

IX Reunião Geral - Projeto Especial FAPESP "Física e Instrumentação de Altas Energias com o LHC-CERN"

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# A diffusion-advection model of impurities propagation inside gaseous detectors of radiation

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# Gas Electron Multiplier (GEM)

## Micro pattern gaseous detectors (MPGD) 1

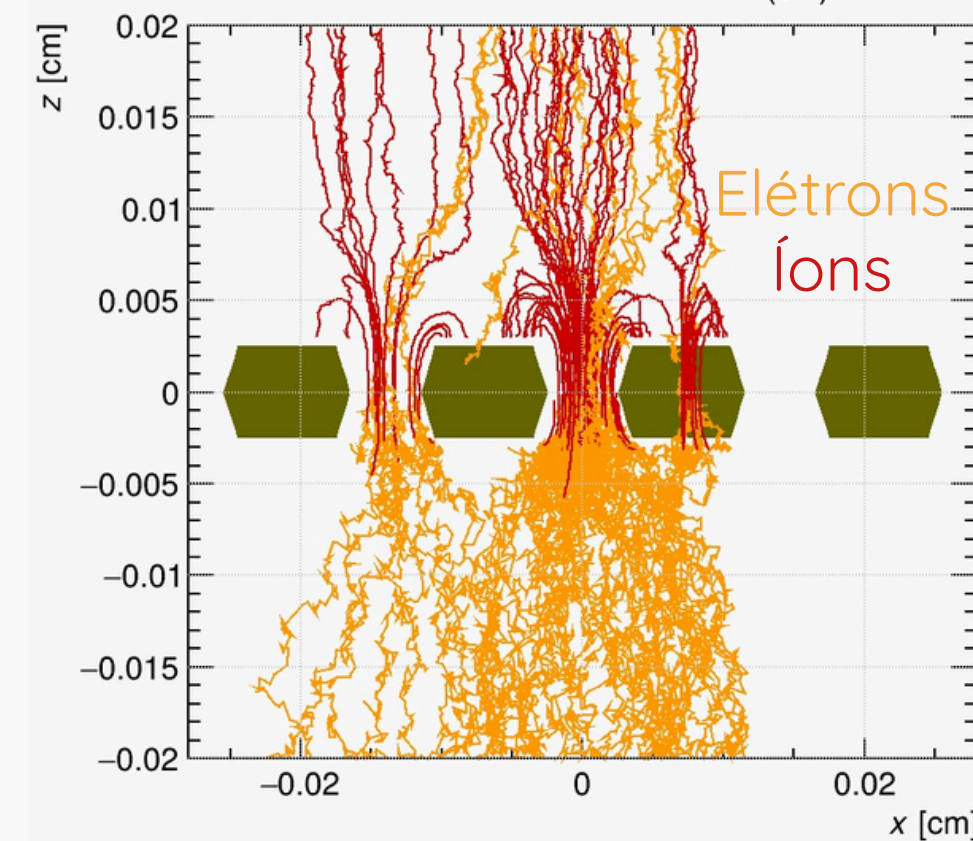
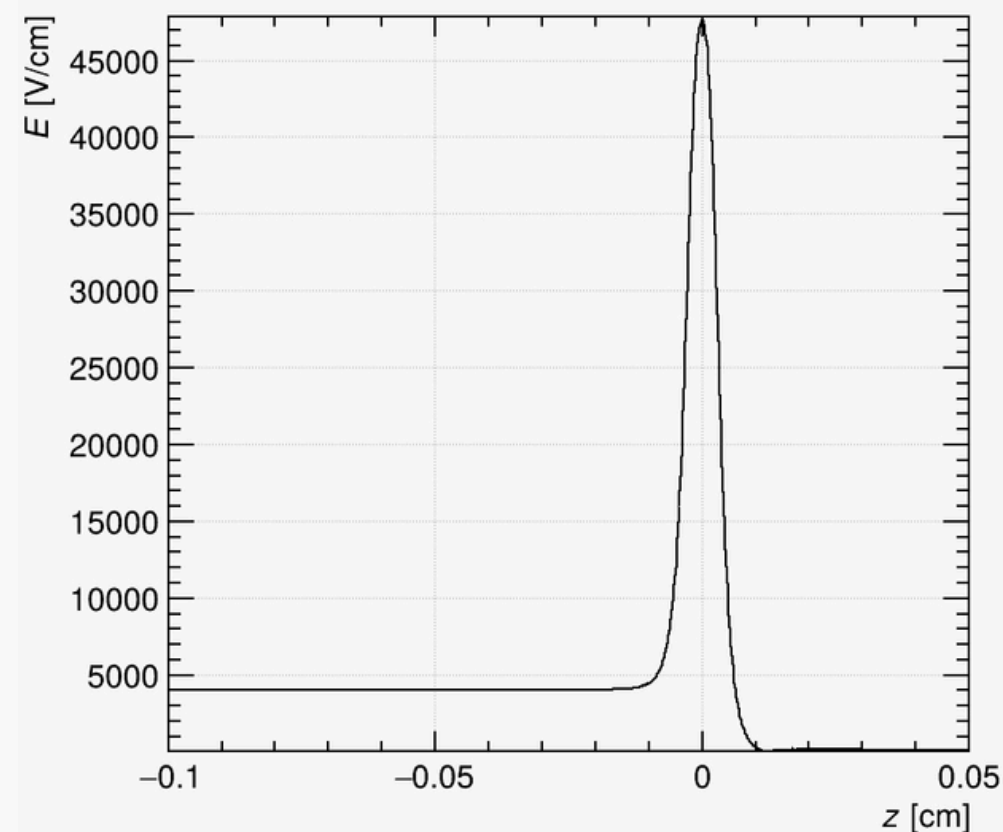
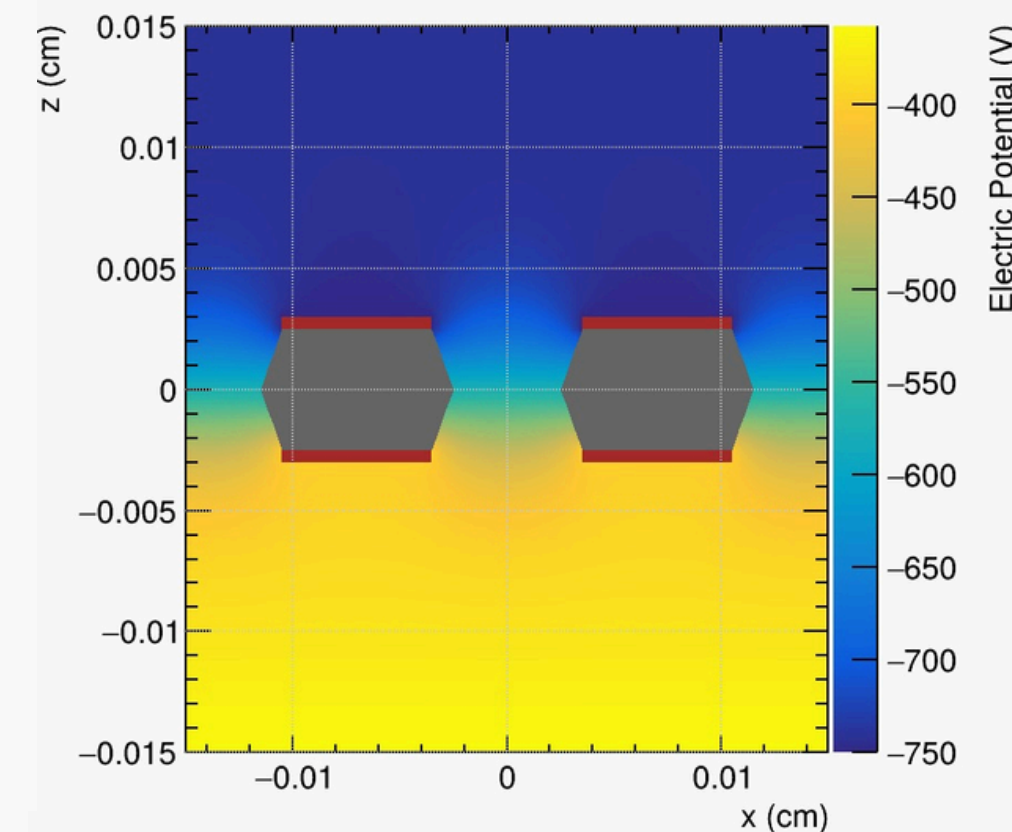
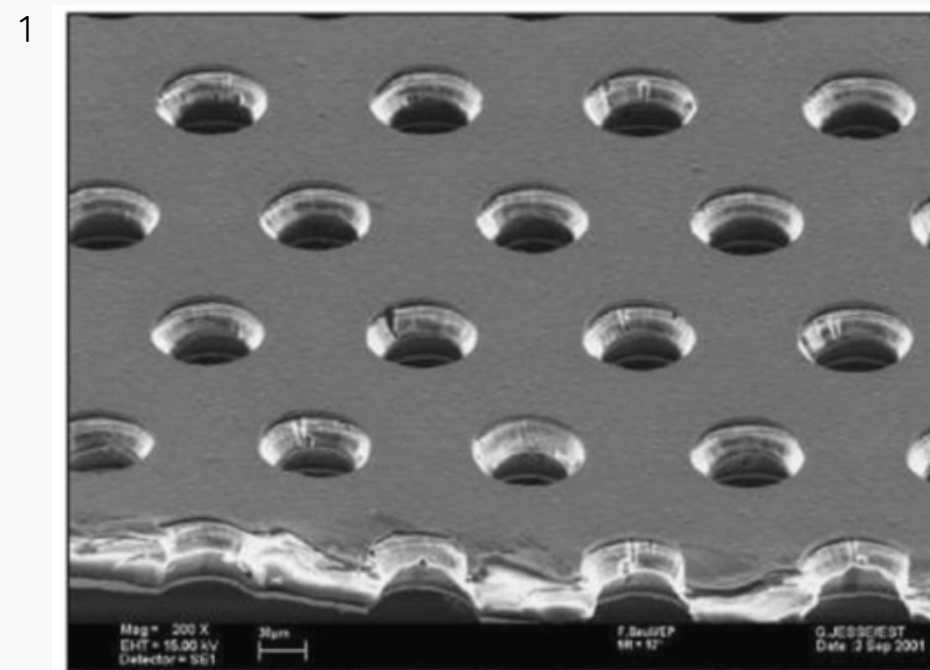
Widely applied in High Energy Physics (HEP);

Large coverage areas;

Discharge resistance;

High counting rates;

Versatile manufacturing.



1 SAULI, Fabio. The gas electron multiplier (GEM): Operating principles and applications. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, v. 805, p. 2-24, 2016.

# GEMs geometries examples

1. GEM detectors can be manufactured with different shapes and internal structures;
2. The operation of these detectors involves a continuous gas flow;
3. Gas renewal is important to provide neutral molecules available for ionization:
  - a. Primary ionization and avalanche processes;
  - b. Some geometrical configurations lead to spatial non-uniformities in gas renewal;
4. This intensifies localized degradation processes:
  - a. Affects the gain;
  - b. Increases the probability of discharges.

## 7. Detectors construction

The early GEM-based detectors, and still many medium-size devices, were realized mounting framed GEM foils within containment vessels built with fiberglass frames, rubber joints and bolts. [Fig. 25](#) is a typical assembly, with the top frame removed, showing the high voltage feed-through and the printed board used to extract the signals, in this case a two-dimensional strip readout [\[20\]](#). The assembled detector is operated in an open gas flow at atmospheric pressure.

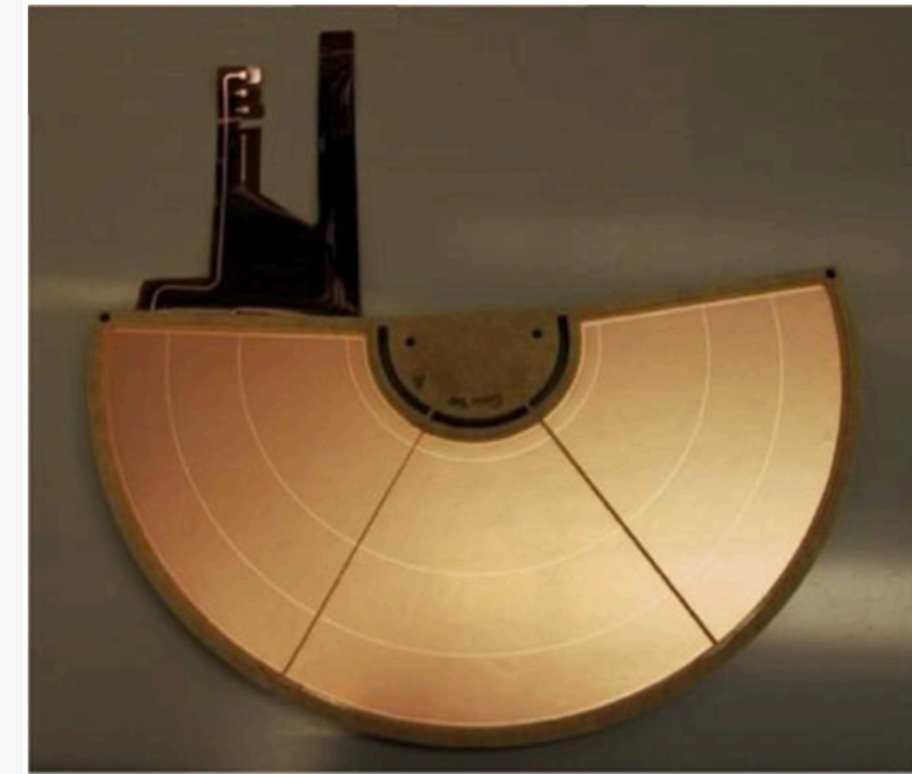


Fig. 30. Half-moon shaped GEM for the TOTEM tracker.

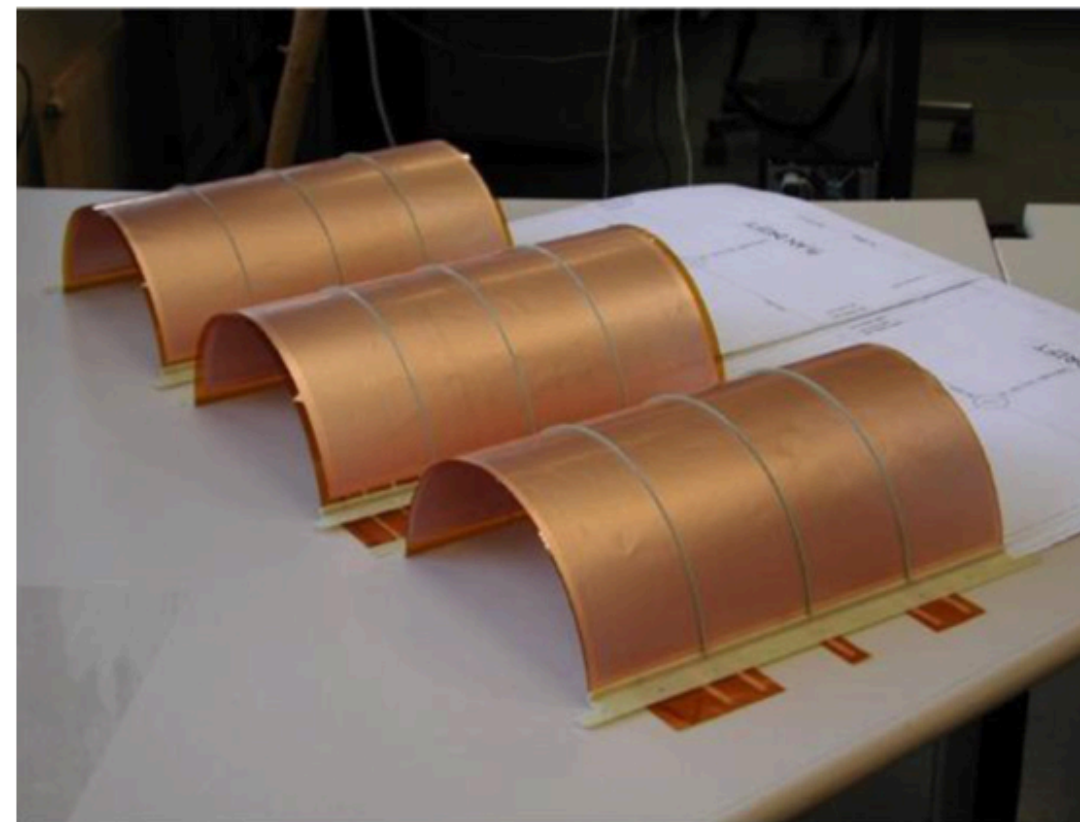


Fig. 35. A set of self-supporting cylindrical GEM electrodes.

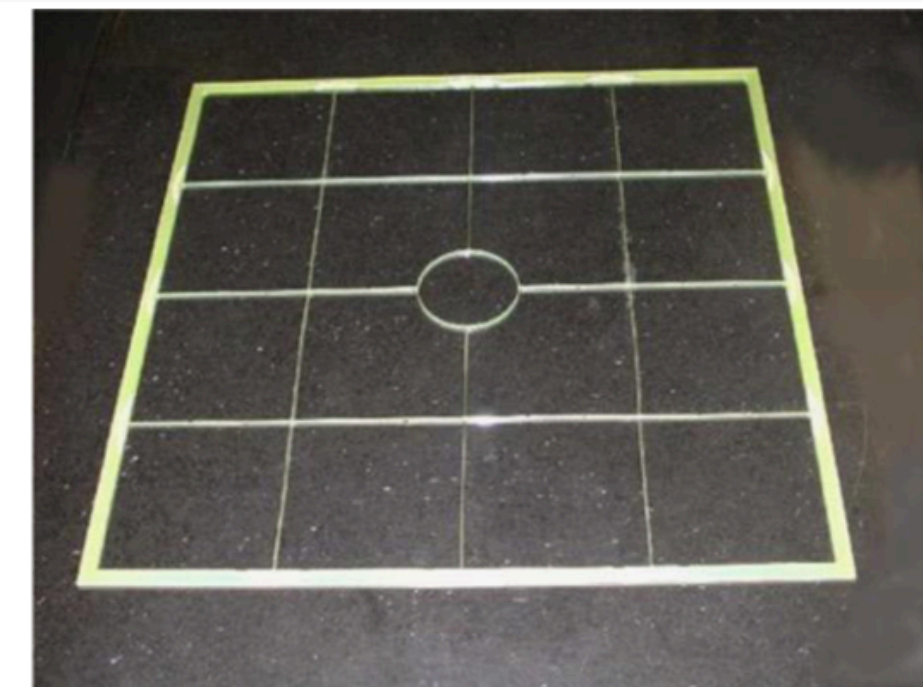


Fig. 28. The thin insulating spacer used to prevent electrostatic deformations of the gaps. The central pattern corresponds to the beam area.

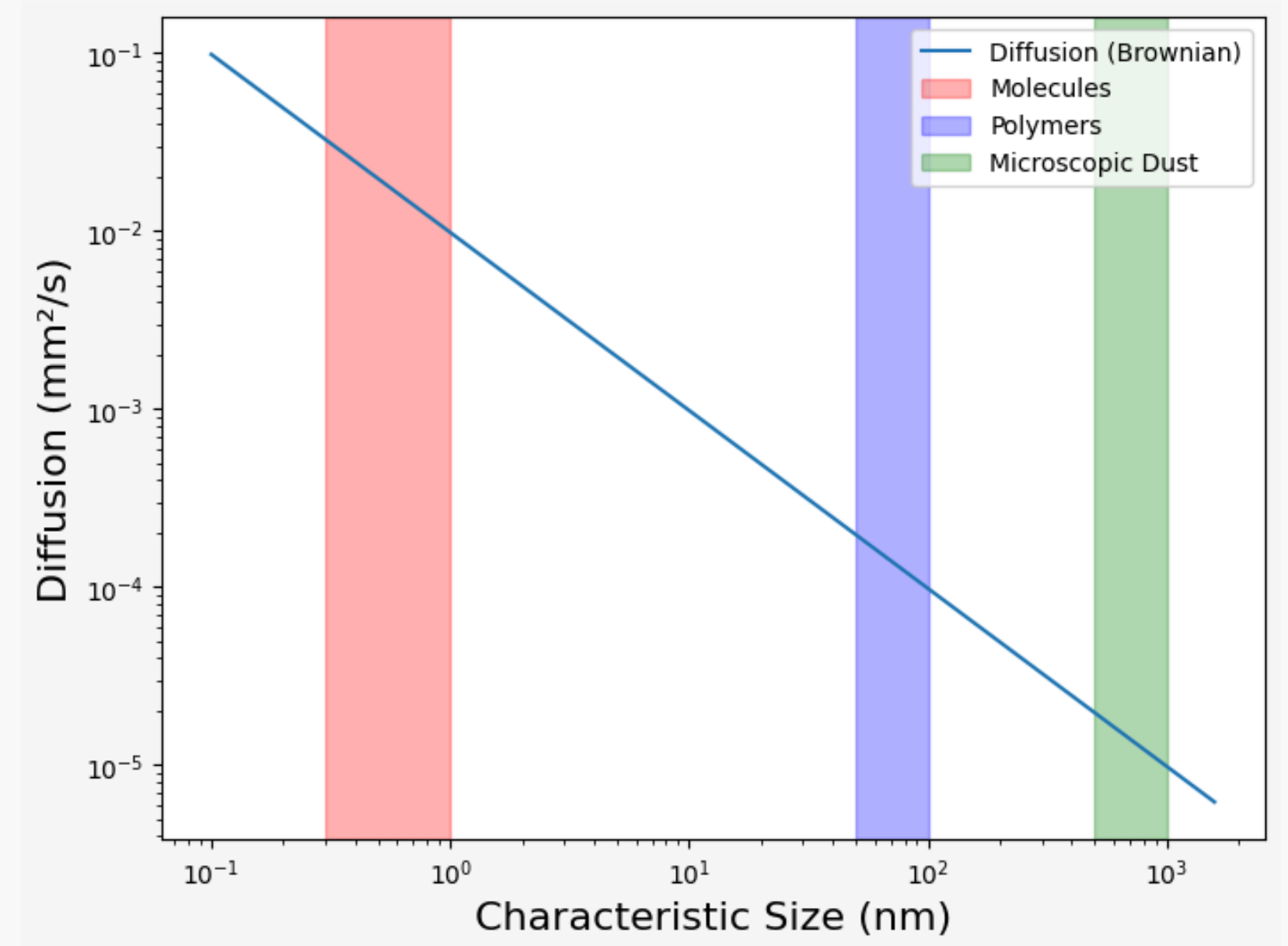
<sup>1</sup> SAULI, Fabio. The gas electron multiplier (GEM): Operating principles and applications. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, v. 805, p. 2-24, 2016.

# Objective

The objective of this work is to investigate whether there are tendencies for impurity accumulation in specific regions inside a chamber containing GEMs, both in a detector designed for data acquisition and in a chamber dedicated to degradation studies.

Element	Characteristic size
Individual molecules (e.g. $O_2$ , $H_2O$ )	0.3–1 nm
Polymers (e.g. Poliimida)	50–200 nm
Microscópico dust	0.5–1 $\mu\text{m}$

Some types of contaminants have dimensions of the same order as the gas molecules, suggesting that the Einstein–Stokes diffusion coefficient may underestimate the diffusion of submicrometric particles.



# Methodology



## Advection

- Design of the problem domain (e.g., fluid volume).
- Exports the results of the Computational Fluid Dynamics (CFD) model.



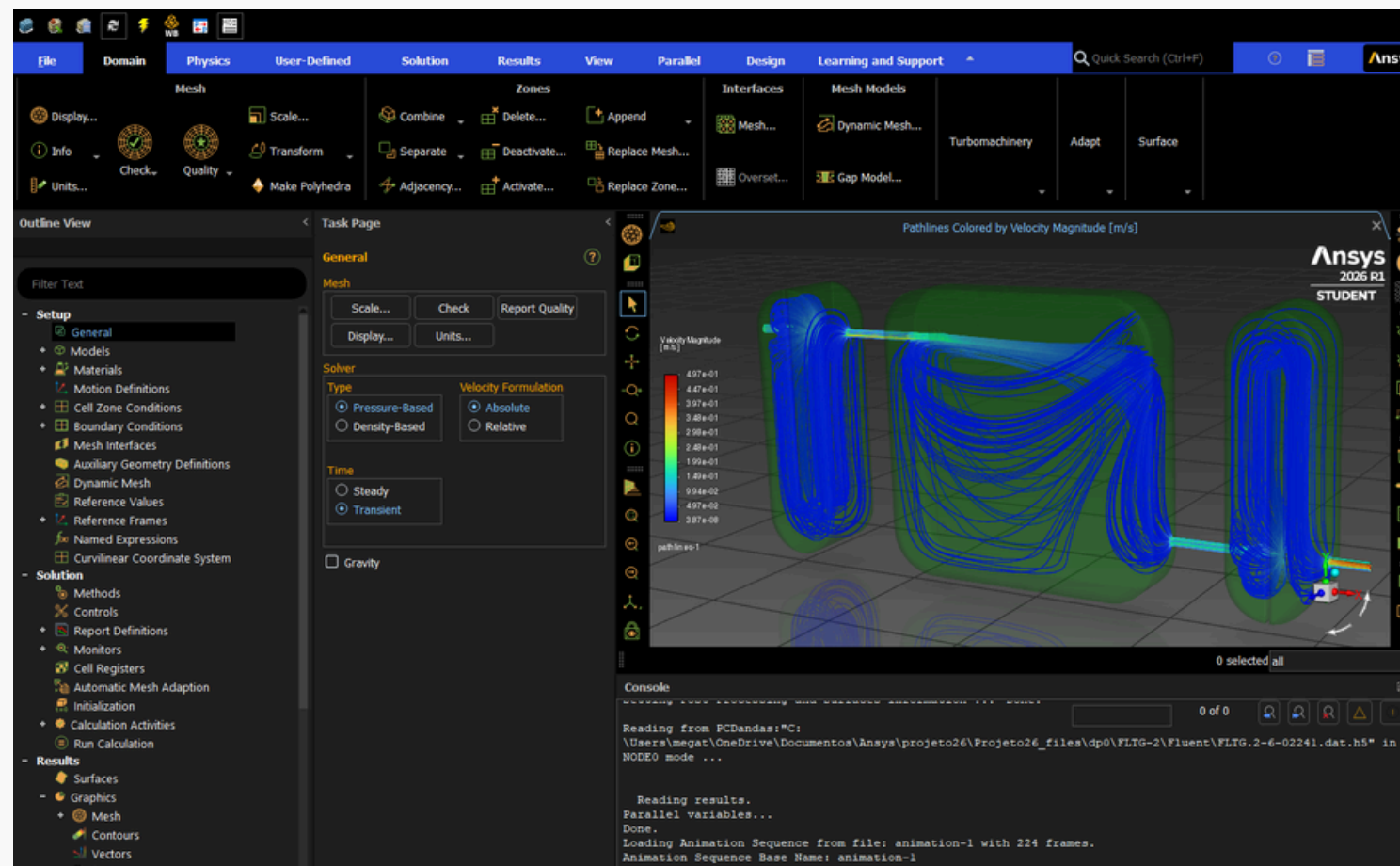
## Diffusion implementation

- Velocity field interpolation
- Time evolution of each injected particle
- Visualization of the results

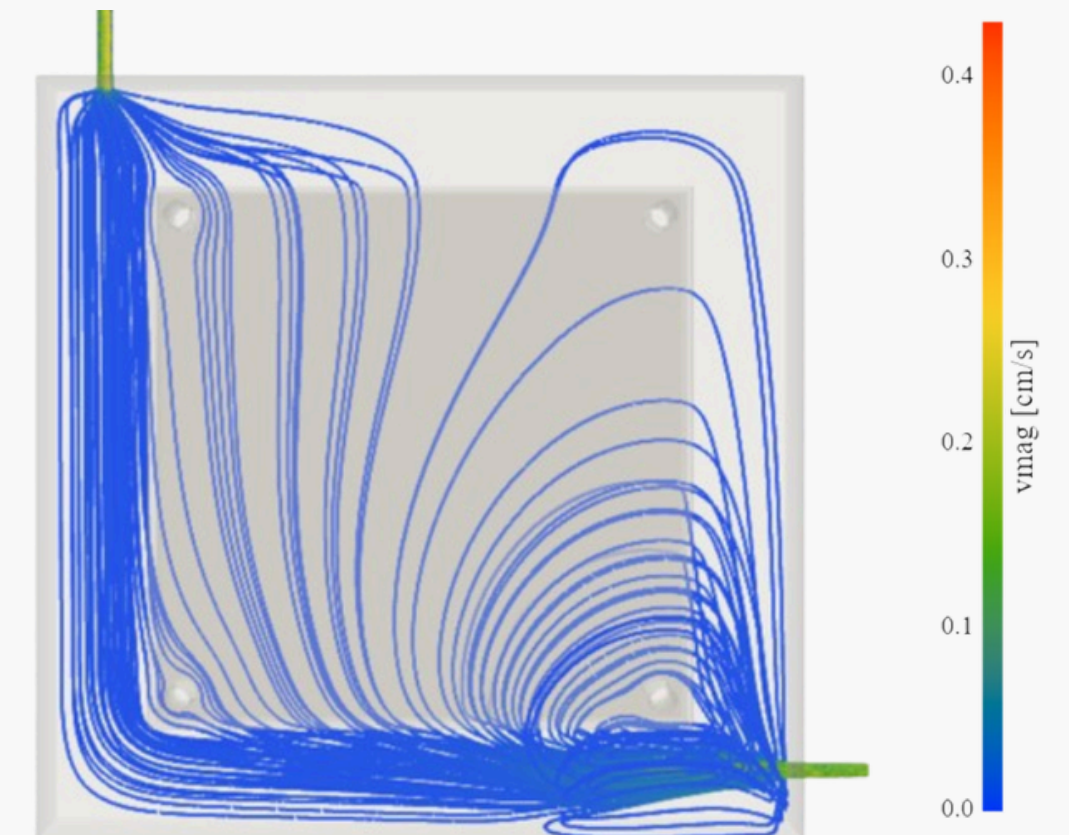
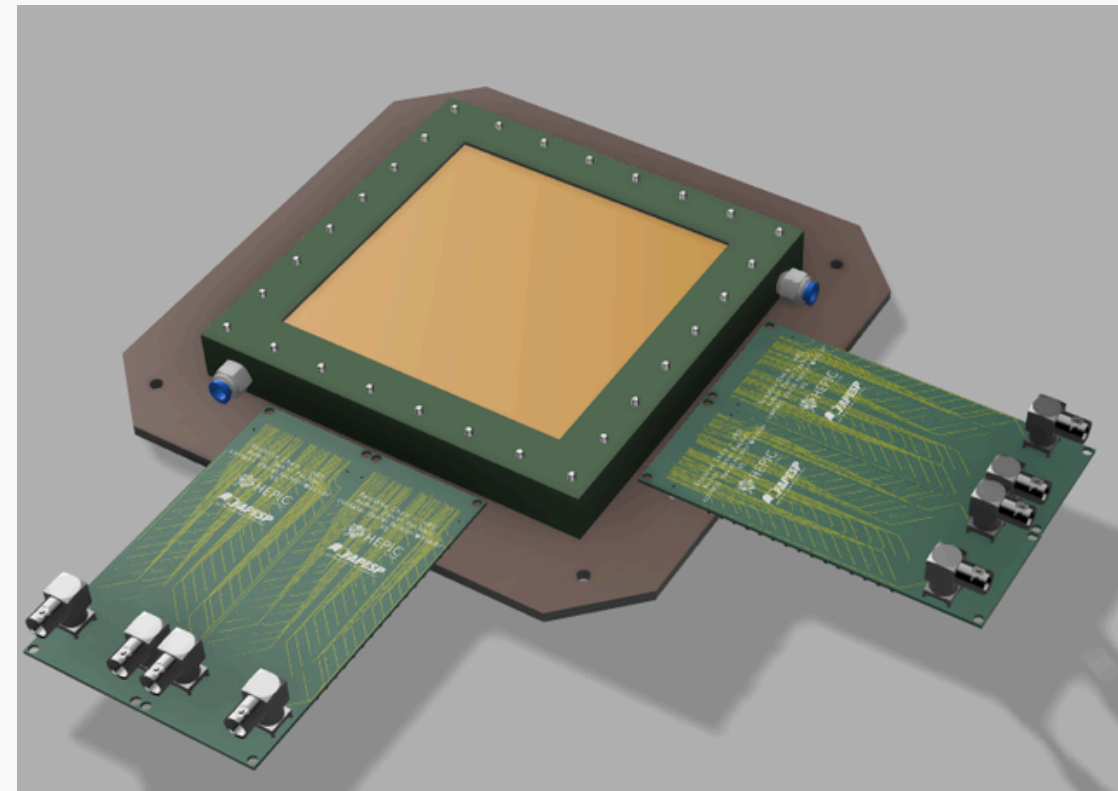
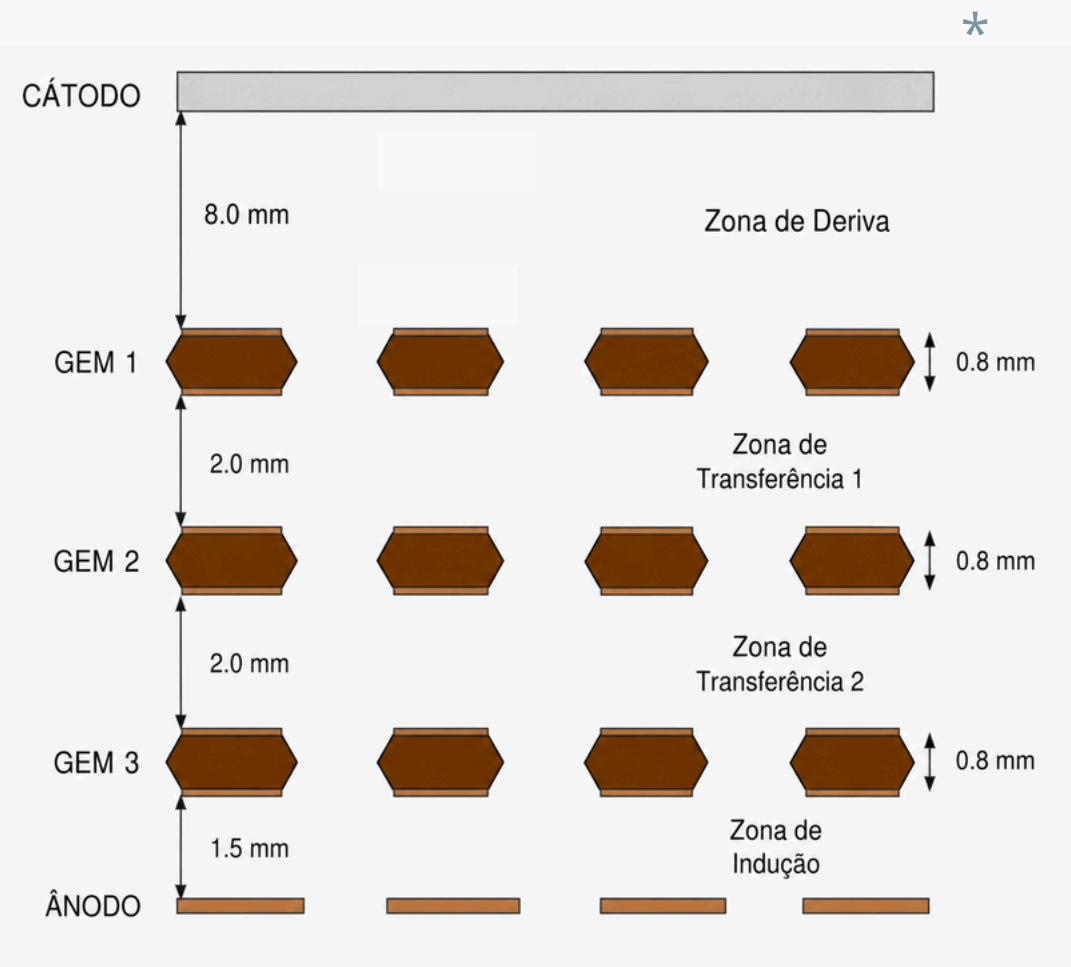


# Fluid Dynamics by Ansys

- Velocity field simulations using the **Ansys Fluent** tool.
- Calculation using the Finite Element Method (FEM)
- Allows the analysis of the impact on the flow under different conditions (e.g., injected gas volume, obstacles used to force the distribution).
- It is also used to identify ways to optimize gas usage in GEMs, ensuring spatially uniform gas renewal.
- Chamber models designed using Ansys software.



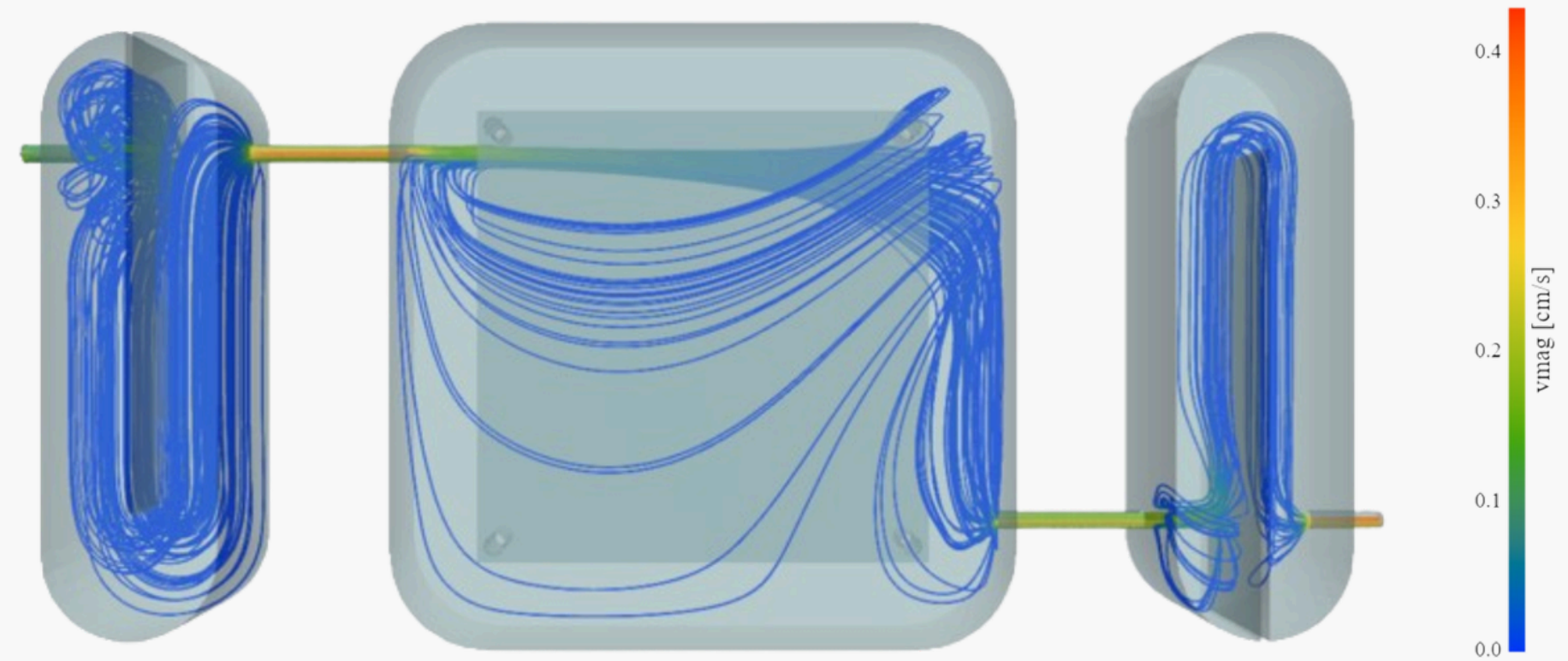
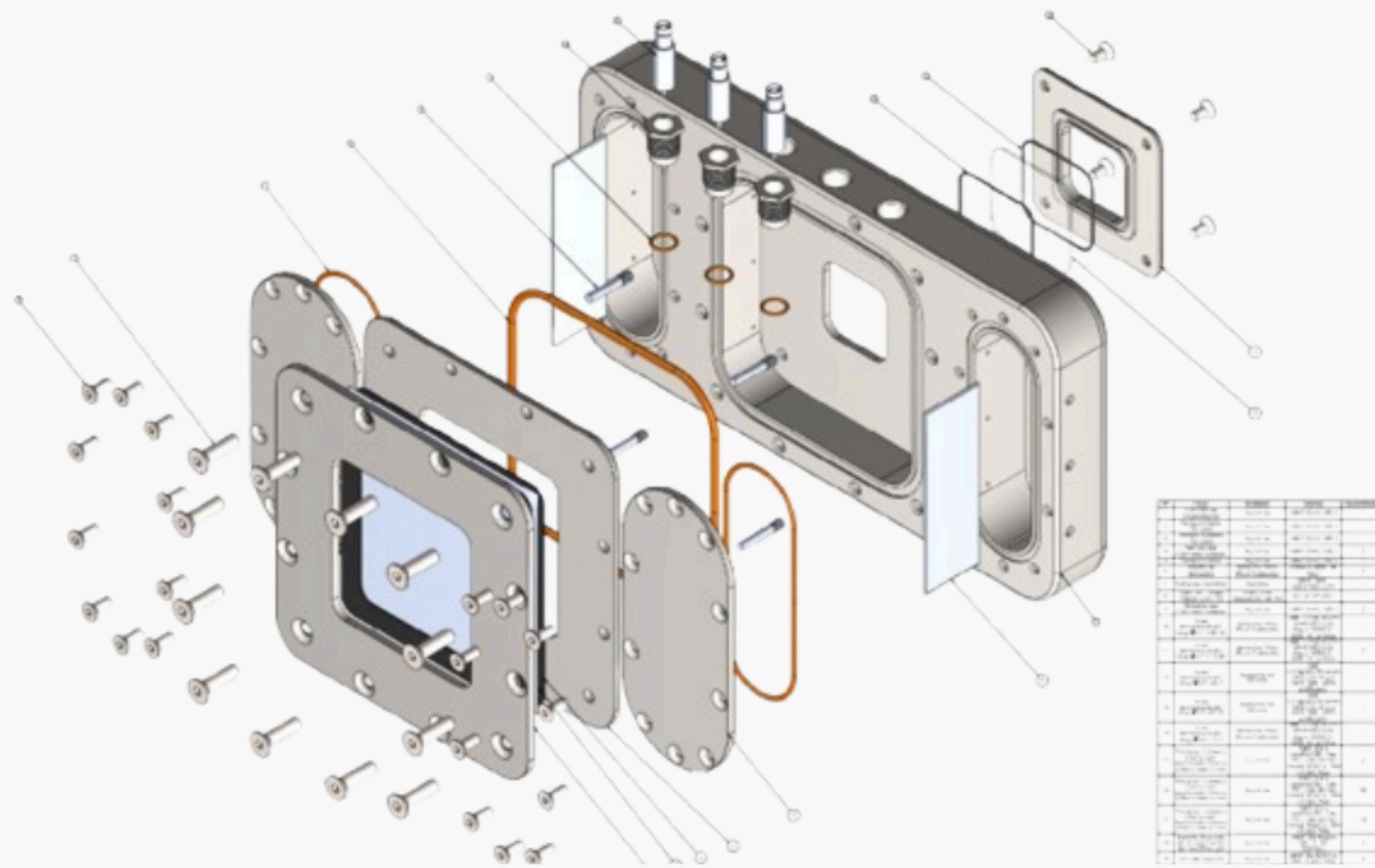
# GEM chamber



- Operation with 6L/h flux

\*SOUZA, Geovane Grossi Araújo de. X-Ray fluorescence imaging system based on Thick-GEM detectors. 2019. Tese de Doutorado. Universidade de São Paulo.

# Aging chamber



- Operation with 7L/h flux



# Diffusion-advection random walk model

Spatial evolution of particles

$$\vec{x}_{n+1} = \underbrace{\vec{x}_n + \vec{v}(\vec{x})\Delta t}_{\text{Advection}} + \underbrace{\vec{\eta}}_{\text{Diffusion}}$$

Einstein-Stokes relation + correction

$$D = Cc \cdot \frac{k_B T}{6\pi\mu R}$$

Cunningham slip correction factor

$$Cc = 1 + \frac{\lambda}{R} \left( 1.165 + 0.483e^{-0.997\frac{\lambda}{R}} \right)^*$$

Mean free path

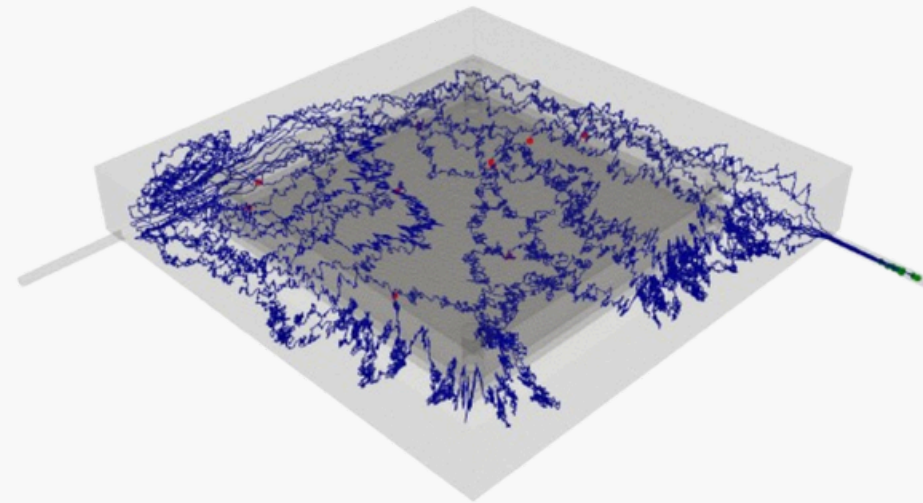
$$\lambda = \frac{k_B T}{4\pi\sqrt{2}PR}$$

Diffusive term

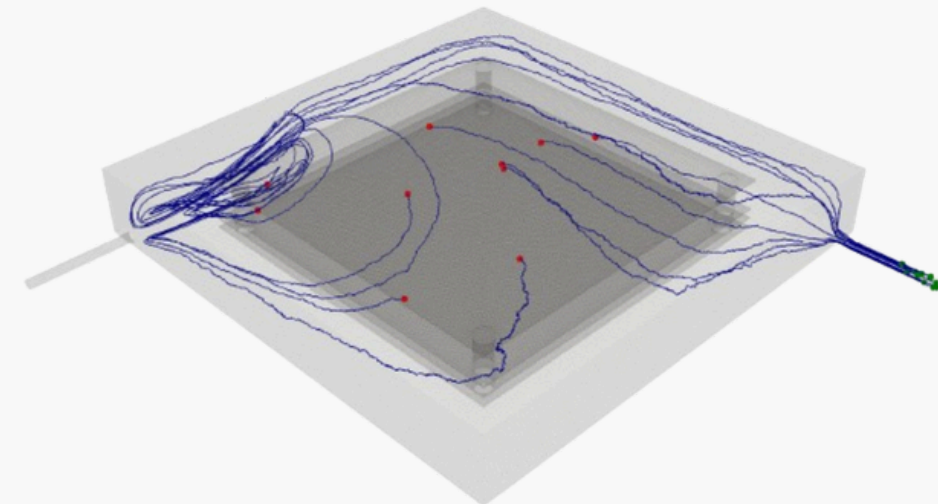
$$\vec{\eta} = \begin{pmatrix} \eta_x \\ \eta_y \\ \eta_z \end{pmatrix} \sim \mathcal{N}(0, 2D\Delta t)$$

\*KOHLI, Rajiv; MITTAL, Kashmiri L. (Ed.). Developments in Surface Contamination and Cleaning, Vol. 1: Fundamentals and Applied Aspects. William Andrew, 2015.

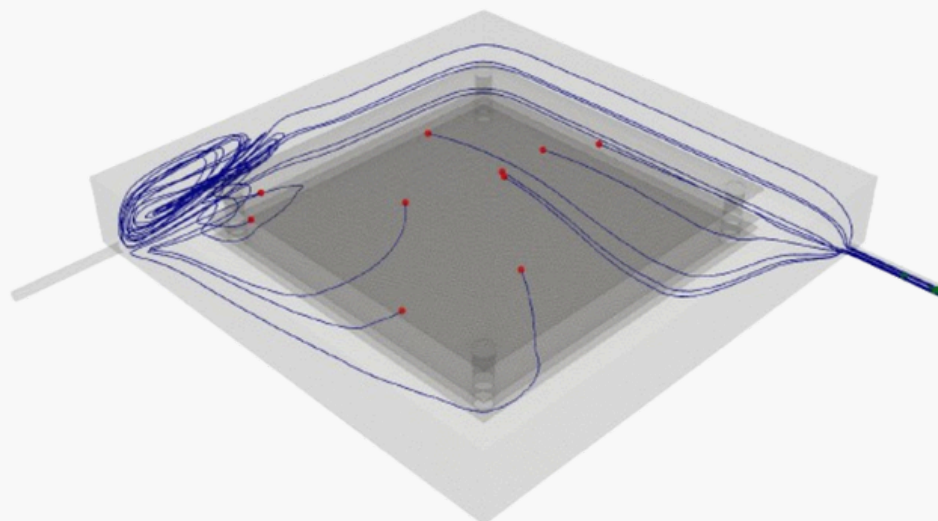
# Impact of particle characteristic size



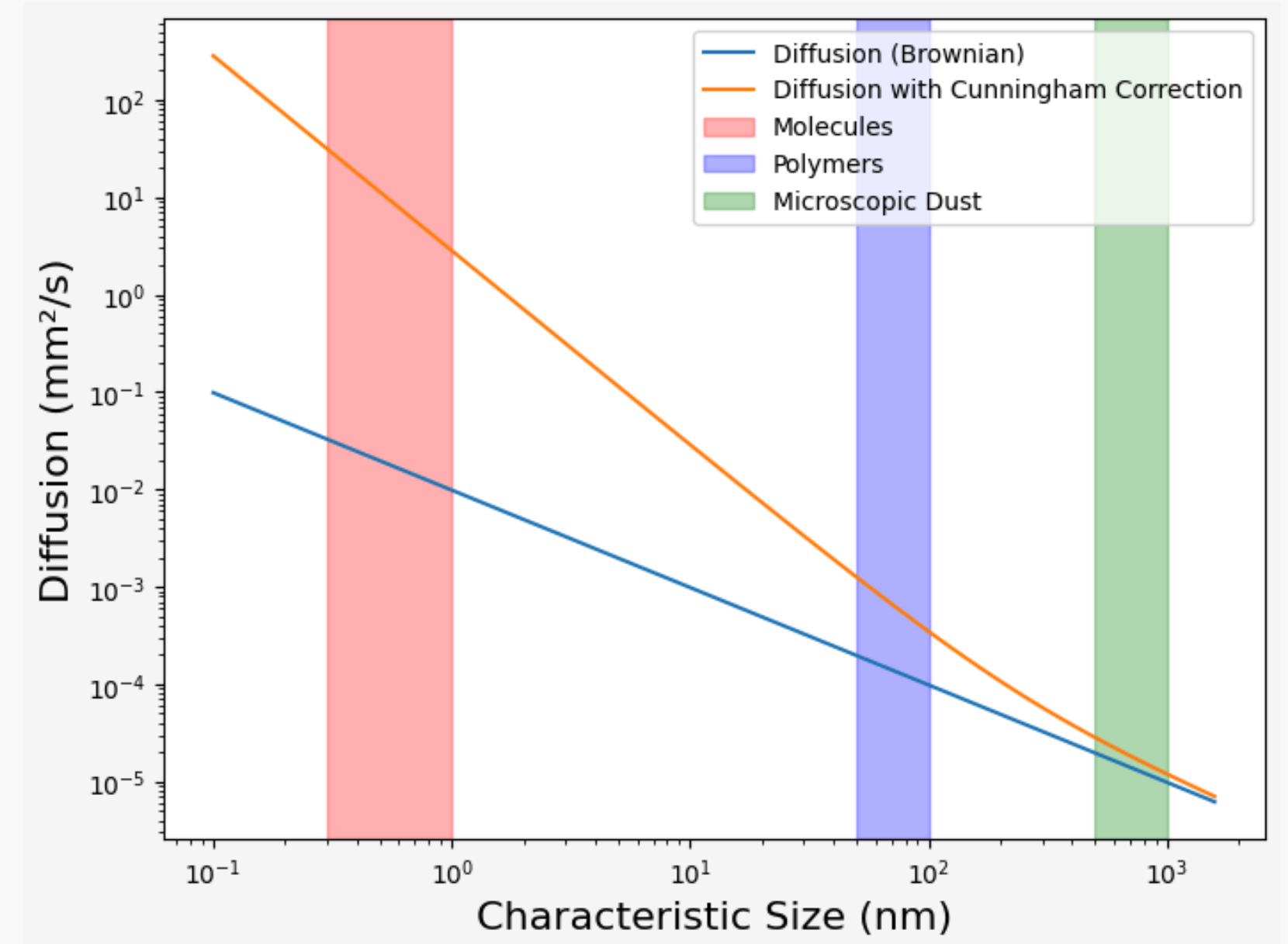
1 nm 300k 930hPa



10 nm 300k 930hPa

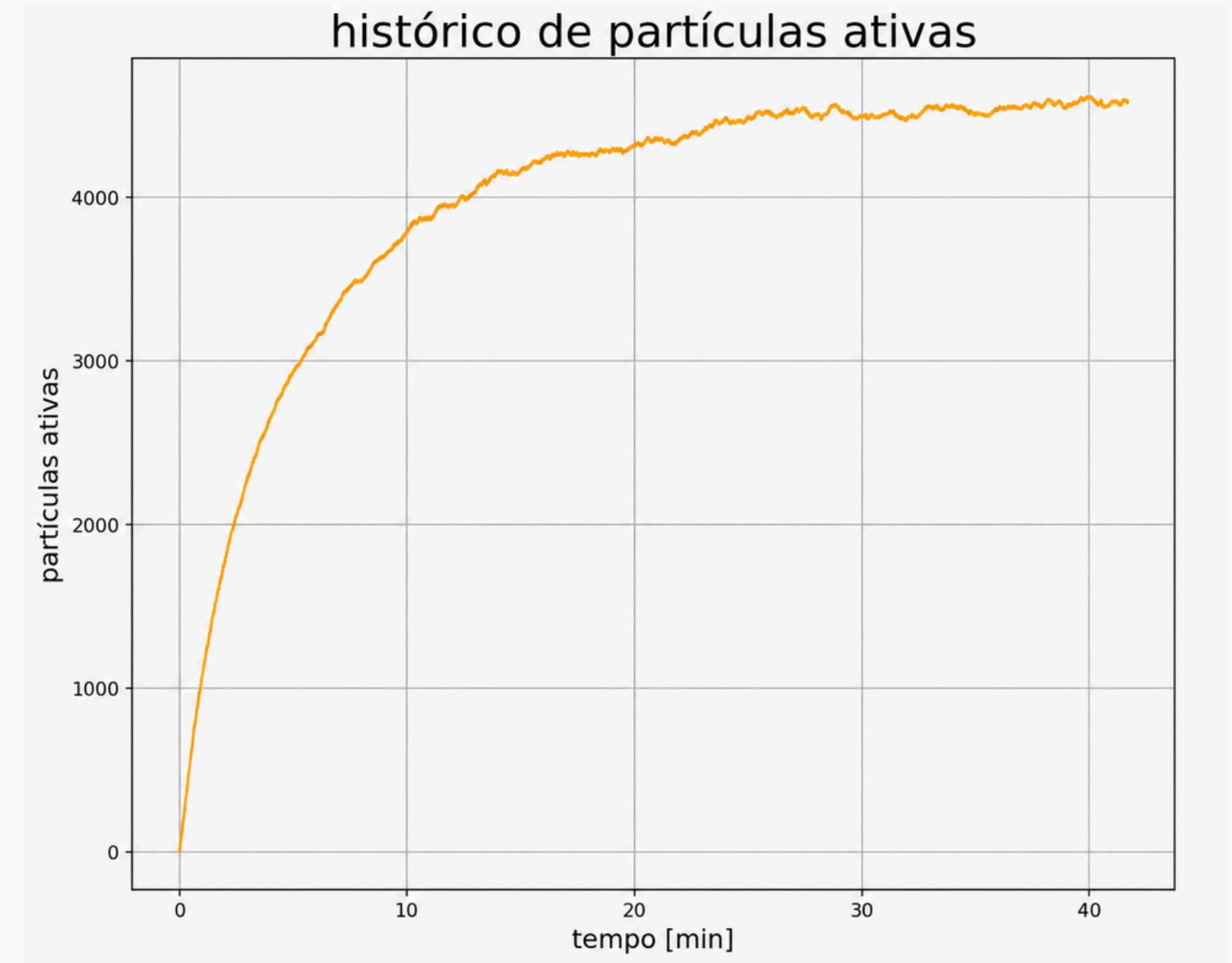


100 nm 300k 930hPa



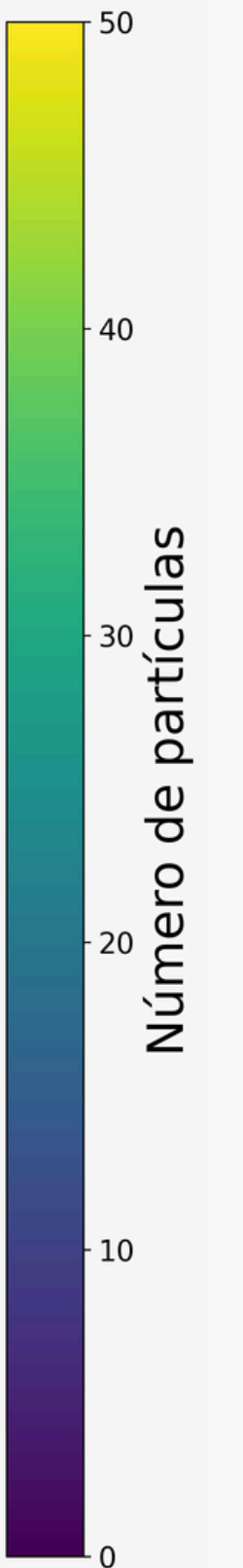
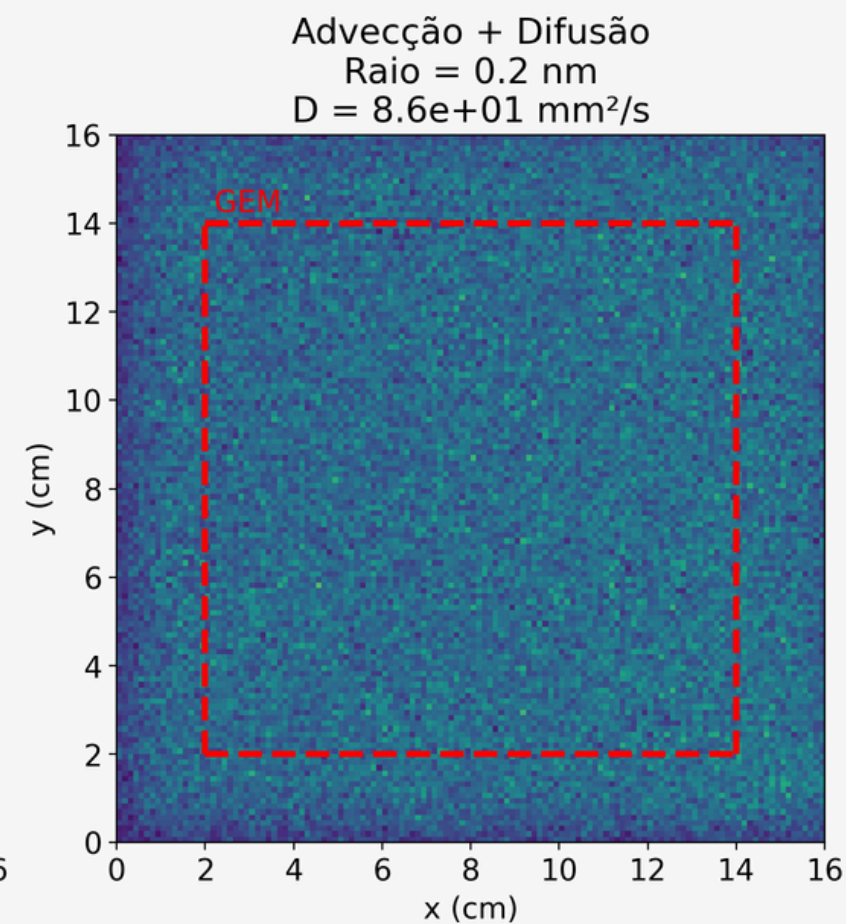
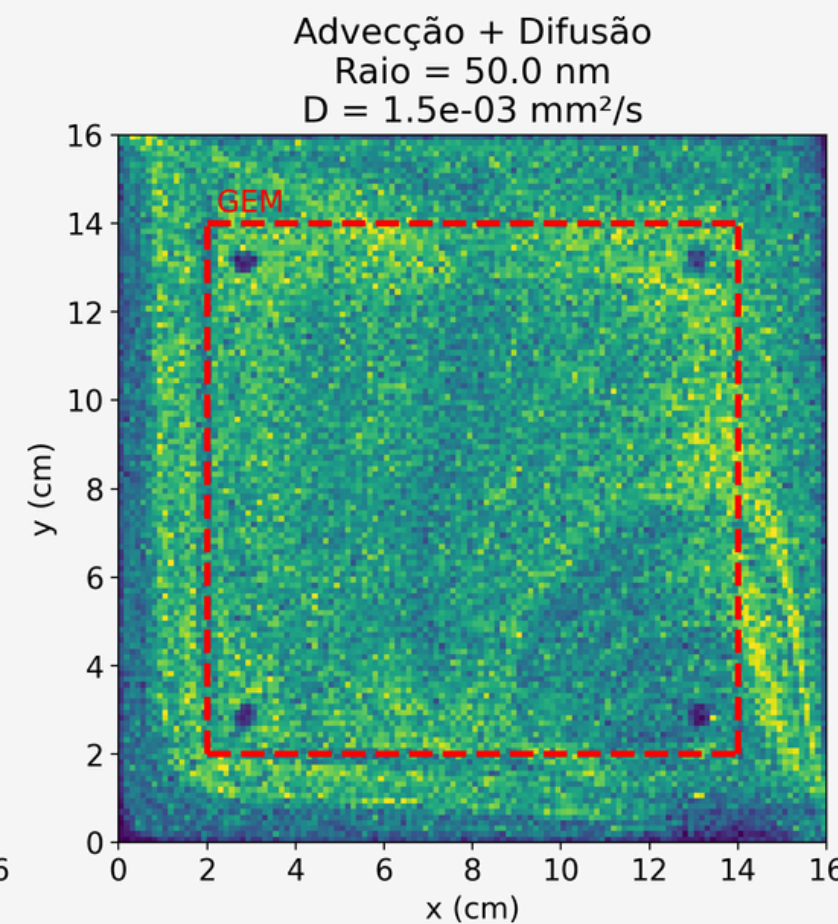
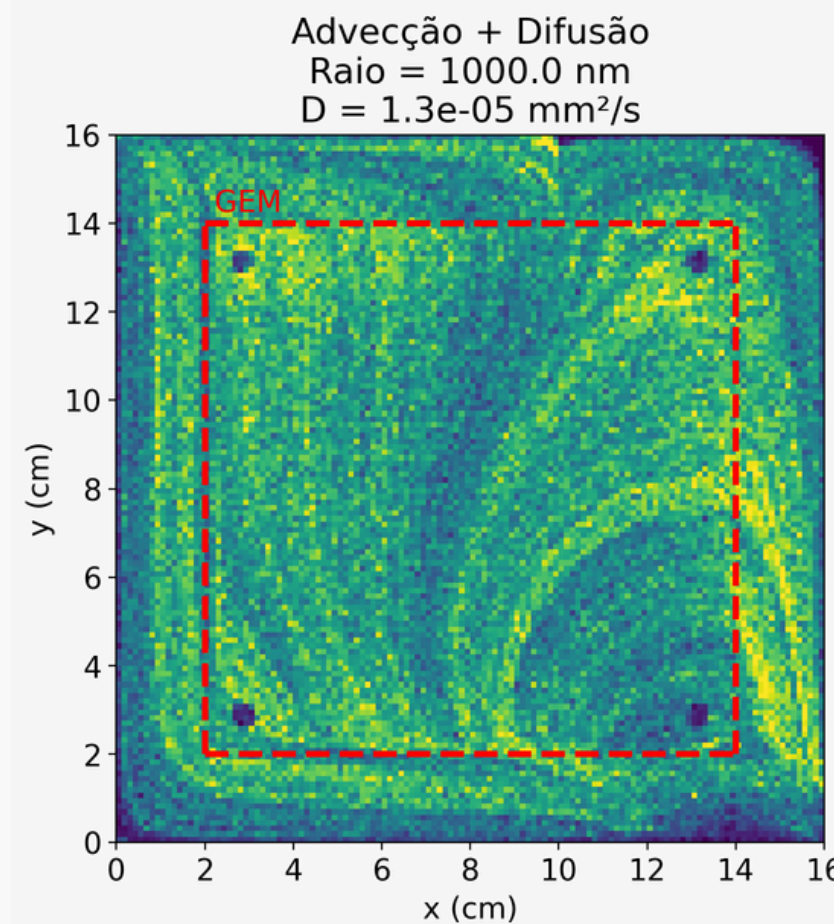
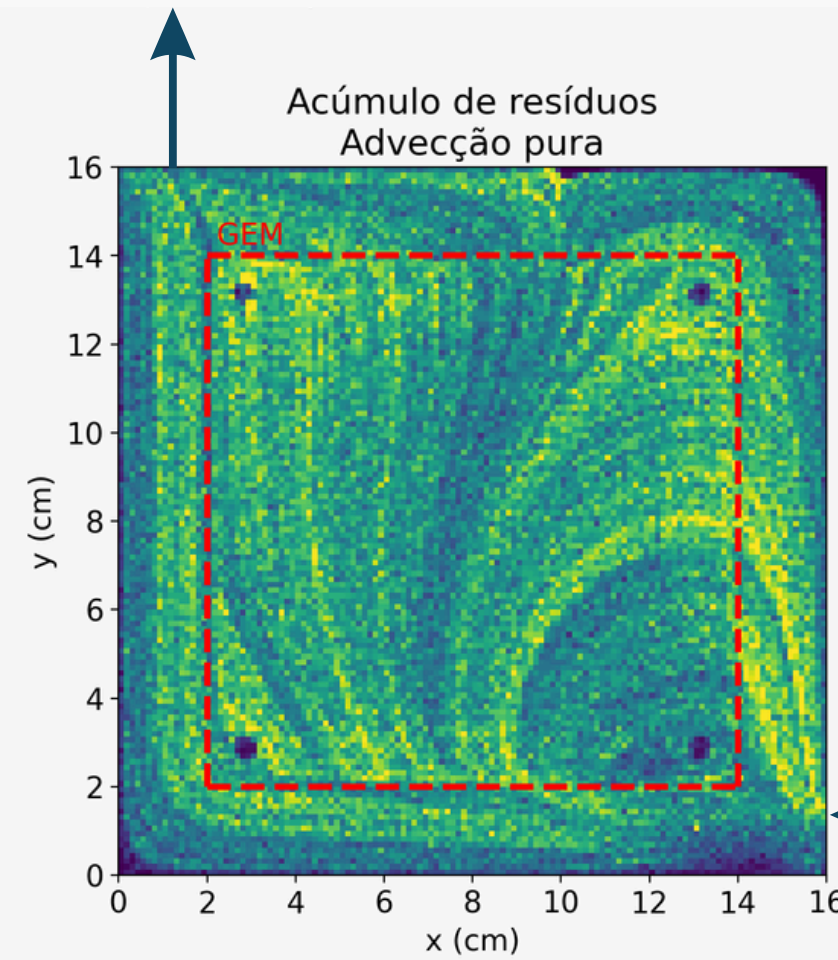
# System evolution parameters

- Injection of 2000 particles/s (20 particles/s computed in parallel), both through the gas inlet and emitted by the GEM;
- A time evolution of 0.05 s represents an average displacement of 0.25 mm at each time step;
- The results are visualized after a steady-state regime is reached (e.g., the number of particles inside the chamber no longer increases).



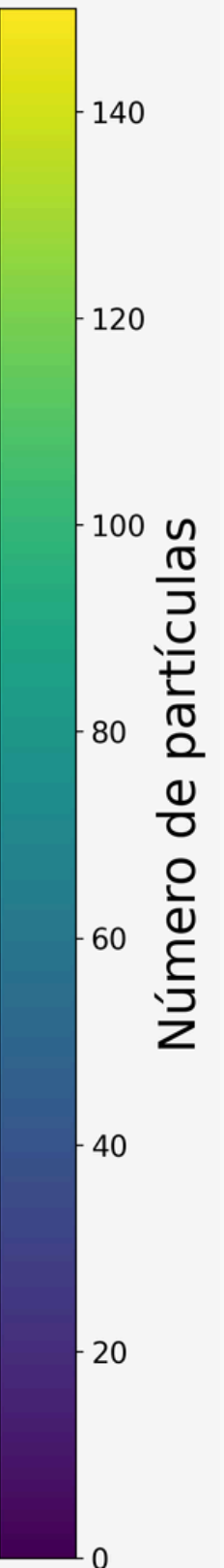
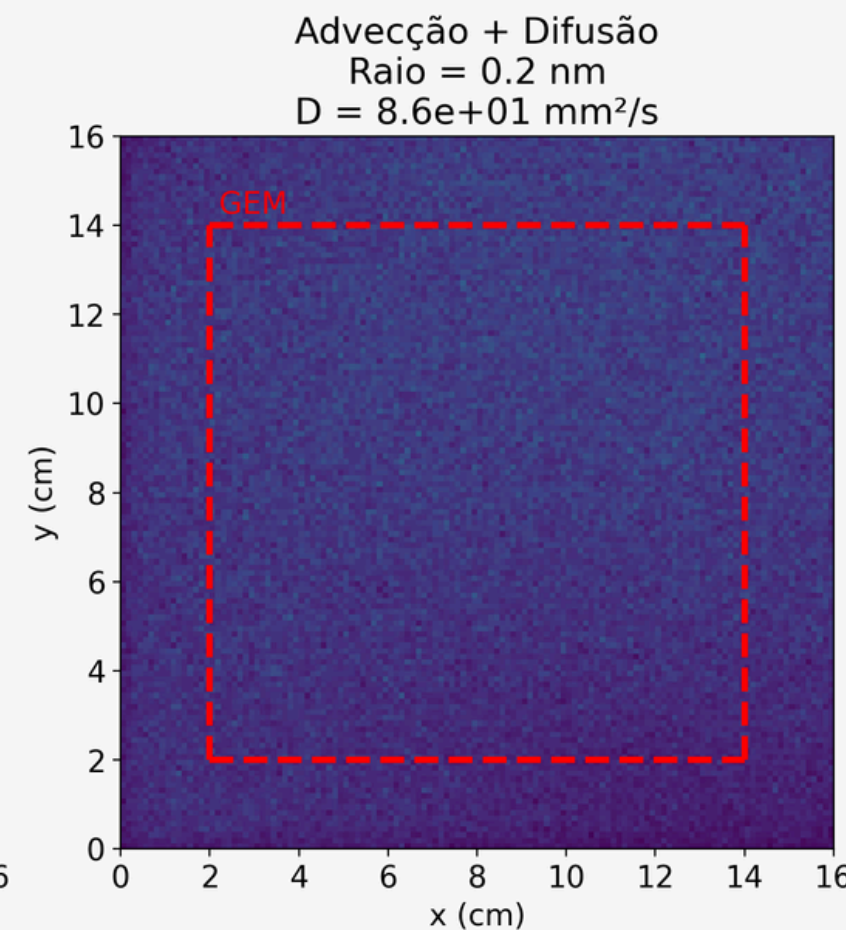
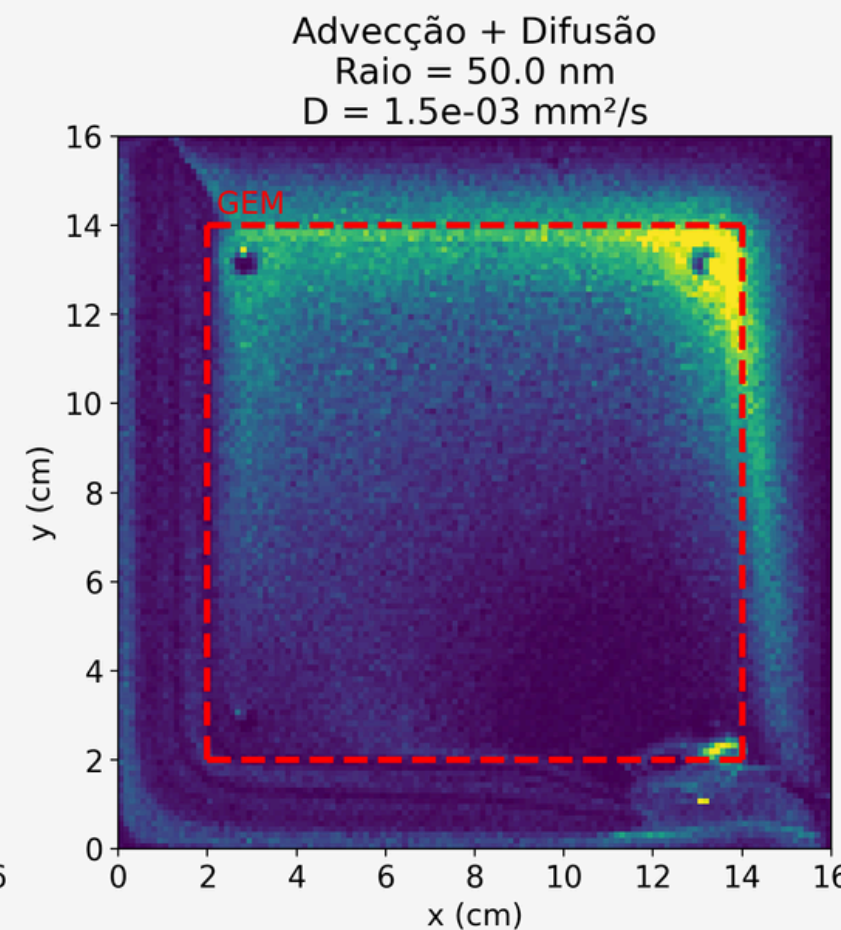
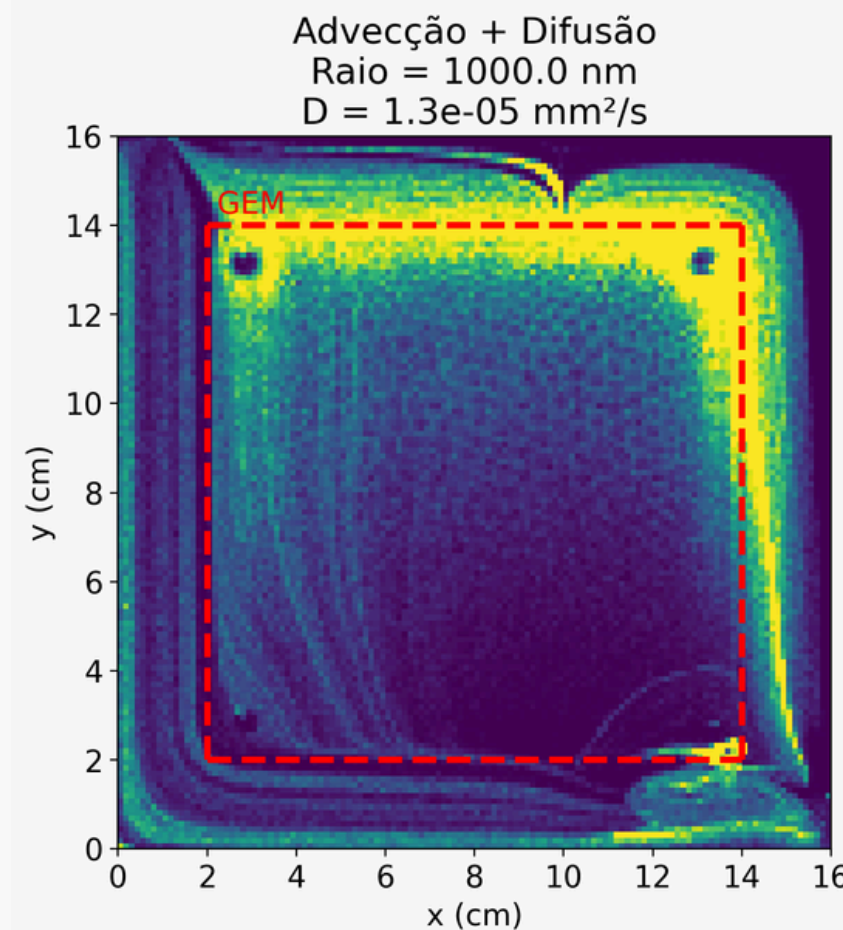
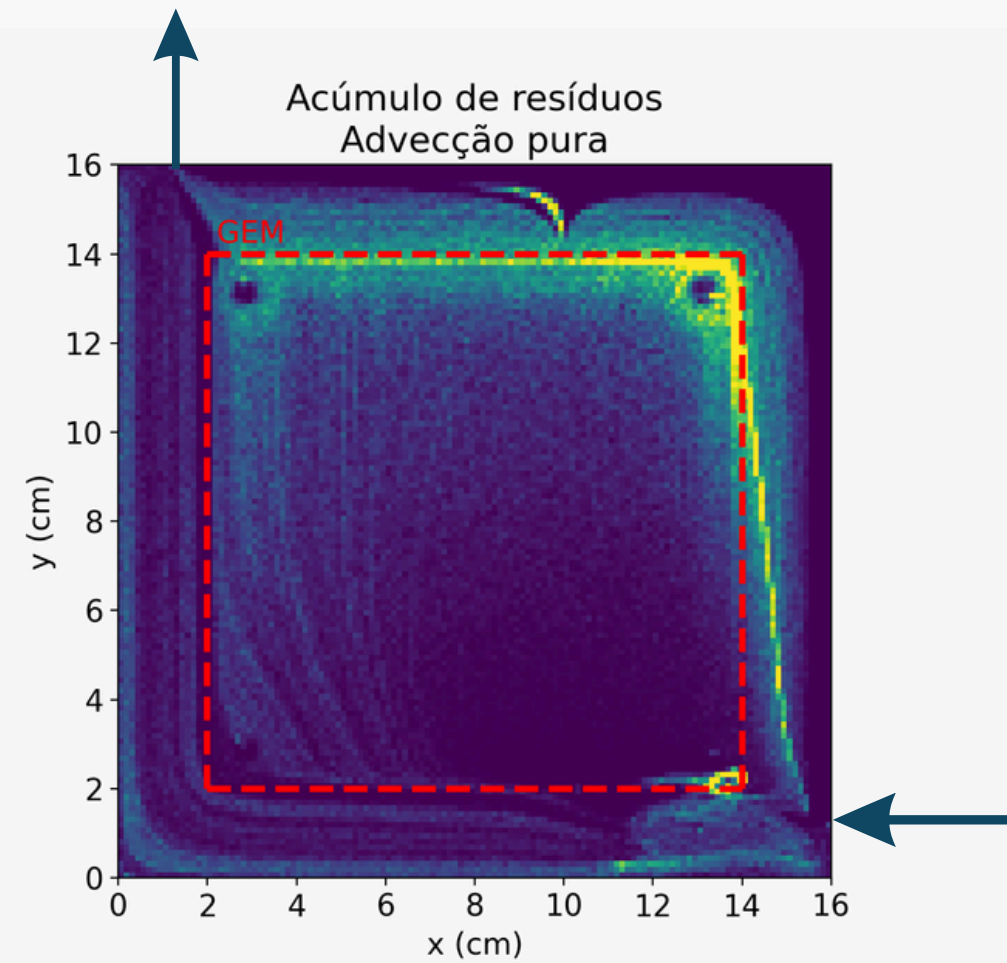
# Particle accumulation in the GEM chamber

Source: gas inlet



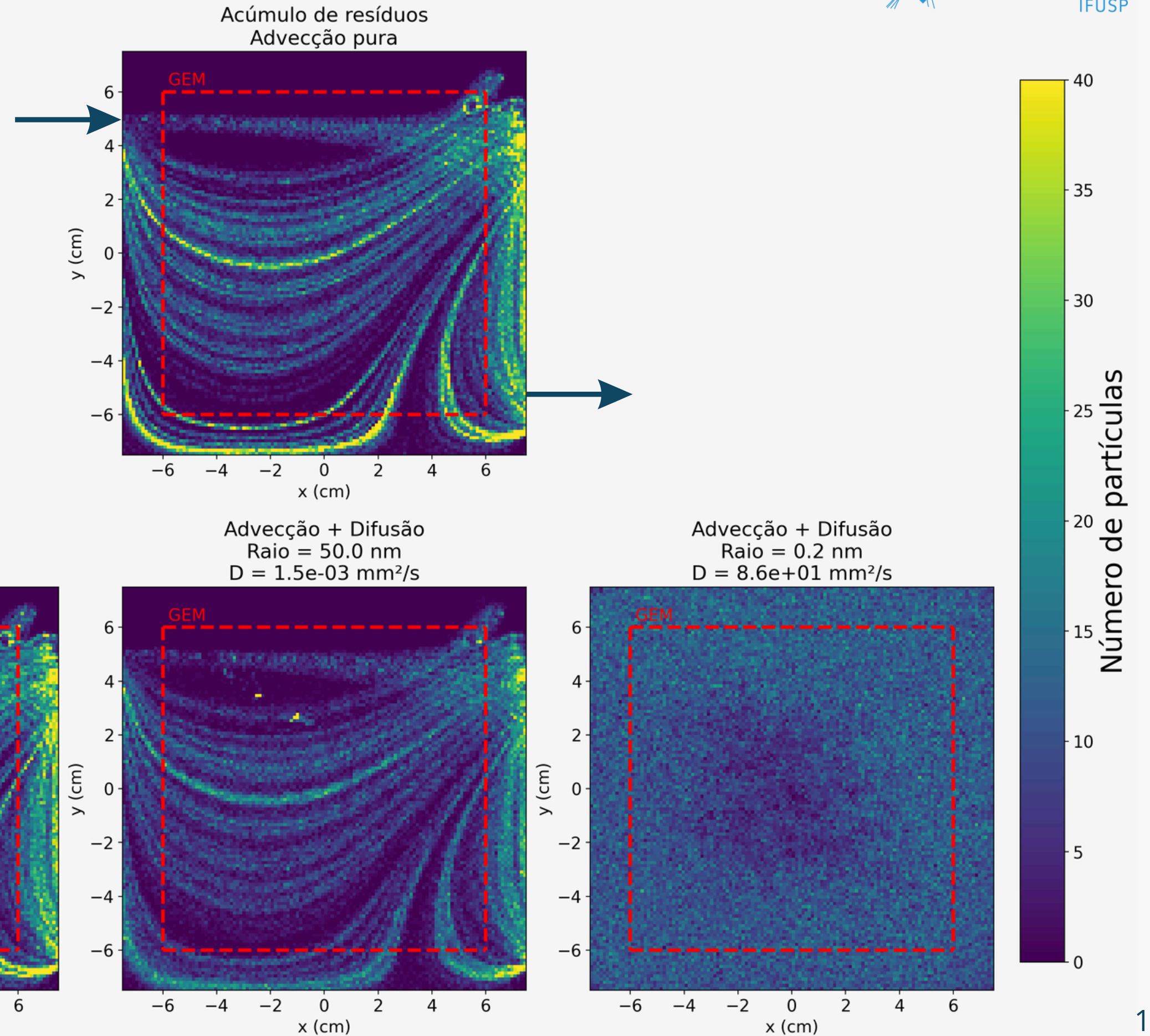
# Particle accumulation in the GEM chamber

Source: first GEM



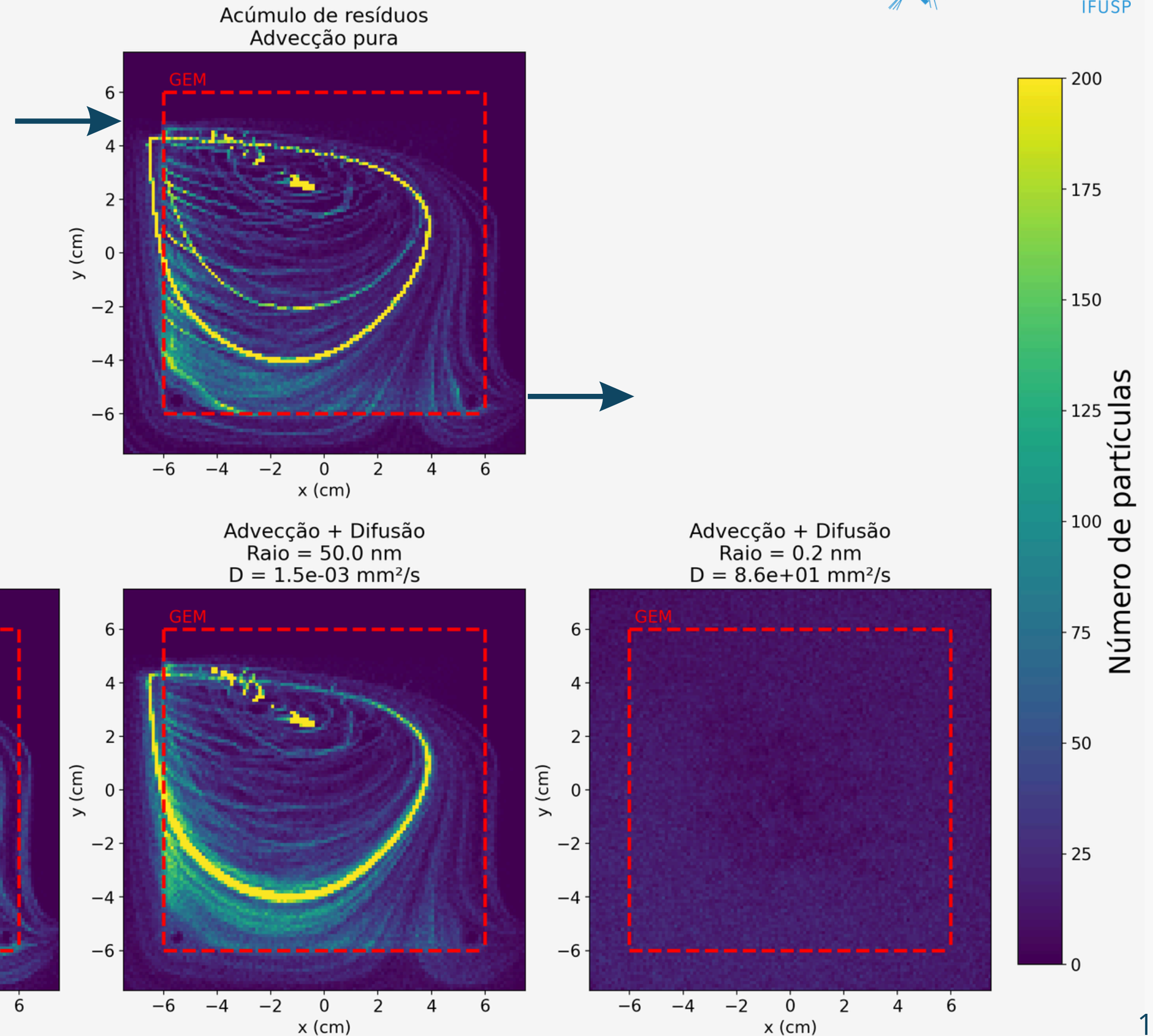
# Particle accumulation in the degradation chamber

Source: gas inlet



# Particle accumulation in the degradation chamber

## Source: GEM emission



# *Conclusion and future work*

It is possible to observe a pattern of impurity accumulation for nanometric particles;

For sub-nanometric particles, there is an indication of uniform accumulation;

The study was based on the standard flow configurations used in the laboratory. Other configurations will be evaluated as the work progresses;

The configuration presented for the GEM chamber suggests that most of the injected gas is not effectively used for gas renewal in the regions of interest. Modifications to the chamber aimed at optimizing the flow are currently being investigated.

