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Optimization of the design of a GEM Tracker based on gas flow simulations with COMSOL

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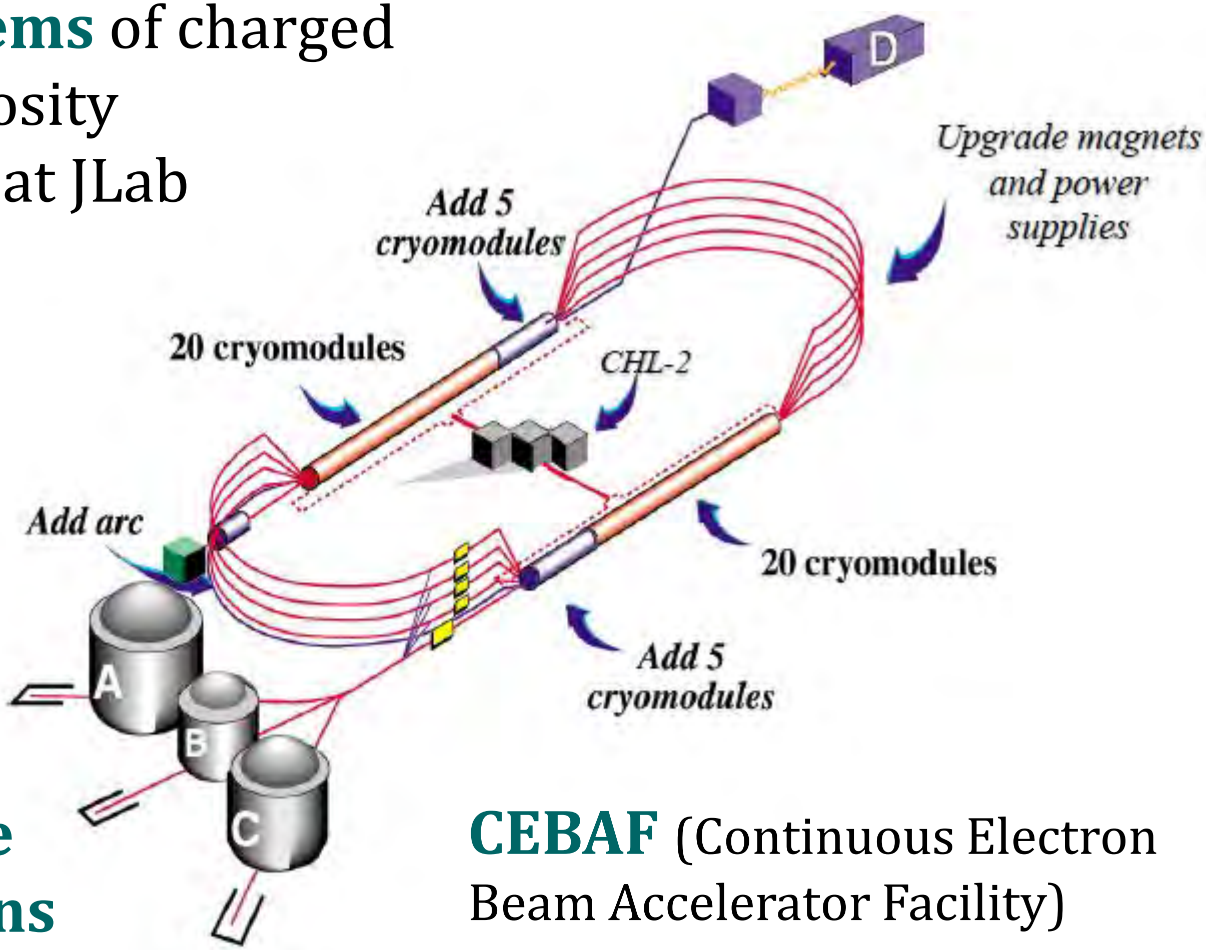
1 Introduction

- **GEM (Gas Electron Multiplier)** chambers currently under development

Jefferson Lab

- Part of **tracking systems** of charged particles for high luminosity spectrometers in Hall A at JLab

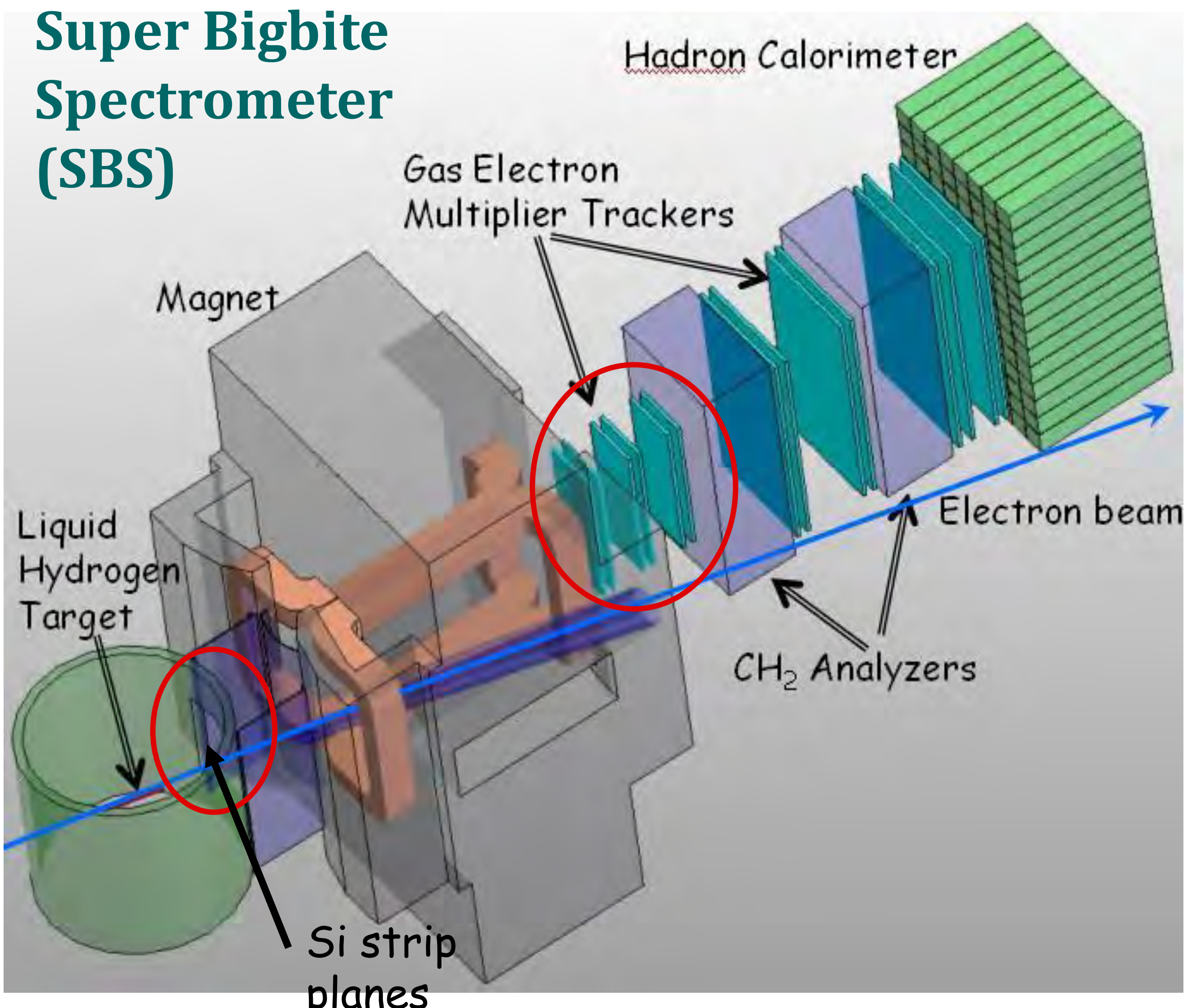
Energy upgrade:
up to 11 GeV in Hall A (2014)



- Investigate the **fundamental structure of protons and neutrons**

CEBAF (Continuous Electron Beam Accelerator Facility)

1 Introduction



Front Tracker:

- two 10 x 20cm^2 silicon strip planes

- six 40 x 150cm^2 GEM chambers:

each made up of three adjacent 40 x 50 cm^2 triple-GEM modules

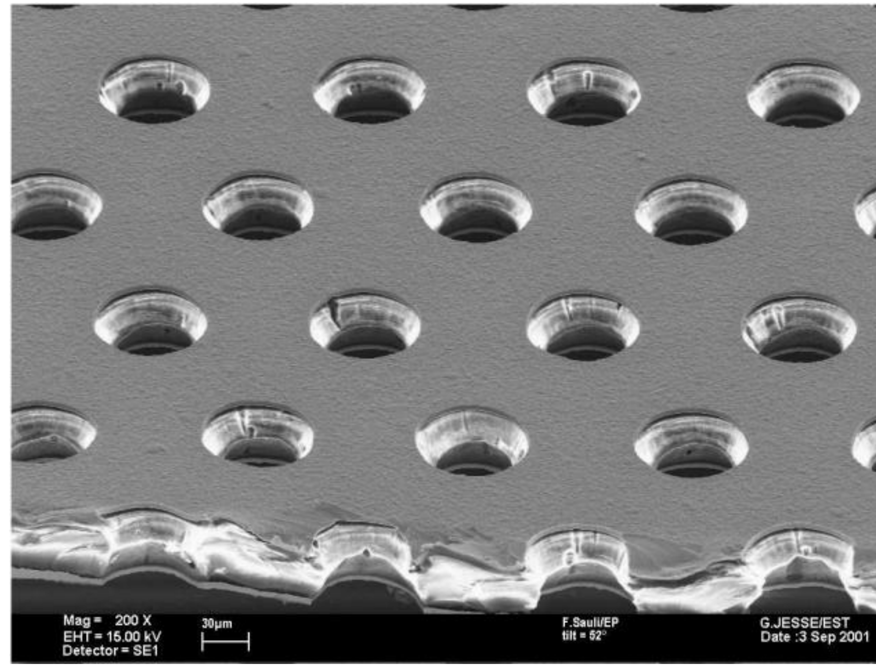
2 The triple-GEM detector

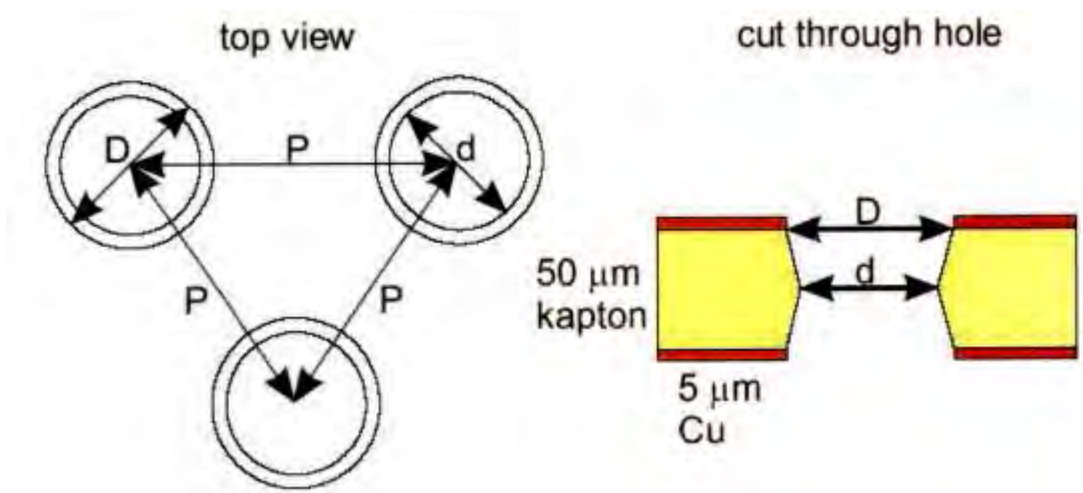
- **GEM foil**

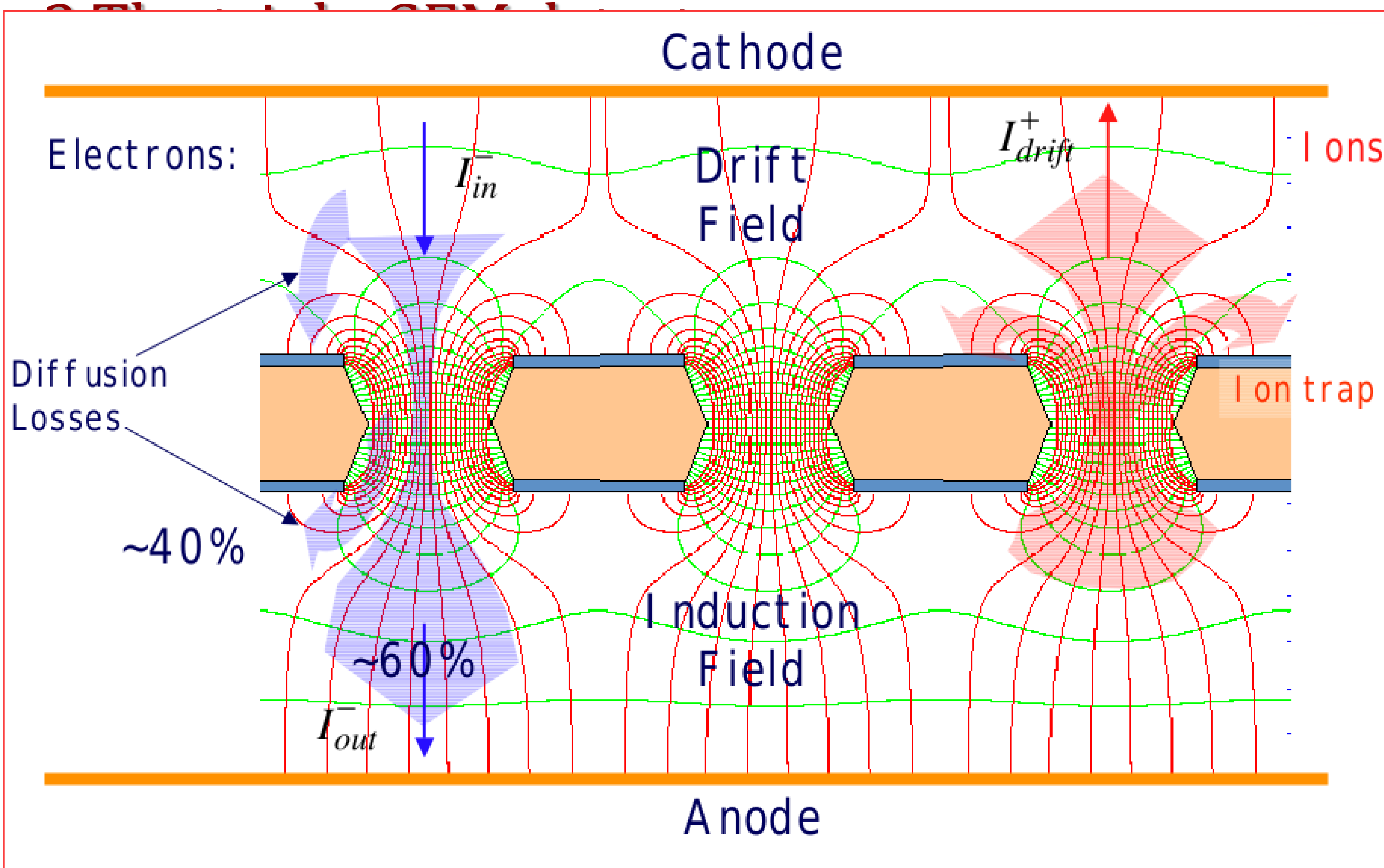
50µm insulating Kapton coated on both sides with 3 to 5 µm Cu

Densily perforated:

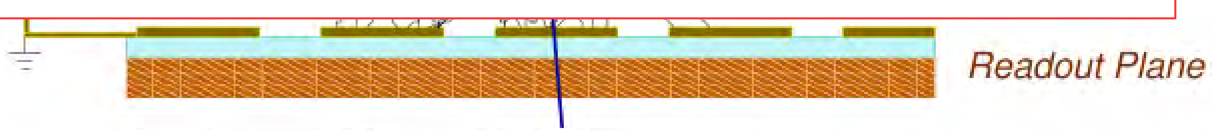
D = 70 µm
d = 50 µm
P = 140 µm







signal on the anode
read-out

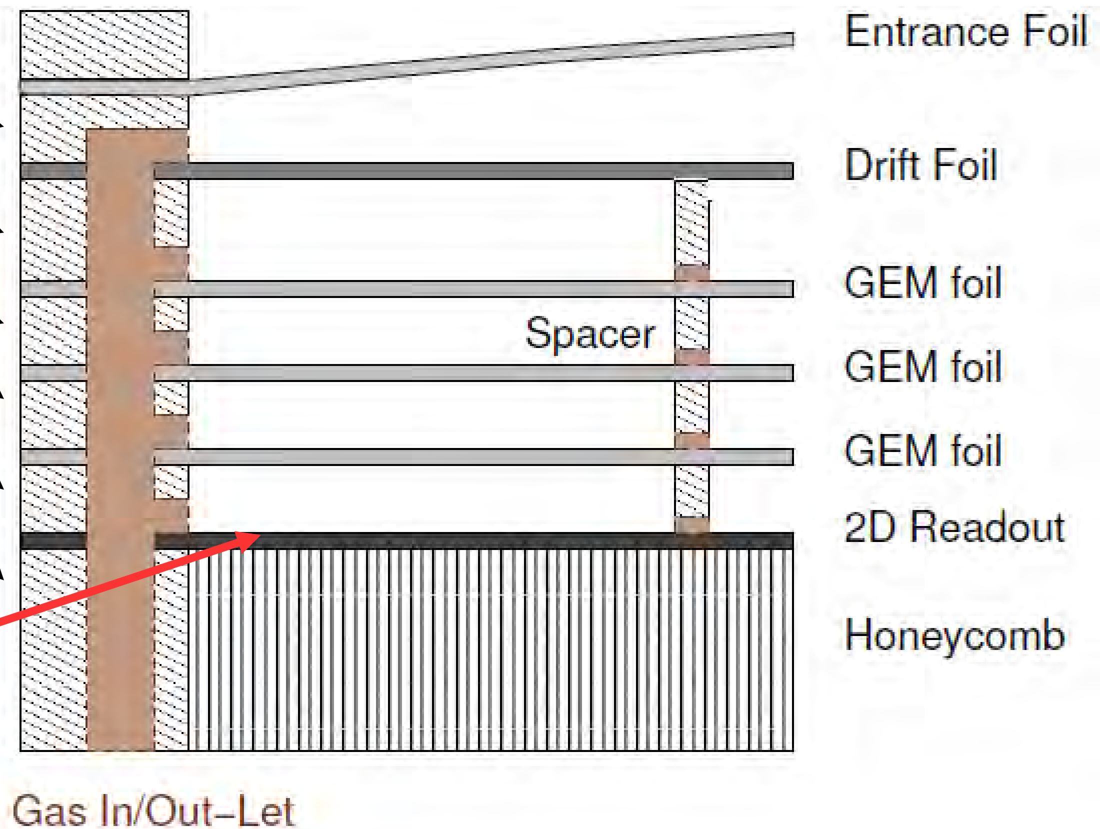


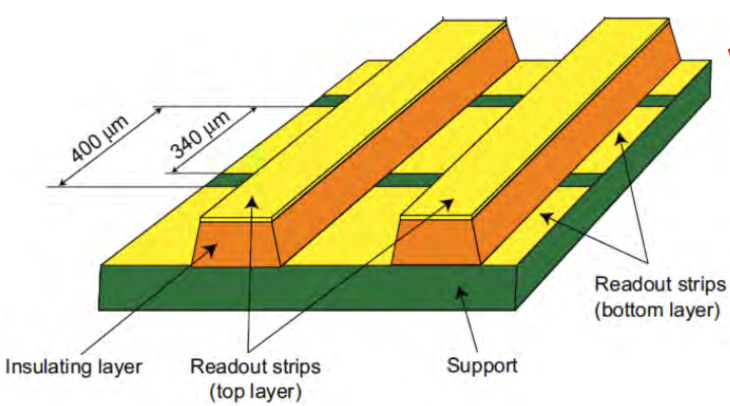
$V_{GEM_1} >> V_{GEM_2} \geq V_{GEM_3}$ (300-350 V)

3 GEM chambers of the SBS Front Tracker

- **The 40 x 50 cm^2 triple-GEM modules**

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)





4 Study and optimization of the gas system

4.2 Method (1)

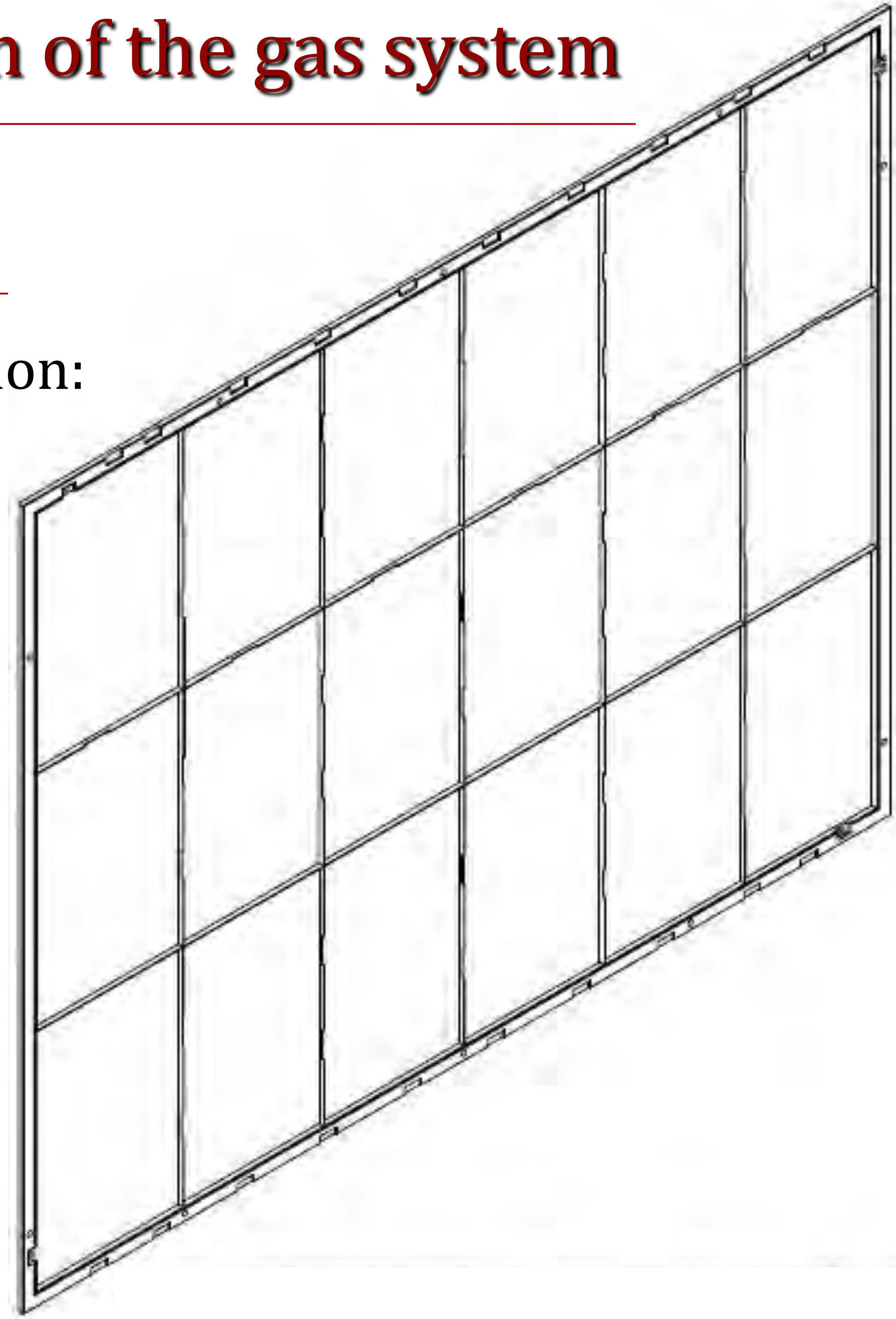
Ar-CO_2 (70/30) gas flow simulation:

COMSOL Multiphysics
CFD module

2D Geometry
& Thin-Film Flow Model

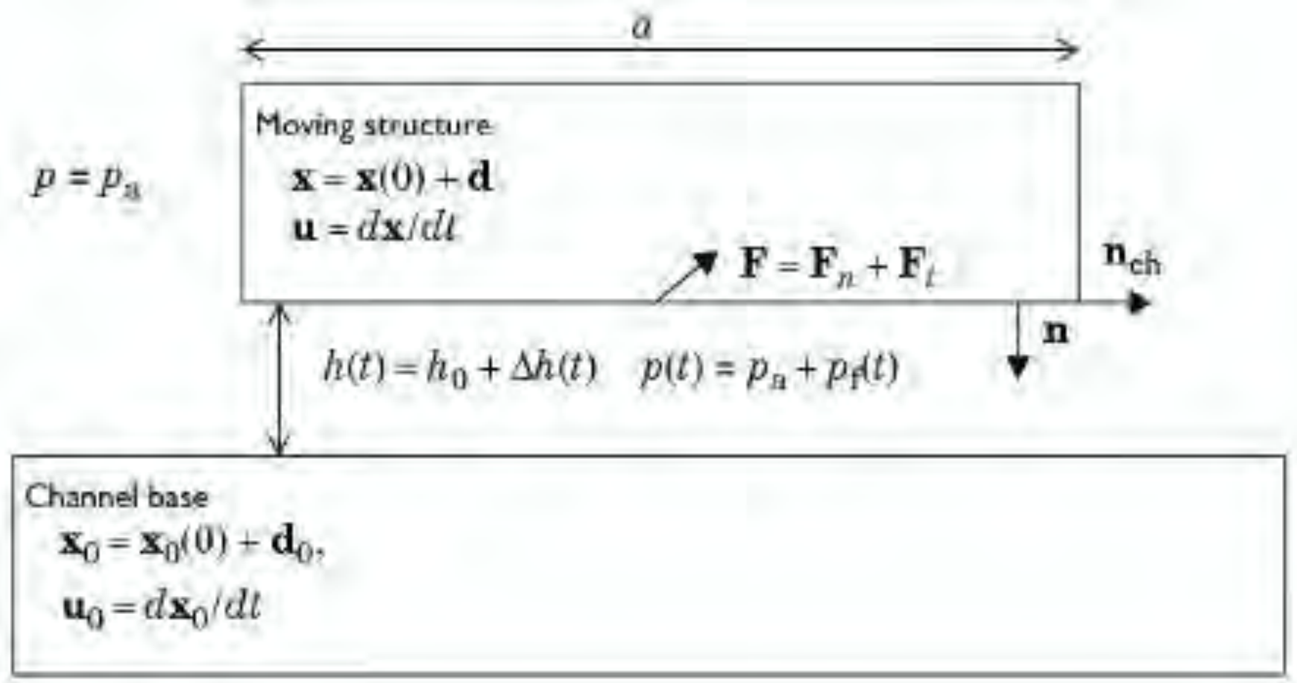
Film thicknesses:
- 2 mm in sectors
- 1 mm in grid openings,
  inlets and outlets

detector response



4.2 Method (2)

- **Thin-Film Flow Model:**



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

- film thickness *h* << dimensions solid structures
- small curvature
- pressure *p* constant over film thickness
- parabolic velocity profile over film thickness

- Newtonian fluid
- laminar
- isothermal
- volume forces neglected

4.2 Method (3)

- **Reynolds equation:**

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

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

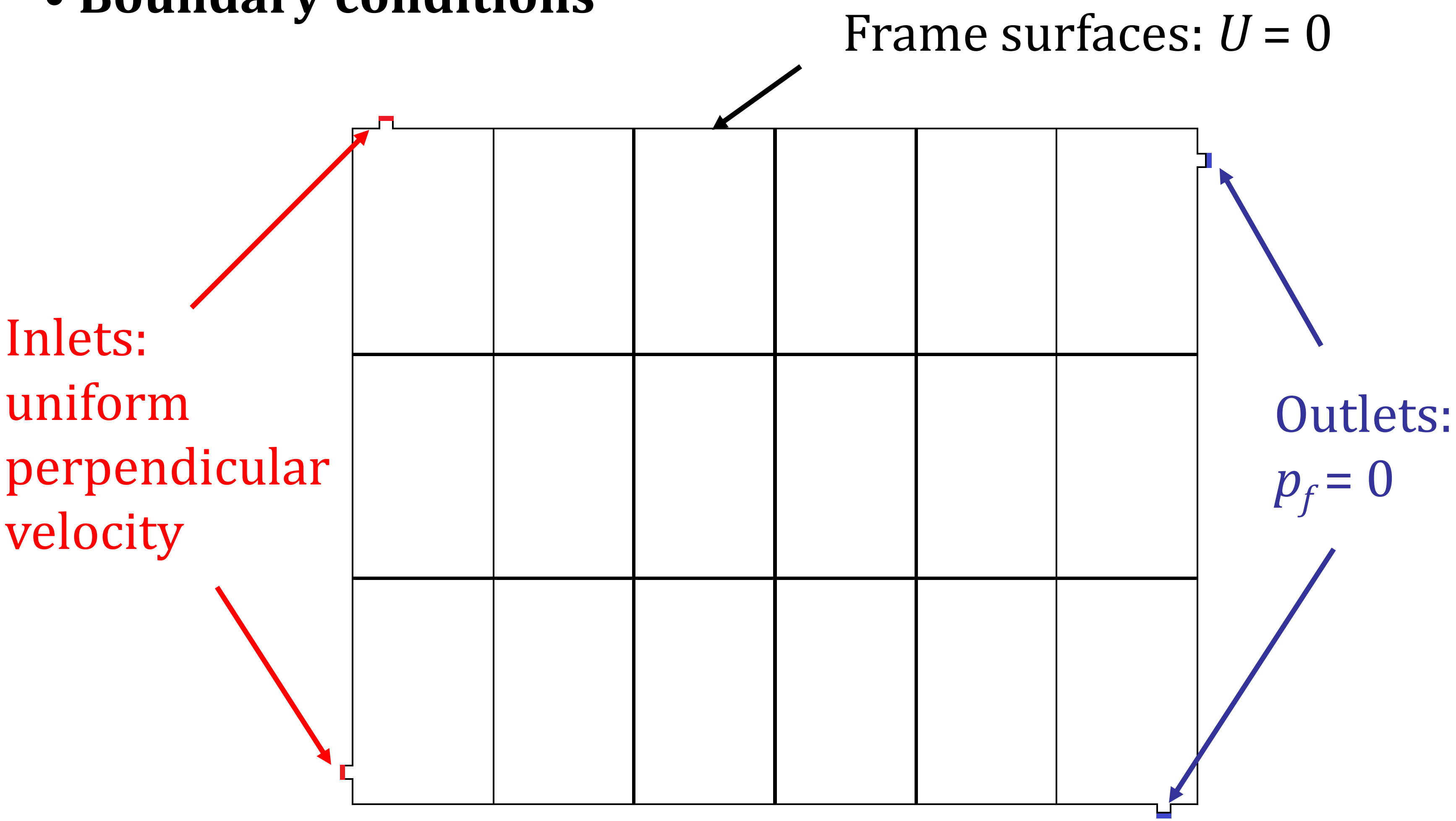
independent of

r and p_a

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

4.2 Method (4)

- **Boundary conditions**



(ambient pressure $p_a = 1$ atm)

4.3 Simulation 1

- **Frame in its prototype version:**

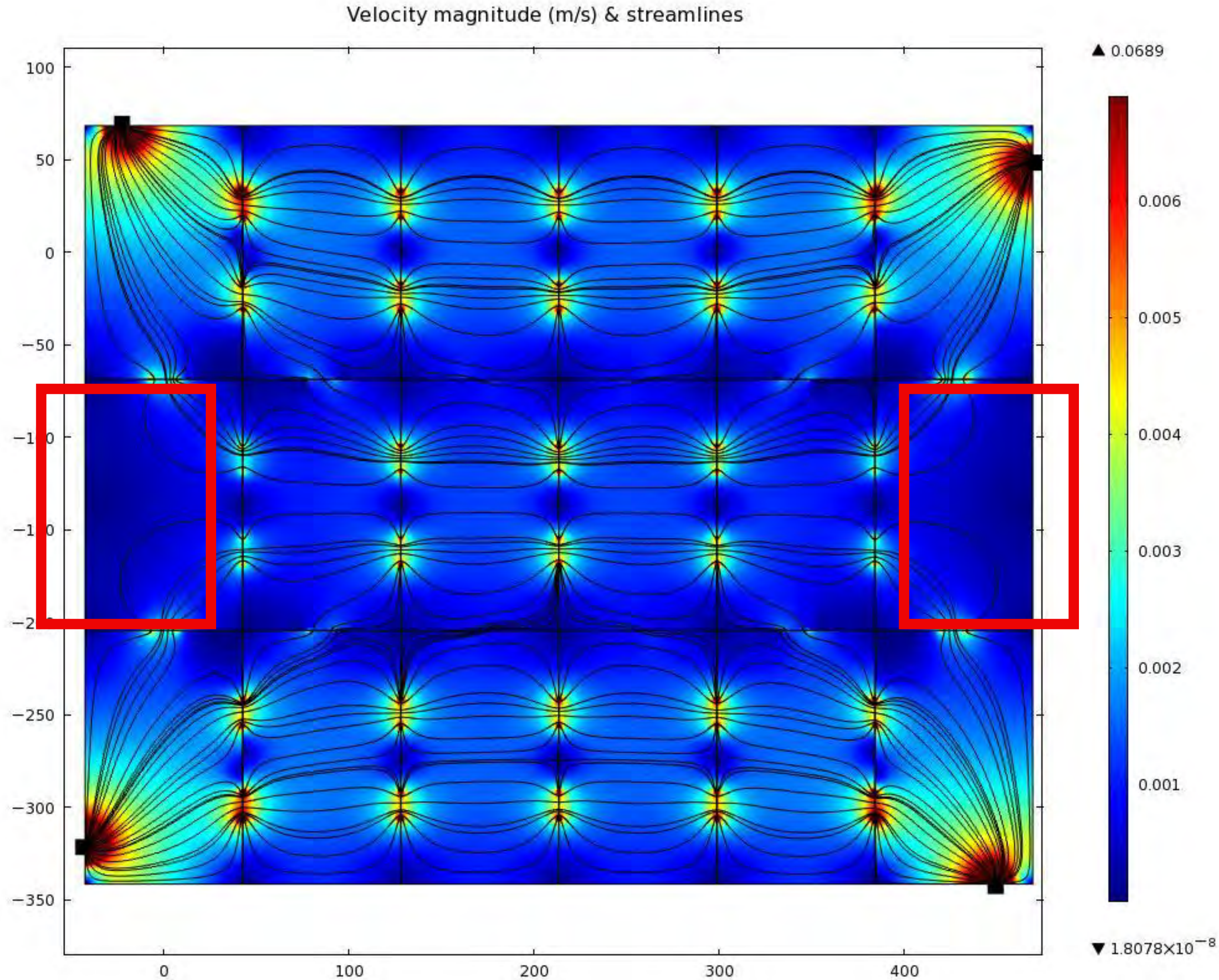
2 inlets

(U_i =0.0625m/s)

2 outlets

18 sectors

2 large low flux zones



4.4 Simulation 2

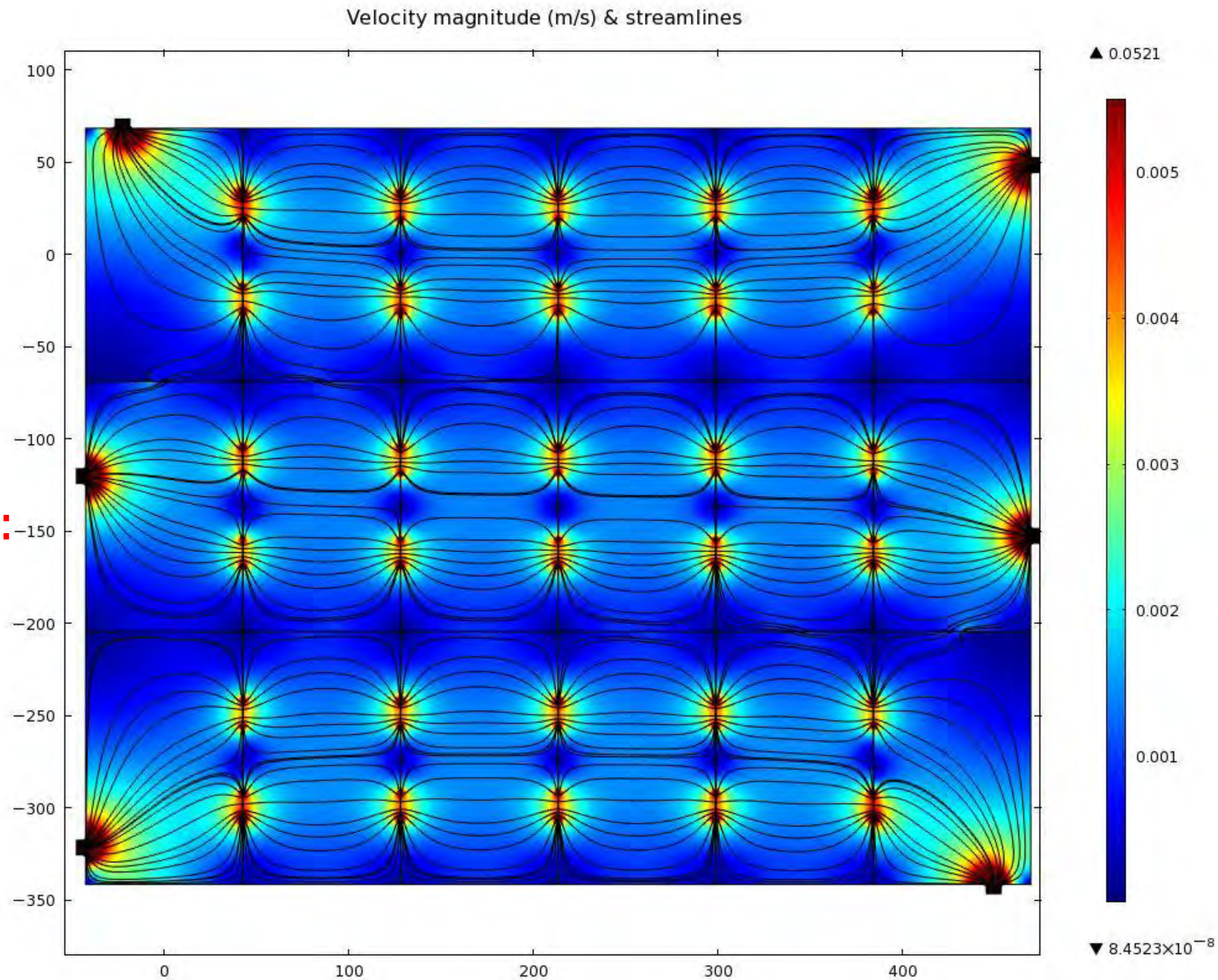
- **Modified inlet and outlet configuration:**

3 inlets
(U_i =0.04167m/s)

3 outlets

18 sectors

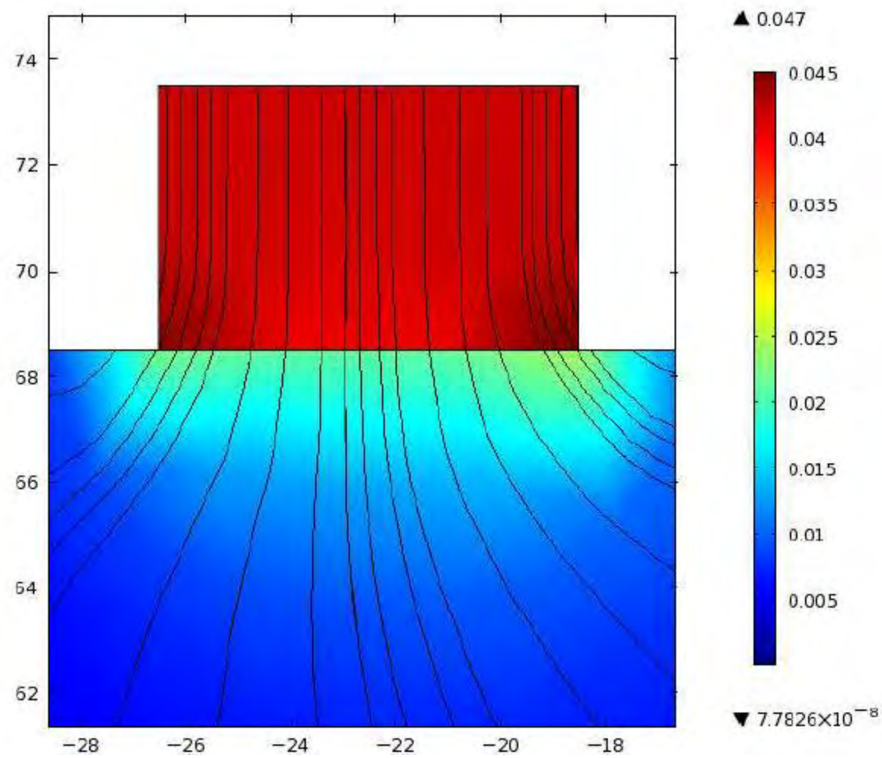
Six-sector rows:
3 rather independent and similar flows



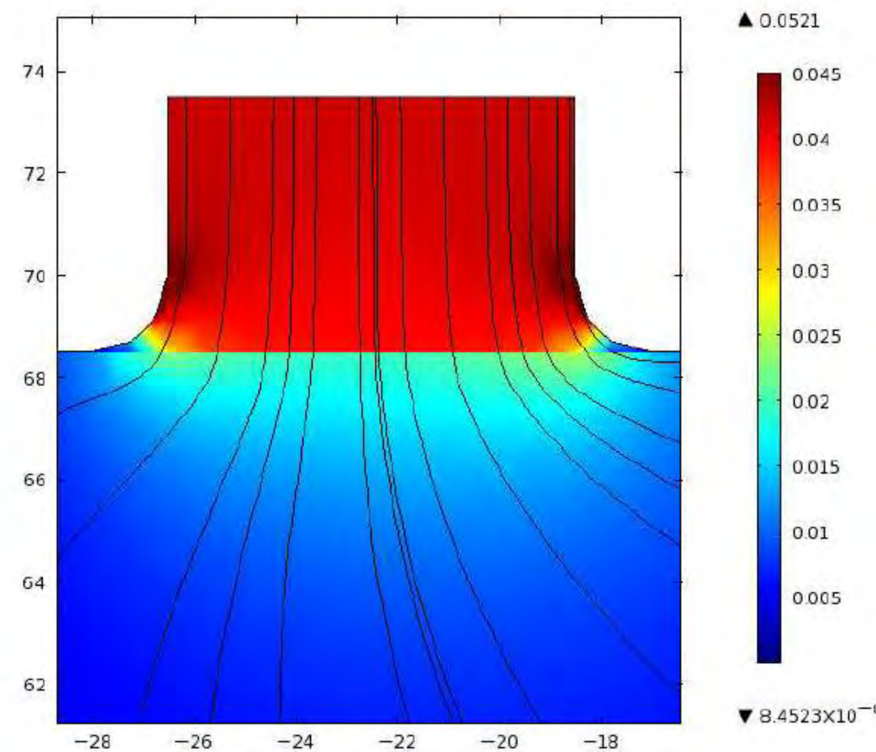
4.4 Simulation 2 (continued)

- **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**

4.5 Simulation 3

- **Reduction from 18 to 12 sectors:**

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

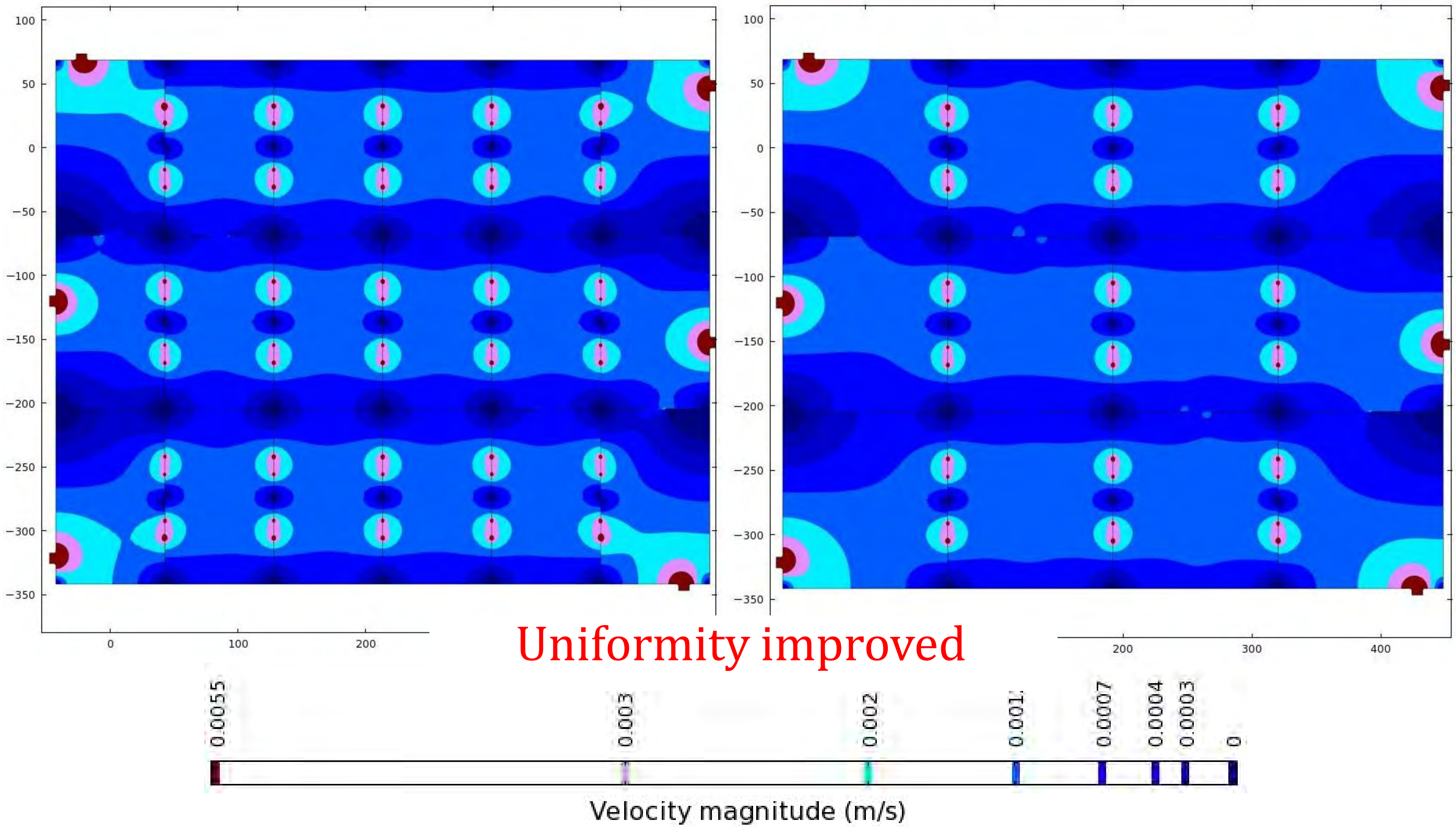
9.81 N/cm
Circumference force per unit length

$\Rightarrow$ **Minimum number of sectors: 9** (sector area = 222 cm²)

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

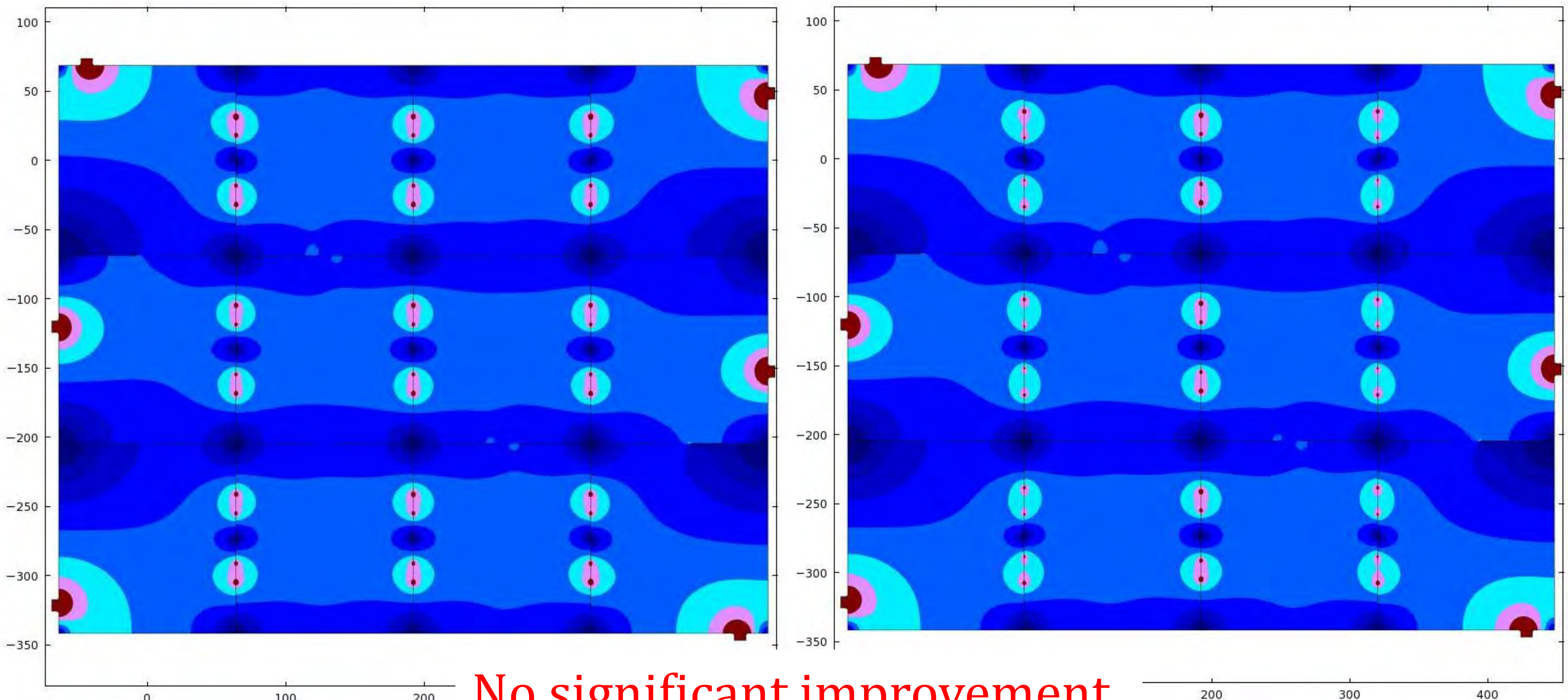
4.5 Simulation 3 (continued)

- **Reduction from 18 to 12 sectors:**



4.6 Simulation 4

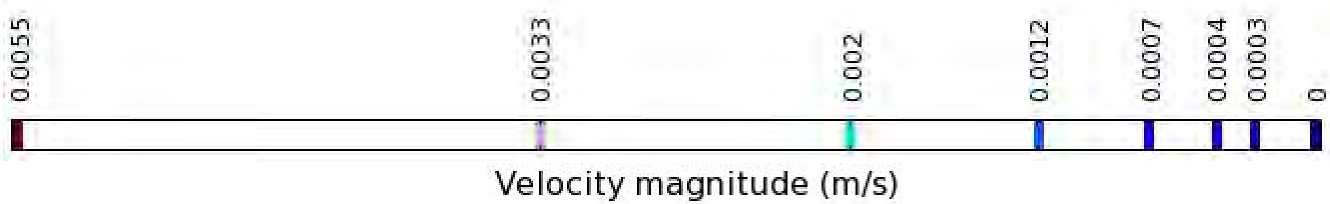
- **Enlargement of openings near inlets & outlets:**



No significant improvement

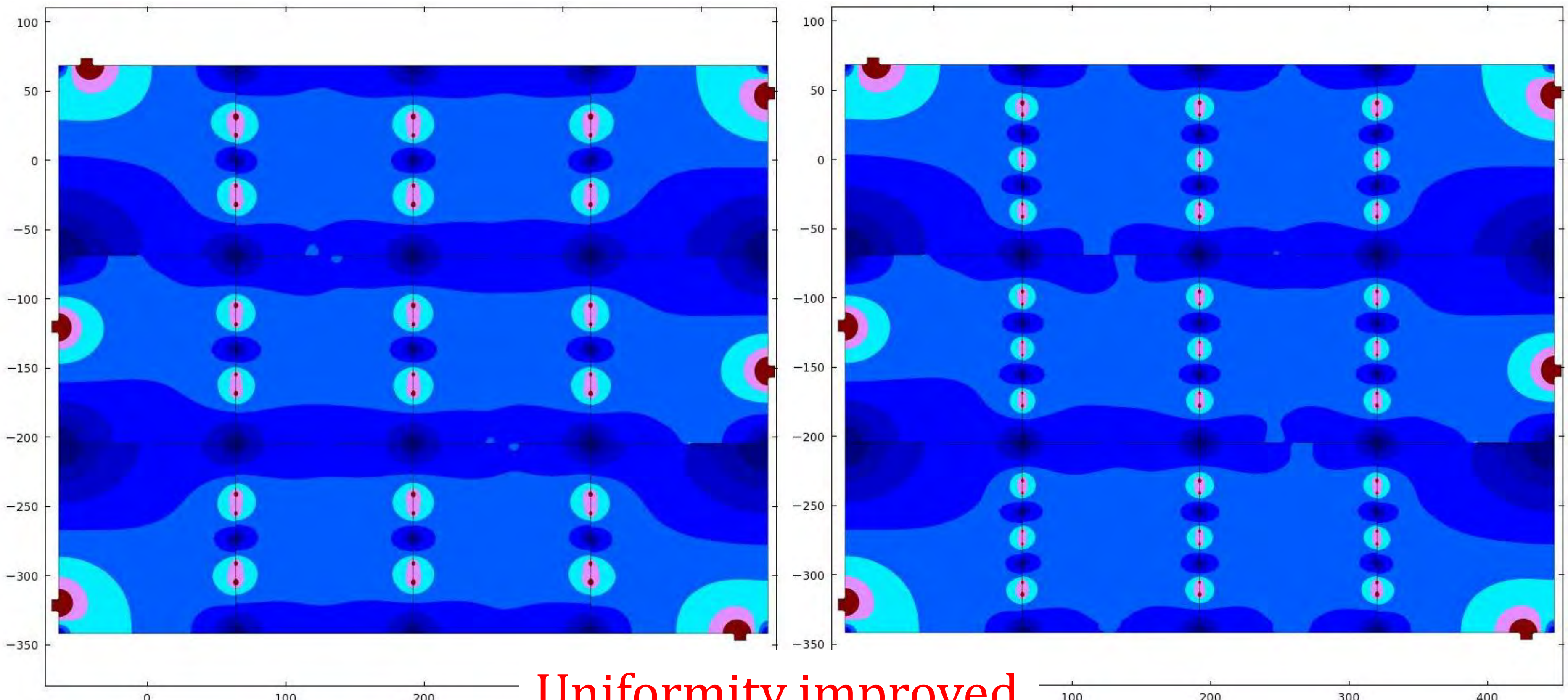
15 mm openings

20 mm openings



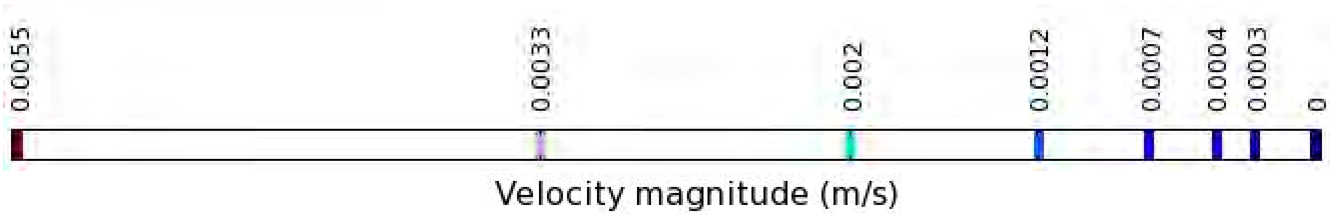
4.7 Simulation 5

- **Modifying the openings in the shortest spacers:**



Uniformity improved

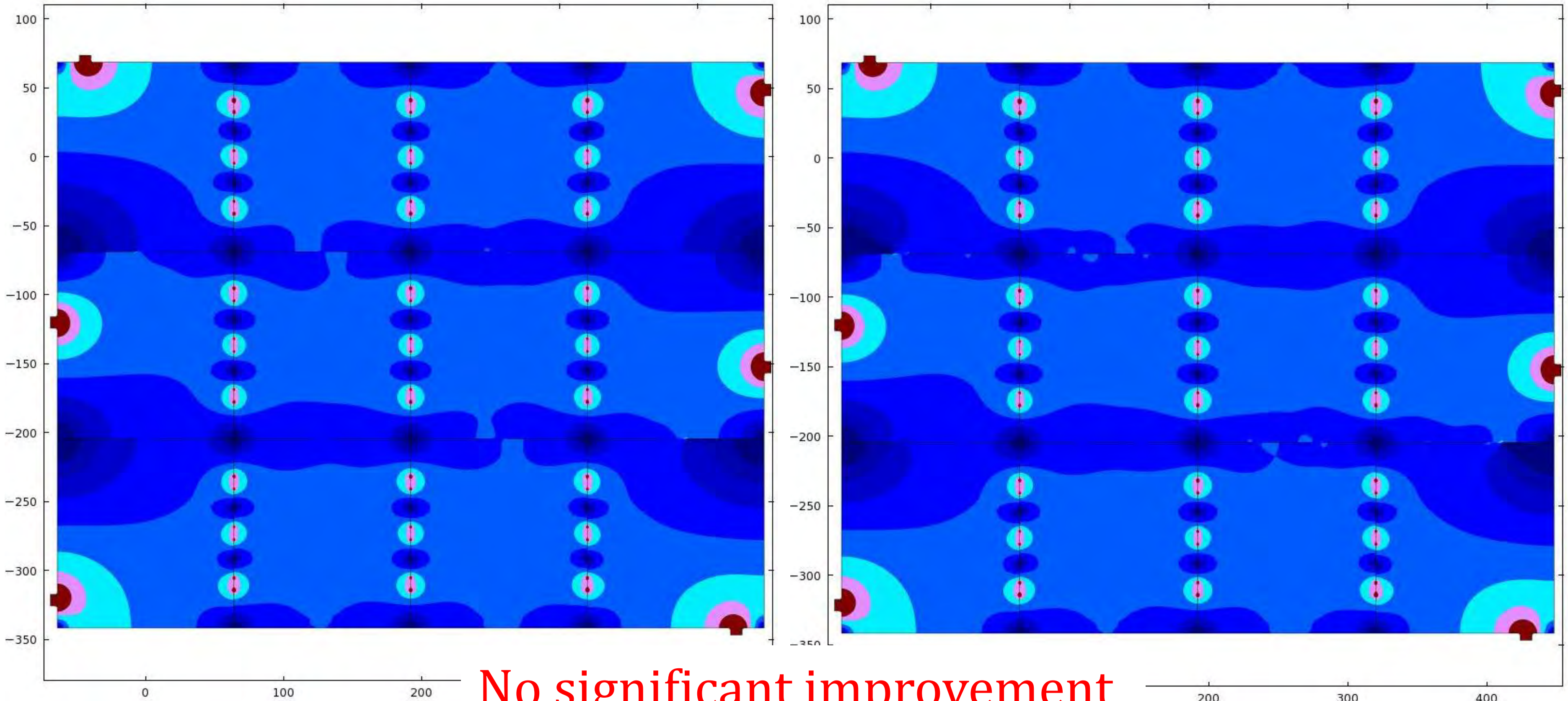
6x 15 mm openings



9x 10 mm openings

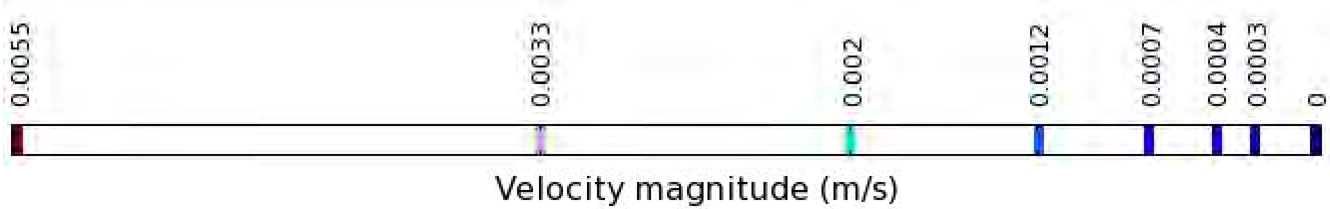
4.8 Simulation 6

- **Doubling the openings in the longest spacers:**



No significant improvement

4x 15 mm openings



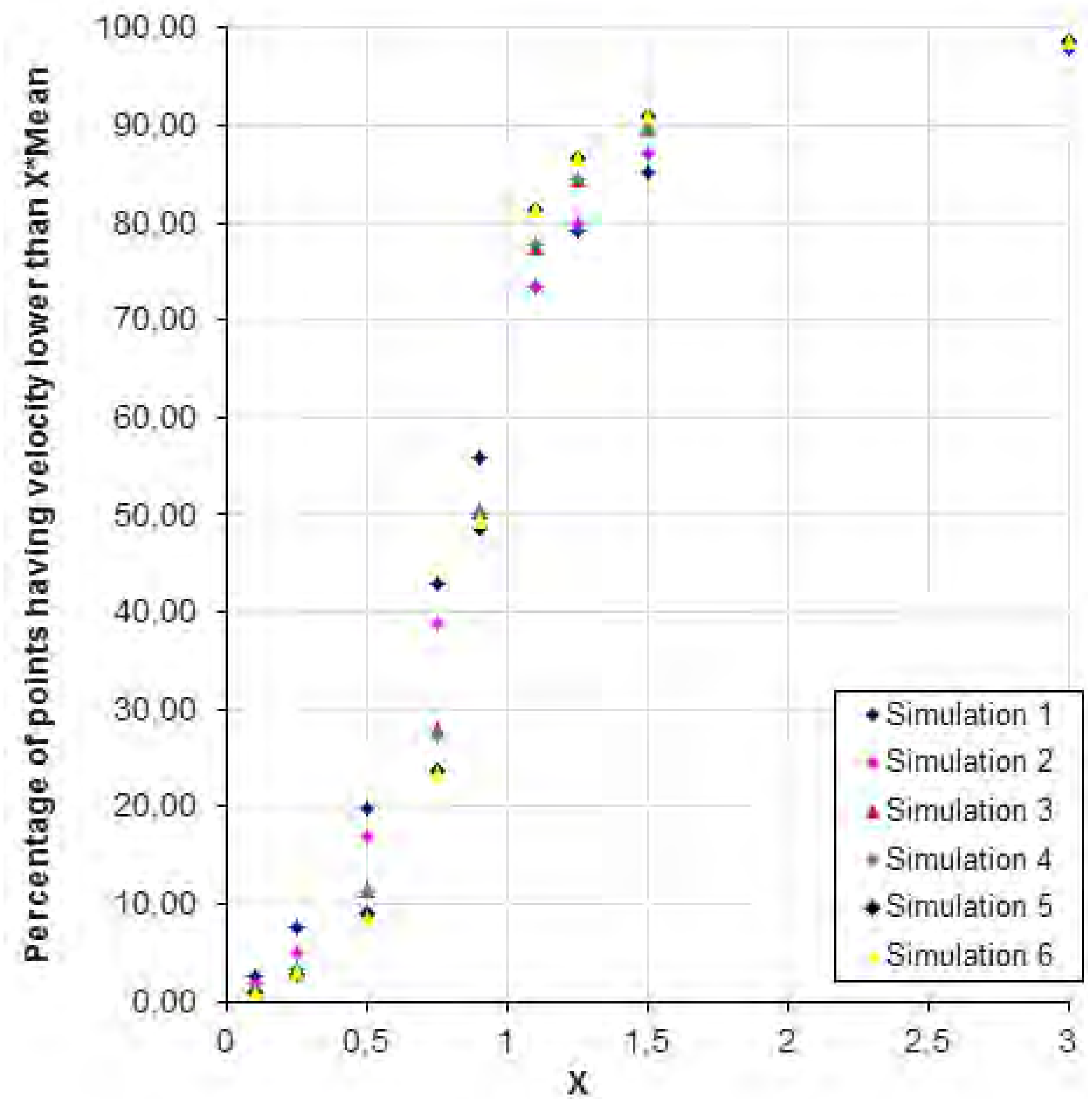
8x 15 mm openings

4.9 Quantitative comparison of the flow uniformity

- 2000 points on a rectangular grid
- Simulation 5 selected as the basis for a new frame design:

9% with $U < 0.5 \cdot U_{av}$ (19 to 20% in Sim. 1)

9% with $U > 1.5 \cdot U_{av}$ (15% in Sim. 1)



5 Conclusion

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

Final

Thank you for your attention

- 3 inl
  (with circular joints)
- 12 sectors
- short spacers:
  9 openings of 10 mm
- long spacers:
  4 openings of 15 mm