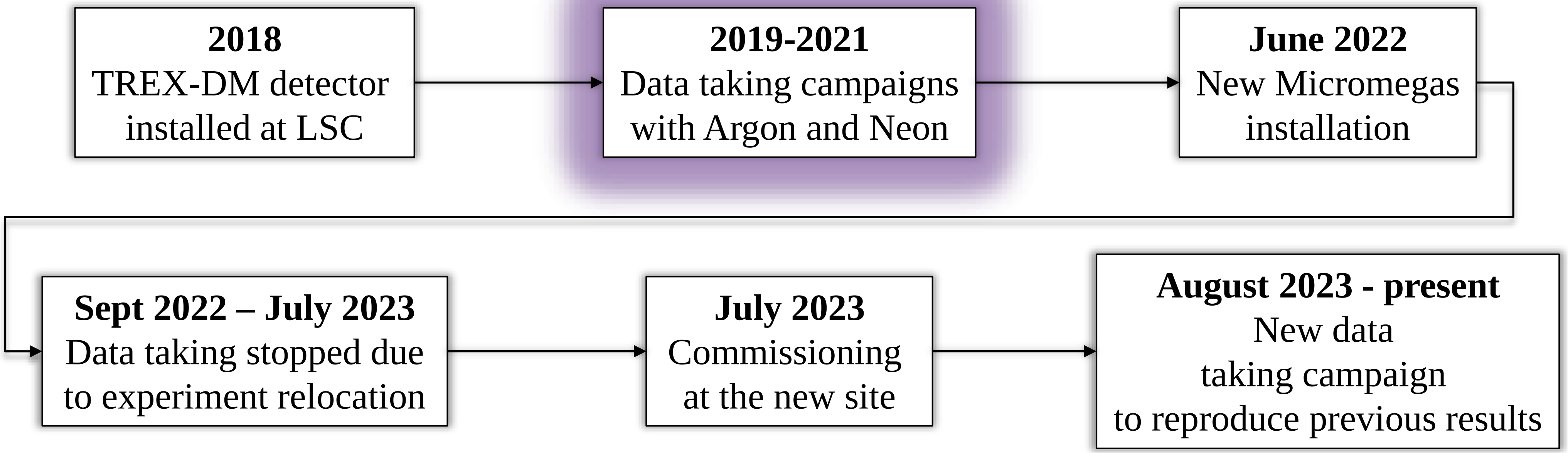






Detector chronology

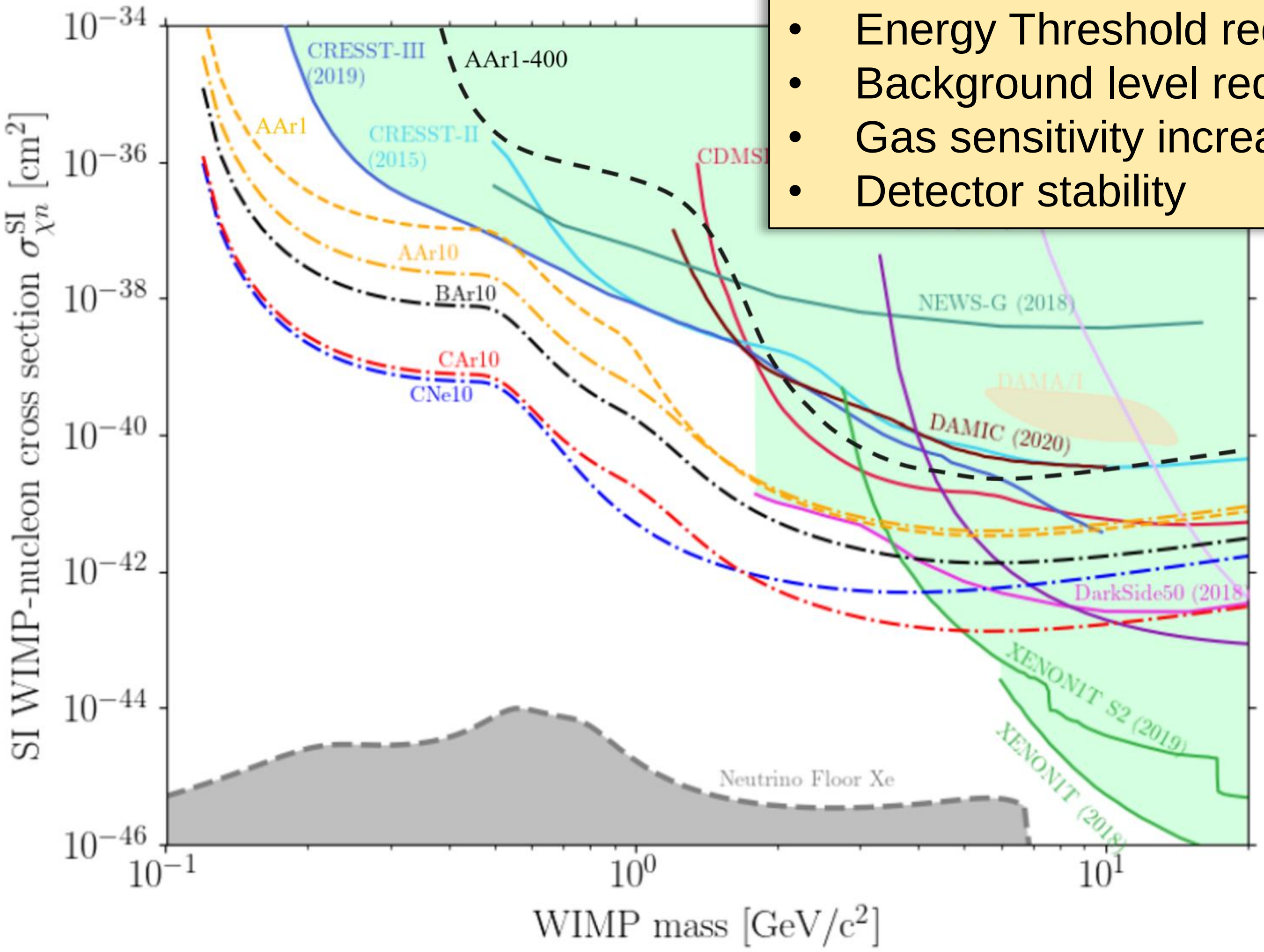
https://youtu.be/HlbEp_Y8nxQ?feature=shared



2019-2021 period:

- Issues with leak currents and connectivity.
- Initial background level 2 orders of magnitude higher than background model → reduced to 1 order
- Restrictions due to the COVID-19 mainly in 2020.
- 4 interventions in clean room to repair connectivity, leak currents and to try to reduce surface contamination.
- Energy Threshold achieved ~ 1.5 KeV_{ee} .

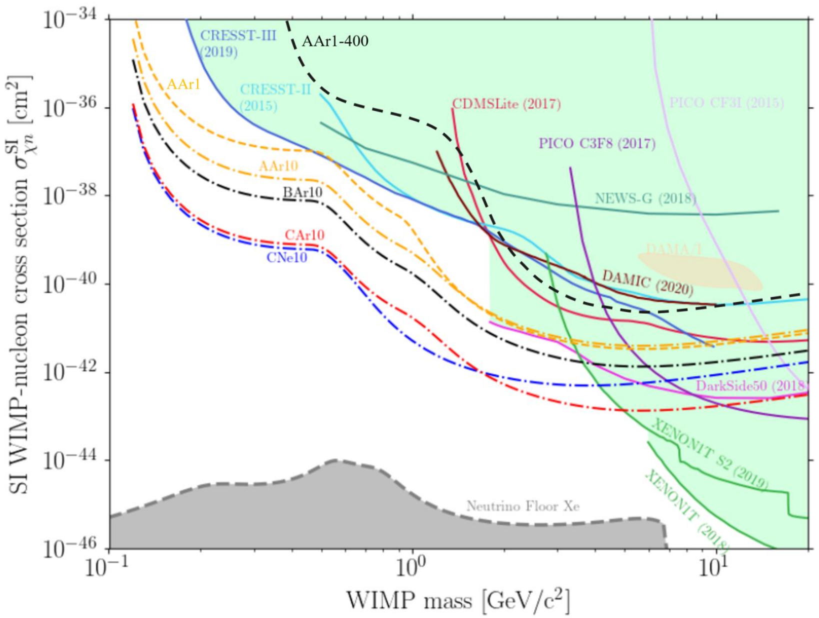
Challenges



Main challenges:
- Energy Threshold reduction
- Background level reduction
- Gas sensitivity increase
- Detector stability

scenario	energy thr (eV_{ee})	backgr level (dru)	isobut (%)	time exposu (year)
AAr1-400	400	10	1	1
AAr1	50	10	1	1
AAr10	50	10	10	1
BAr10	50	1	10	1
CAr10	50	0.1	10	10
CNe10	50	0.1	10	10

Challenges



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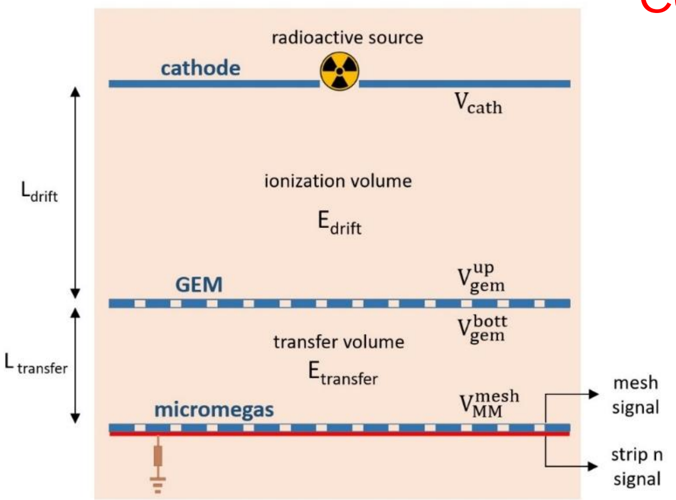
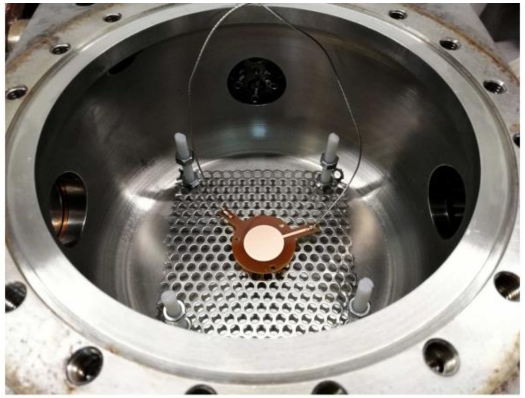
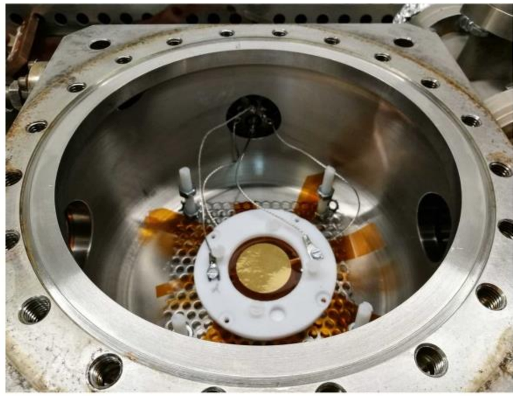
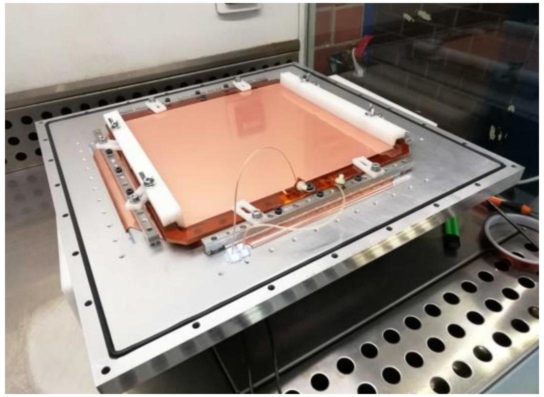
2019-2021 Energy Threshold ~ 1.5 KeV_{ee} limited by **noise**, Micromegas **gain** and **trigger efficiency** for low energy events

Combined **GEM-MM system: 10-100** pre-amplification factor









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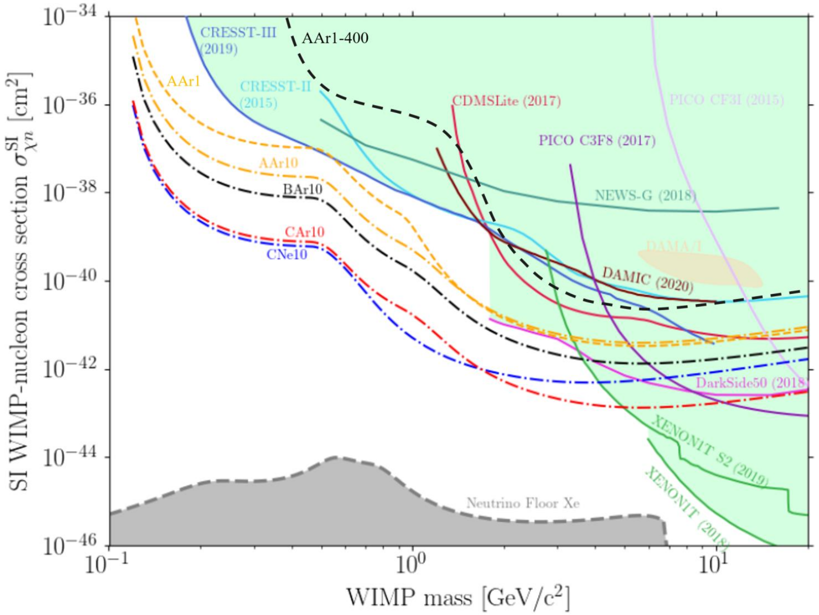

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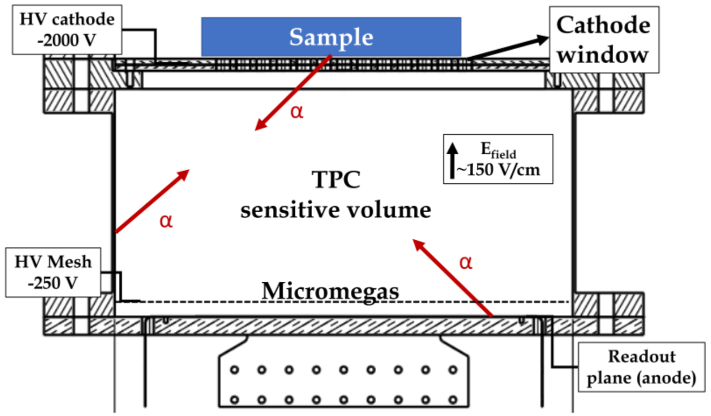
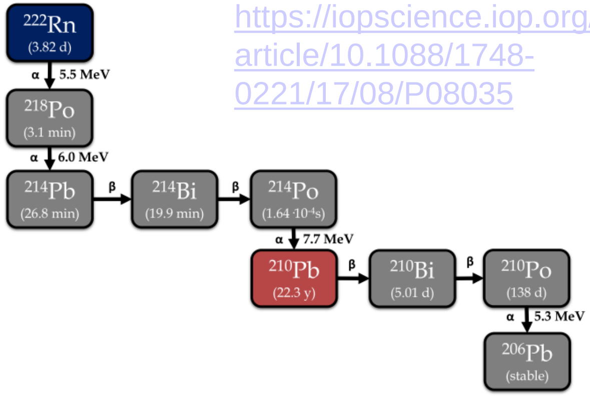
2019-2021 Background Level ~ 80 dru dominated by **pieces contamination** with radon progeny

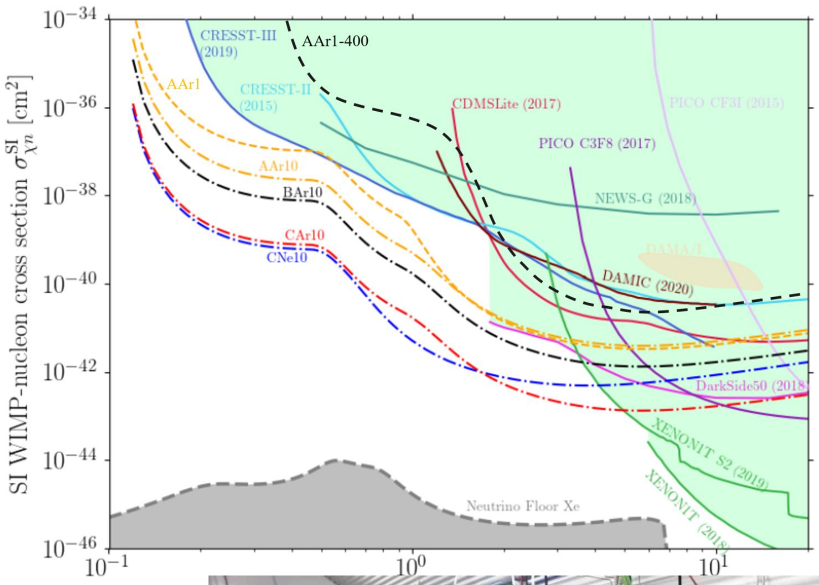
AlphaCAMM: screening alpha surface contamination → **100 nBq·cm^{-2}**





https://iopscience.iop.org/article/10.1088/1748-0221/17/08/P08035

Challenges



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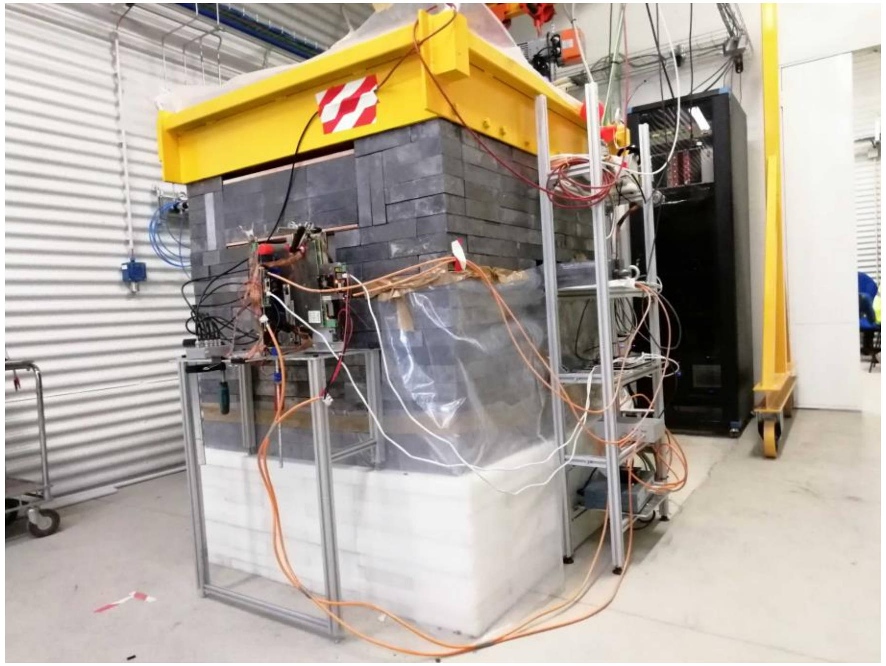

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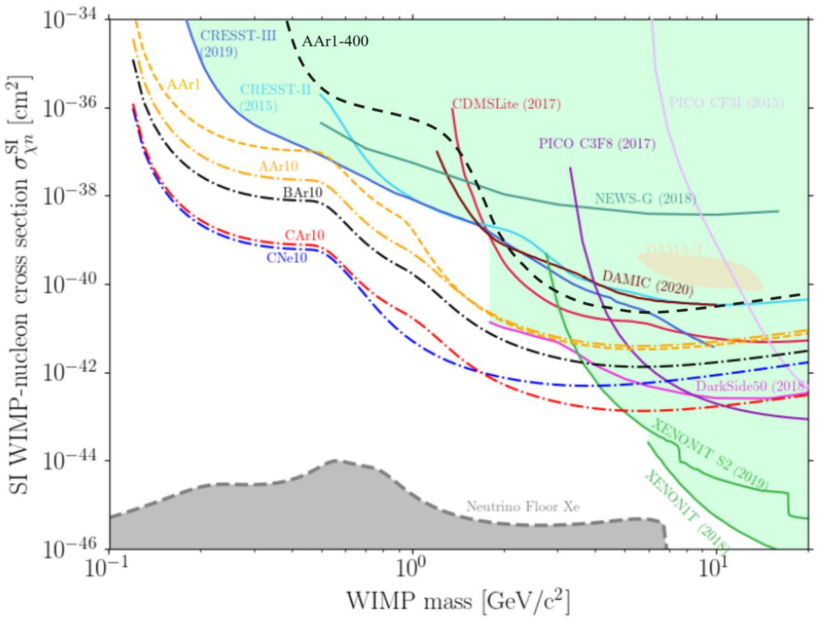

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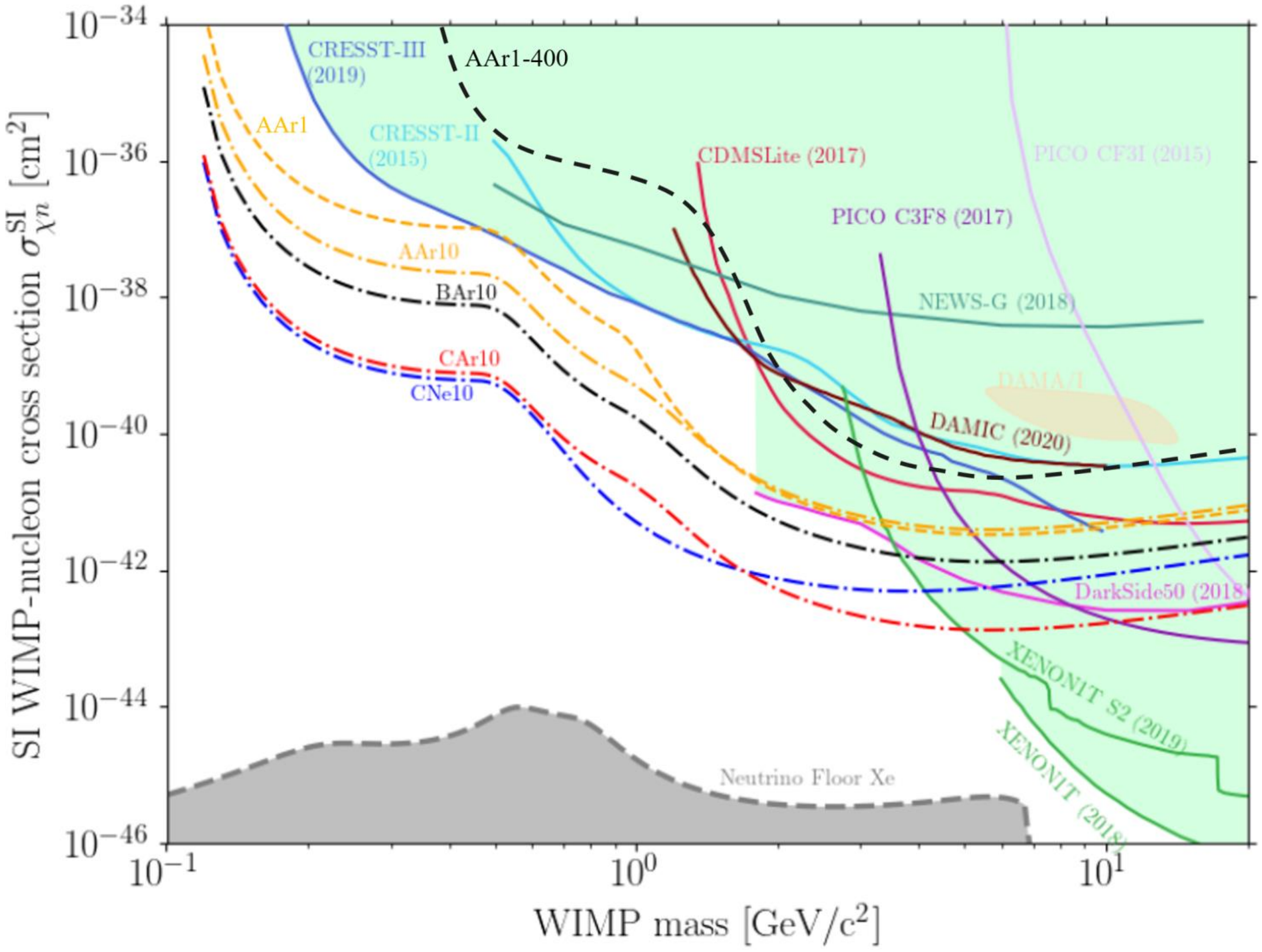
New **Micromegas** already installed. Several issues addressed:
- Connection problems (leak currents [nA] between pads in the footprints & channel loss)
- leak currents between the tracks in the own Micromegas circuit.
- Leak currents between the strips in the active area.

Gas quality
- Outgassing (pumping for days/weeks)
- Tightness (10^{-6} mbar*l/s Helium test)
  → Minimizing retro-diffusion.
- Virtual leaks (careful design & assembling)

Noise stabilization
- Robust connections
- Screening with aluminum foil & dedicated grounding
- Limitation of devices connected in the laboratory

Challenges



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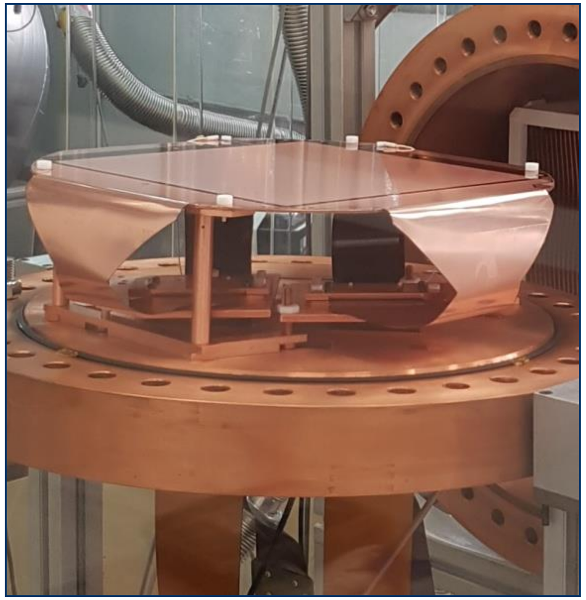
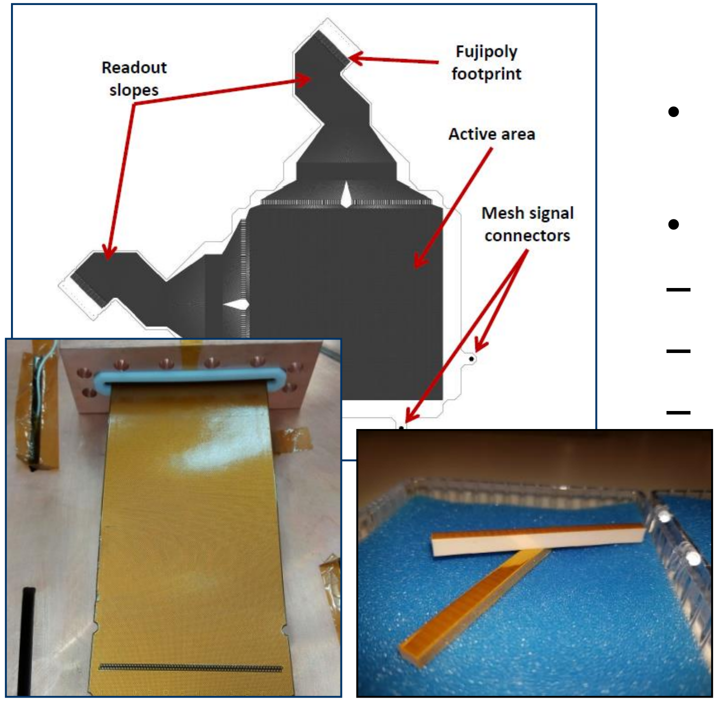
R&D: Riveting & Distressing
every time a problem is solved a new one appears

ADDITIONAL MATERIAL

Micromegas technology as readout plane

- ✓ **New Microbulk Micromegas readouts:** the largest surface (~25x25 cm^2) ever produced with this technology.
  - Two planes manufactured at CERN and first installed at the Zaragoza set-up in September, 2017. **256 X strips, 256 Y strips, ~1 mm pitch**
  - **Flat cables** take out signals from strips and connect to the interface cards out of the vessel.
  - Connections at both sides of flat cables made now by special silicone-based **connectors** (Zebra Gold 8000C from Fujipoly) checked to be more radiopure.



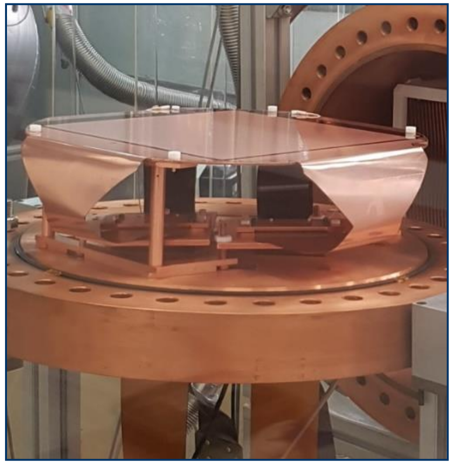


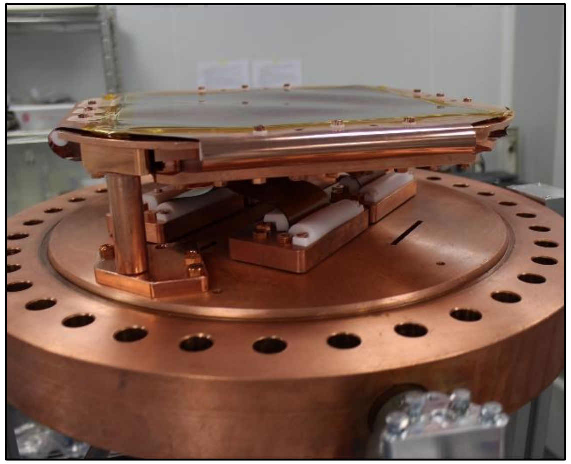
- **Micromegas** are consolidated **readout structures**: simple, high granularity, large surfaces
- Different **technologies**:
  - Classical (CAST, COMPASS, ATLAS, …)
  - Bulk (T2K, nTOF, MIMAC, …)
  - **Microbulk**: more homogeneous and radio-pure (CAST, nTOF , PANDAX-III, …)

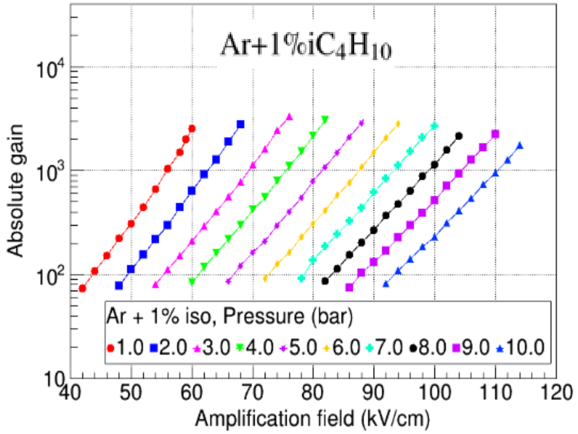
Challenges: Detector stability

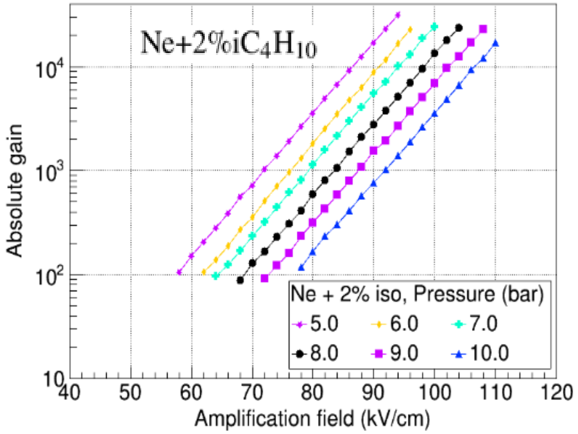
New Micromegas already installed. Solved:

- Connection problems (leak currents [nA] between pads in the footprints & channel loss)
- Leak currents between the tracks in the own Micromegas circuit.
- Leak currents between the strips in the active area.









Parámetro	MM v1	MM v2
Distancia mínima entre canales (um)	75	500
Distancia mínima entre vías de canal y tierra (um)	200	4000
Número de lengüetas (ud)	2	4
Distancia entre pads en la fuella del conector (um)	150 (fujipoly)	4000 (FtF)
Distancia de amplificación (um)	50	50
Distancia entre strips en el área activa (um)	50	100
Patrón de agujeros (D-P) (um)	50 - 100	60 - 110

Table 8.1: Comparación de los parámetros de diseño entre la Micromegas v1 (instalada en TREXDM en 2018) y la Micromegas v2 (instalada en TREXDM en 2022).

Challenges: Detector stability

New Micromegas already installed. Partially solved:

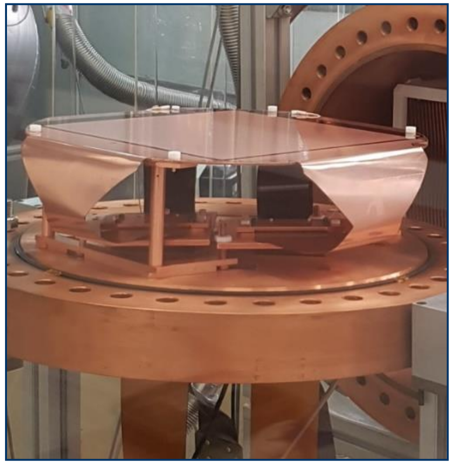
- Connection problems (leak currents [nA] between pads in the footprints & channel loss)
- leak currents between the tracks in the own Micromegas circuit.
- Leak currents between the strips in the active area.

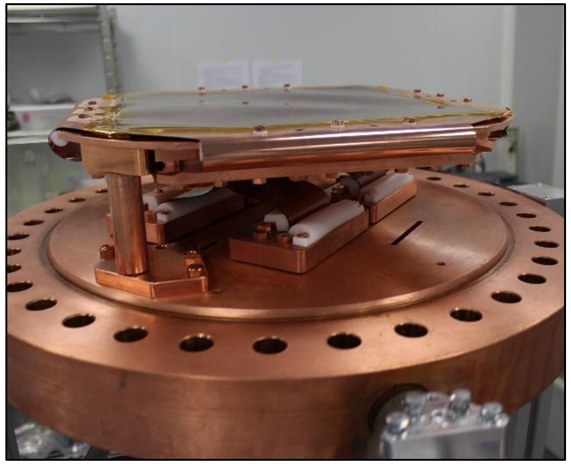
Gas quality

- Outgassing (pumping for days/weeks)
- Tightness (10^{-6} mbar*l/s Helium test) → Minimizing retro-diffusion.
- Virtual leaks (careful design & assembling)

Noise stabilization

- Robust connections
- Ad-hoc aluminum foil installation & grounded copper wires
- Control of devices connected in the laboratory





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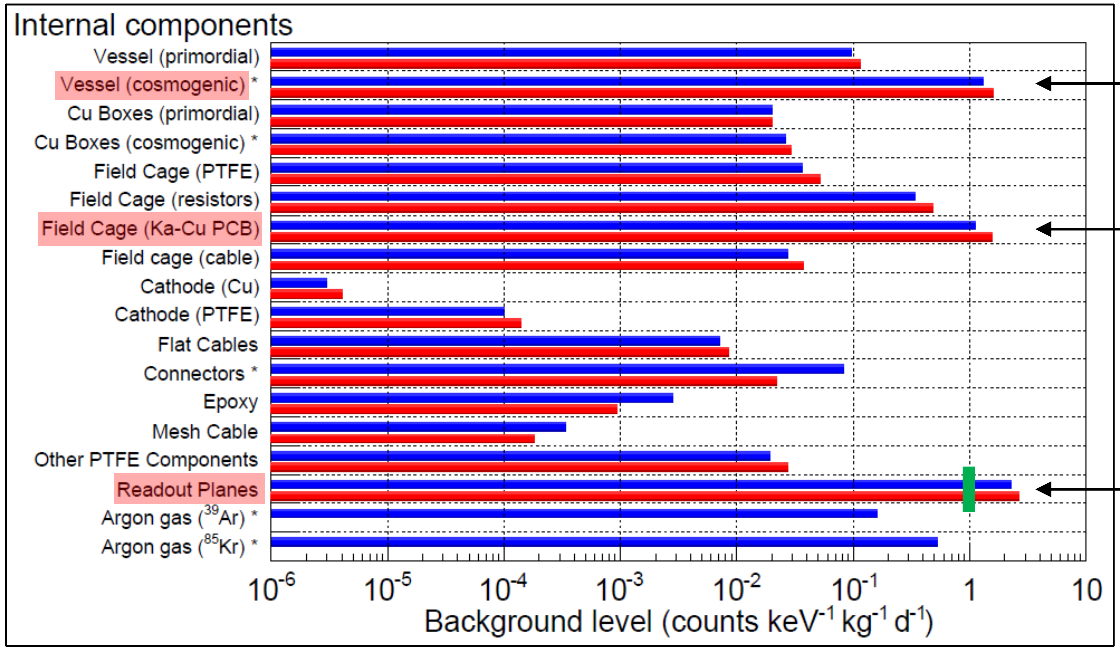
Challenges: Background level reduction



Next step once the background is dominated by the vessel activation.

New design on going.

Factor ~ 3 of contamination reduction respect to the previous Micromegas.

Main challenges in radio-purity of materials:

- Search of clean commercial materials. Large screening programs
- Synthesize clean materials.
- Control of processes in companies
- Storage in controlled environments

2012 JINST 7 P04007

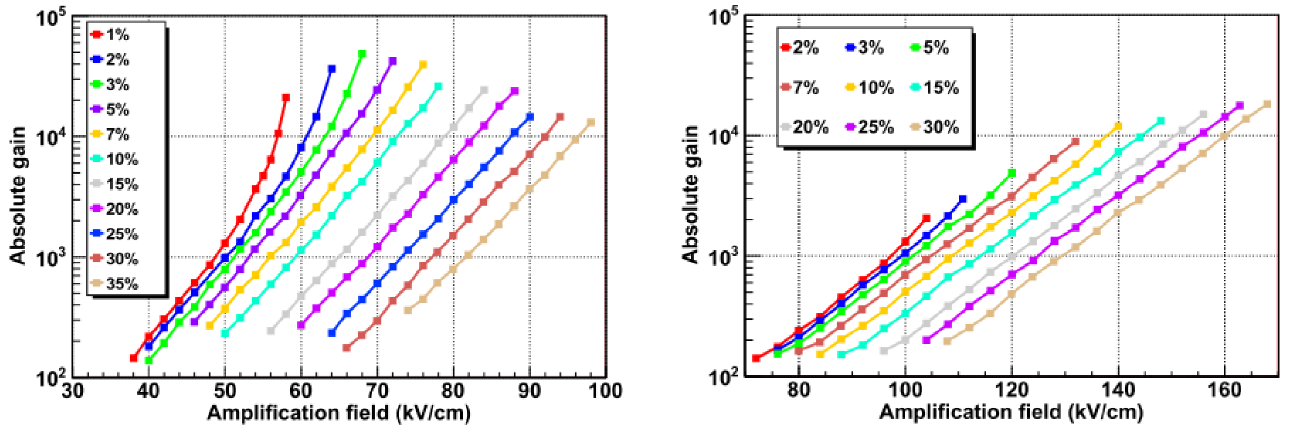


Figure 6. Dependence of the absolute gain with the amplification field for two microbulk detectors with gaps of 50 (left) and 25 μm (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.

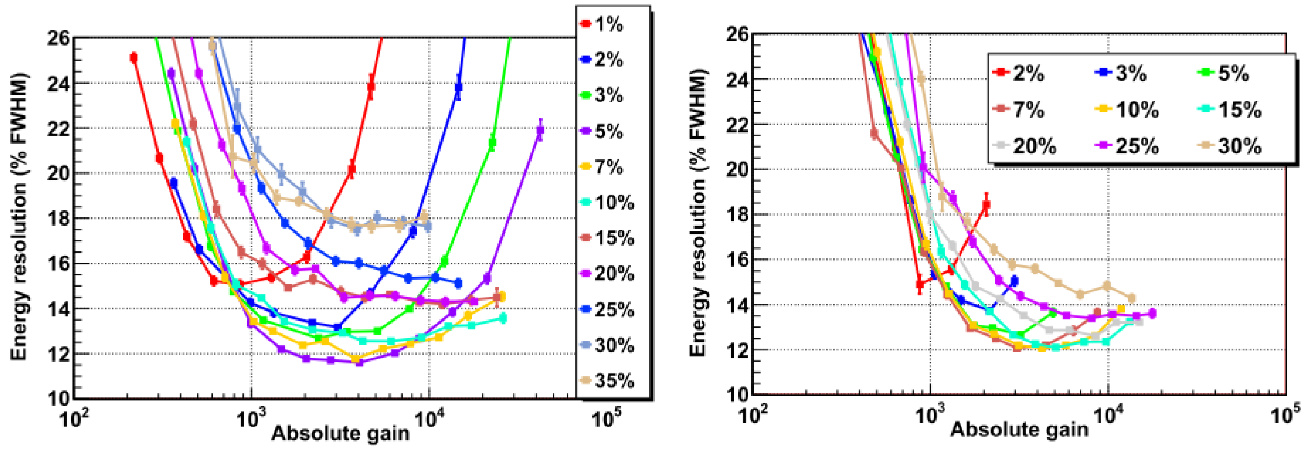
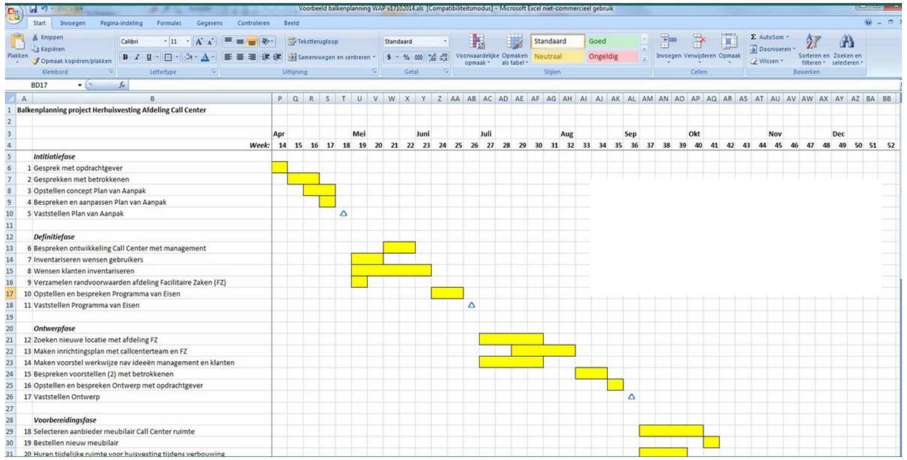


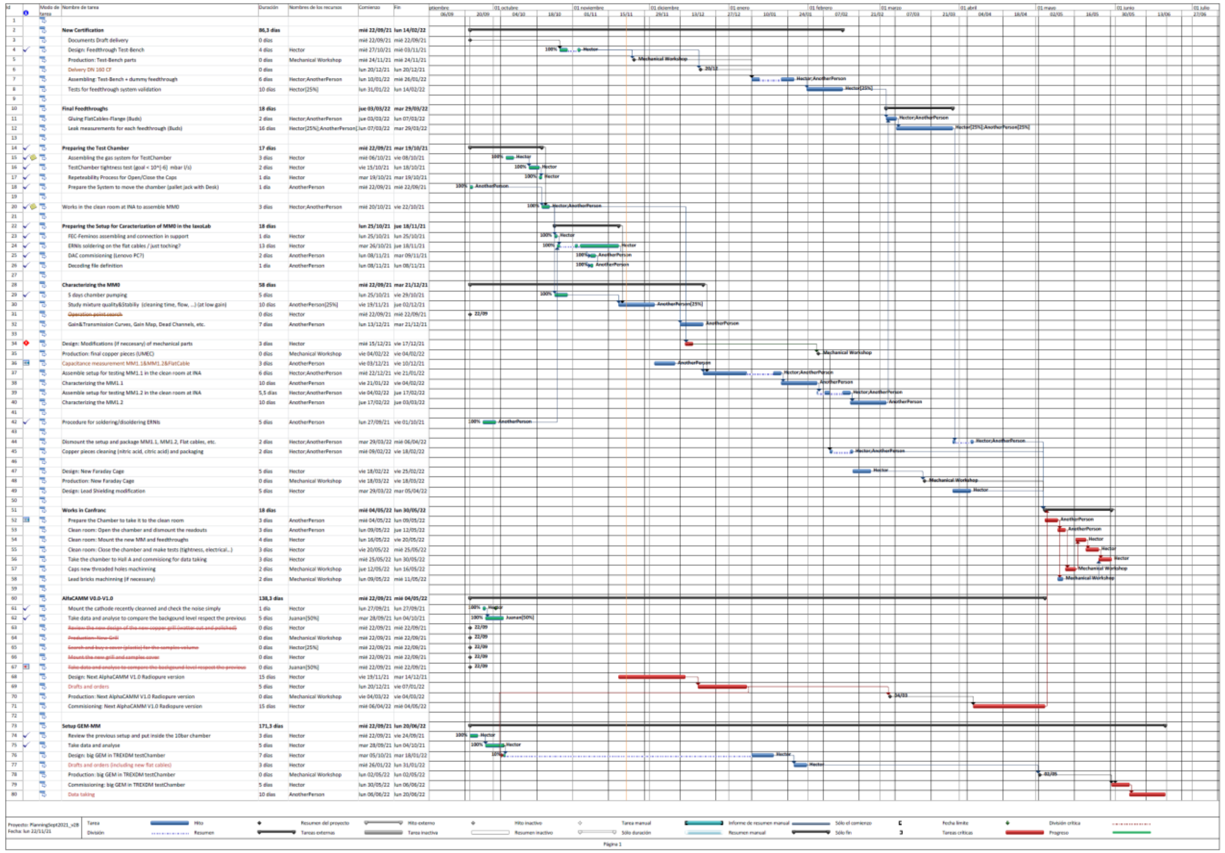
Figure 7. Dependence of the energy resolution with the absolute gain for two detectors of 50 (left) and 25 μm-thickness-gap (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.

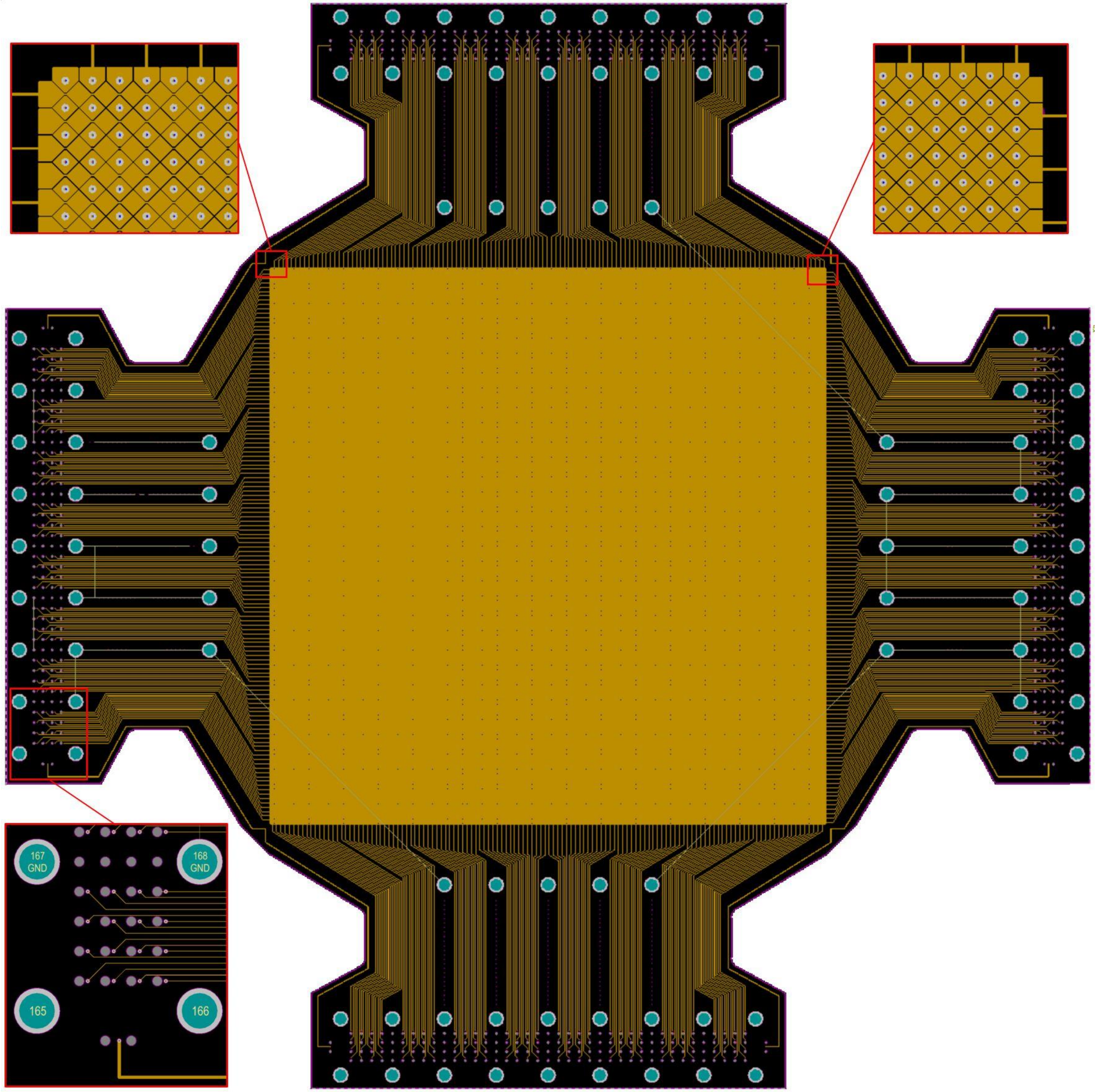
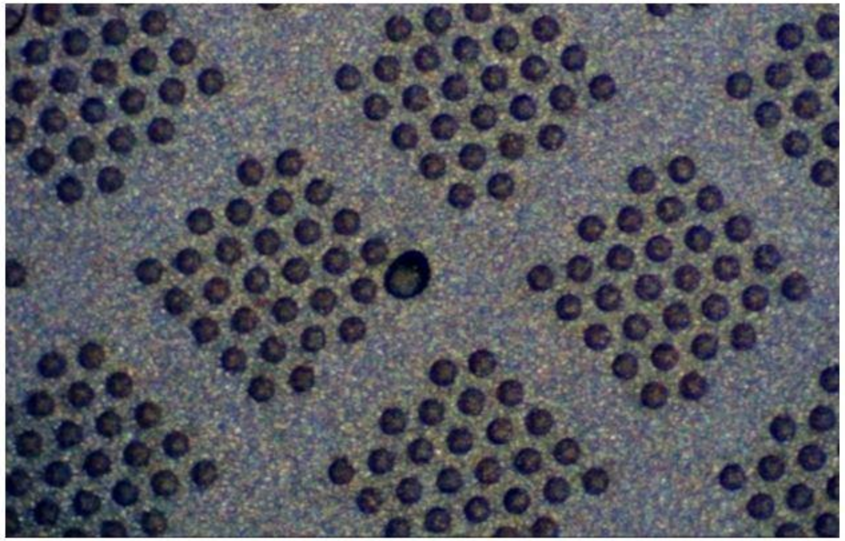
Prospects & Planning

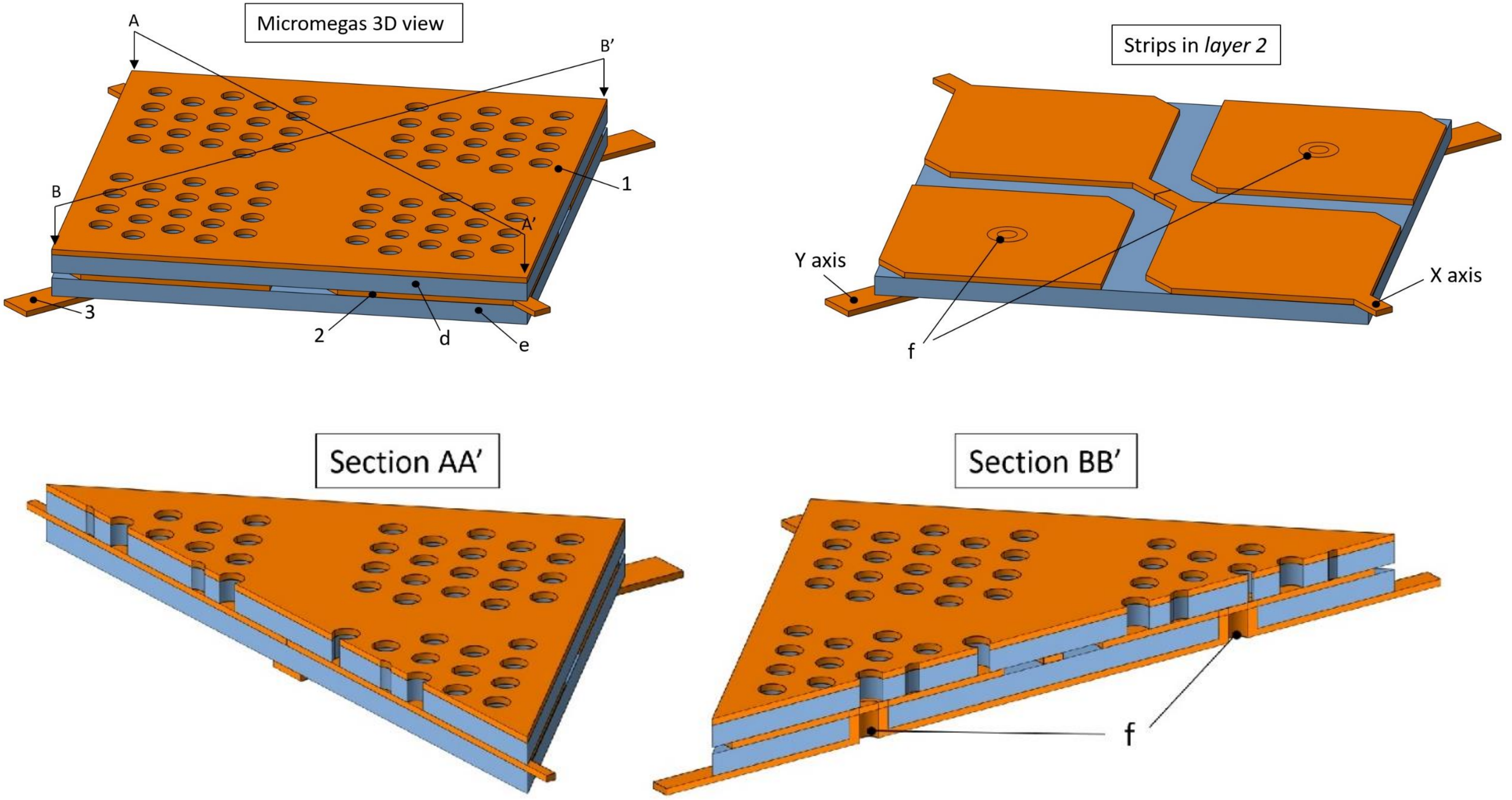
1. A planning is never fulfilled and people is frustrated
2. First though → very optimistic   Second though → optimistic   Third???
3. For execution, the most realistic planning. Team people opinion

Discussed and agreed
One person in charge
Updated frequently.






167
GND
168
GND
165
166




Micromegas 3D view
A
B'
B
A'
1
2
3
d
e
Strips in *layer 2*
Y axis
X axis
f
Section AA'
Section BB'
f

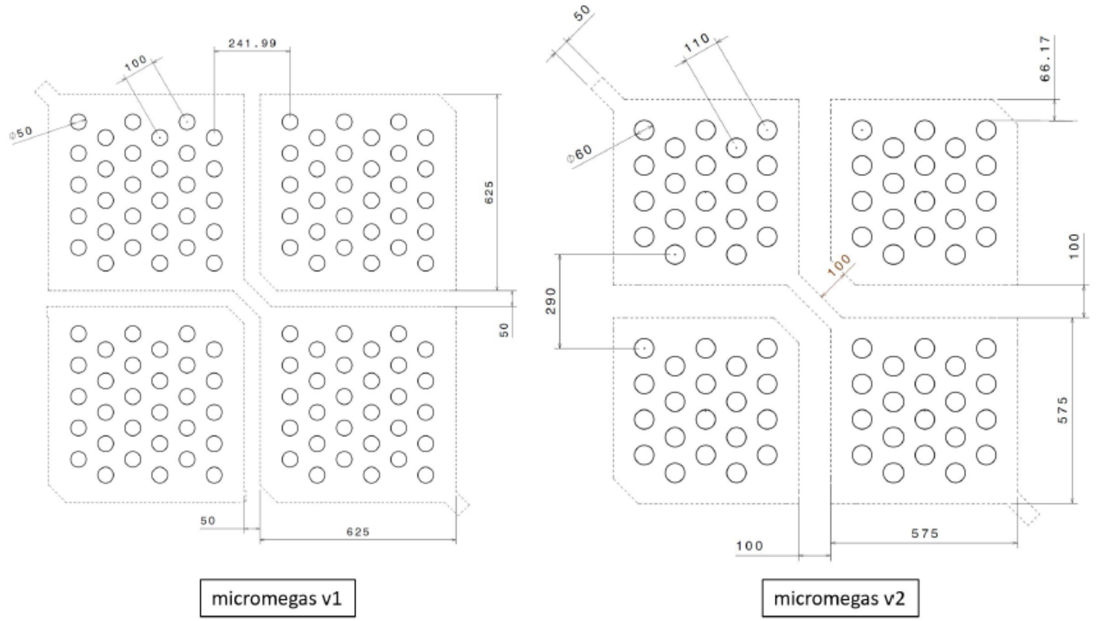


Figure 8.6: Patrón de agujeros en la mesh superpuesto a la geometría de los pixels/strips. • Izquierda: primera Micromegas instalada en TREXDM con 50 um de diámetro de agujero, 100 um de separación entre centros y 50 um de separación entre pixeles. • Derecha: nueva Micromegas con 60 um de diámetro de agujero, 110 um de separación entre centros y 100 um de separación entre pixeles.

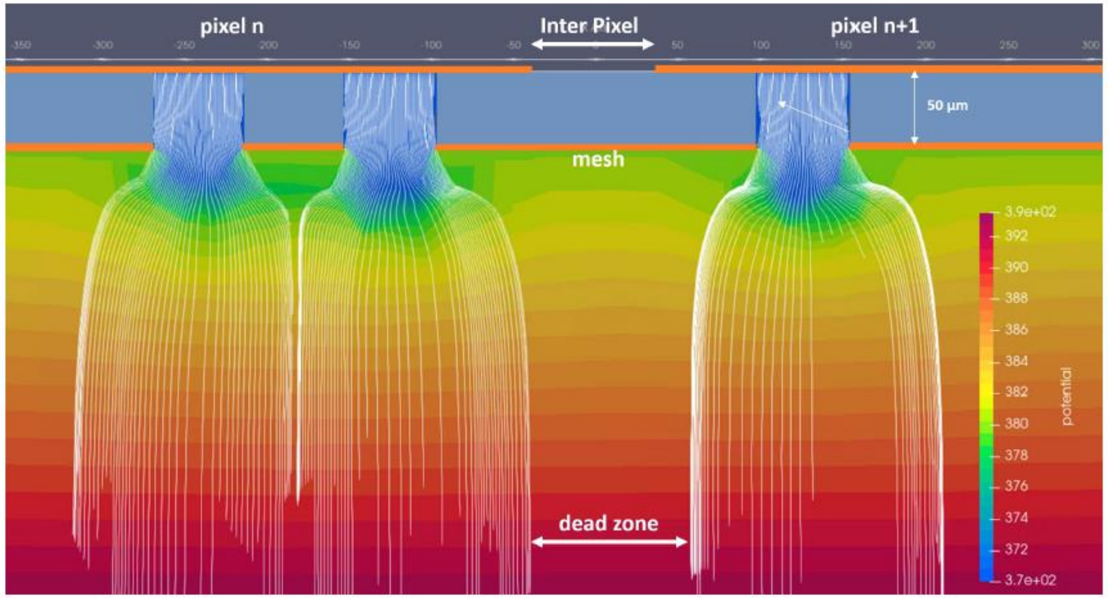
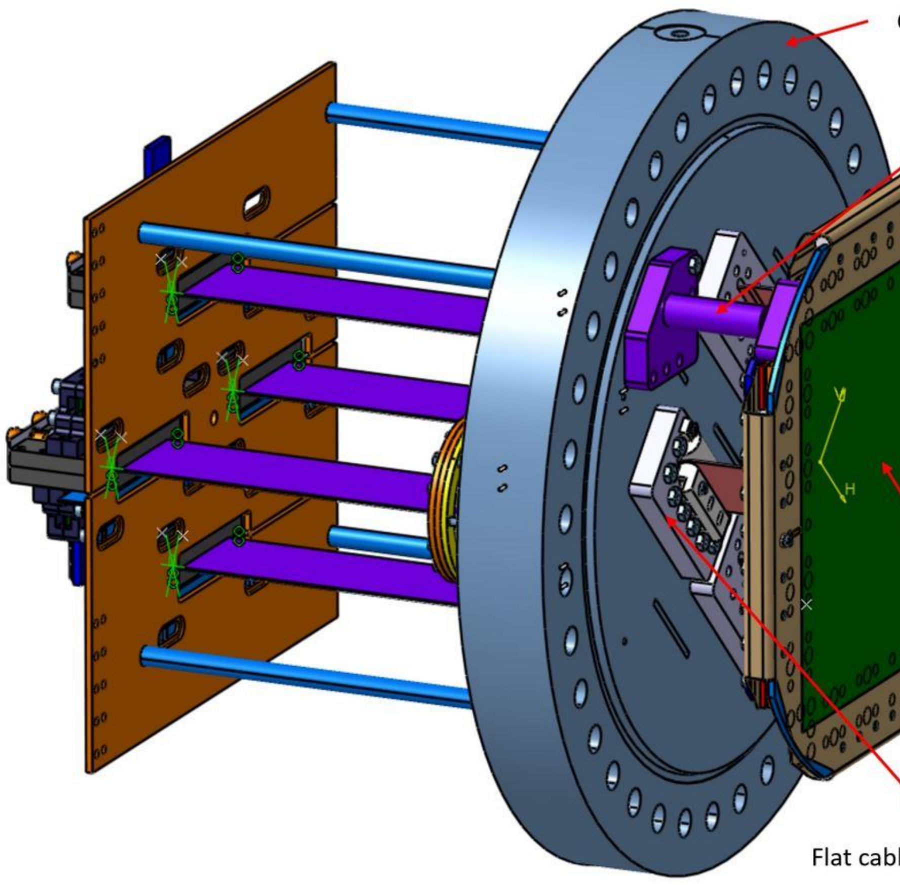
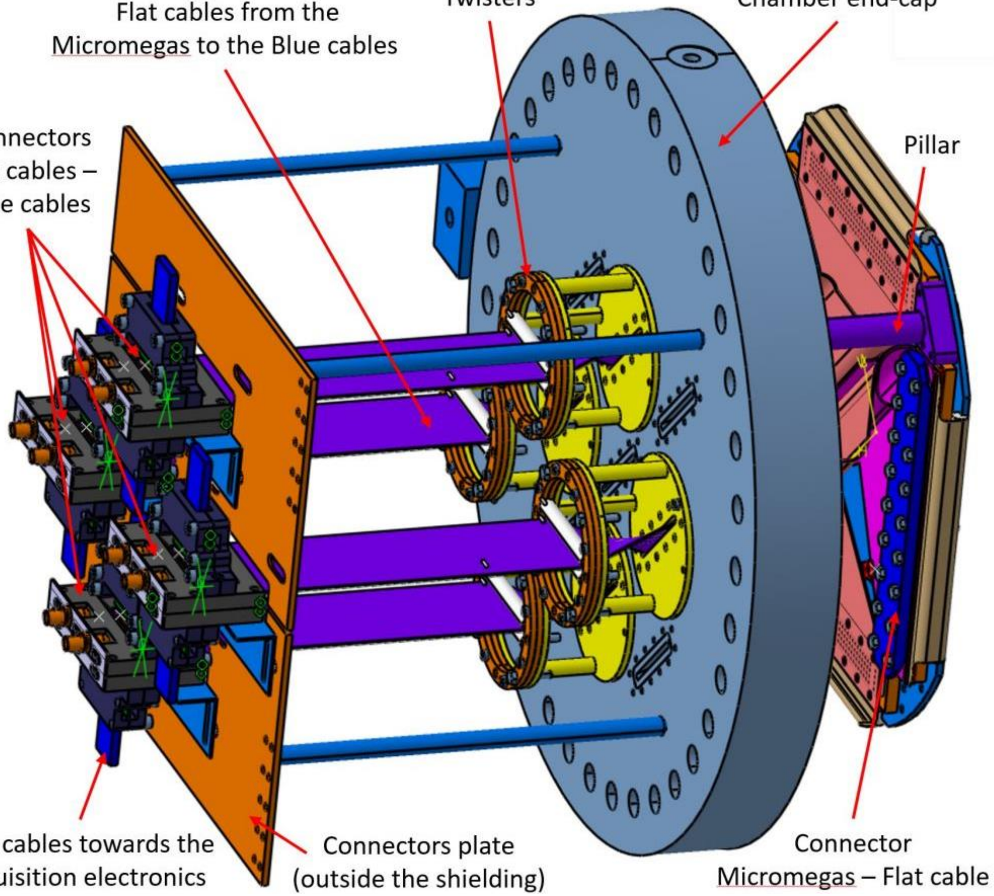


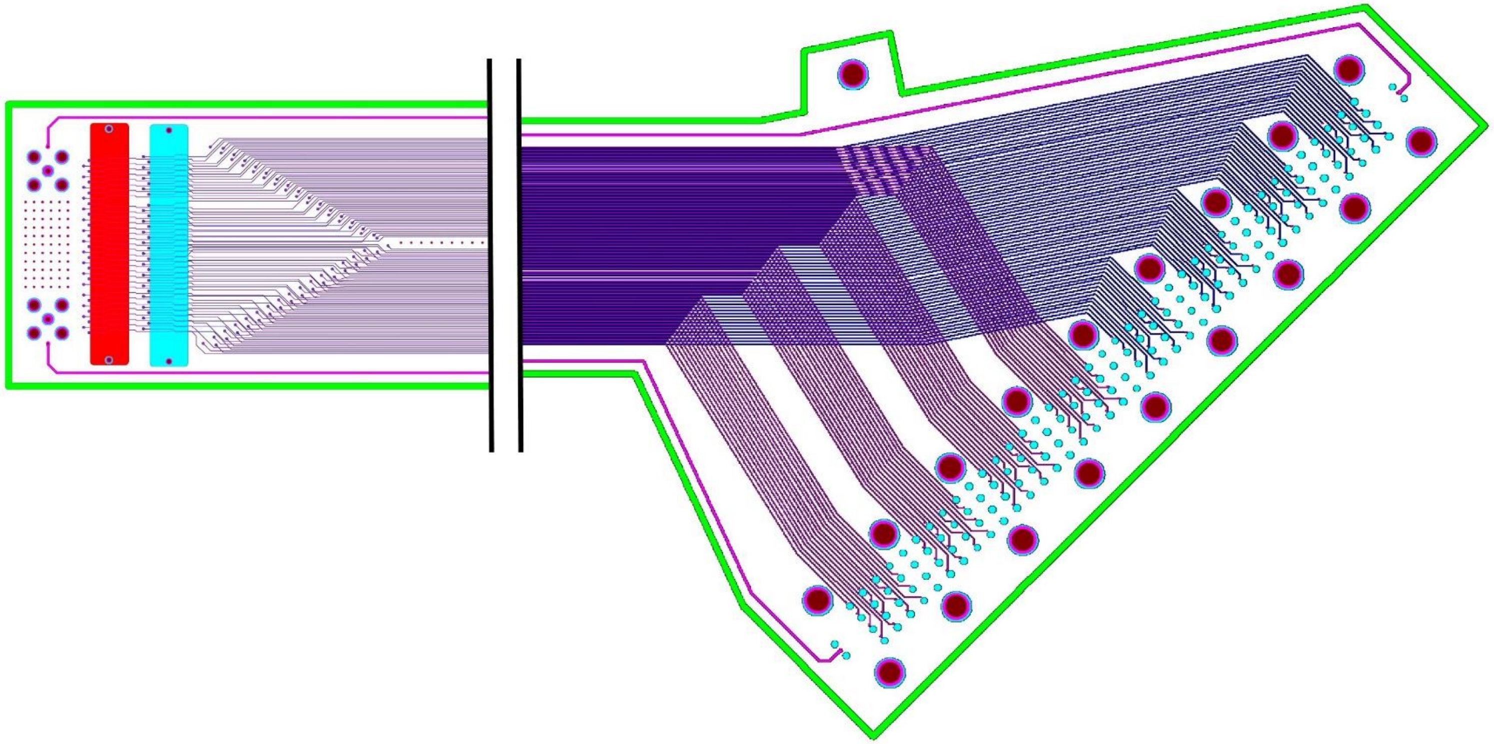
Figure 8.7: Simulación del campo eléctrico próximo a la mesh para la Micromegas D60P120IP260. Condiciones de simulación: 3 bar, 380 V en la mesh y un campo de deriva de 150 V/cm*bar. Se observa la zona muerta entre píxeles. Es necesario aclarar que por simplificación no se han añadido más agujeros de amplificación ni a la derecha ni a la izquierda de la imagen, ya que el objetivo era cuantificar la pérdida de electrones primarios en la zona entre píxeles.

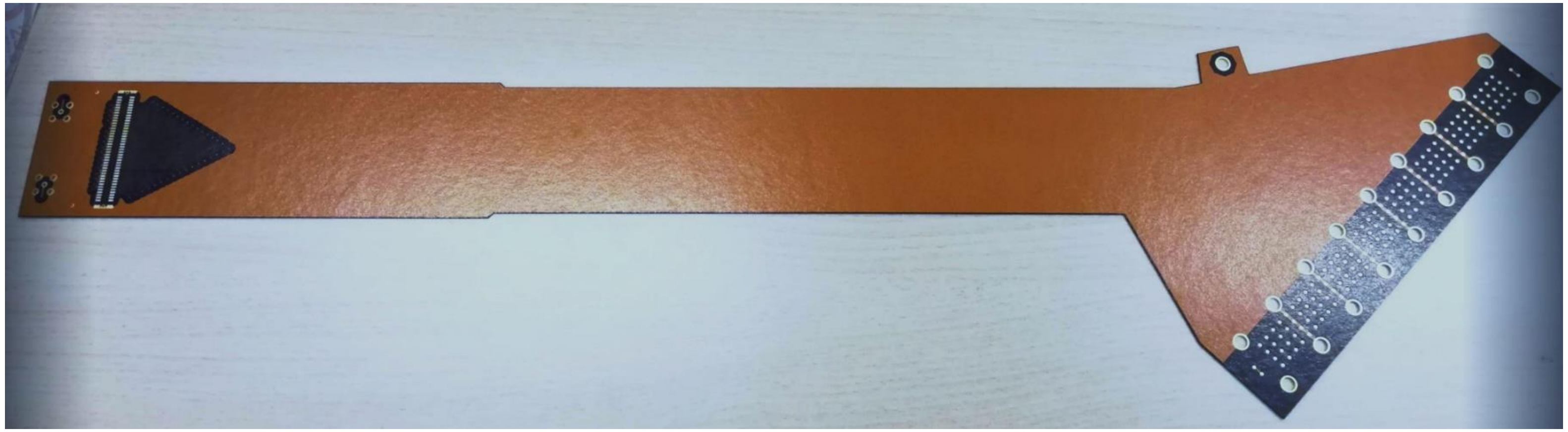
Pressure (bar)	Mesh Voltage	Eficency D50P100IP240	Eficency D60P120IP260	Eficency D60P110IP290
1.5	350	88%	84%	76%
3	350	76%	73%	65%
4	350	74%	70%	63%
6	350	69%	65%	58%
8	350	66%	63%	56%
10	350	64%	60%	54%

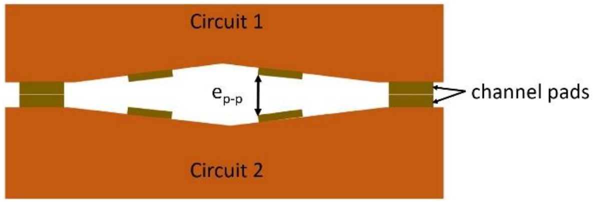
Table 8.2: Eficiencia en la recolección de electrones primarios para tres patrones diferentes con diferentes distancias entre agujeros de píxeles contiguos (IP) de 240 um, 260 um y 290 um. En la figura 8.6 pueden verse dos de estos tres patrones, con IP de 240 y 290 um. Estaría bien volver a hacer el cálculo de las eficiencias con mejor precisión y hacer un gráfico lineal con barras de error


Chamber end-cap
Pillar
Micromegas
(TREXDM.v2)
Flat cable Feedthrough

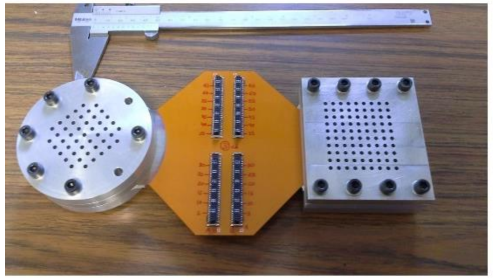

Flat cables from the
Micromegas to the Blue cables
Twisters
Chamber end-cap
Connectors
Flat cables –
Blue cables
Pillar
Blue cables towards the
acquisition electronics
Connectors plate
(outside the shielding)
Connector
Micromegas – Flat cable

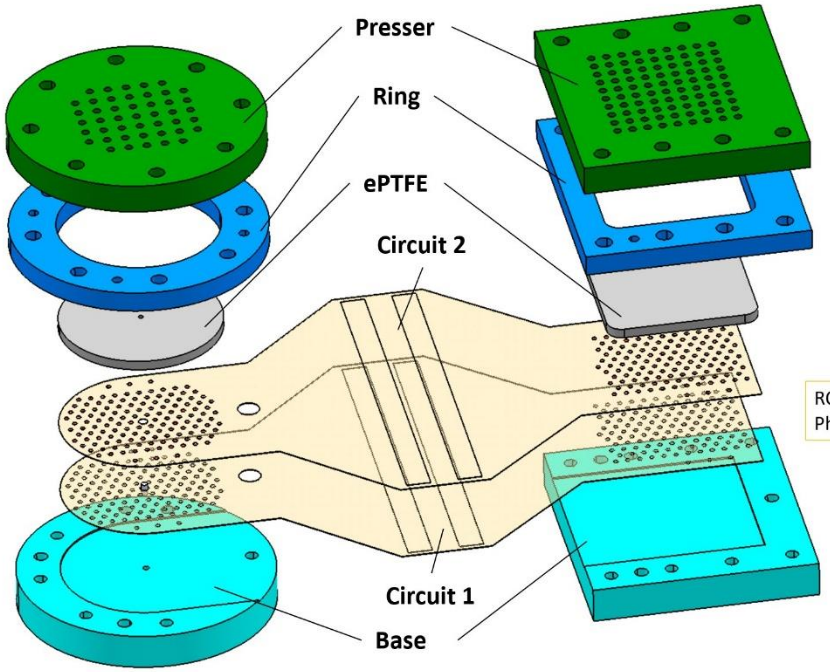




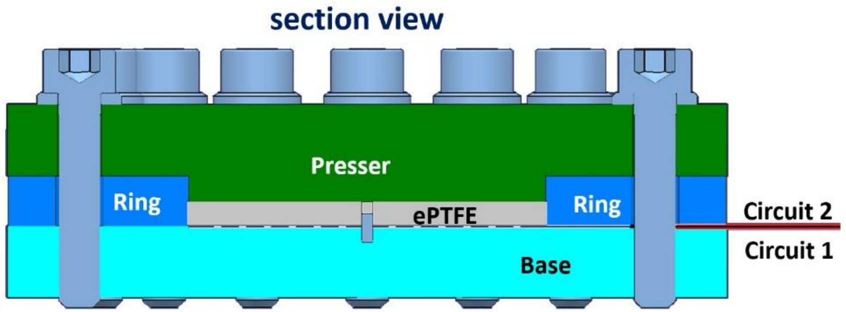


Circuit 1
e_{p-p}
channel pads
Circuit 2

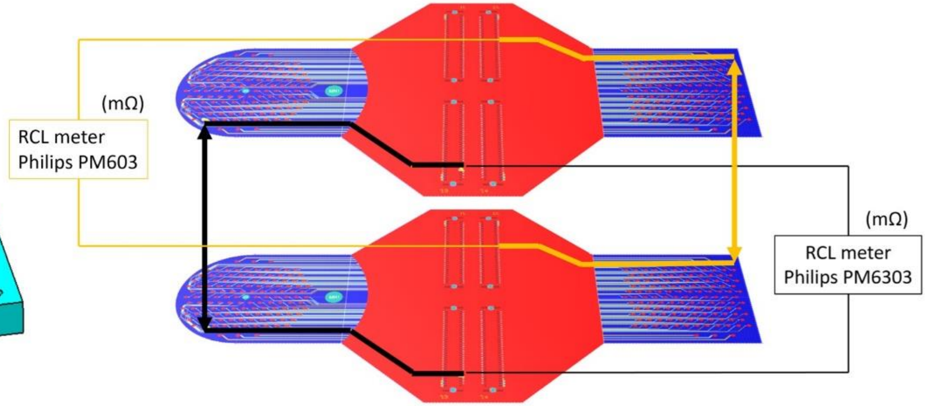




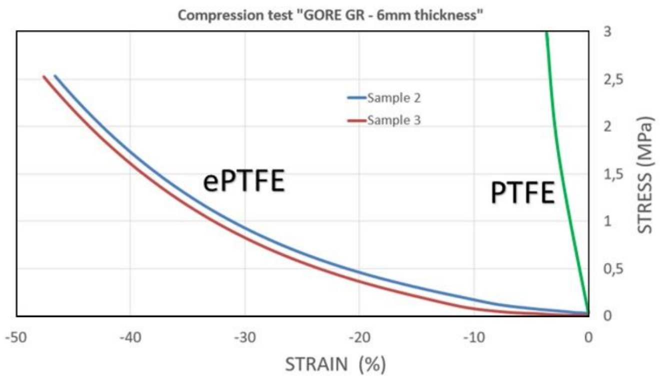
Presser
Ring
ePTFE
Circuit 2
Circuit 1
Base



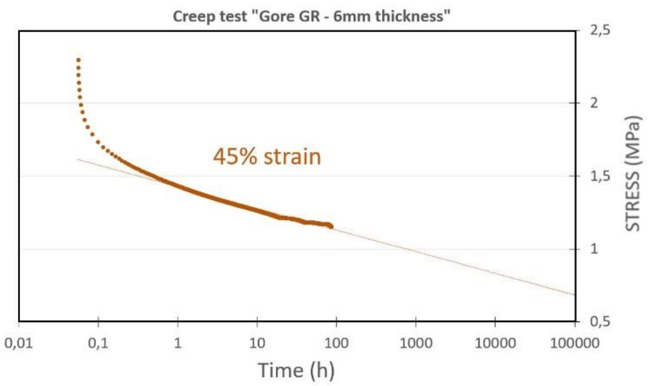
section view
Presser
Ring
ePTFE
Ring
Circuit 2
Circuit 1
Base



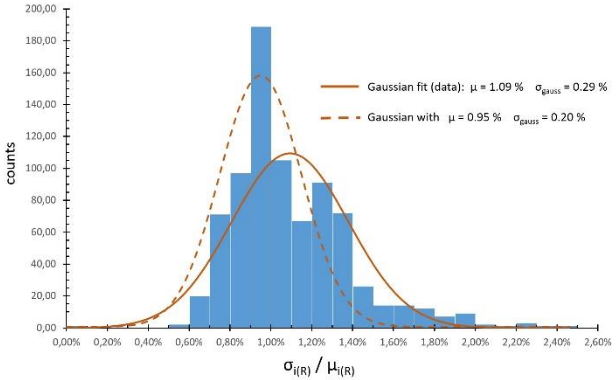
(mΩ)
RCL meter
Philips PM603
(mΩ)
RCL meter
Philips PM6303



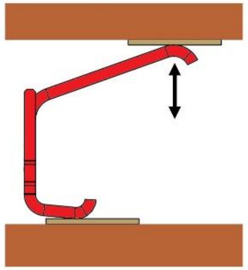
Compression test "GORE GR - 6mm thickness"
Sample 2
Sample 3
ePTFE
PTFE
STRESS (MPa)
3
2,5
2
1,5
1
0,5
0
-50
-40
-30
-20
-10
0
STRAIN (%)

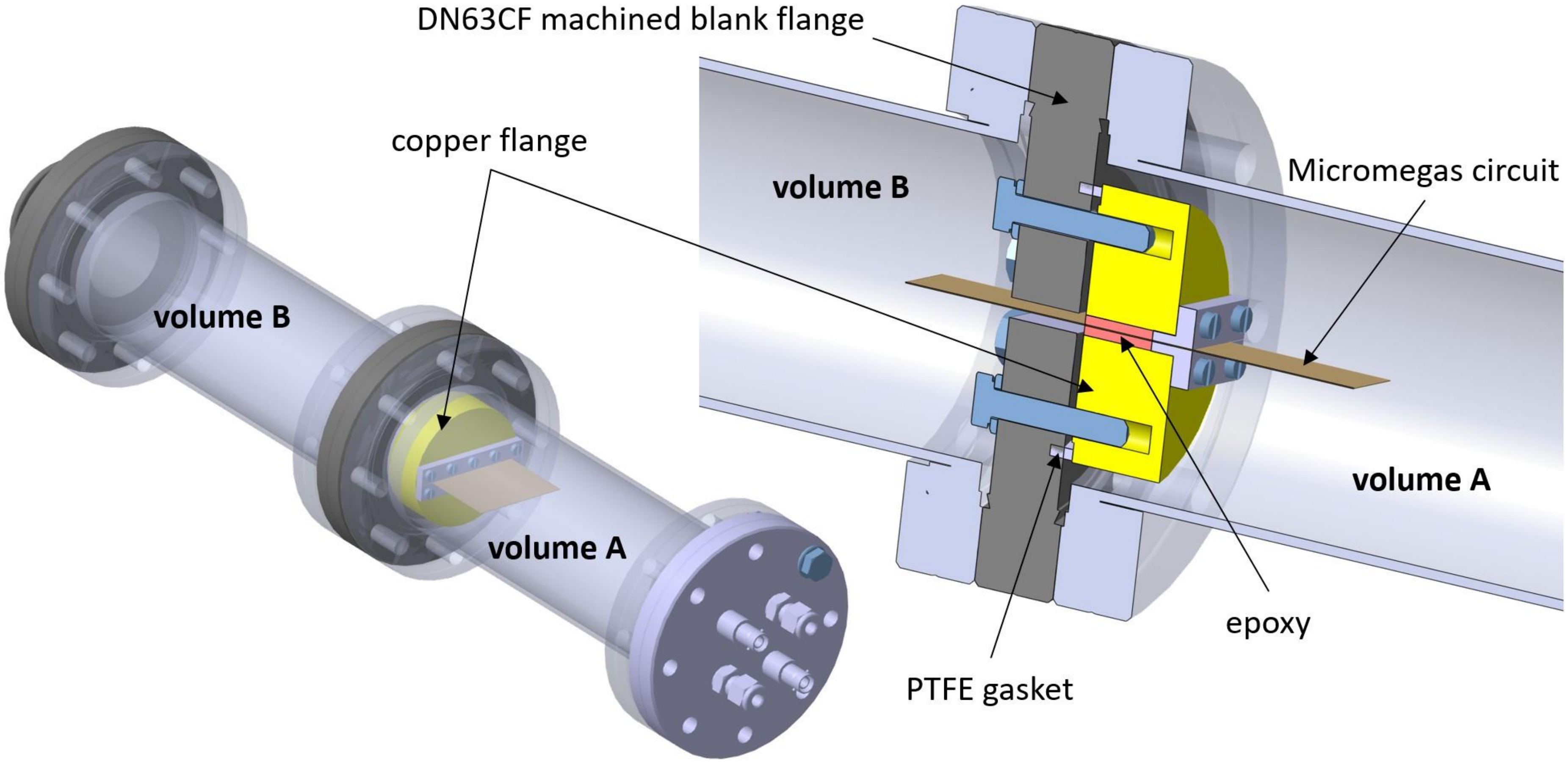


Creep test "Gore GR - 6mm thickness"
45% strain
STRESS (MPa)
2,5
2
1,5
1
0,5
0,01
0,1
1
10
100
1000
10000
100000
Time (h)



Gaussian fit (data): μ = 1.09 % σgauss = 0.29 %
Gaussian with μ = 0.95 % σgauss = 0.20 %
counts
200,00
180,00
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0,00%
0,20%
0,40%
0,60%
0,80%
1,00%
1,20%
1,40%
1,60%
1,80%
2,00%
2,20%
2,40%
2,60%
σi(R) / μi(R)




DN63CF machined blank flange
copper flange
volume B
Micromegas circuit
volume B
volume A
volume A
epoxy
PTFE gasket