



**HAL**  
open science

# Lid-driven cavity highly turbulent flow subjected to high magnetic field

Luca Marioni, François Bay, Elie Hachem

► **To cite this version:**

Luca Marioni, François Bay, Elie Hachem. Lid-driven cavity highly turbulent flow subjected to high magnetic field . 10th PAMIR International Conference Fundamental and Applied MHD , Jun 2016, Cagliari, Italy. 2016. hal-01311023

**HAL Id: hal-01311023**

**<https://hal.science/hal-01311023v1>**

Submitted on 3 May 2016

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

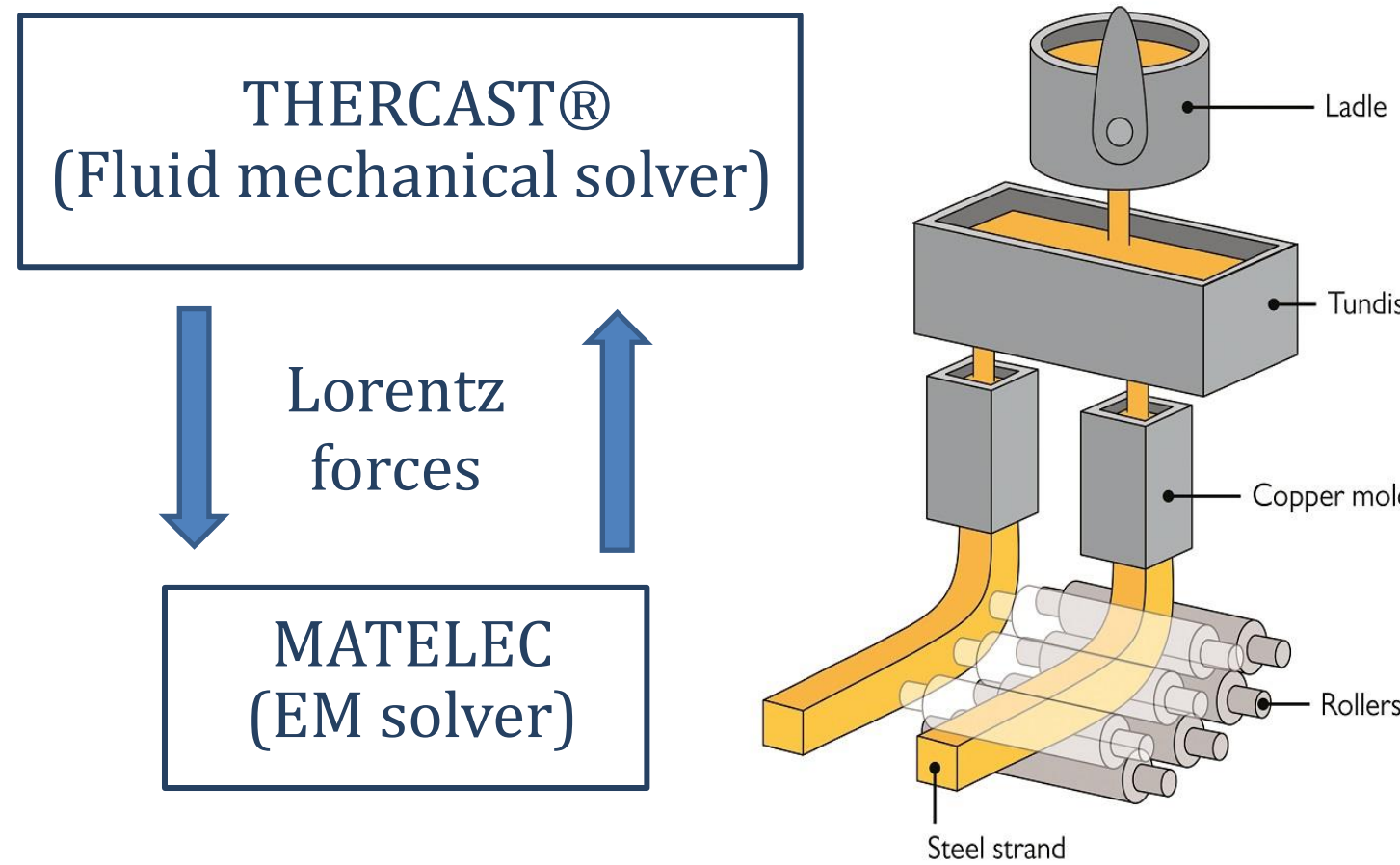
L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Lid-driven cavity highly turbulent flow subjected to high magnetic field

## Determination of critical time-step for explicit MHD schemes

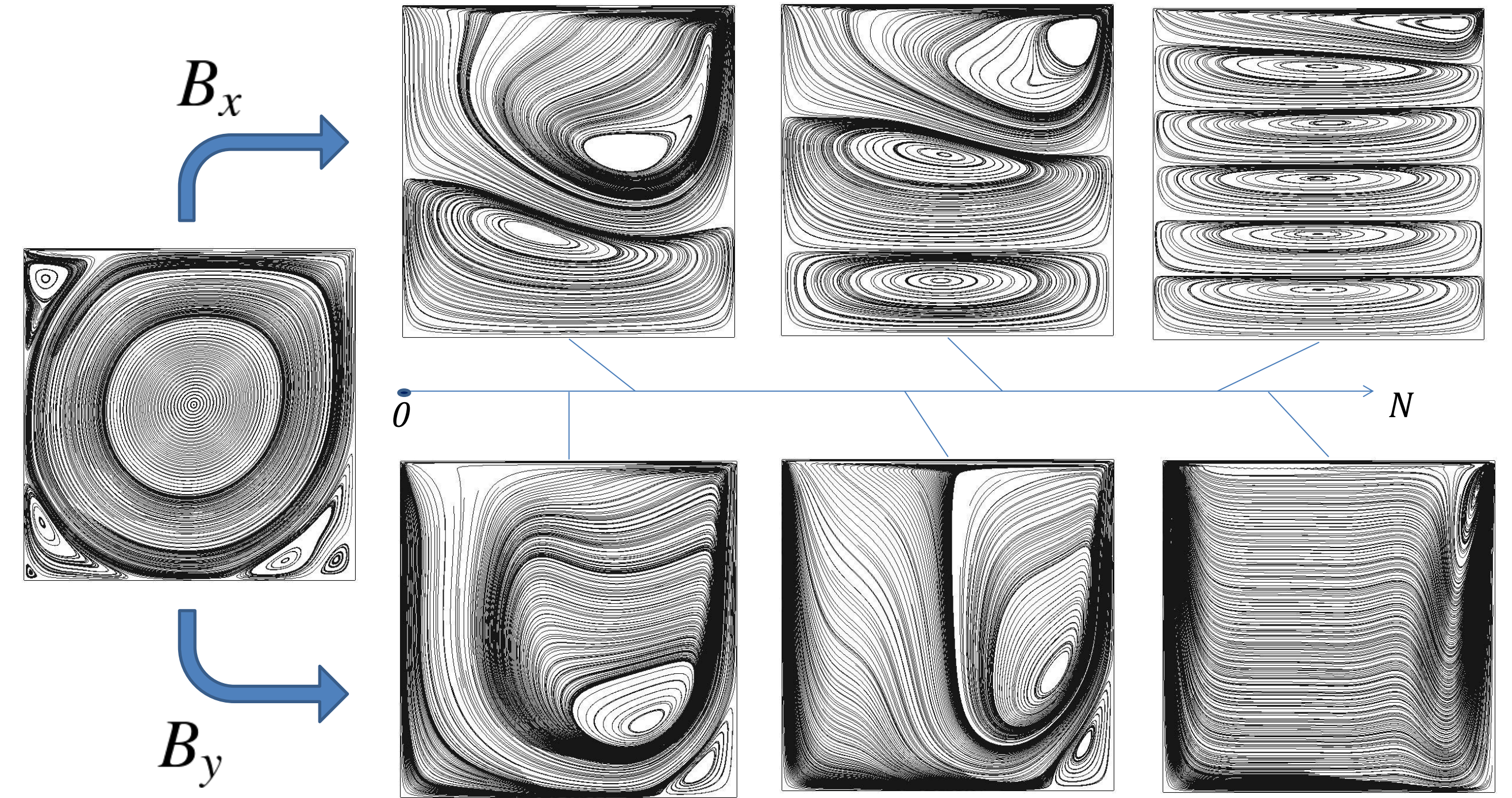
### Control of fluid flow in CC:

- Electromagnetic **braking** and **stirring** in **continuous casting** process of steel
- Coupled simulation in commercial software:



### A representative study case:

- Problem:
  - Highly **turbulent flow**
- Solution:
  - Impose a constant magnetic field to control and **brake the flow**
- Numerical procedure:
  - Lid-driven cavity benchmark<sup>[1]</sup>
  - Relate the **Stuart number** (N) to the target braking level



### Computational model:

Electromagnetic Field:

$$\Delta\phi = \partial_z(u_x B_y - u_y B_x) \equiv 0$$

Lorentz Forces:

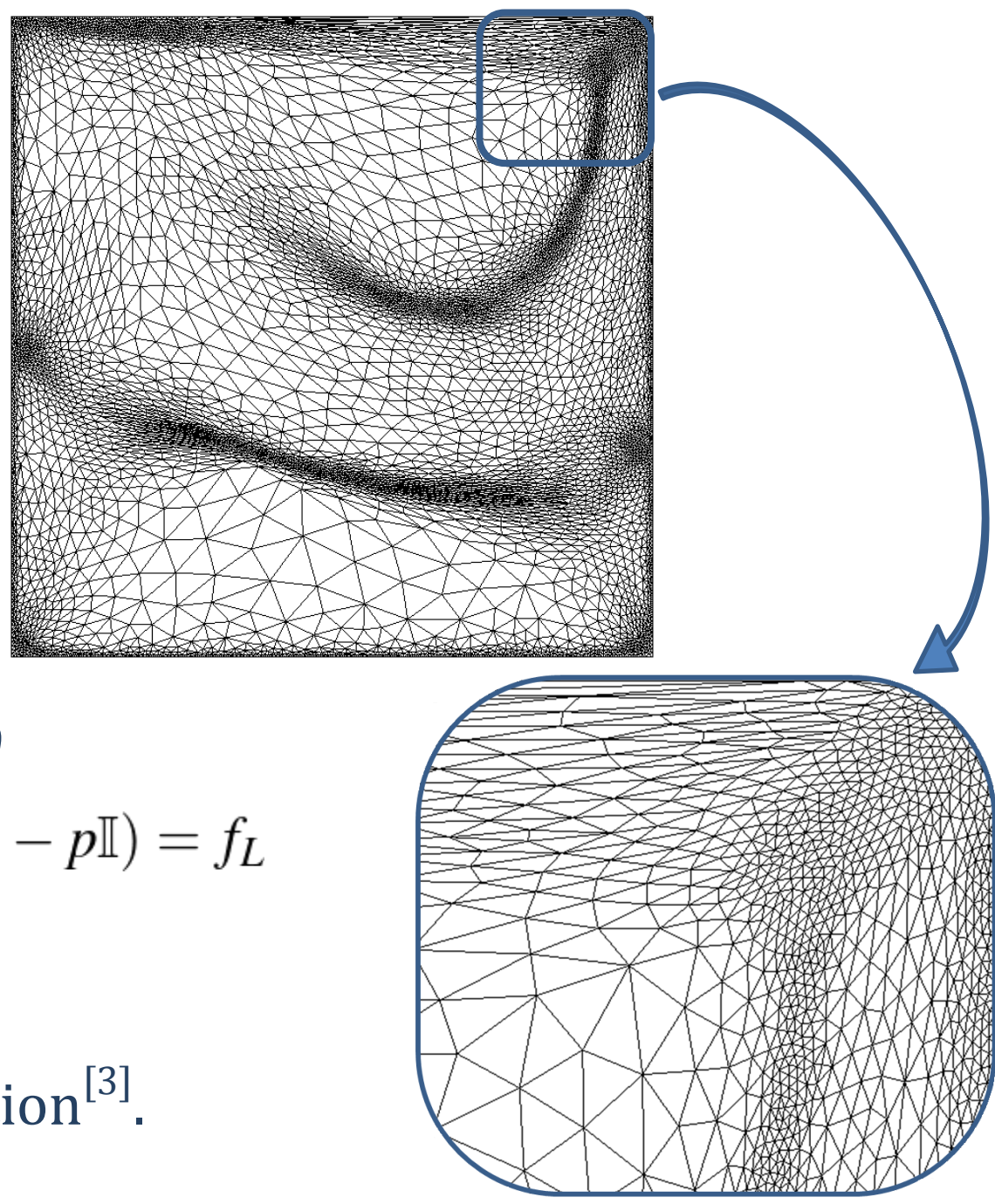
$$f_L = \sigma(u \times B) \times B$$

Navier-Stokes:

(multiscale stabilized FE<sup>[2]</sup>)

$$\begin{cases} \rho(\partial_t u + u \cdot \nabla u) - \nabla \cdot (2\mu \varepsilon(u) - p\mathbb{I}) = f_L \\ \nabla \cdot u = 0 \end{cases}$$

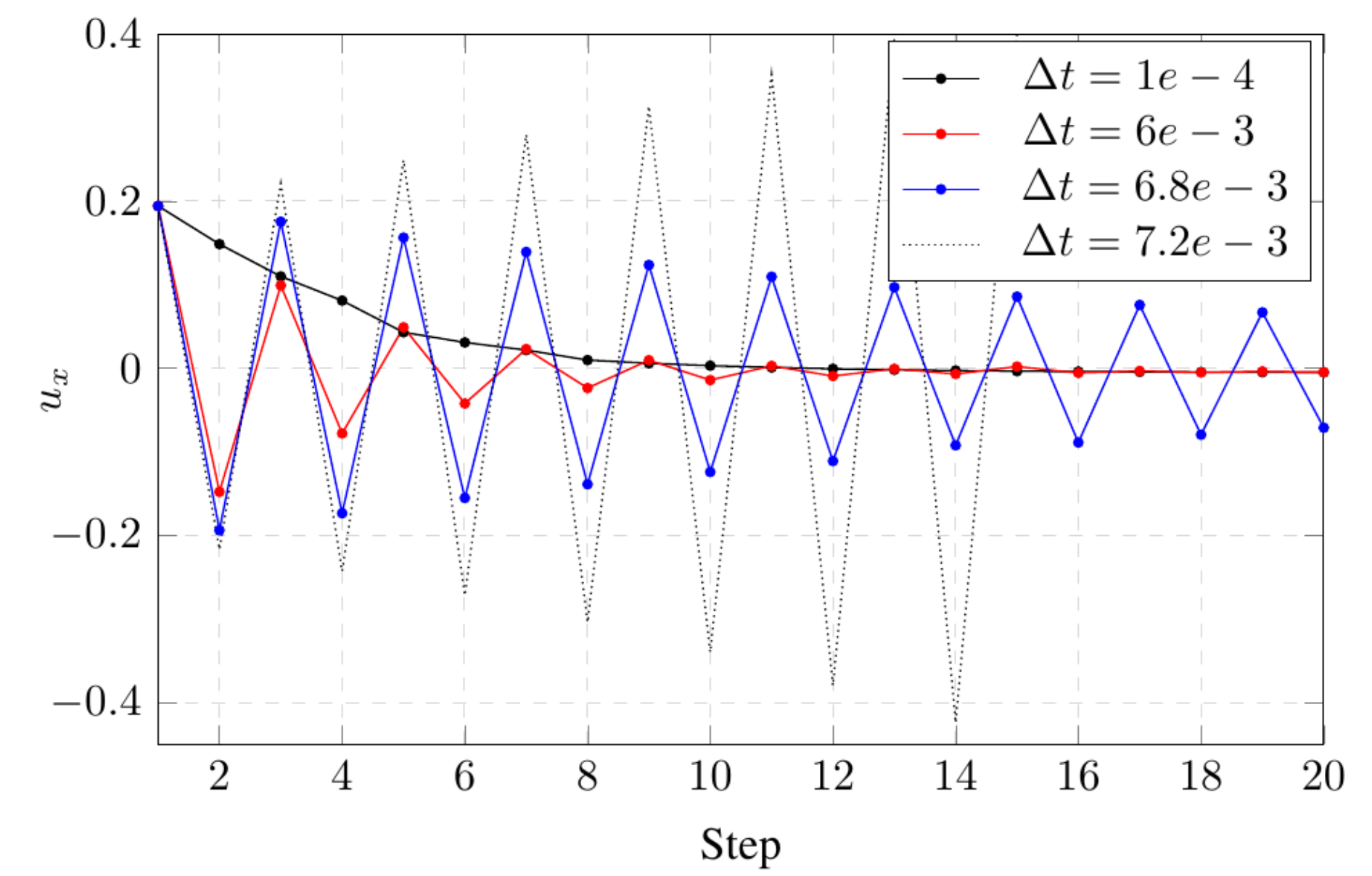
Anisotropic mesh adaptation<sup>[3]</sup>.



### Numerical instabilities:

- The Lorentz force is tracked **explicitly**.
- The excessive size of the time-step leads to completely brake the flow normally to  $B$  and to accelerate it in the opposite direction, i.e.  $u^n \cdot f_L^n < 0$ .
- The CFL condition is not capable anymore to guarantee **numerical convergence**.

$$\Delta t_{CFL} < C \frac{h}{u}$$

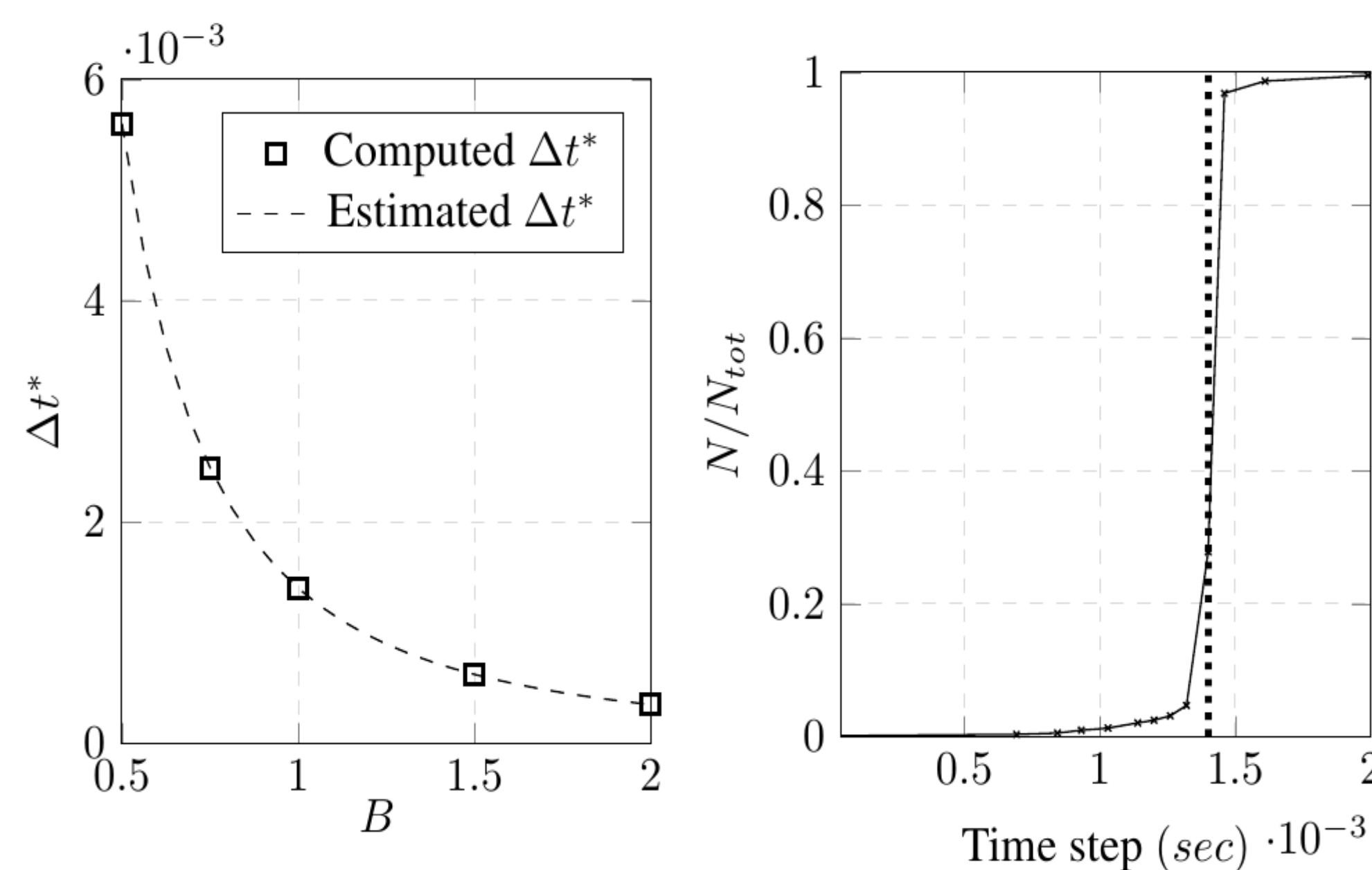
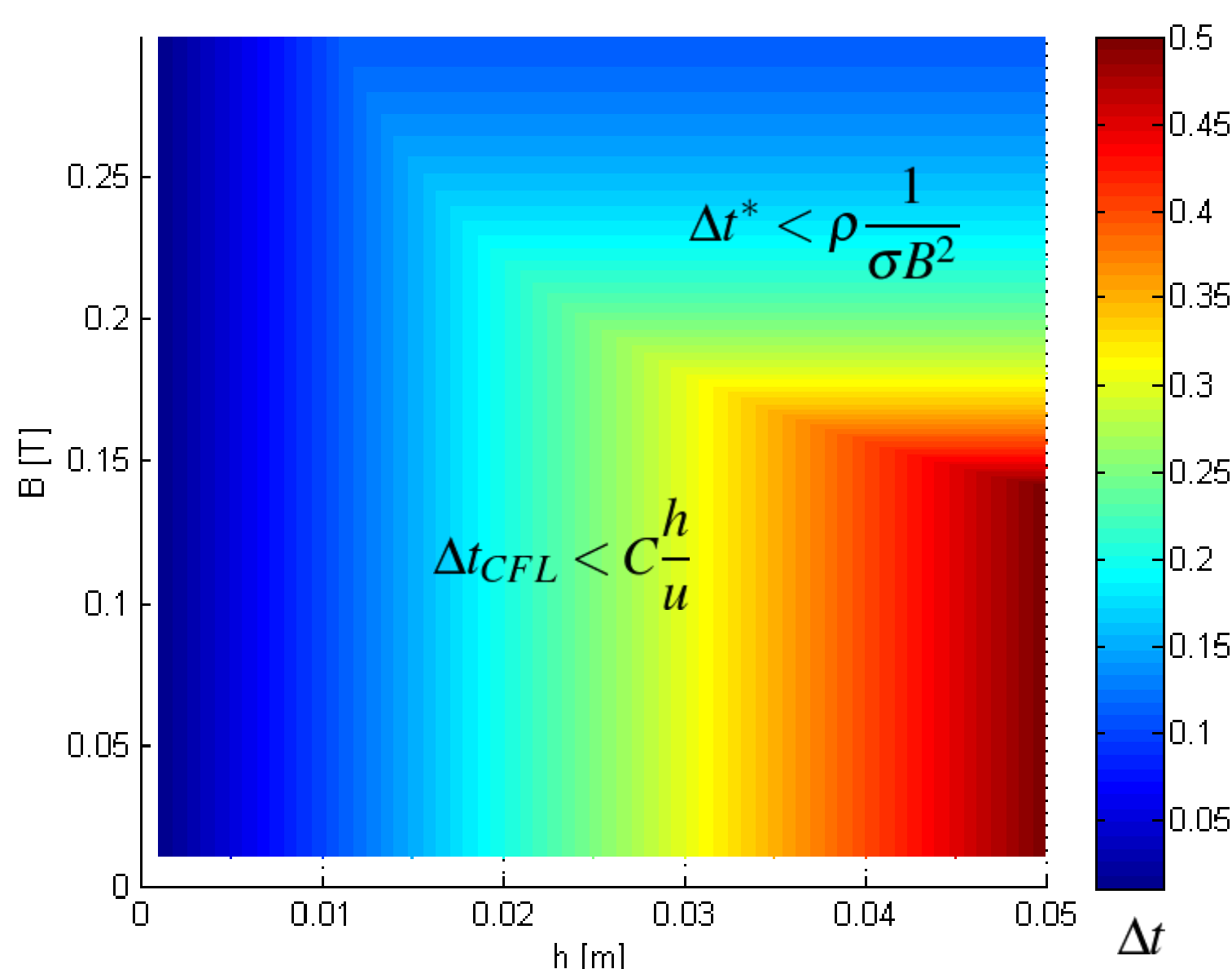
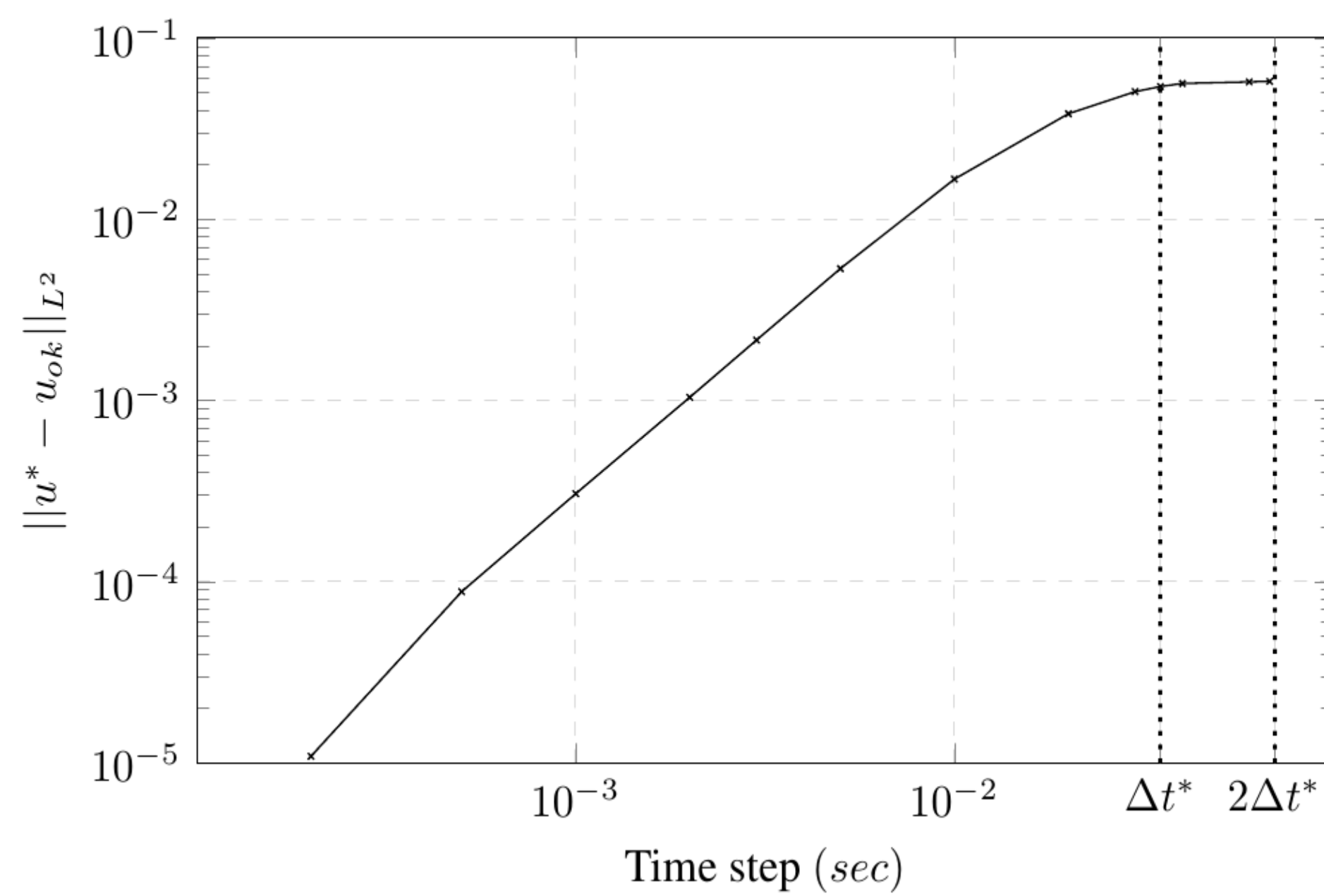


### Determination of the critical time-step:

➤ Solution:

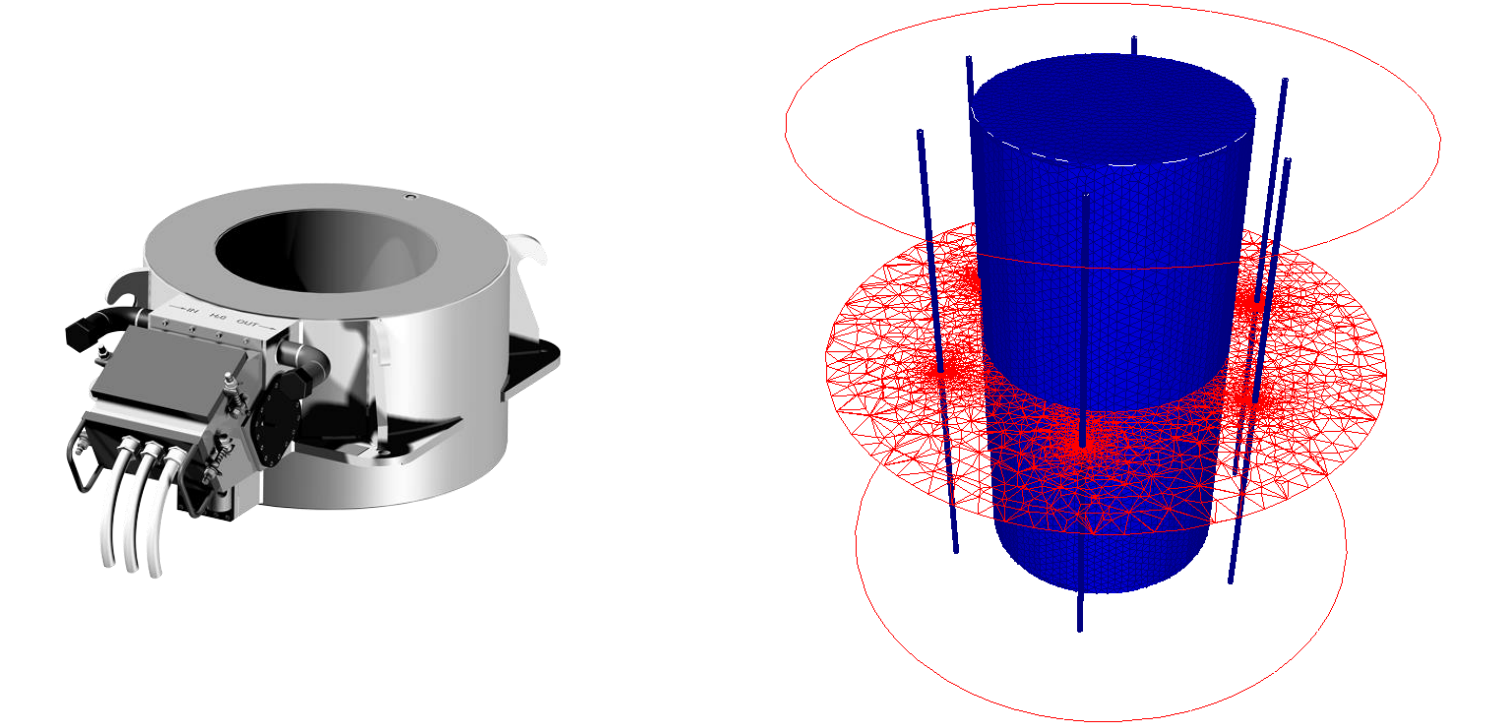
- Computation of the **limit time-step** as the time-step which leads to a complete dissipation of the kinetic energy within one time increment when the magnetic field is normal to the velocity.

$$\Delta t^* < \rho \frac{1}{\sigma B^2}$$



### Conclusions & Perspectives:

- The flow is highly affected by the magnetic field and its direction.
- In some configurations, the CFL condition is not enough to guarantee the **numerical convergence**.
- A new **time-step threshold** which guarantees convergence in **explicit schemes** is proposed.
- An **implicit** modelling of the Lorentz force has to be included in the multiscale stabilized finite-elements solver.
- The braking effect will be taken into account in the complete simulation of **electromagnetic stirring**.



### Acknowledgements:

The authors would like to gratefully thank Transvalor for funding this research and for the continuous support which allowed the full exploitation of its software's capabilities.

### References:

- [1] U. Ghia, K. N. Ghia, and C. Shin. High-resolution for incompressible flow using the Navier-Stokes equations and a multigrid method. *Journal of computational physics*, 48(3):387–411, 1982.
- [2] E. Hachem, B. Rivaux, T. Kloczko, H. Dignonnet, and T. Coupez. Stabilized finite element method for incompressible flows with high Reynolds number. *Journal of computational physics*, 229:8643–8665, 2010.
- [3] T. Coupez and E. Hachem. Solution of high-Reynolds incompressible flow with stabilized finite element and adaptive anisotropic meshing. *Computer Methods in Applied Mechanics and Engineering*, 267:65–85, 2013.

