Optimization of the Gas Flow in a GEM Tracker with COMSOL and TENDIGEM Development

Francesco Noto

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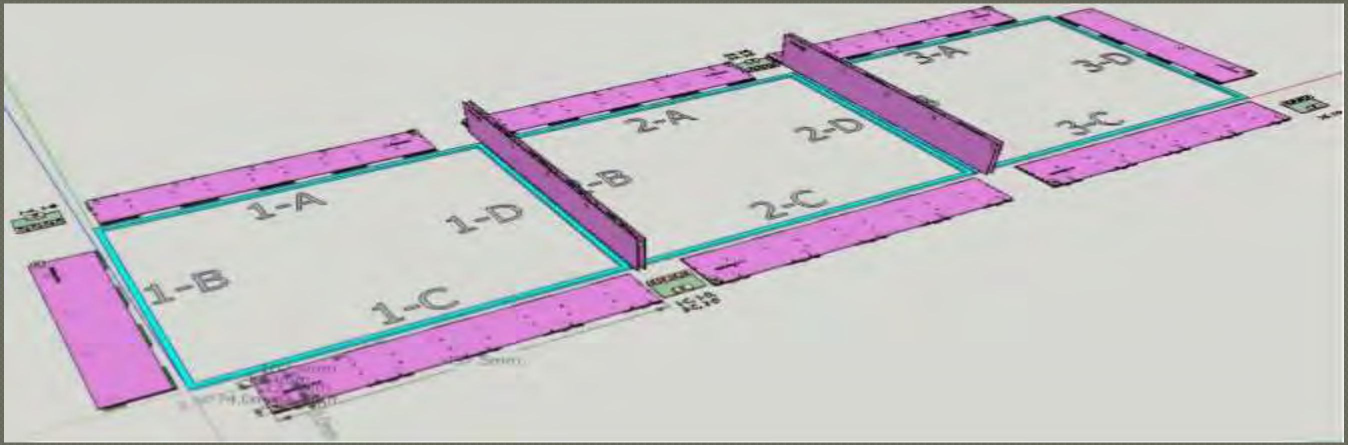
V. Bellini, E. Cisbani, V. De Smet, F. Librizzi, F. Mammoliti, F. Noto, C. Sutera

Overview

1. Introduction
   - The triple-GEM detector
2. **Study and optimization of the gas system**
3. **Tendigem developement**
4. Conclusion

1 Introduction

- The GEM (Gas Electron Multiplier) chambers is currently under development
  - Front Tracker:
    - two 10 x 20 cm^2 silicon strip planes
    - six 40 x 150 cm^2 GEM chambers (each made up of three adjacent 40 x 50 cm^2 triple-GEM modules)
- Energy upgrade of the Jlab CEBAF (Continuous Electron Beam Accelerator Facility): up to 11 GeV in Hall A (2014)



The triple-GEM detector

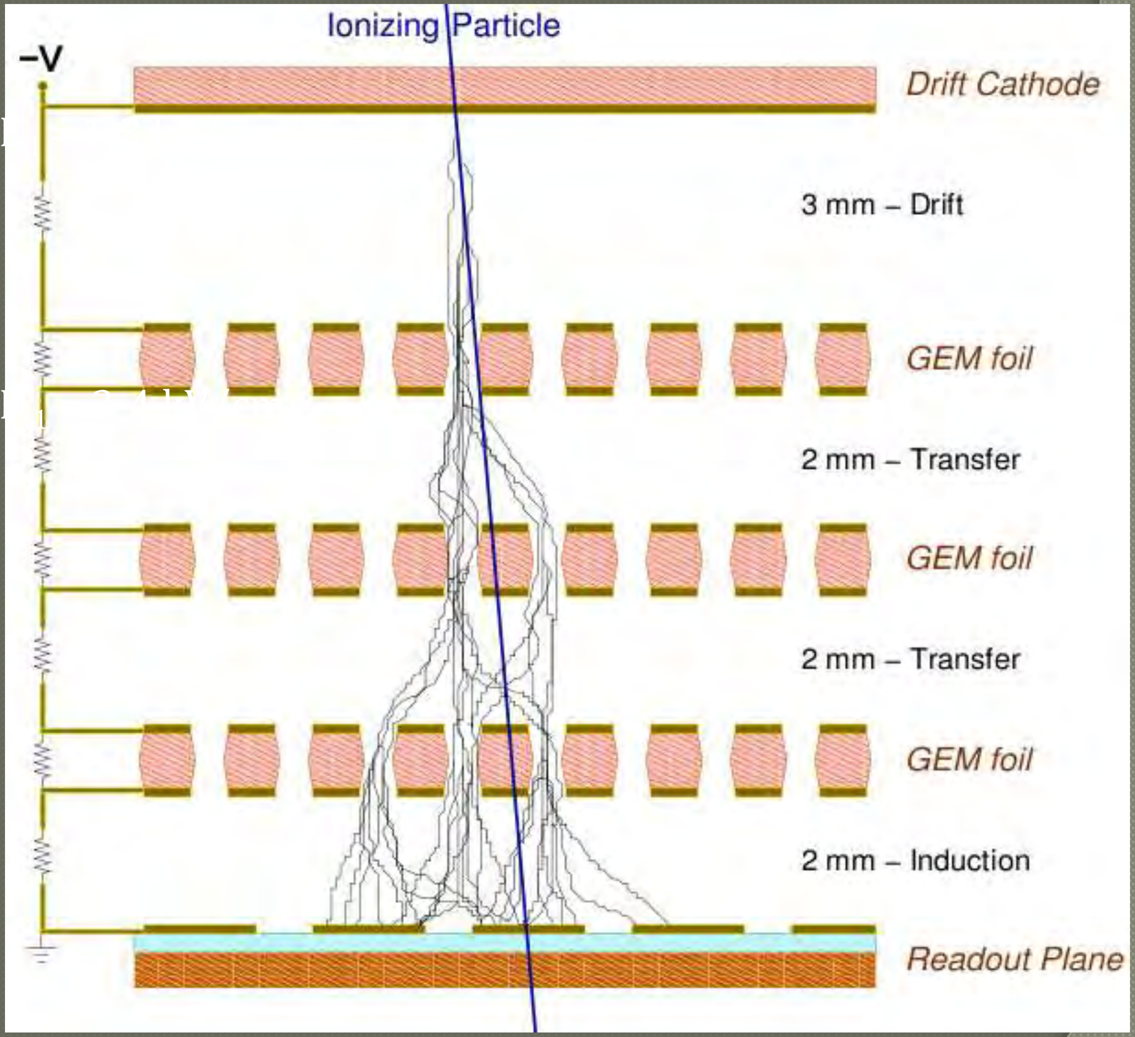
- **Working Principle**

Ionization by the charged particle

Charge multiplication in holes of GEM foils

Drift of electrons in induction gap induce signal on the anode read-out

Excellent intrinsic spatial resolution: ~40 µm RMS



The triple-GEM detector

1 cover frame (3 mm)

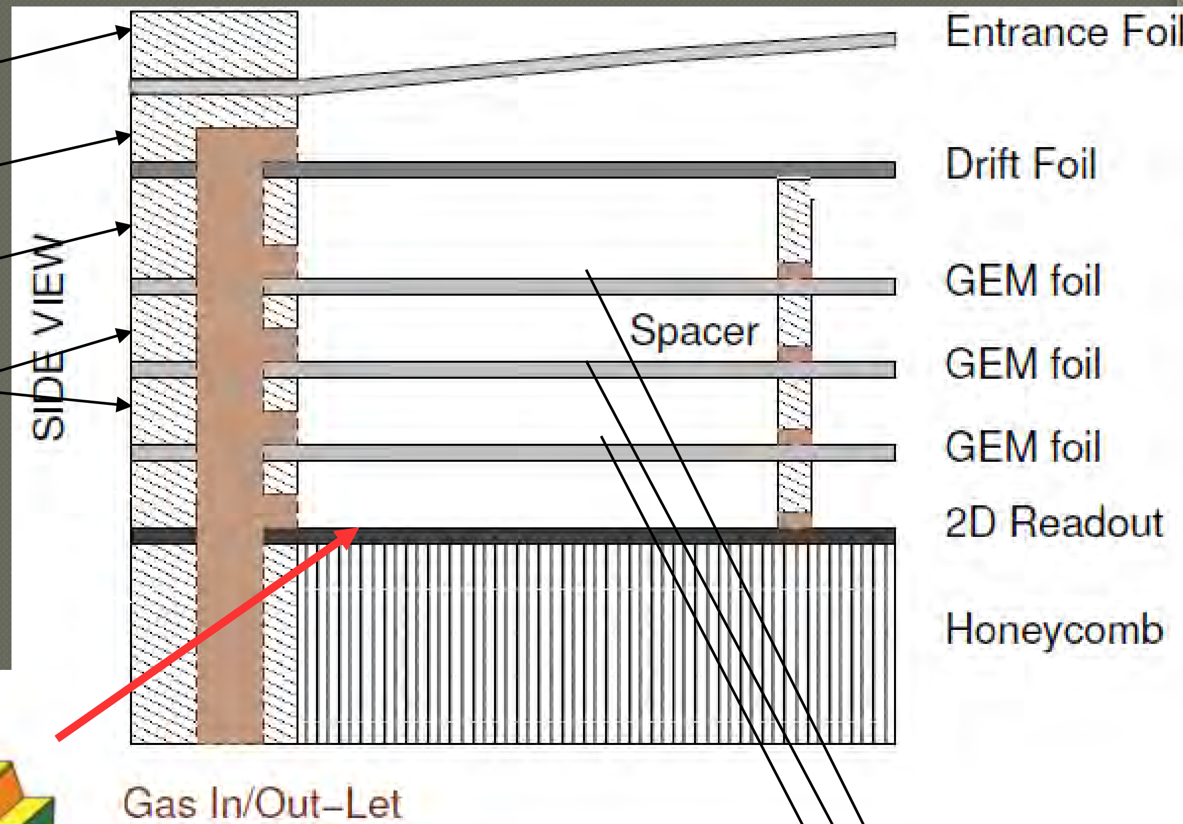
1 entrance frame (2mm)

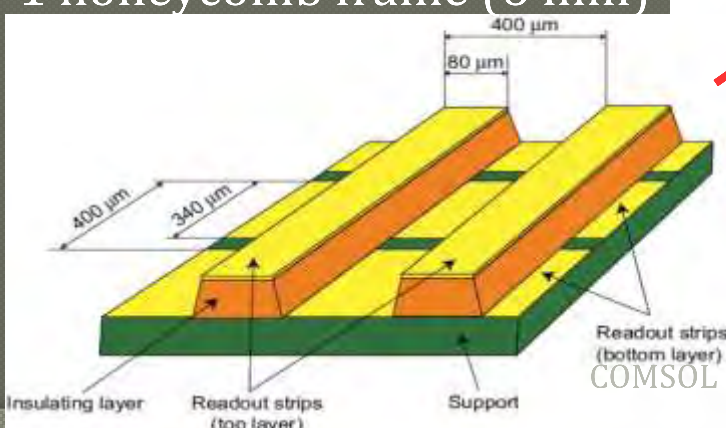
1 drift frame (3 mm, grid)

2 GEM frames (2 mm, grid)

1 induction frame (2 mm, grid)

1 honeycomb frame (6 mm)





20 Cu sectors

20 x 5 cm^2

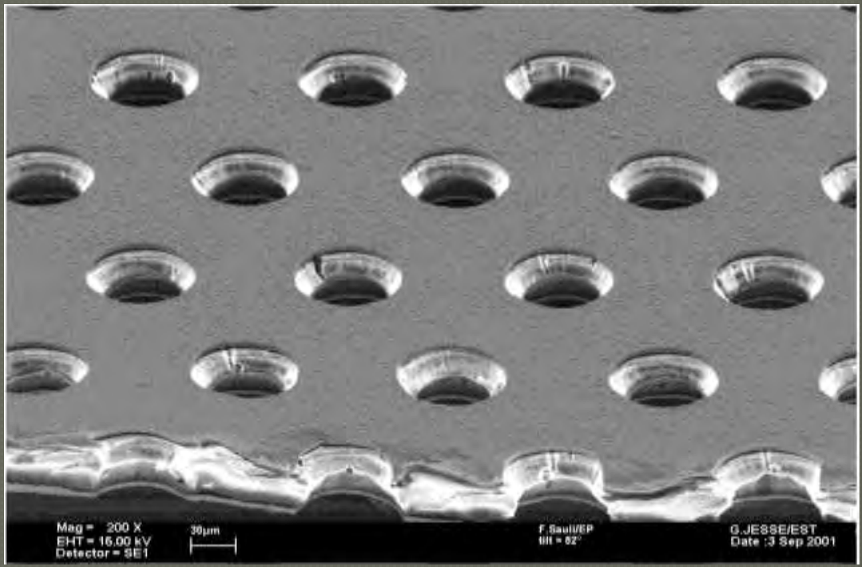
The triple-GEM detector

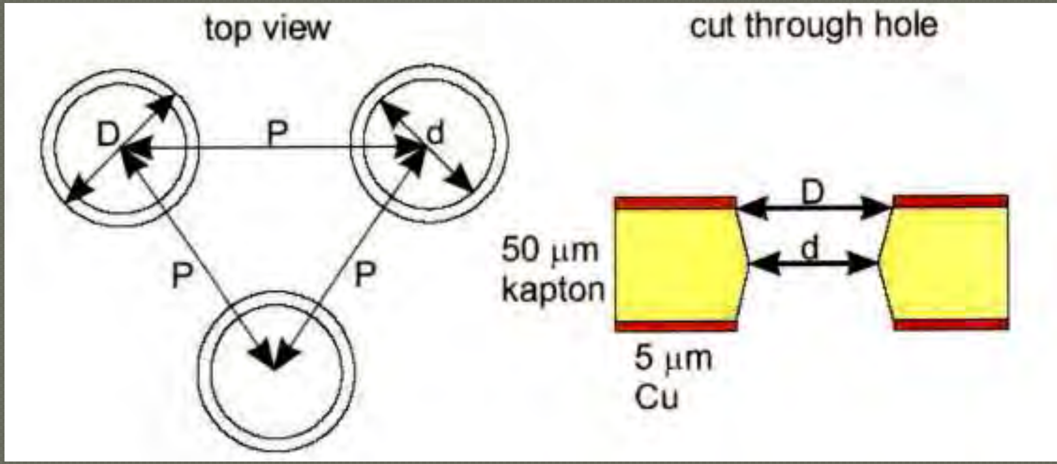
- **GEM foil**

50µm insulating Kapton coated on both sides with 3 to 5 µm Cu

Densily perforated:

D = 70 µm
d = 50 µm
P = 140 µm (Lead)





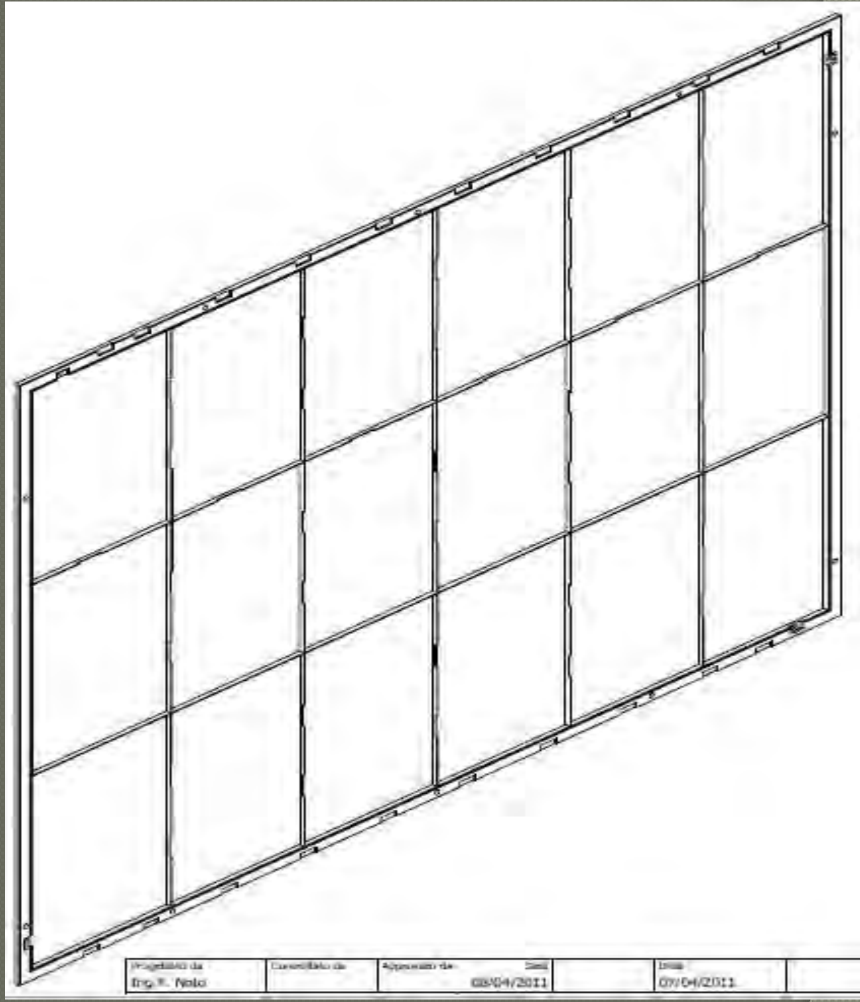
Study and optimization of the gas system

- Optimization of the GEM frame design
- 2 main goals:

1) Improve gas flow uniformity :
   by optimizing the design of the grid in the frame

   ⇒ Study performed with :
   - a geometry defined in 2D
   - Thin-Film Flow Model
   Model of 1 single frame as if its volume were delimited by 2 solid walls

2) Avoid turbulence :
   by optimizing the diameter of the tubes leading to the inlets and outlets
   by optimizing the design of the inlets and outlets



Method

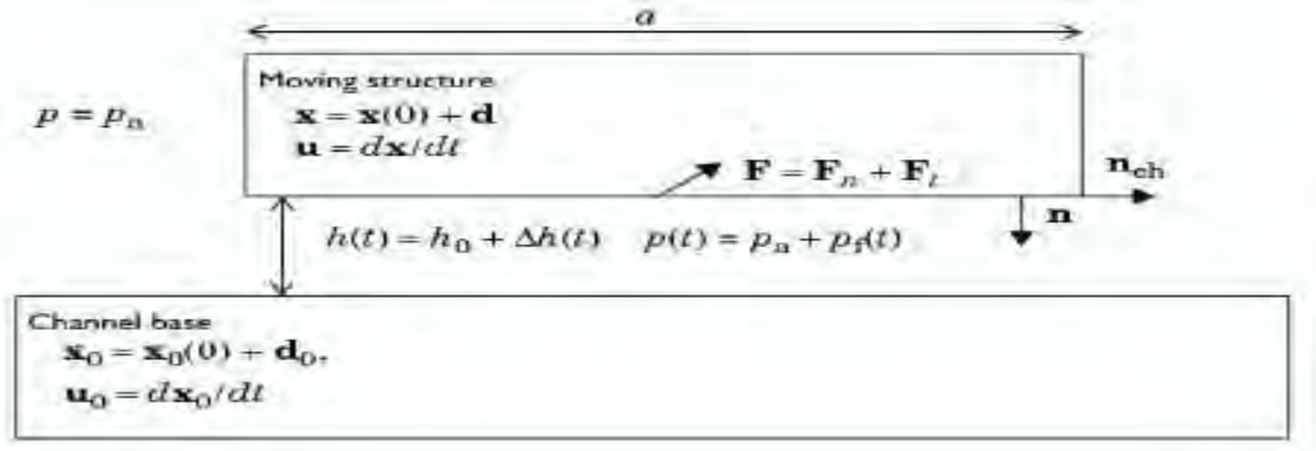
- Finite Element Method
  using COMSOL Multiphysics

- 2D Geometry & Thin-Film Flow Model
  film thickness: 2 mm in sectors
  1 mm in grid openings, inlets and outlets

- Choice of model & mesh design:
  influenced by requiring computational capacity

Method (2)

Thin-Film Flow Model:



CFD Module User's Guide v4.1, COMSOL AB, 2010.

- The film thickness *h* remains very small respect to the dimensions of solid structures
- The channel curvature is small
- The inertial effects in the fluid are negligible compared to the viscous effects, thus the flow is laminar.
- The pressure p = pa + pf is constant over the film thickness h.
- The velocity profile over the film thickness is parabolic.
- The fluid is isothermal

Method (3)

- **Reynolds equation:**

$$\cancel{\frac{\partial(\rho h)}{\partial t}} + \overrightarrow{\nabla}_{\mathrm{tg}} \cdot (\cancel{\rho}\cancel{h}\vec{U}) - \rho(\cancel{\overrightarrow{\nabla}_{\mathrm{tg}} \Delta h_m} \cdot \vec{u}_m - \cancel{\overrightarrow{\nabla}_{\mathrm{tg}} \Delta h_b} \cdot \vec{u}_b) = 0$$

$$\vec{U} = -\frac{\overrightarrow{\nabla}_{\mathrm{tg}} p}{12\mu} h^2 Q_{\mathrm{ch}} + \cancel{\frac{\vec{u}_m + \vec{u}_b}{2}}$$

- 3 volume renewals per hour => total inlet flow 60 cm^3/min
- constant density ρ=1.8417 kg/m^3 (U_s =314 m/s >> U_i = 0.0625 m/s)
- constant dynamic viscosity μ=1.9696 · 10^{-5} Pa.s (Reichenberg's formula)
- immobile solid structures: *h* constant, $\Delta h_m = \Delta h_b = u_m = u_b = 0$
- continuum => Q_{ch} = 1

Method (3)

- **Reynolds equation:**

$$\overrightarrow{\nabla}_{\mathrm{tg}} \cdot \overrightarrow{\nabla}_{\mathrm{tg}} p_f = 0$$

$$\vec{U} = -\frac{h^2}{12\mu} \overrightarrow{\nabla}_{\mathrm{tg}} p_f$$

independent of r and p_a

- 3 volume renewals per hour => total inlet flow 60 cm^3/min
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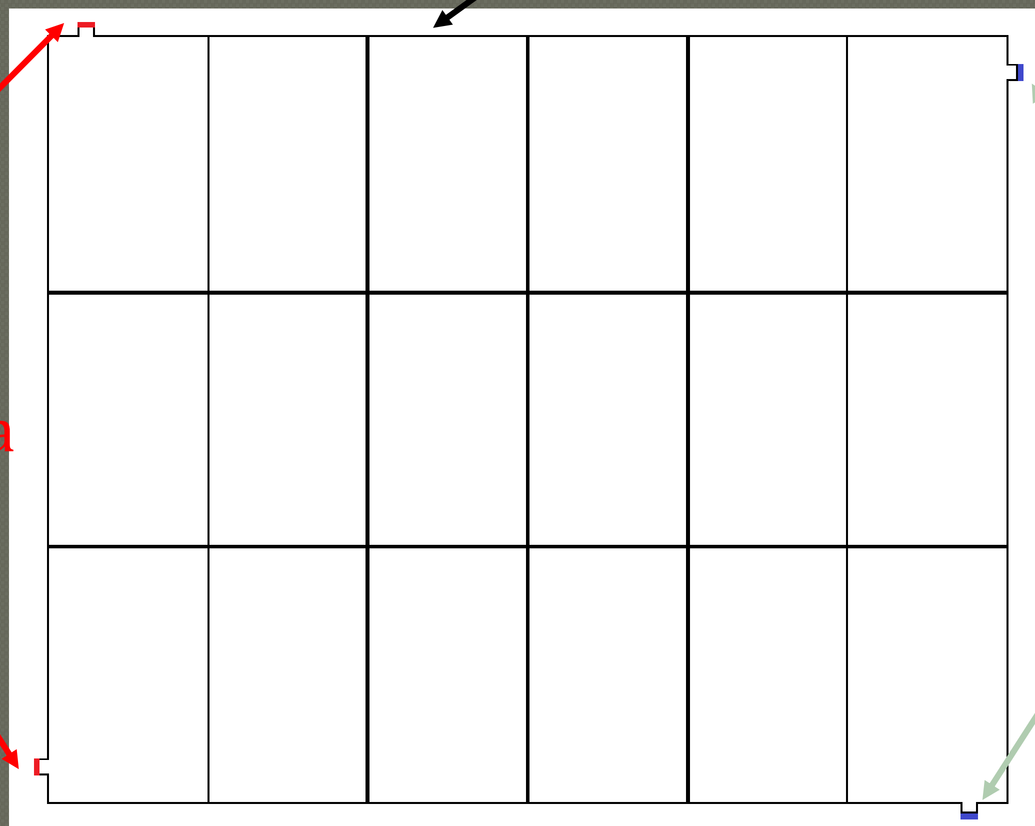
- immobile solid structures: *h* constant, Dh_m=Dh_b=u_m=u_b=0
- continuum => Q_{ch} = 1

Method (3)

- **Boundary conditions**

Frame surfaces U = 0



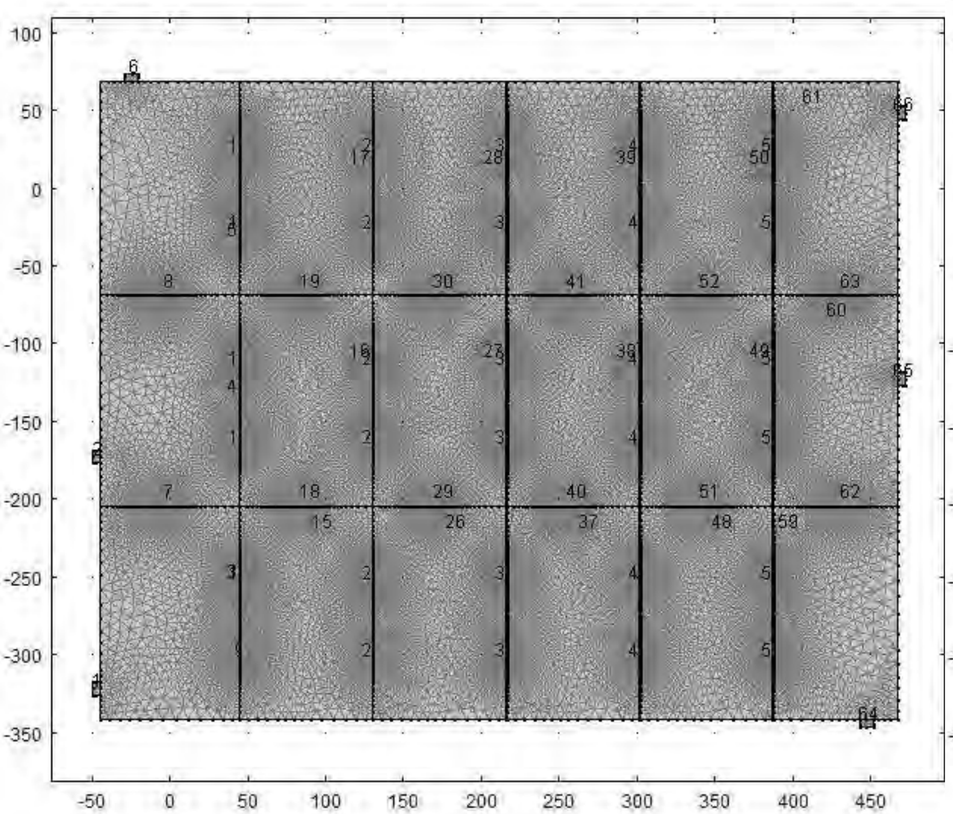
Inlets: uniform perpendicular velocity

Outlets: $p_f = 0$

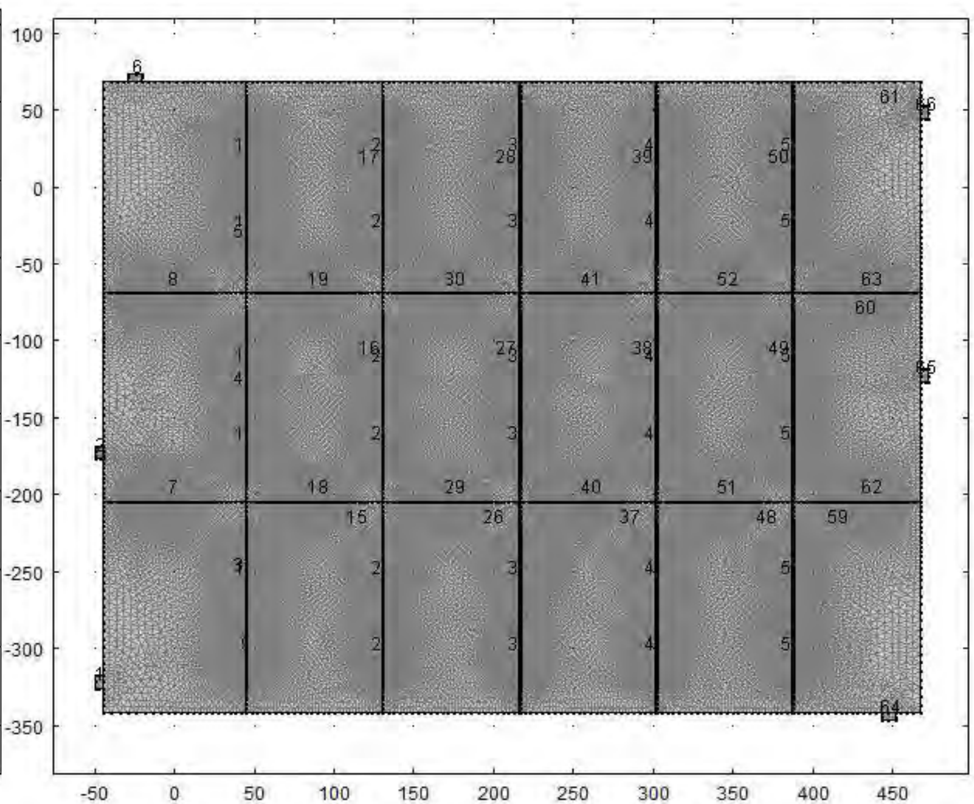
(ambient pressure p_a = 1 atm)

Method (3)

Mesh Quality



Mesh with only 1 predefined « size » : Fine



Mesh with only 1 predefined « size » : Extra fine

Method (3)

Extra fine Mesh Quality

Statistics

Complete mesh

Element type: All elements

Triangular elements:	399736
Quadrilateral elements:	111244
Edge elements:	18524
Vertex elements:	264

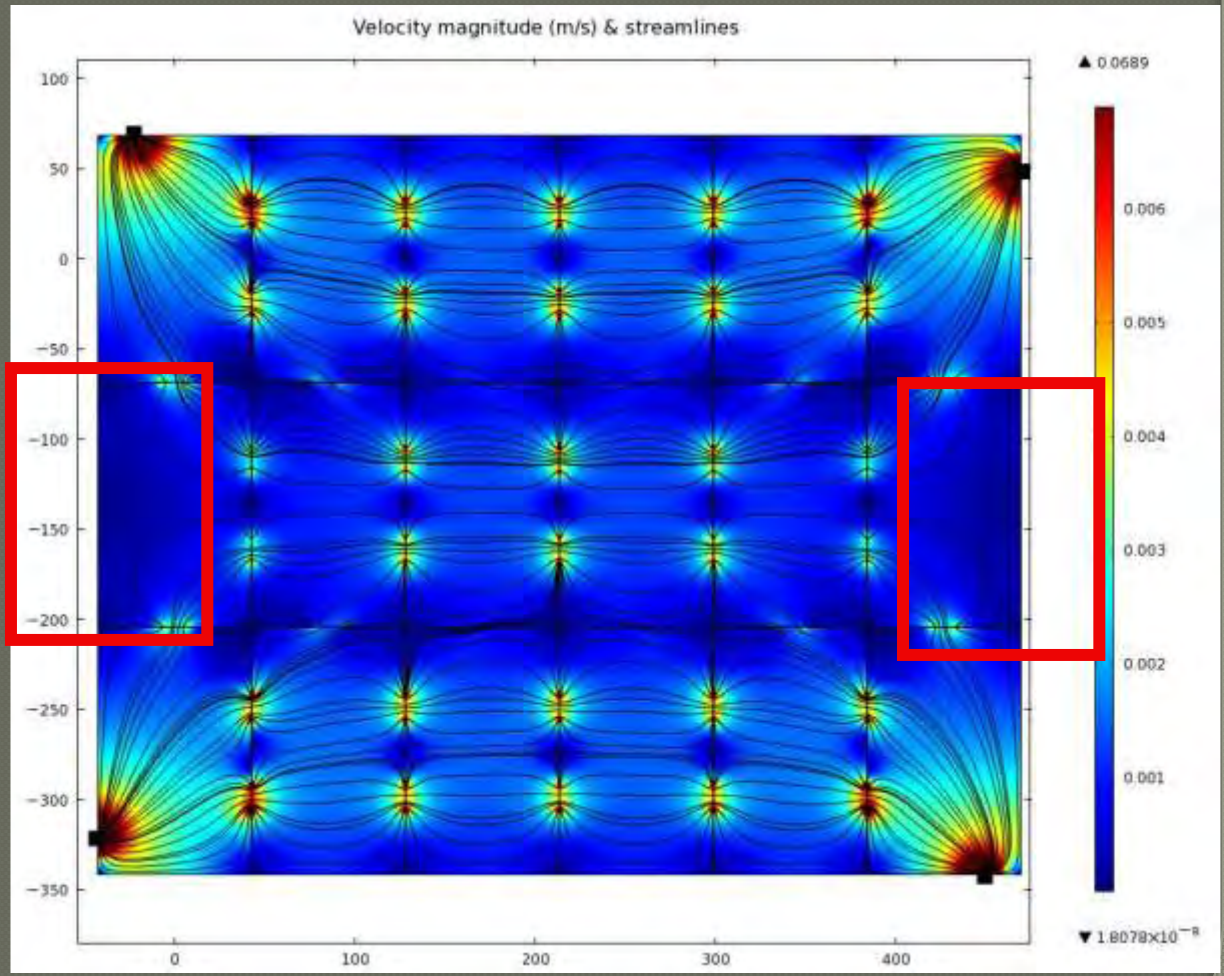
Domain element statistics

Number of elements:	510980
Minimum element quality:	0.06352
Average element quality:	0.7898
Element area ratio:	3.329E-6
Mesh area:	209400.0 mm^2

Element Quality Histogram

Simulation 1

Prototype version:



2 inlets
(U_i =0.0625m/s)

2 outlets

18 sectors

2 large low flux zones

Simulation 2

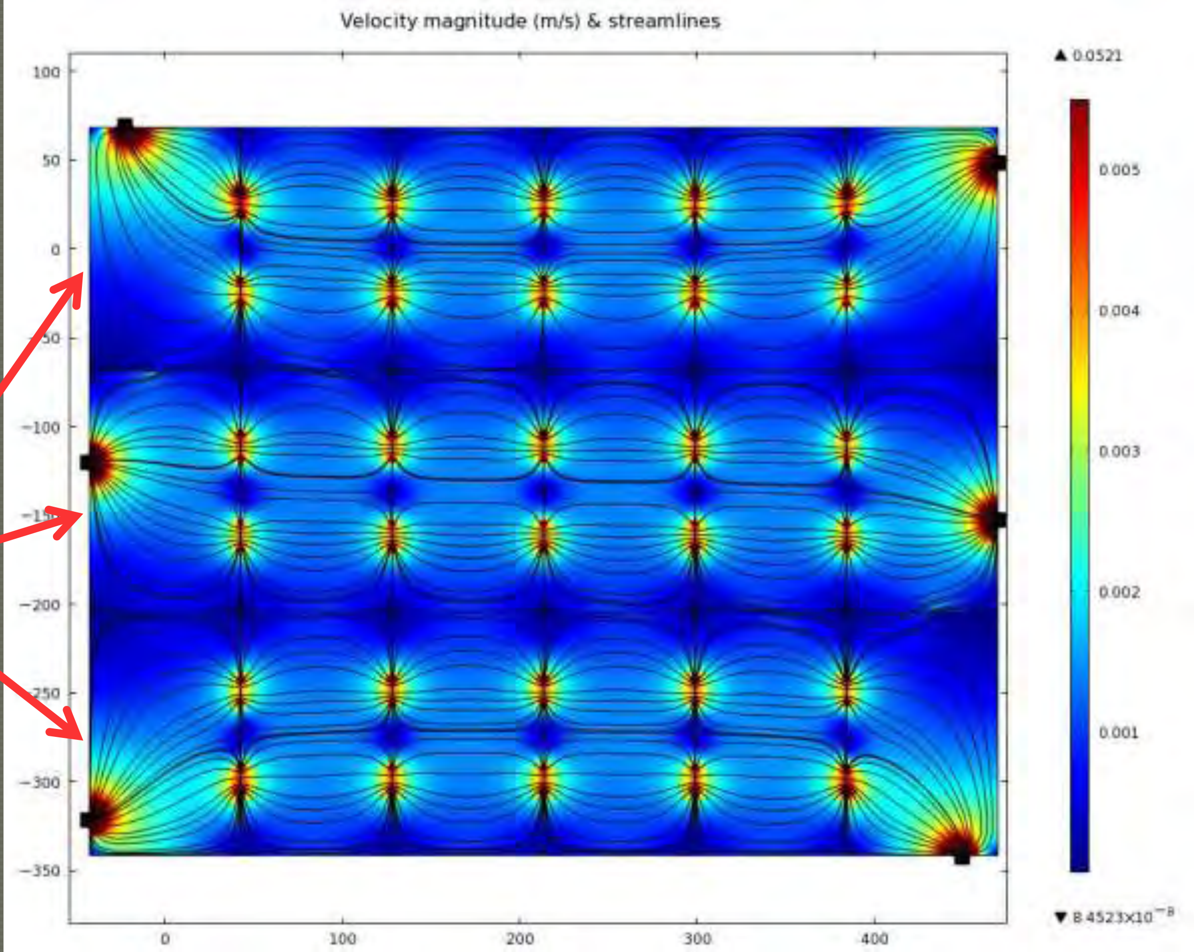
Modified inlet and outlet configuration

3 inlets
(U_i =0.04167m/s)

3 outlets

18 sectors

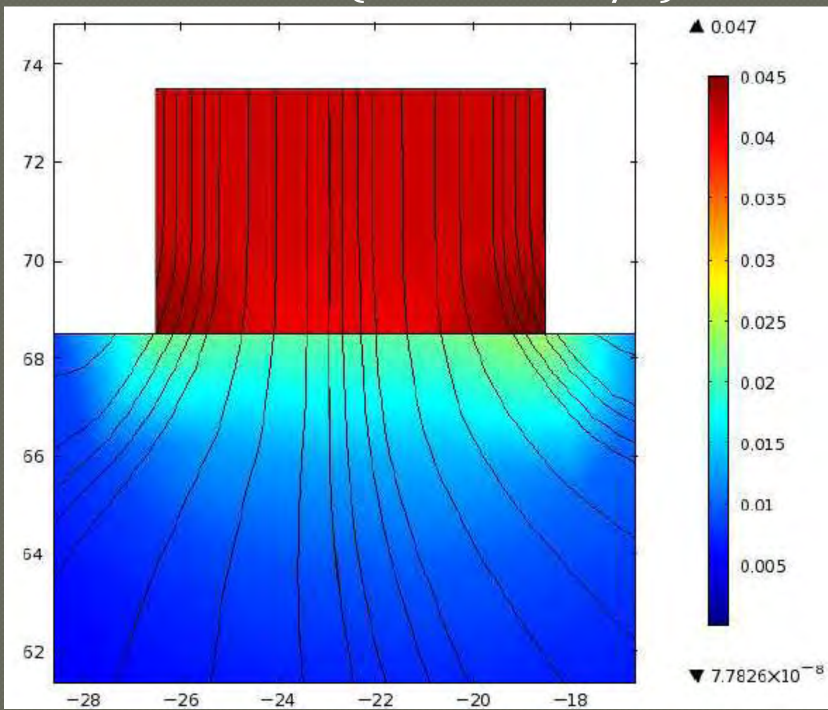
Six-sector rows:
3 independent and similar flows



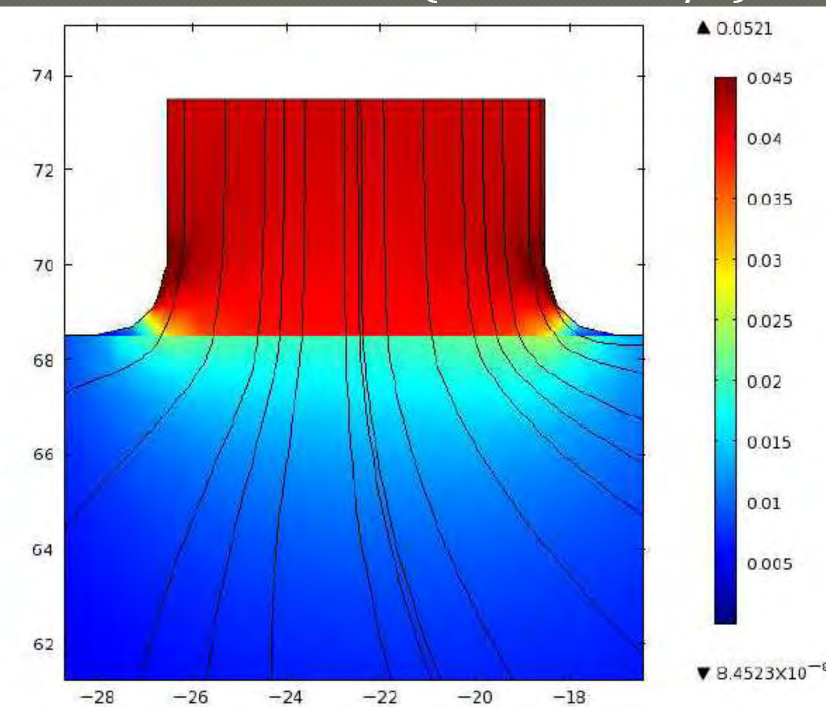
Simulation 2 (continued)

Modified inlet and outlet configuration

Simulation 1 (0,04167 m/s)



Simulation 2 (0,04167 m/s)



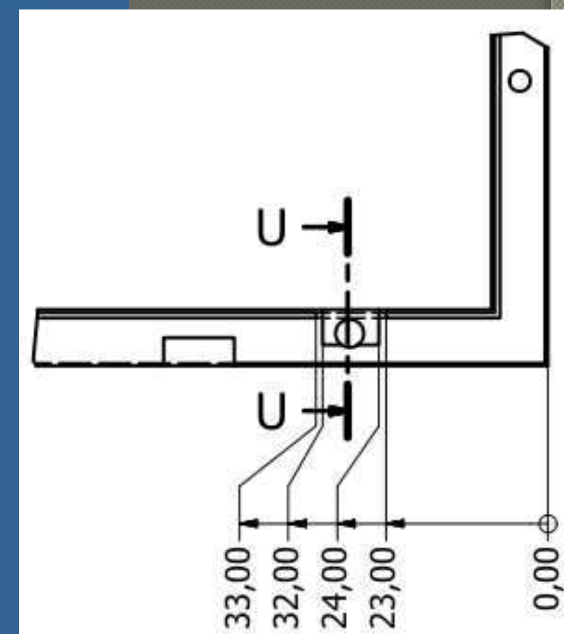
circular joints 1.5 mm radius at inlets & outlets

=> **slight reduction of the high velocities inside sector**

& stabilization of the boundary layers

Simulation 2 (continued)

Modified inlet and outlet configuration



Simulation 3

Reduction from 18 to 12 sectors:

The idea is to reduce the number of vertical spacers in order to have less «dead angles» (the velocity of the gas is too slow in these corners)

Planarity of the GEM foils

Normal pressure
10 N/m²

$$u_{\max} = \kappa(\zeta)\frac{PS}{T}$$

Maximum sector area: 265 cm²

20µm
Maximum deformation

< 0.074
Geometrical factor

9.81 N/cm
Circumference force per unit length

⇒ Minimum number of sectors: 9 (sector area = 222 cm²)

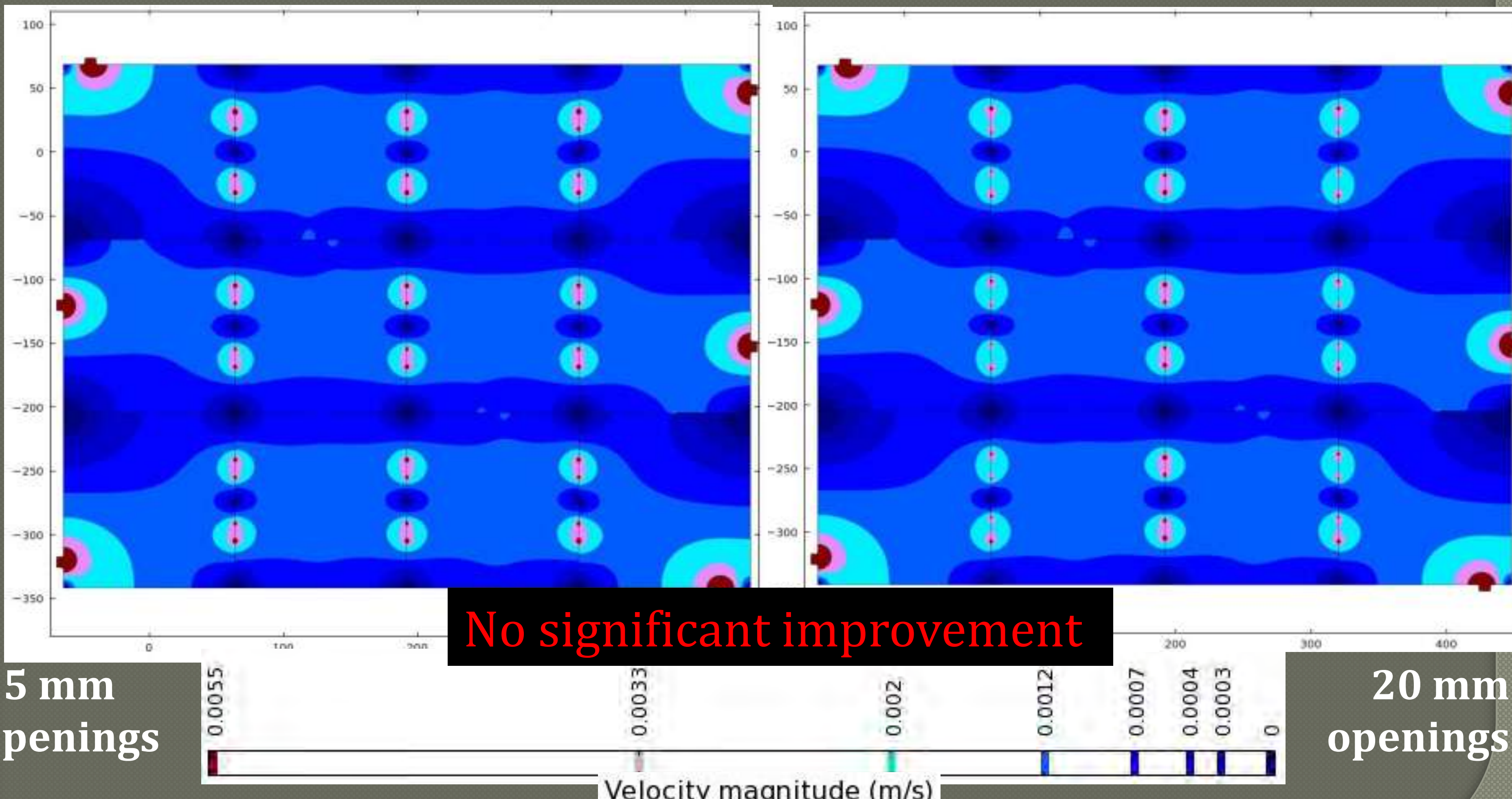
Conservative choice: 12 sectors (sector area = 166 cm²)

Simulation 3 (continued)

Reduction from 18 to 12 sectors:

Simulation 4

Enlargement of openings near inlets & outlets



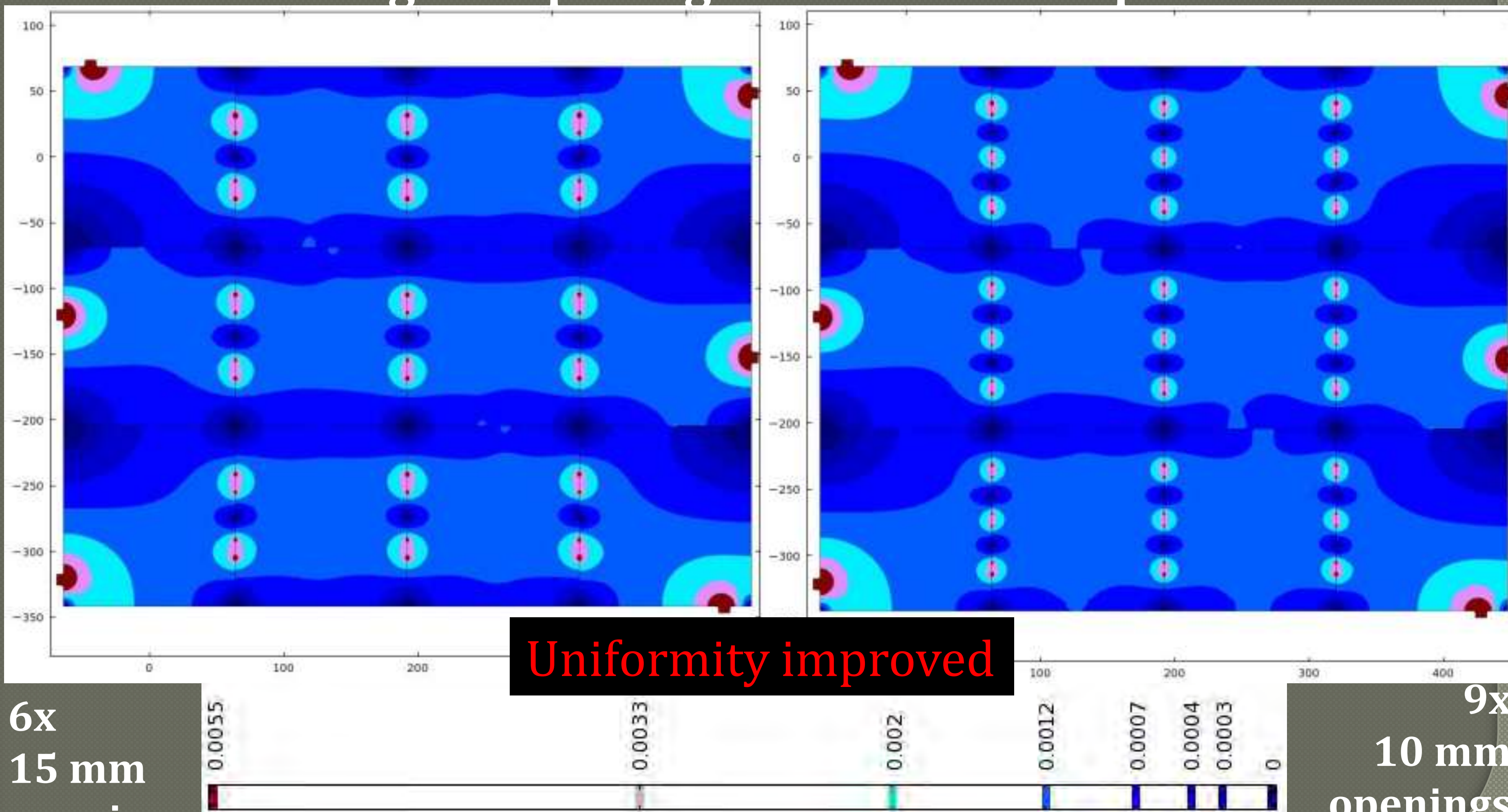
No significant improvement

15 mm openings

20 mm openings

Simulation 5

Doubling the openings in the vertical spacers:

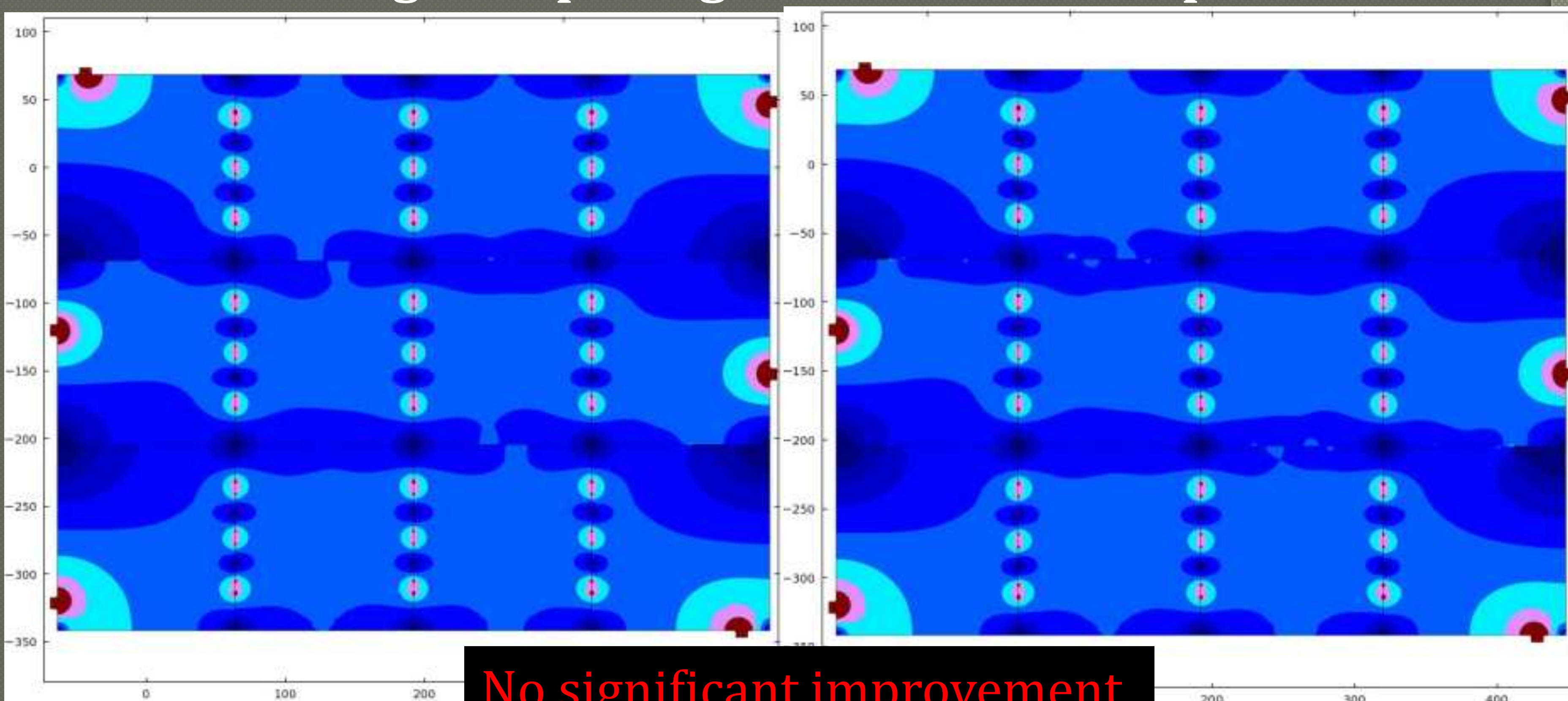


6x
15 mm
openings

9x
10 mm
openings

Simulation 6

Doubling the openings in the orizontal spacers:

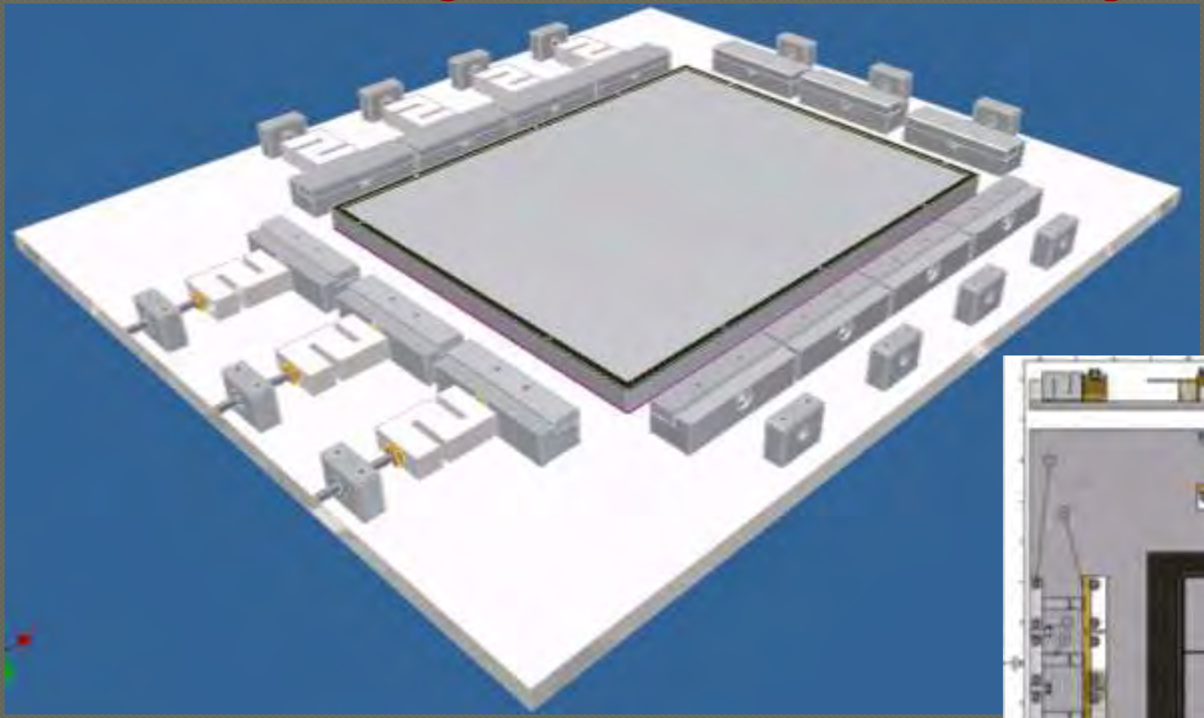


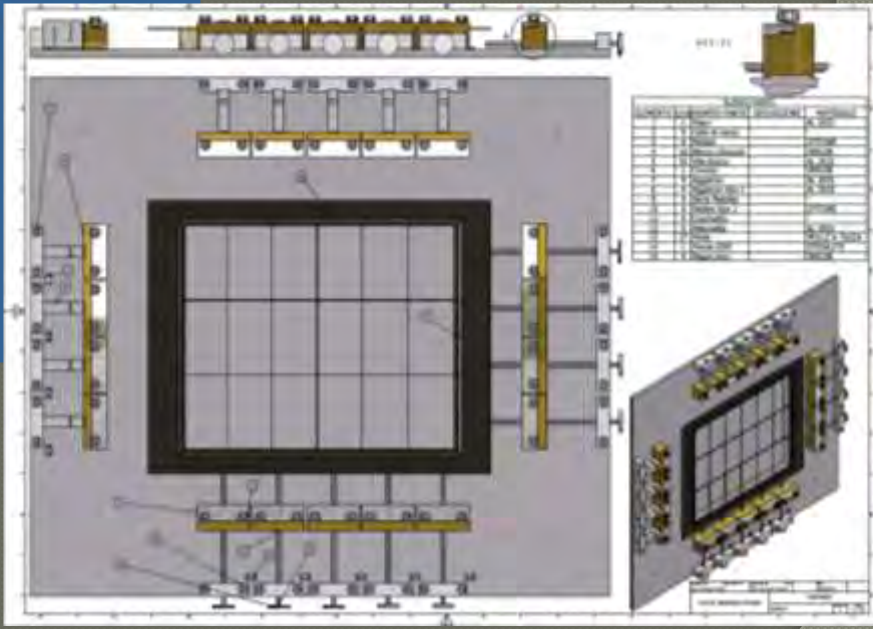
4x 15 mm openings

8x 15 mm openings

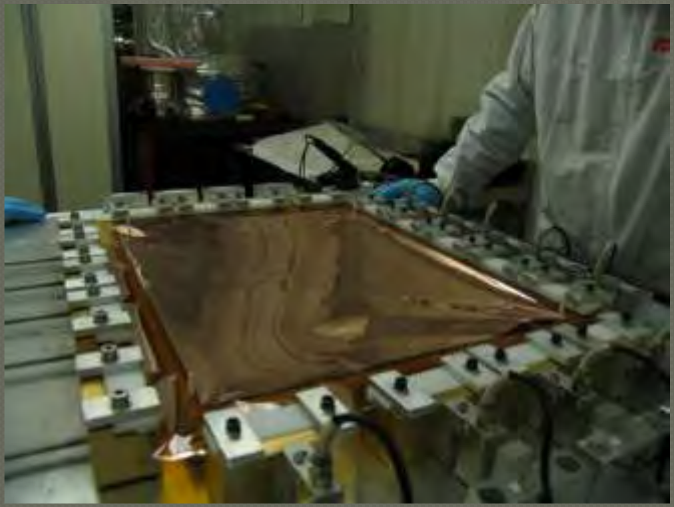
TENDIGEM

Tendigem machine is a tool for the gem foils stretching.

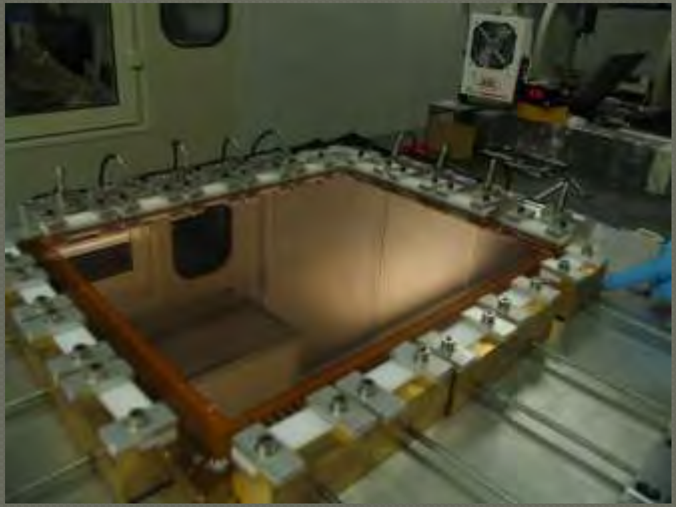




TENDIGEM



Stretching



Gluing the next frame with spacers

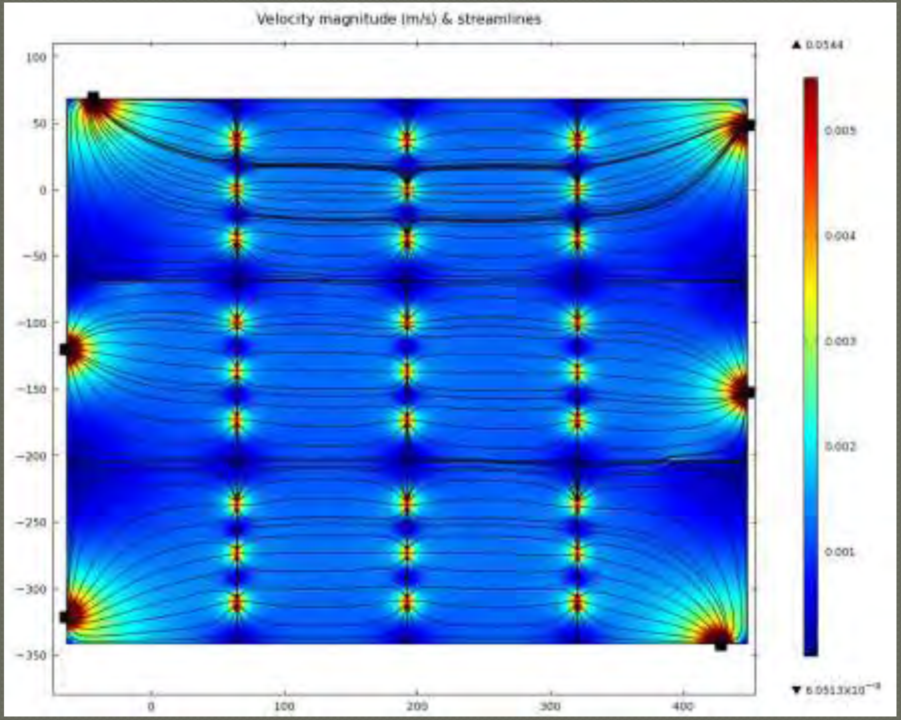
Conclusion

Study and optimization of the gas system

- **Significant improvement of the gas flow uniformity** in the 2 mm gap between 2 GEM foils of a 40 x 50 cm^2 module

Final frame design:

- 3 inlets and 3 outlets (with circular joints)
- 12 sectors
- vertical spacers: 9 openings of 10 mm
- orizontal spacers: 4 openings of 15 mm



- **Inlet and outlet pipes cause a very large fraction of the total pressure loss** in a 40 x 50 cm^2 module

Thank you for your attention