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Investigation of « vortex self turbulence » and Reynolds number effects for wake decay and transport IGE

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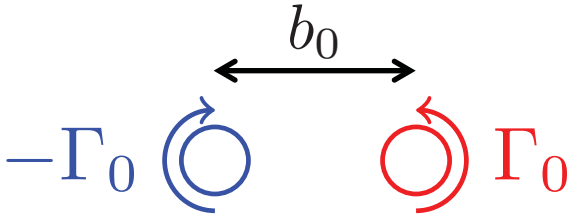
Aim of this work

- Provide realistic simulation of a turbulent wake vortex system interacting with the ground…



$$Re = \frac{\Gamma_0}{\nu}$$

$$V_0 = \frac{\Gamma_0}{2\pi b_0}$$

$$t_0 = \frac{b_0}{V_0}$$

- …in the worst possible case: no background turbulence, no head wind, no cross wind, vortex system parallel to ground, no long-wave instability.
- and with more realistic two-vortex system, i.e., one that is « turbulent and at equilibrium ».

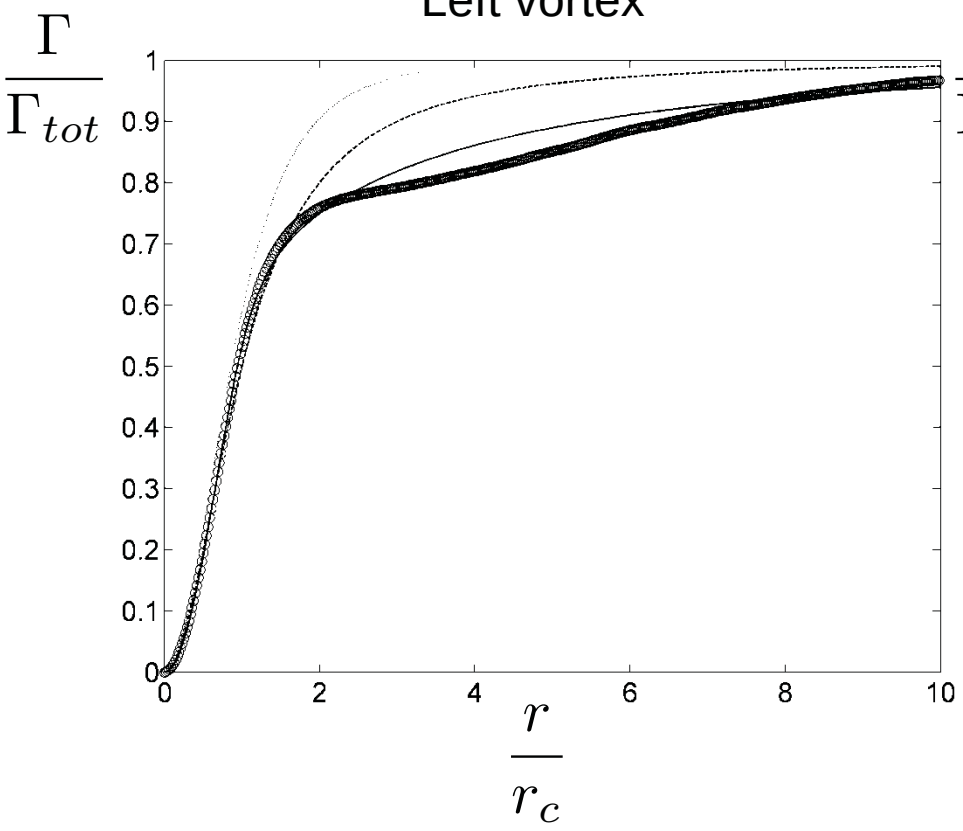
Equilibrium turbulent two-vortex system

- Burnham-Hallock two-vortex system (BH-2VS)
  - Simple as analytical; but Γ(r) not very realistic
  - No turbulence, added white noise with maximum amplitude of 1% of max u_θ

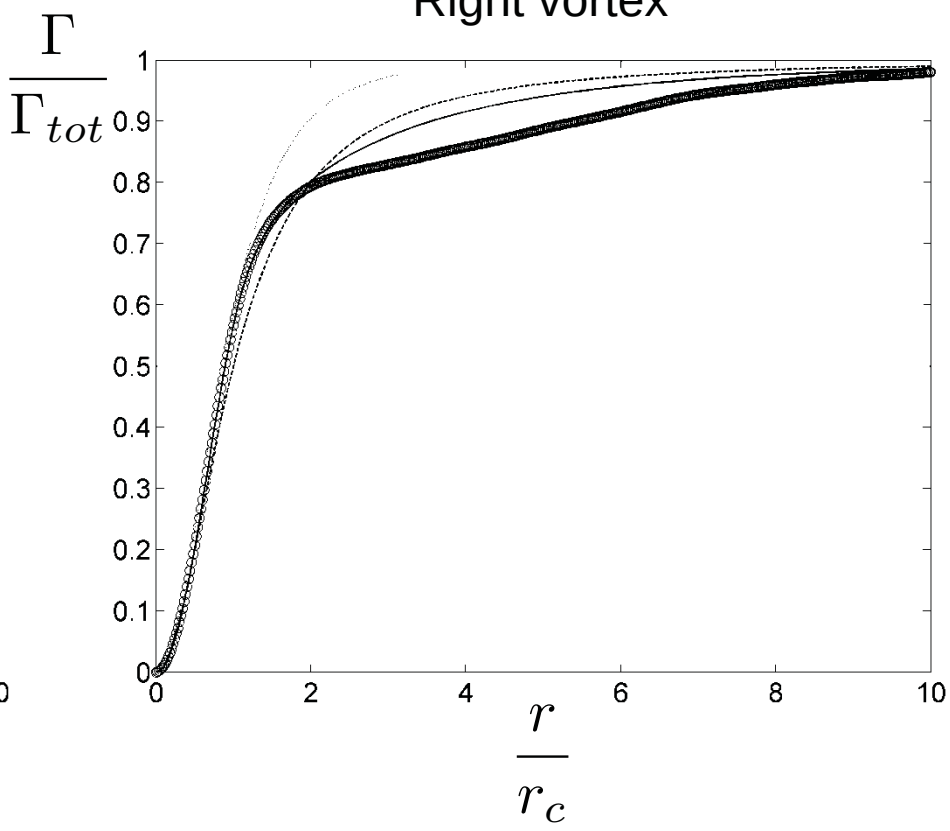
- We here wish a realistic turbulent two-vortex system (T-2VS)
- How we obtain it: (see Ph.D. theses L. Bricteux and I. De Visscher)
  - We put a BH-2VS, with $\frac{r_c}{b_0} = 0.05$, in a very weak turbulent atmosphere (here, its energy was roughly 1/130 of that of the 2VS)
  - We let this 2VS develop in time.
  - It indeed reaches a "turbulent equilibrium", with realistic turbulence and Γ(r)
  - Note that it maintains $\frac{r_c}{b_0} \approx 0.05$

Obtained T-2VS: circulation profile

Left vortex



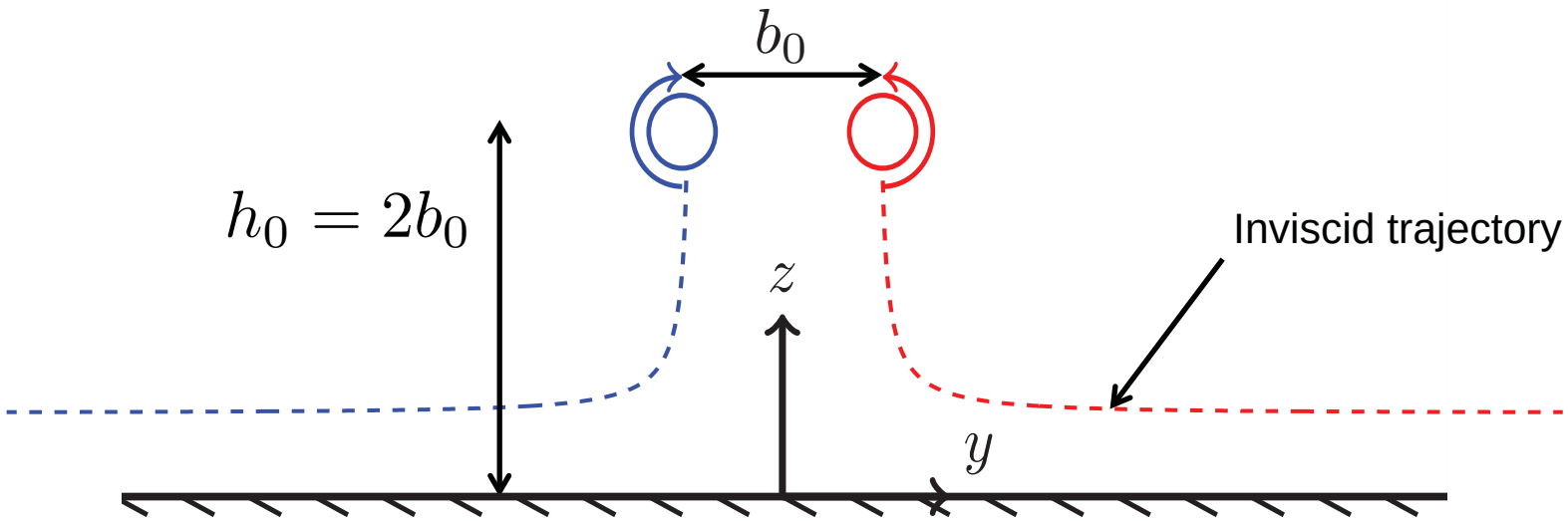
Right vortex



Ph.D. theses of L. Bricteux and I. De Visscher

- ∘ LES data (T-2VS)
- - - · Fit Low-order algebraic model (BH-2VS)
- ····· Fit High-order algebraic model
- —— Fit Proctor-Winckelmans model

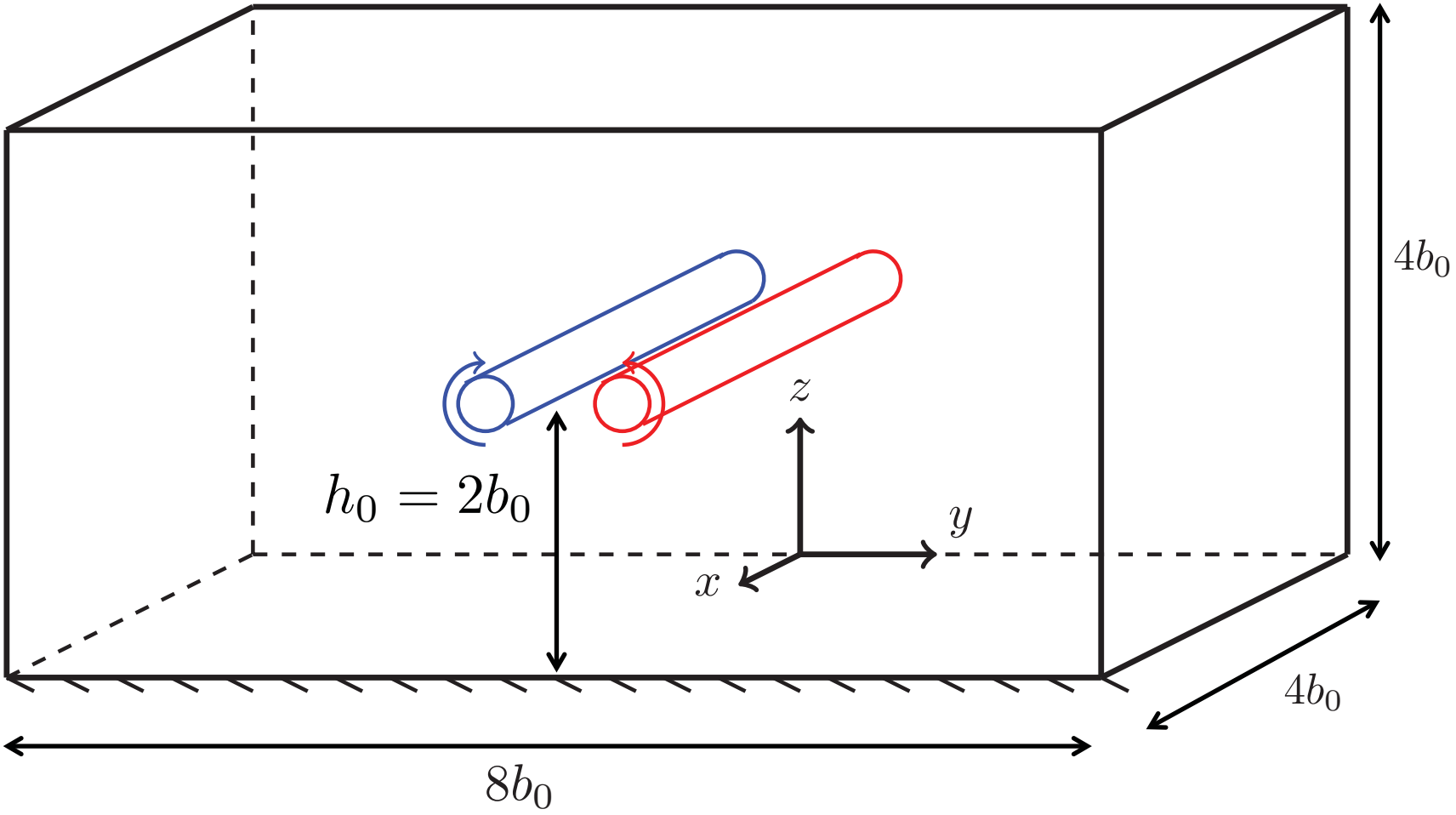
T-2VS initially released in near ground effect (NGE)



We here use:

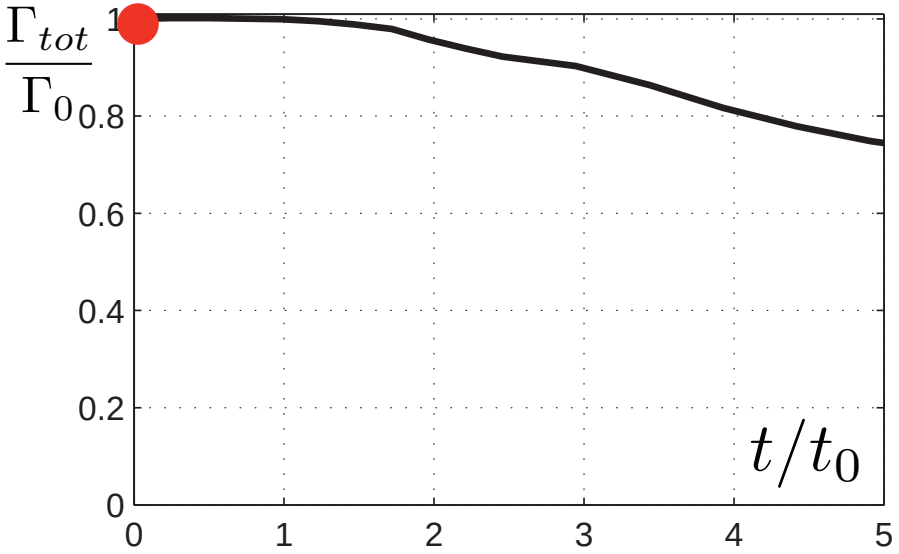
- $Re = \dfrac{\Gamma_0}{\nu} = 2.10^5$ which is 10 times higher than our previous LES simulations
- $h_0 = 2b_0$ which is twice higher than our previous LES simulations

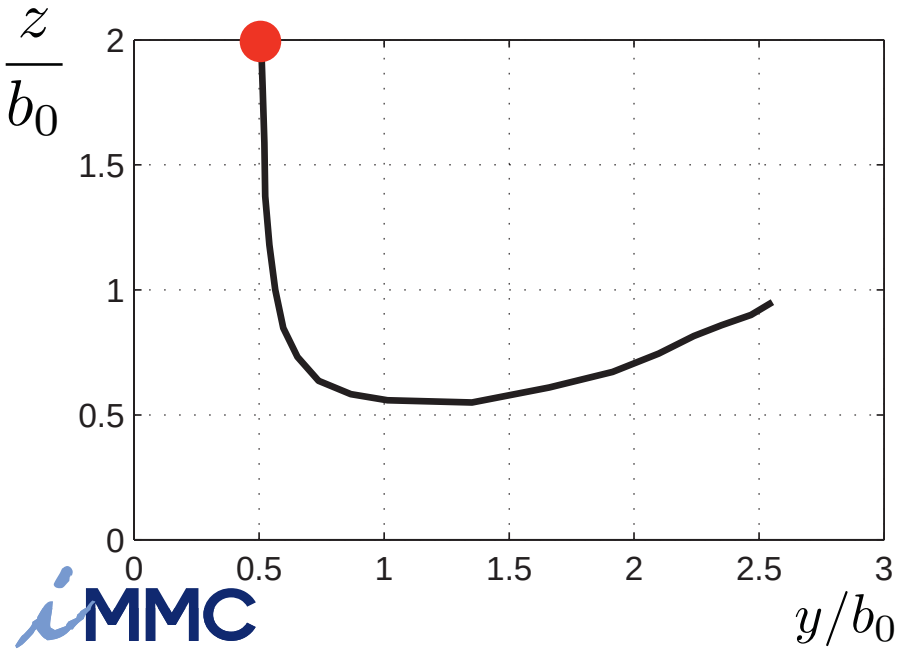
Numerical setup

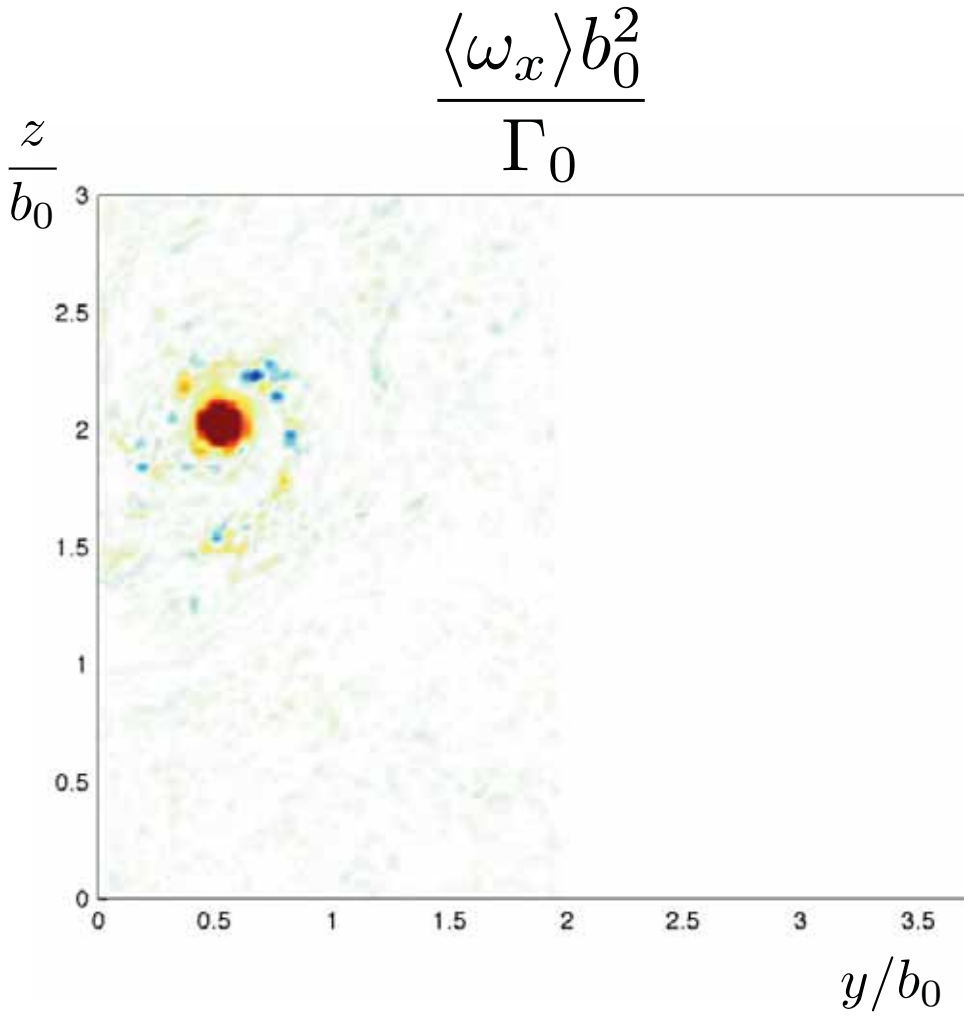


Code based on fourth order finite differences

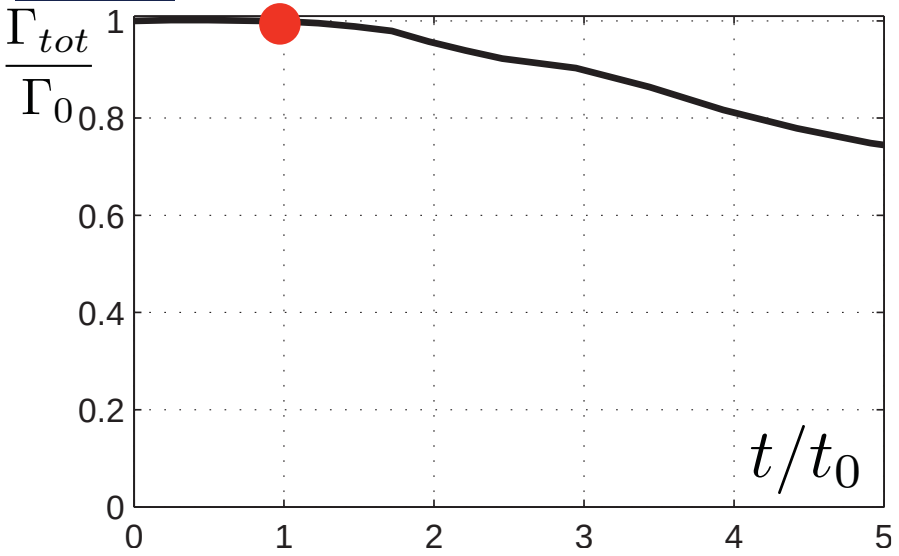
Diagnostics at Re=2.10^5 at t/t_0=0

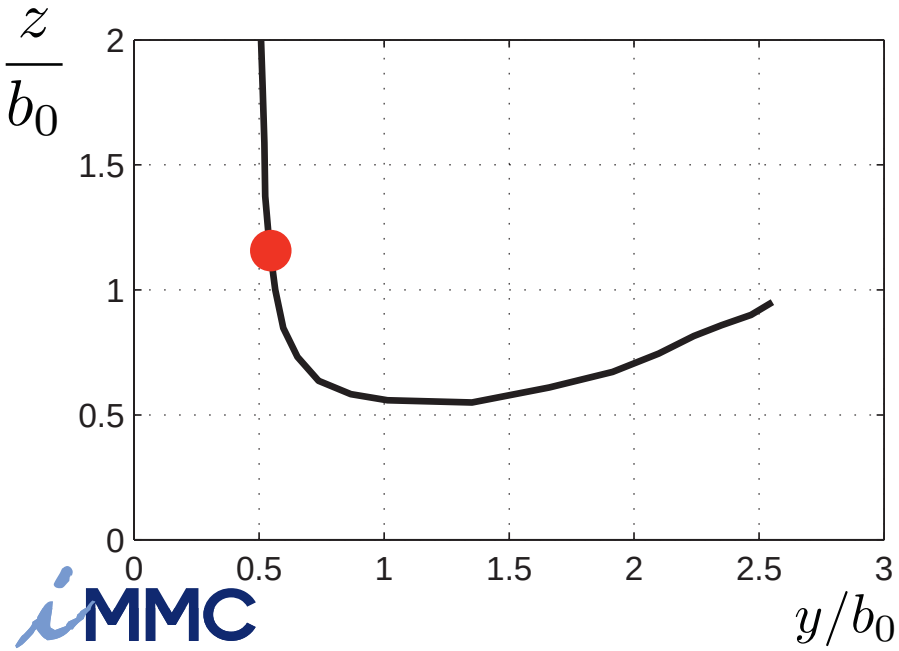


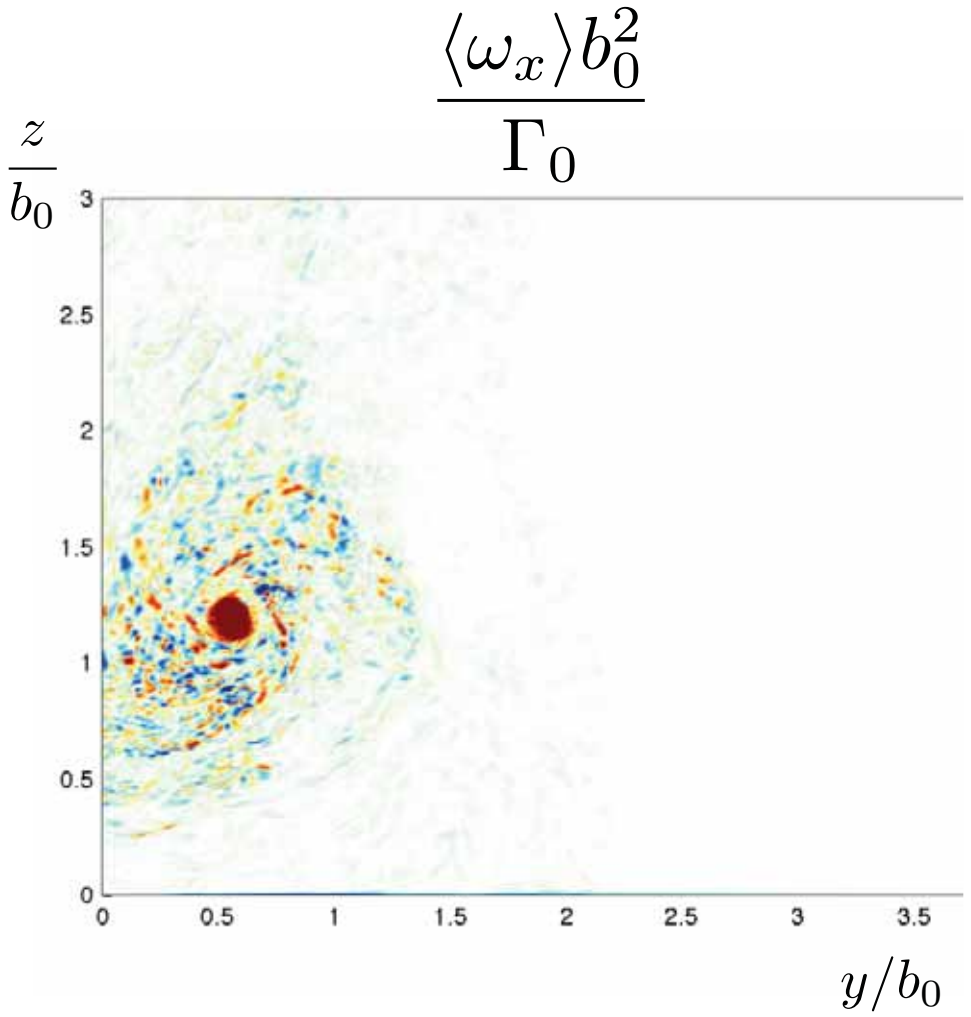




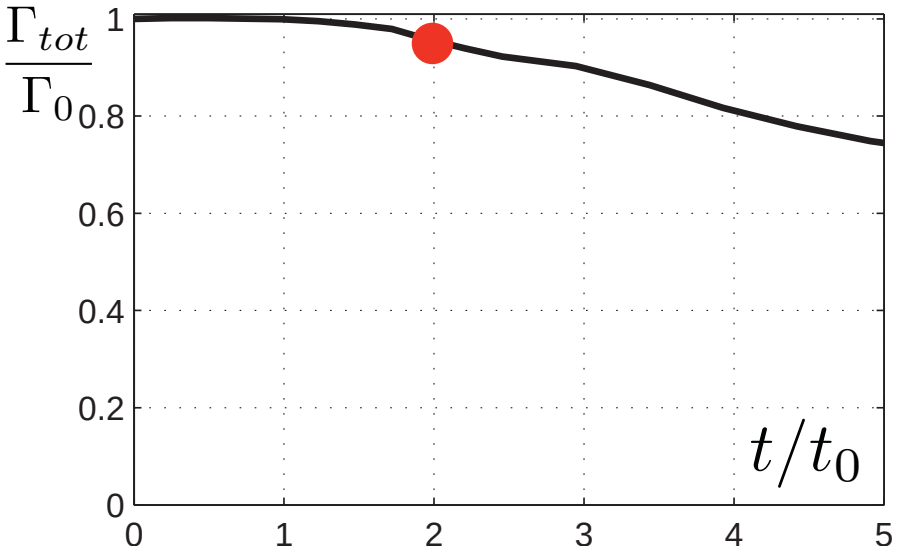
Diagnostics at Re=2.10^5 at t/t_0=1

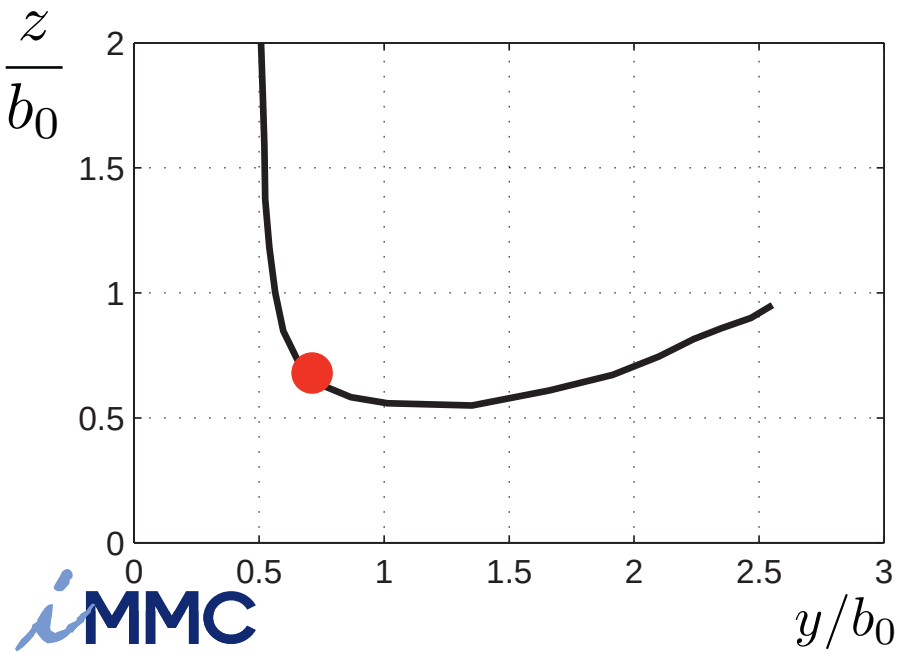


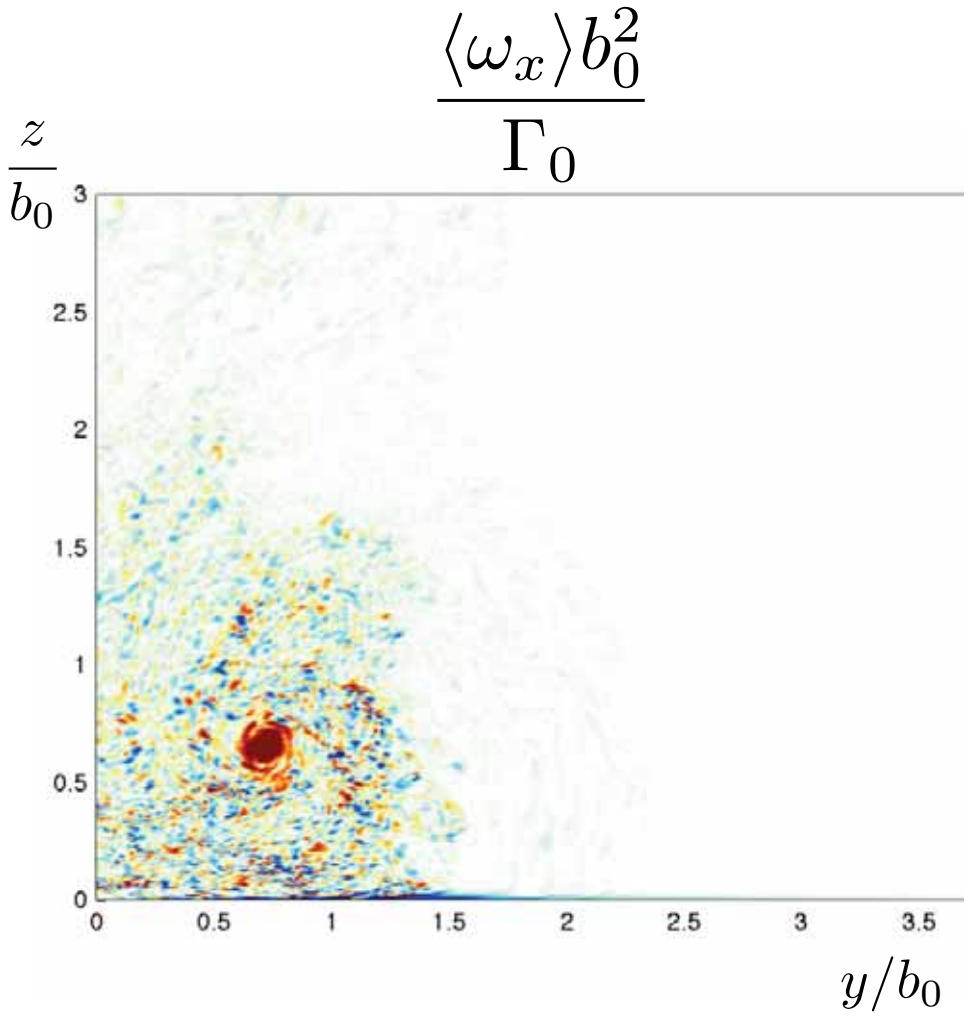




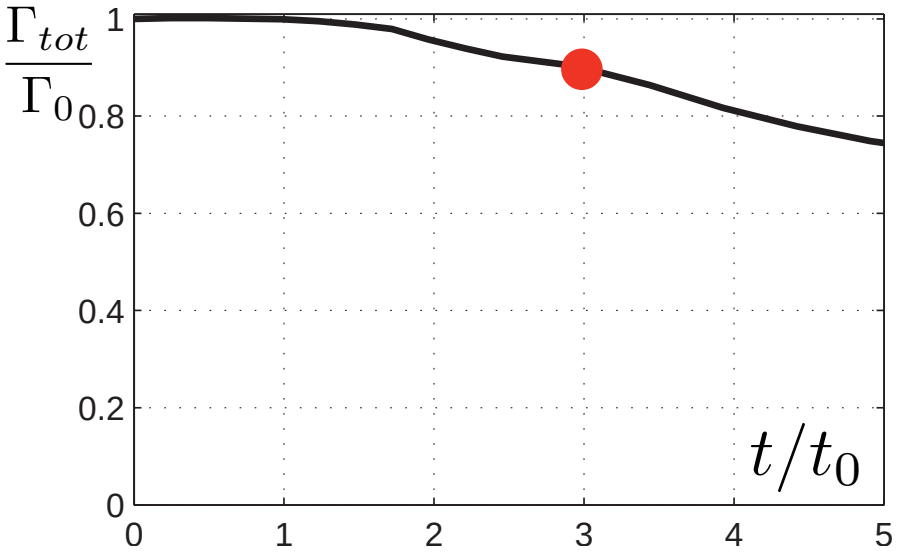
Diagnostics at Re=2.10^5 at t/t_0=2

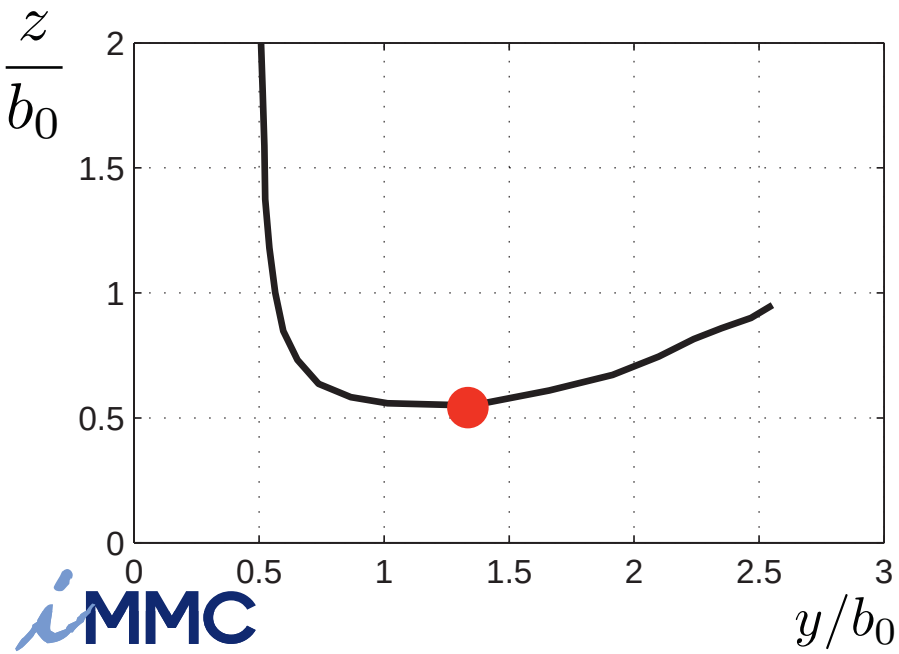


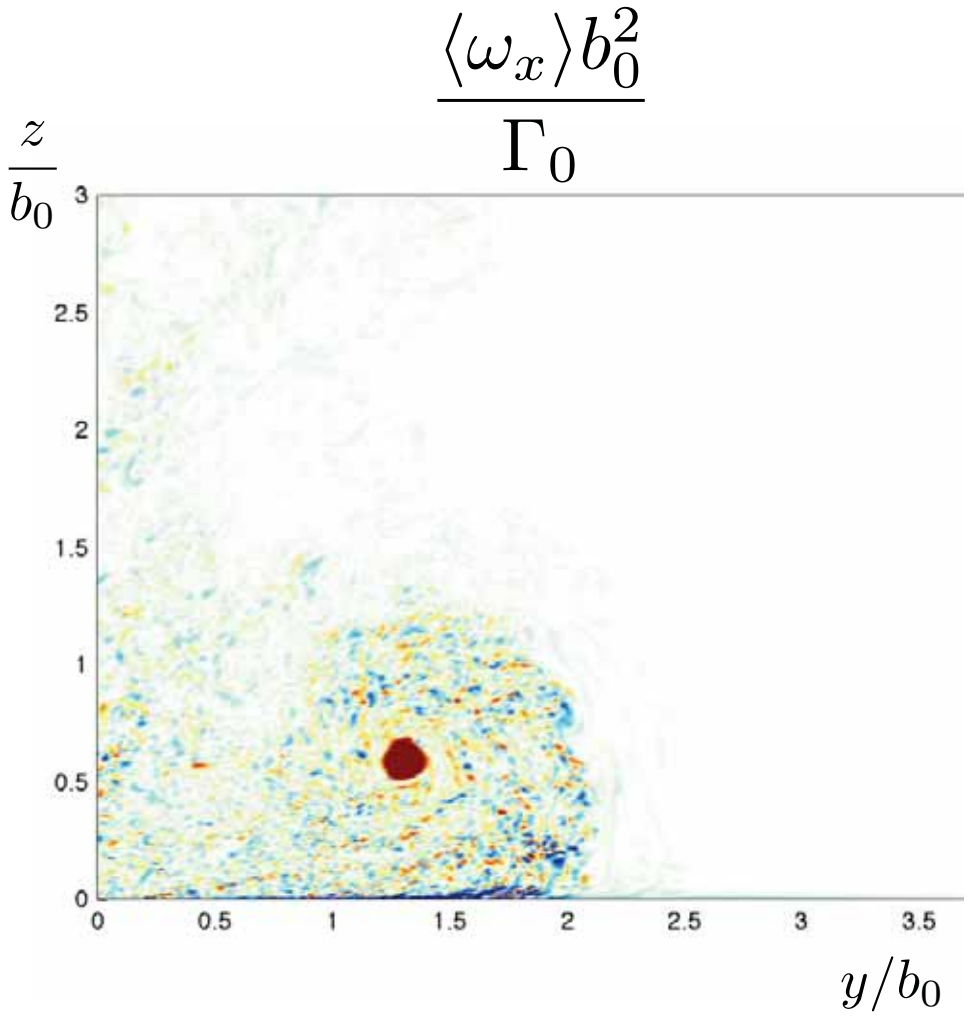




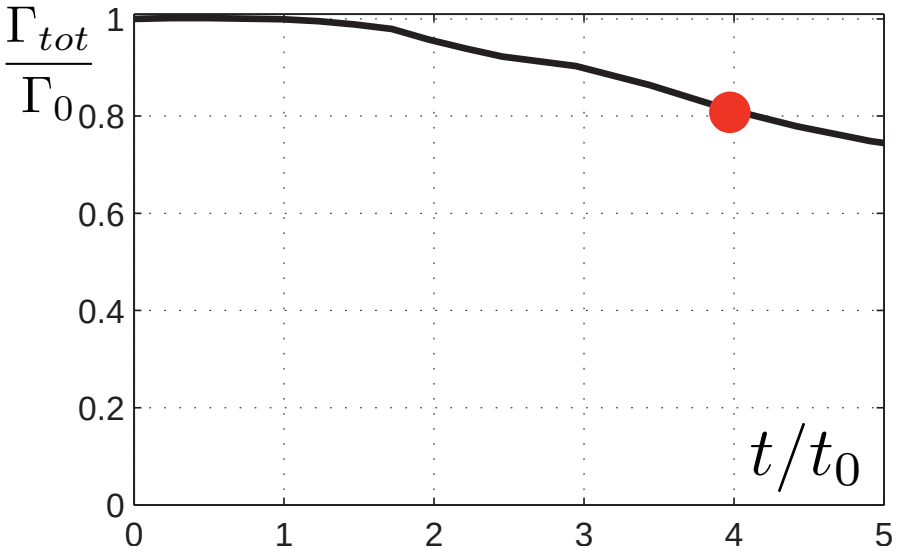
Diagnostics at Re=2.10^5 at t/t_0=3

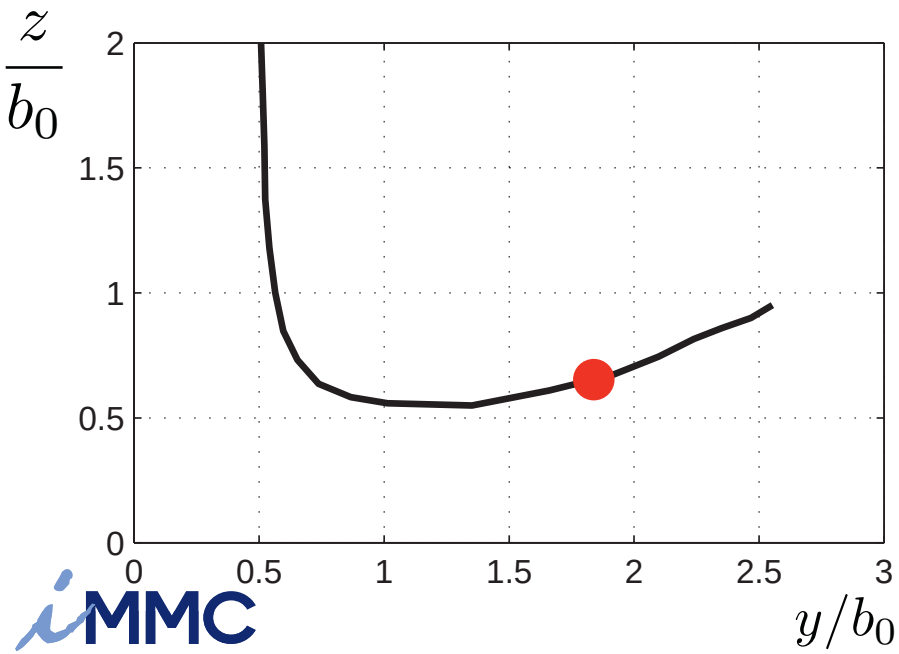


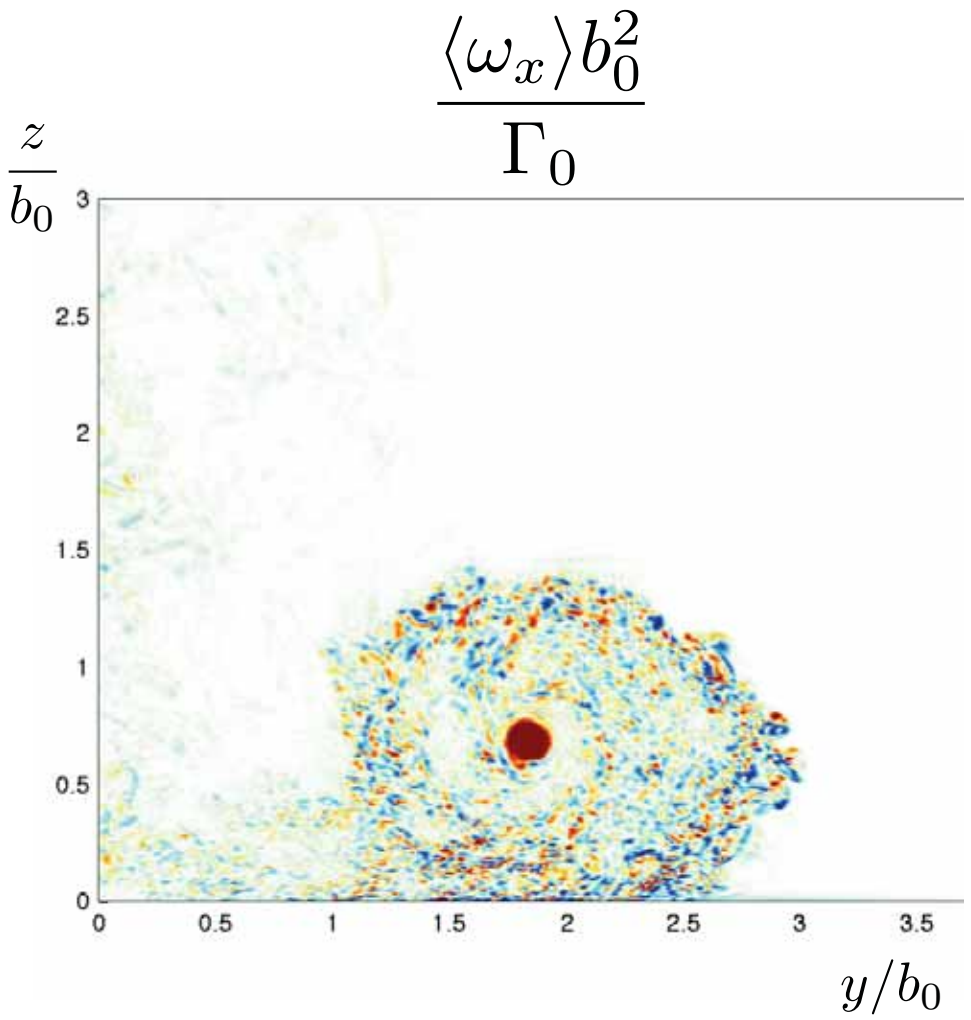




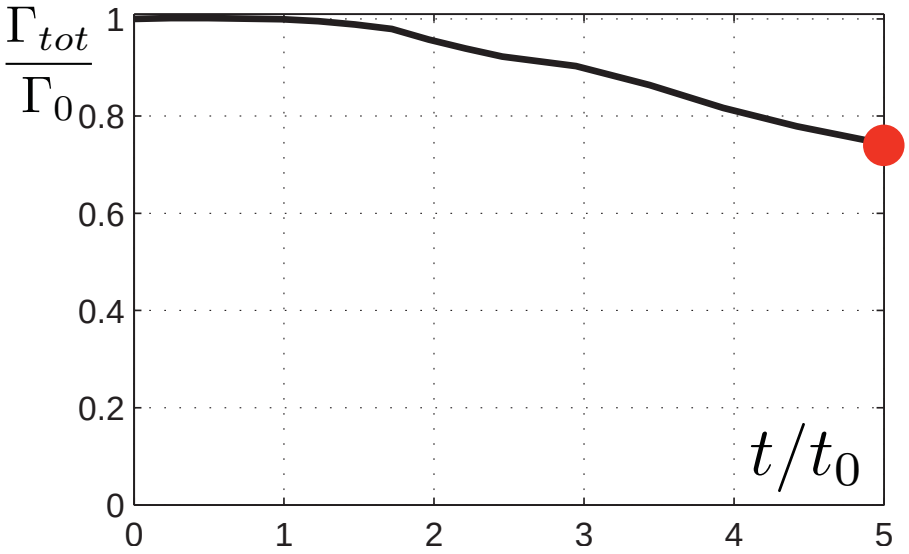
Diagnostics at Re=2.10^5 at t/t_0=4

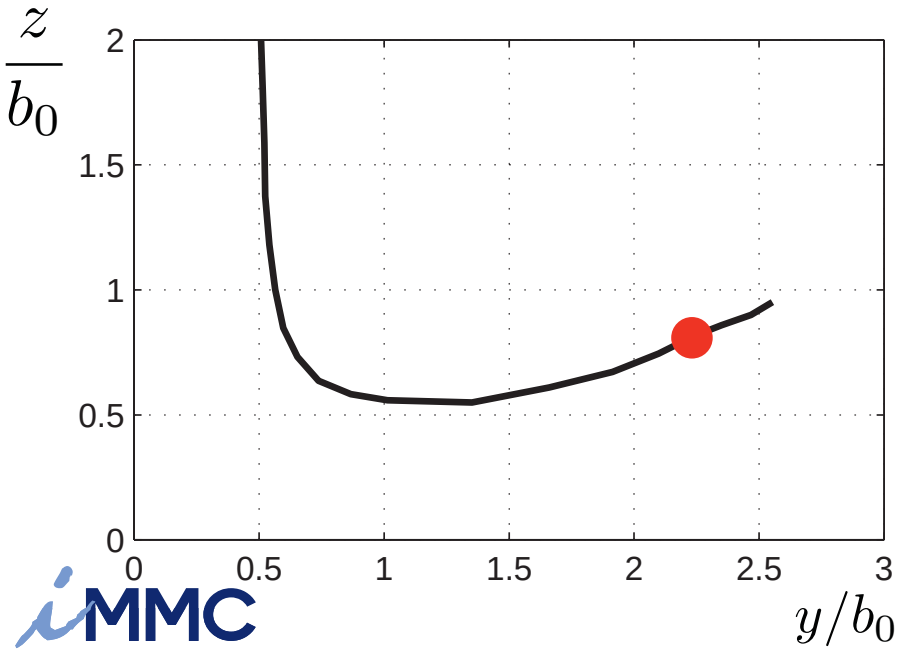


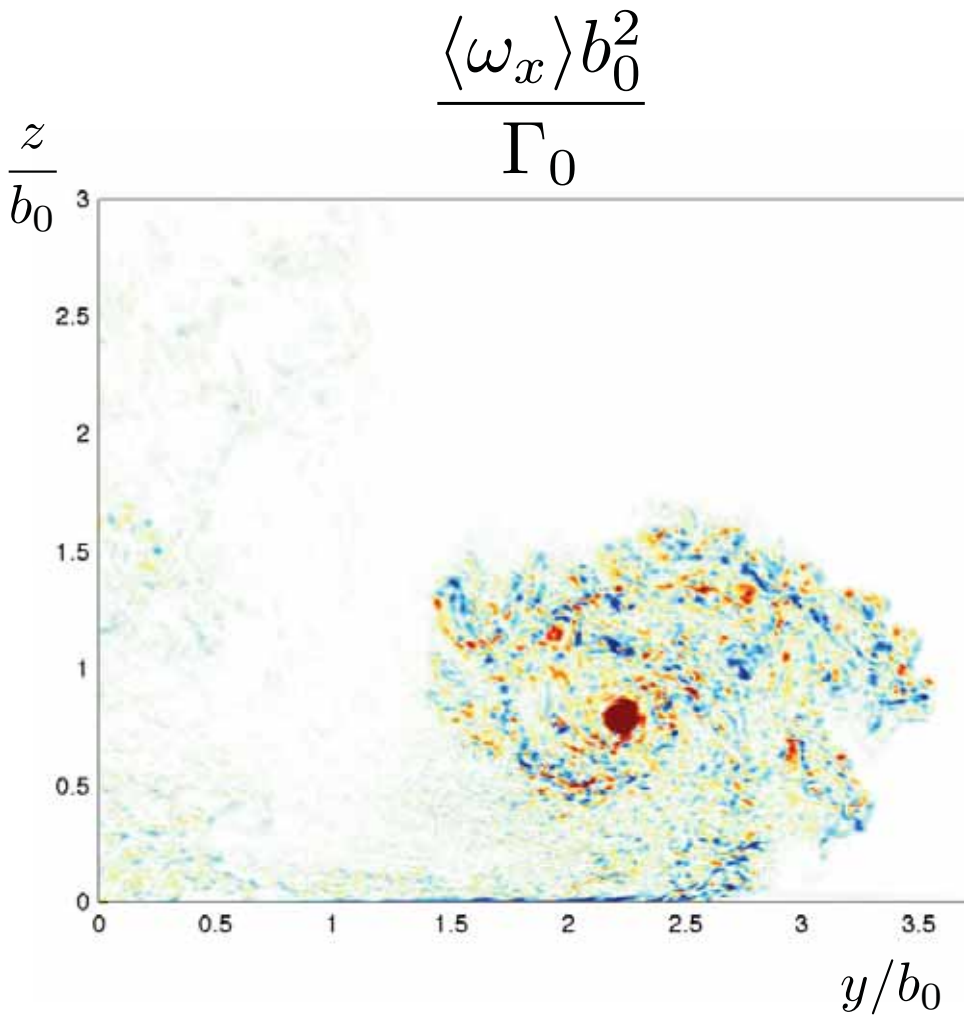




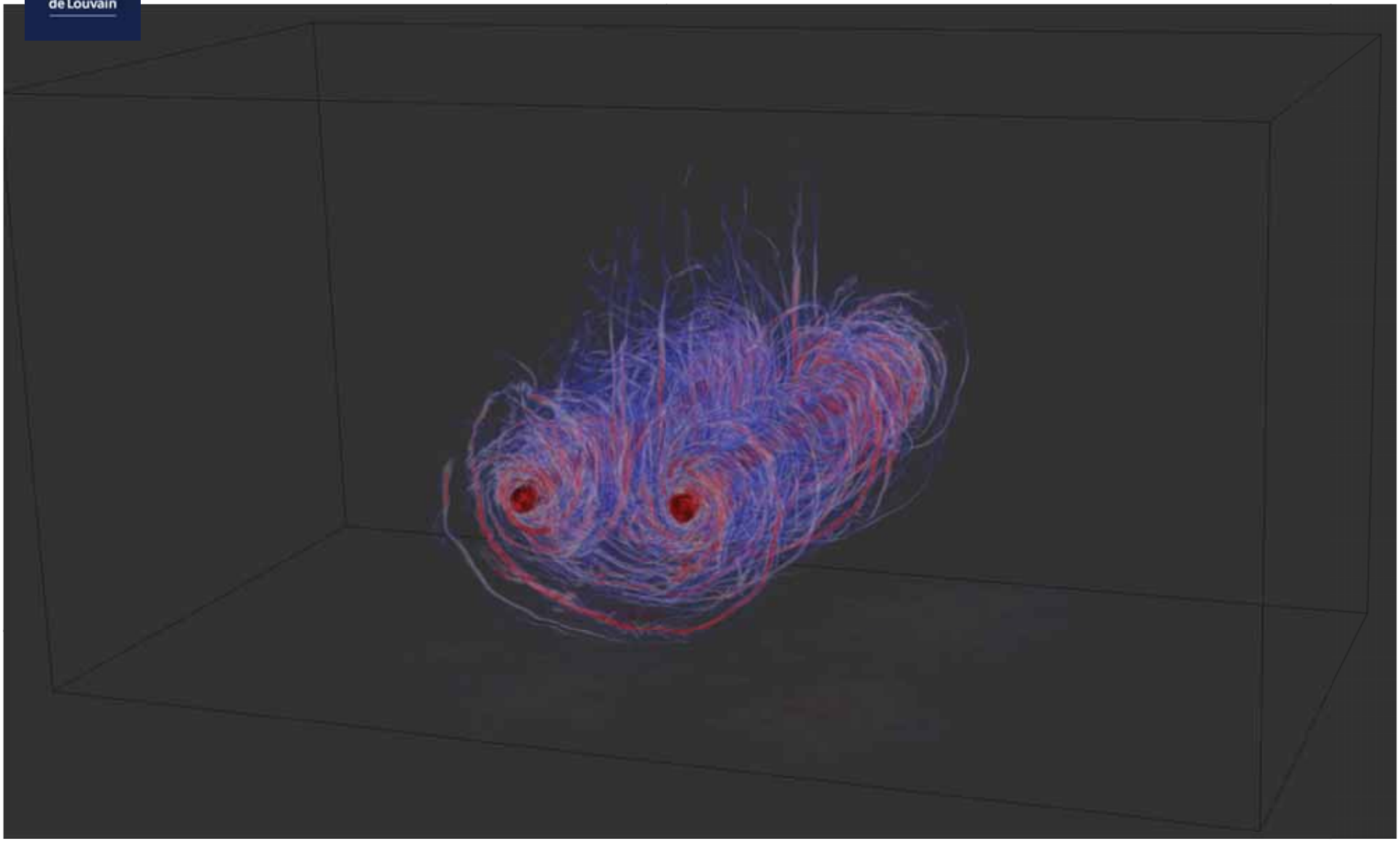
Diagnostics at Re=2.10^5 at t/t_0=5



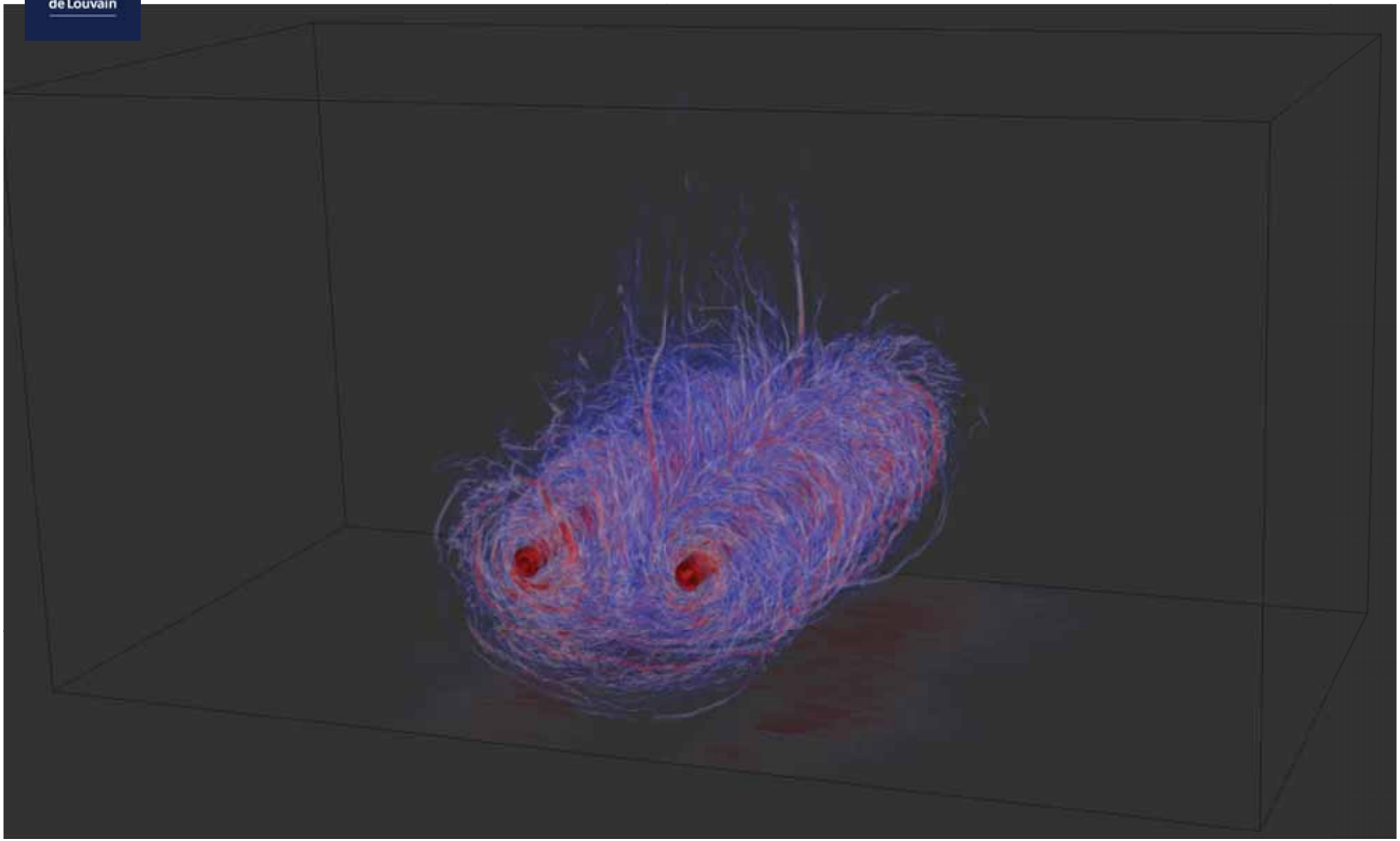




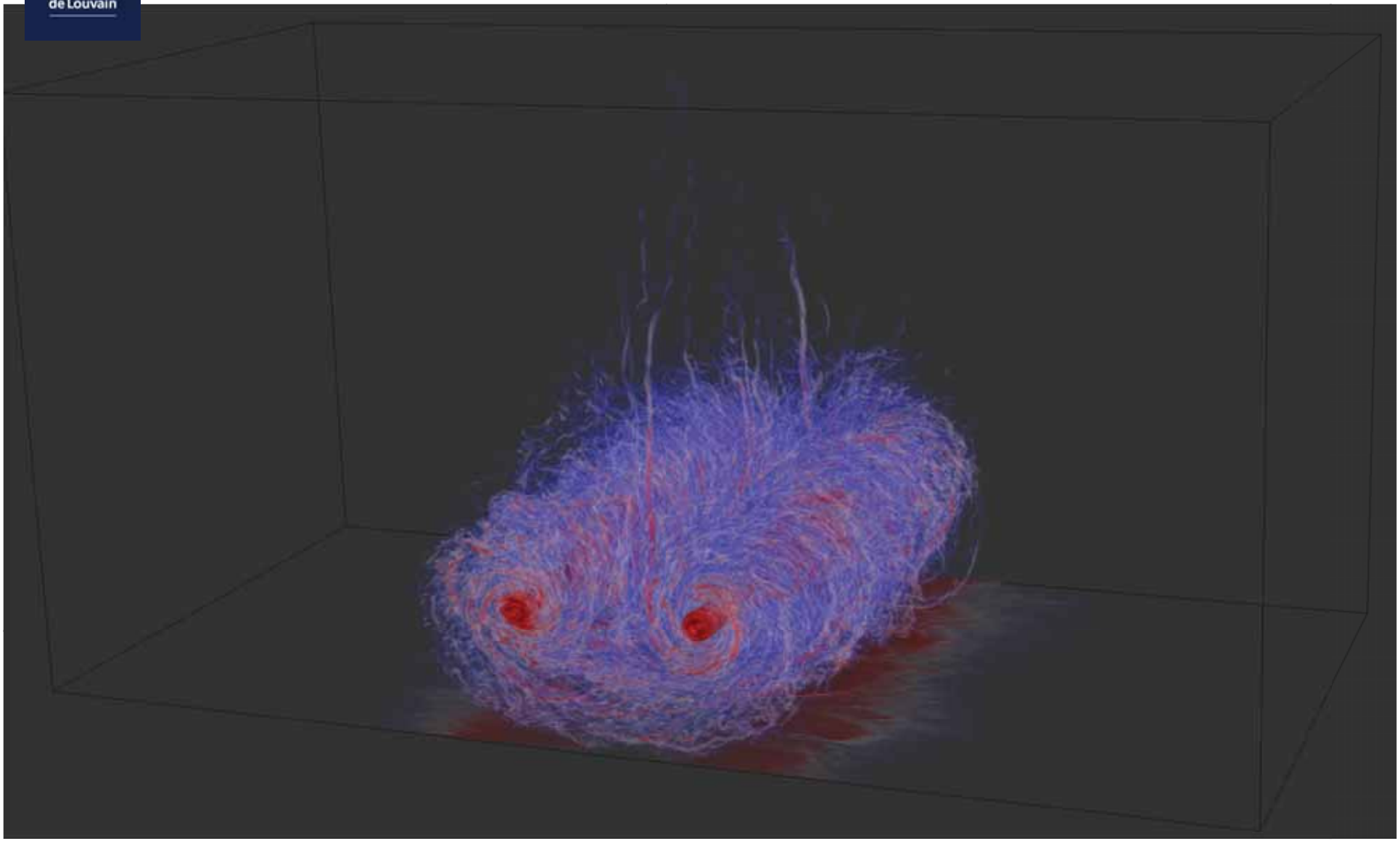
Flow topology at Re = 2.10^5 and t/t_0=0.5



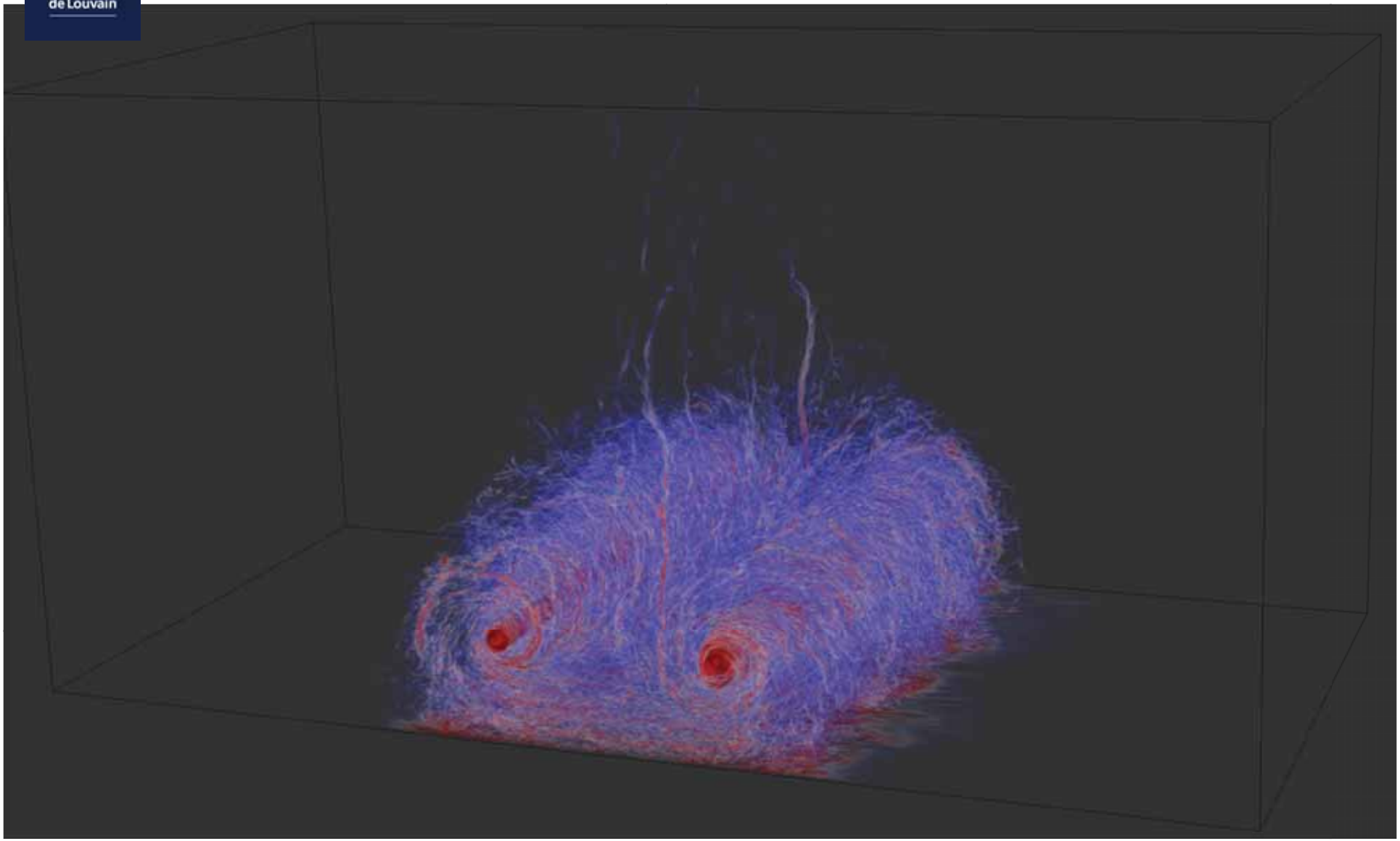
Flow topology at Re = 2.10^5 and t/t_0=1.0



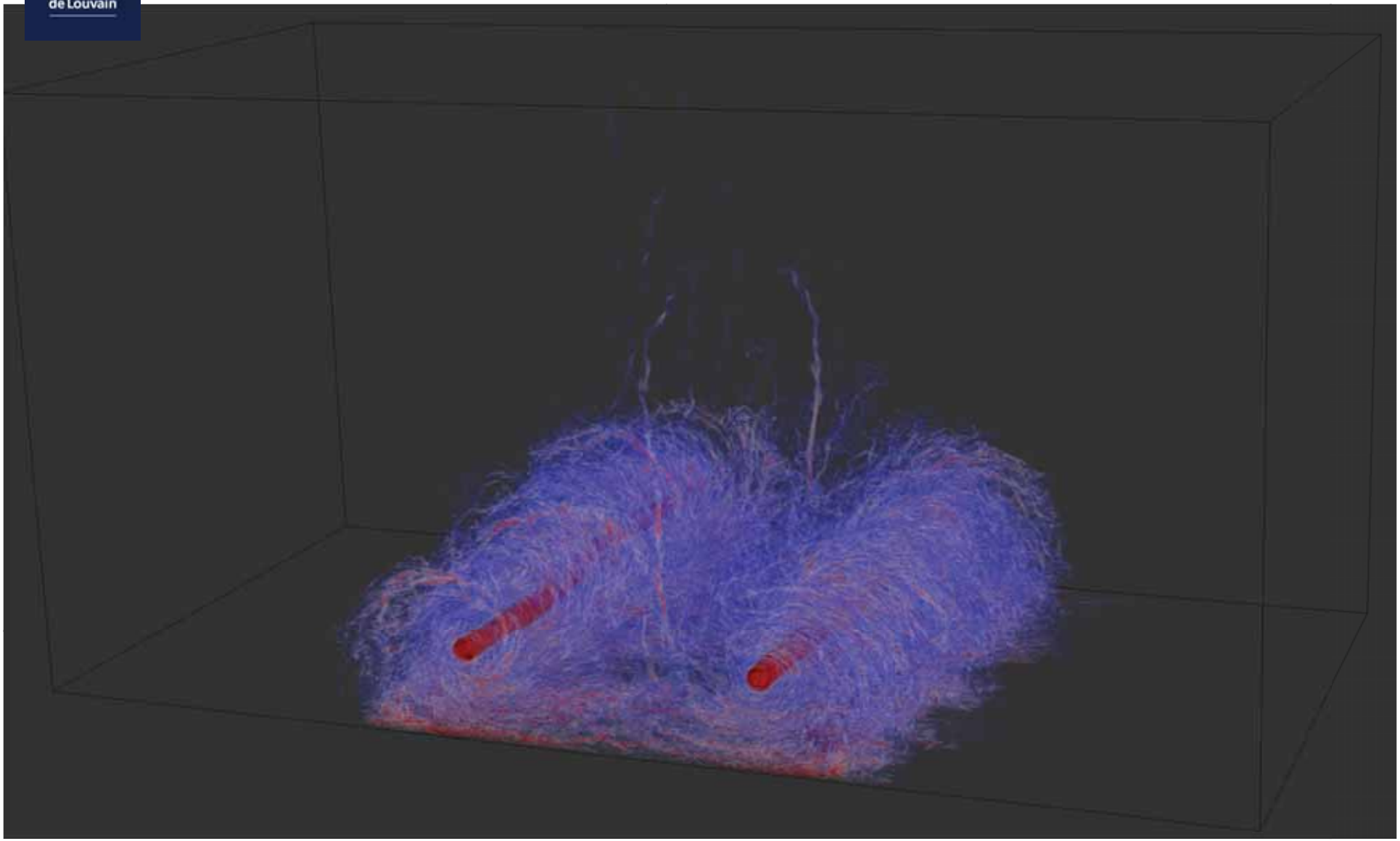
Flow topology at Re = 2.10^5 and t/t_0=1.5



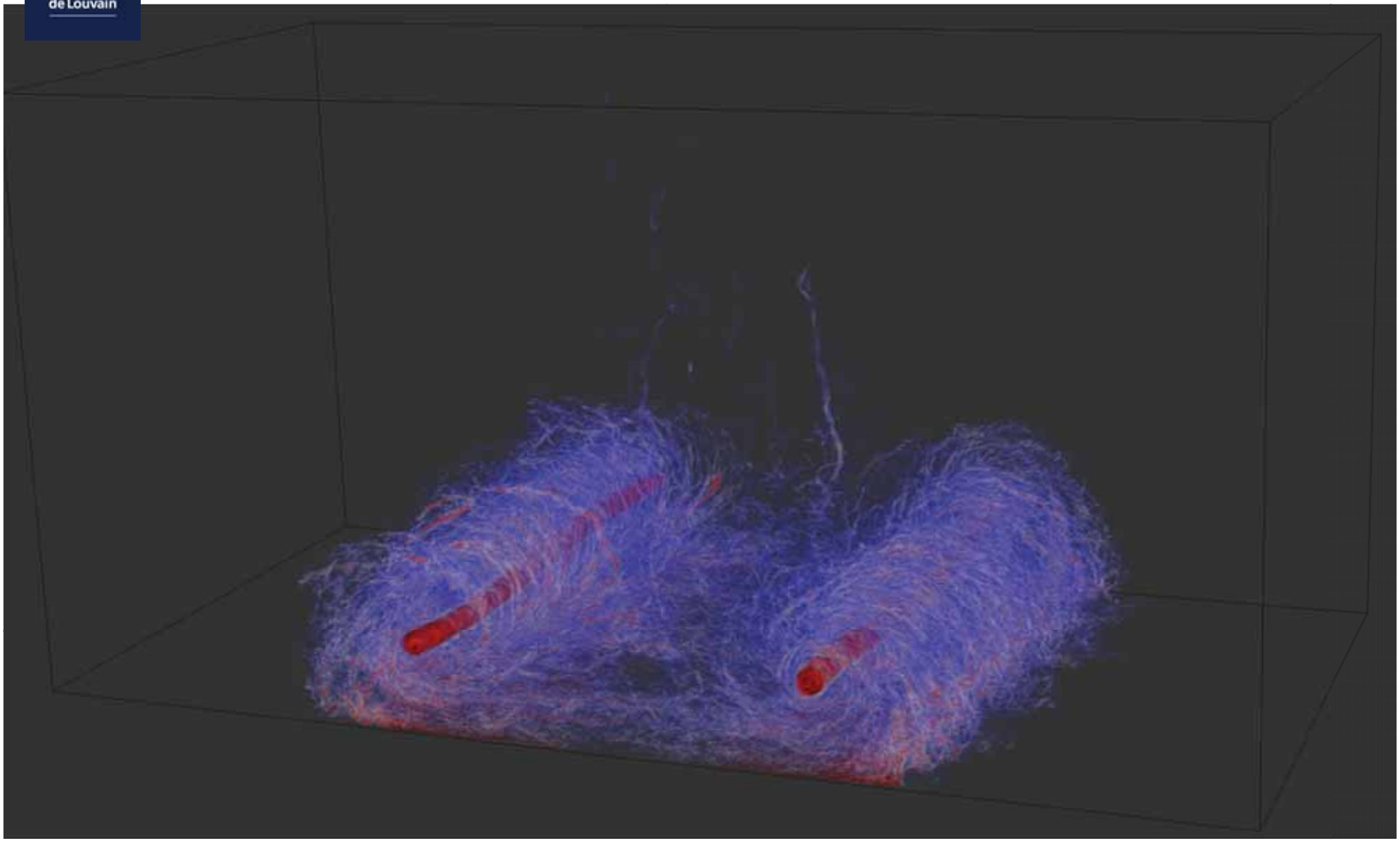
Flow topology at Re = 2.10^5 and t/t_0=2.0



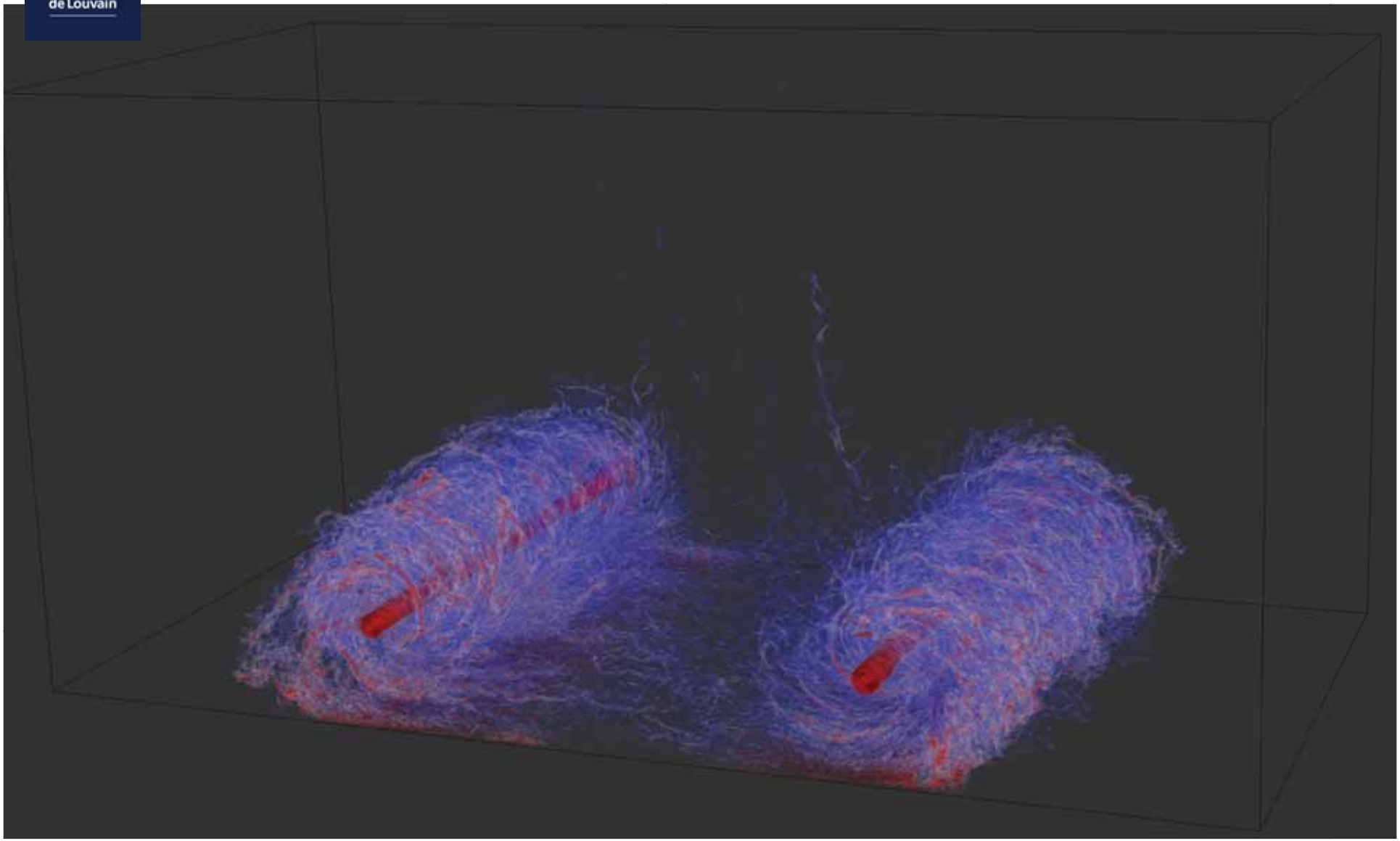
Flow topology at Re = 2.10^5 and t/t_0=2.5



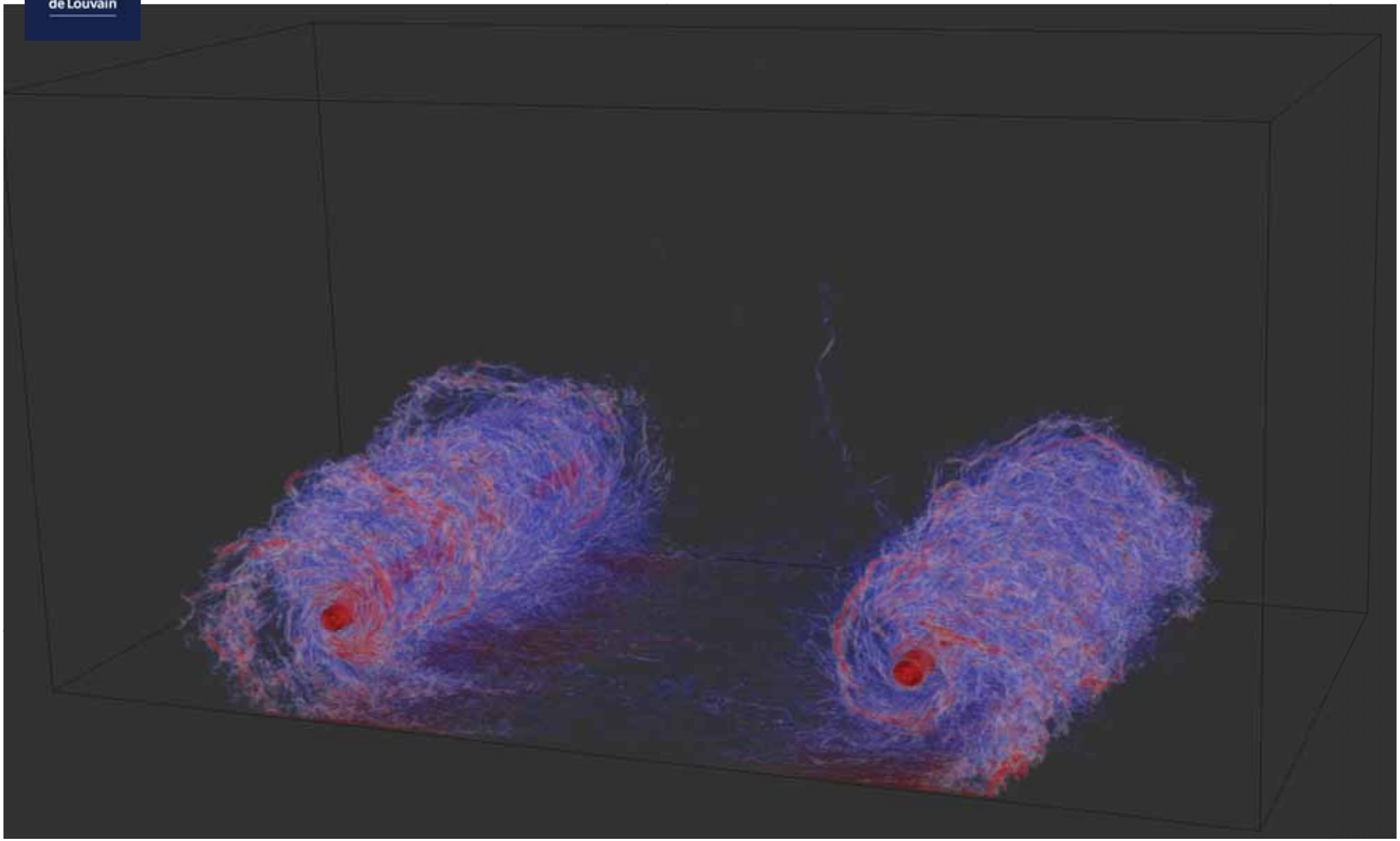
Flow topology at Re = 2.10^5 and t/t_0=3.0



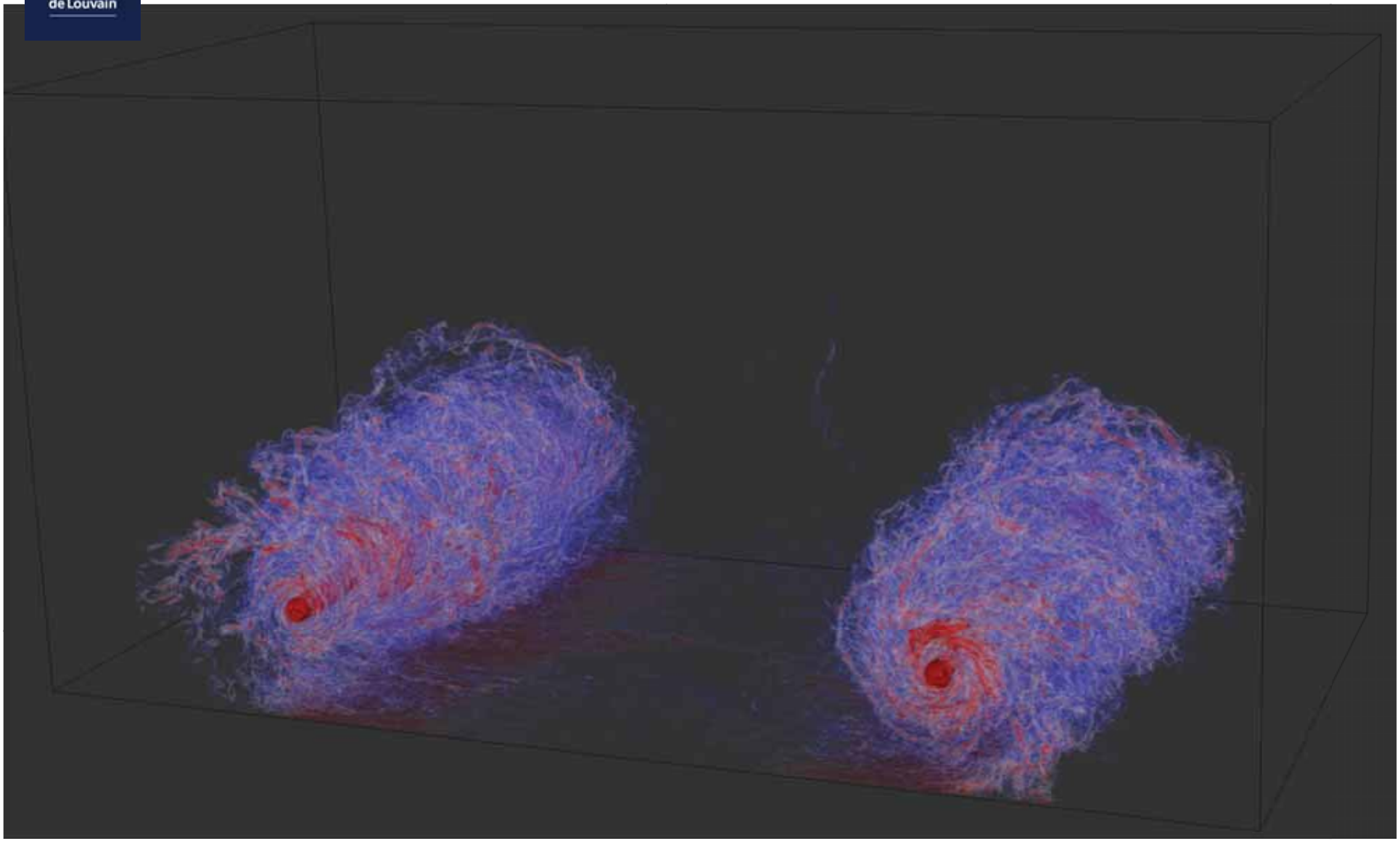
Flow topology at Re = 2.10^5 and t/t_0=3.5



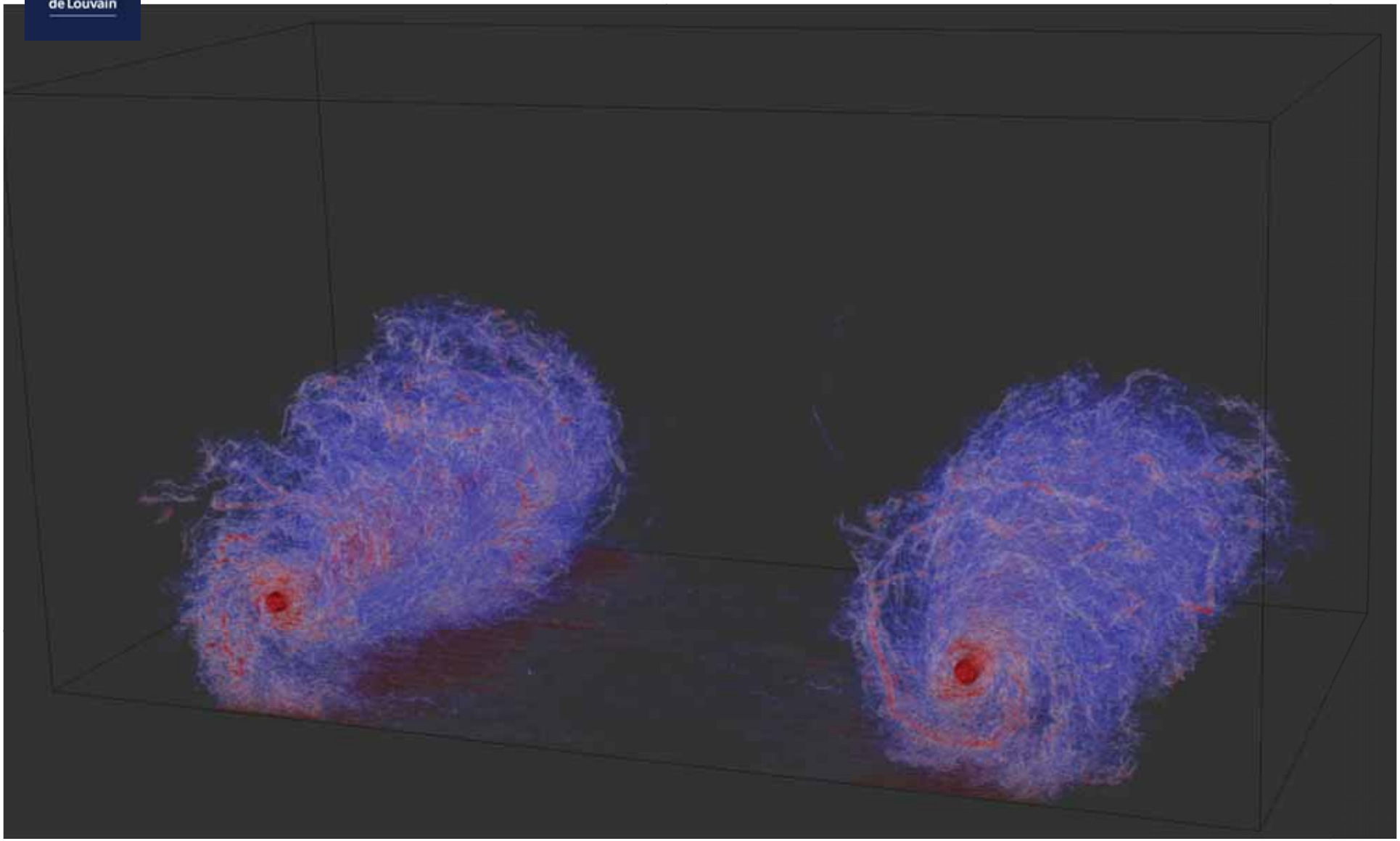
Flow topology at Re = 2.10^5 and t/t_0=4.0



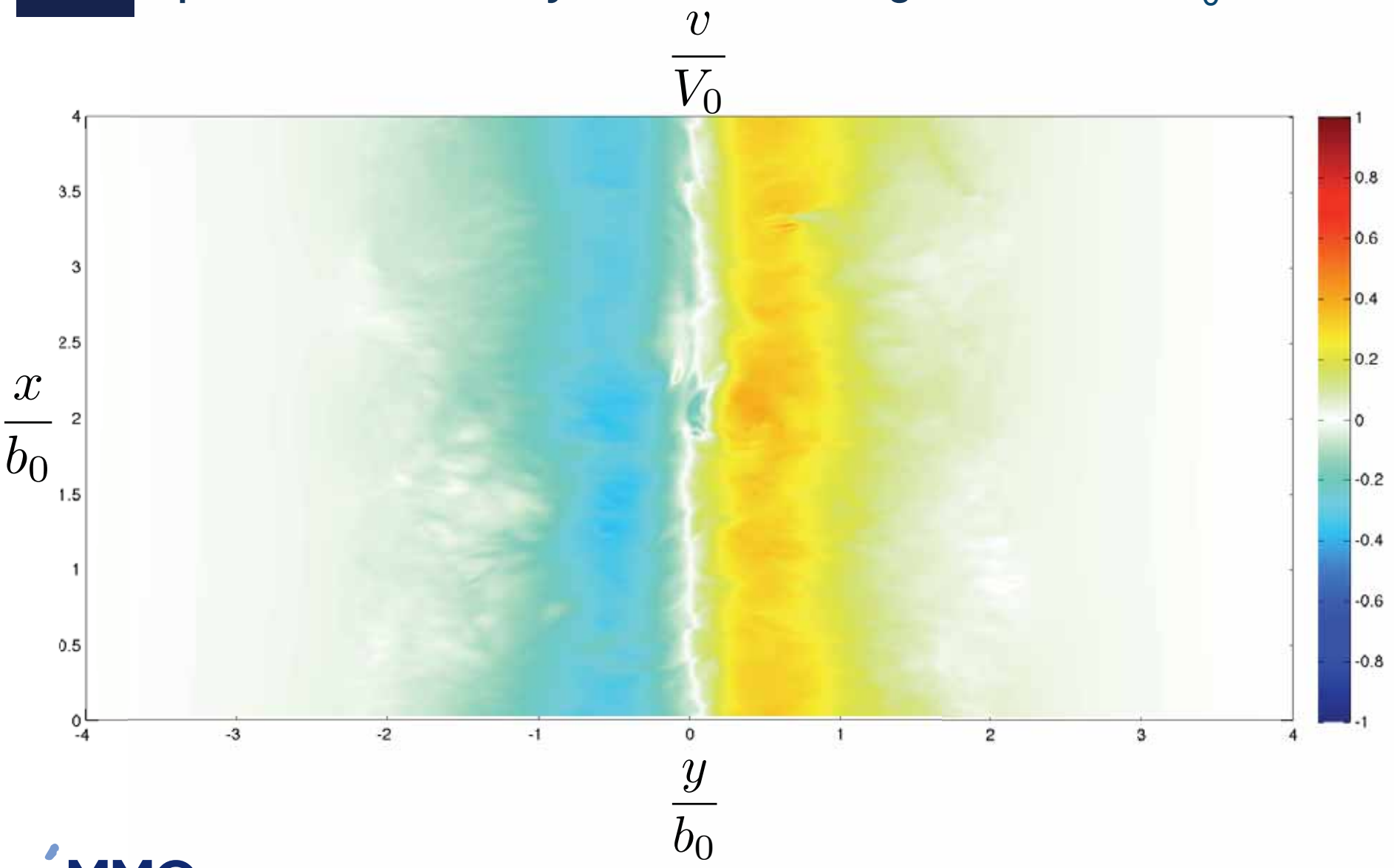
Flow topology at Re = 2.10^5 and t/t_0=4.5



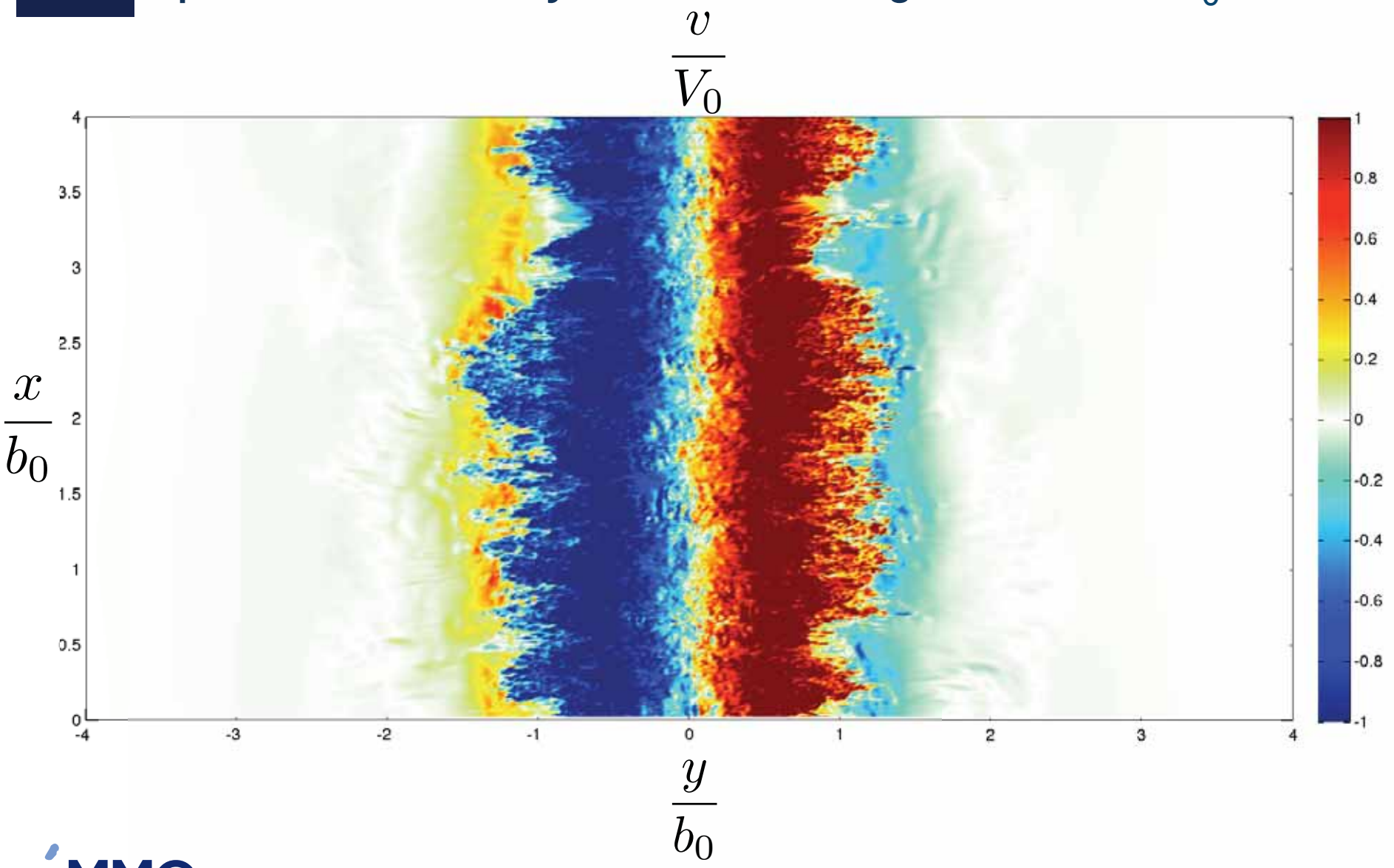
Flow topology at Re = 2.10^5 and t/t_0=5.0



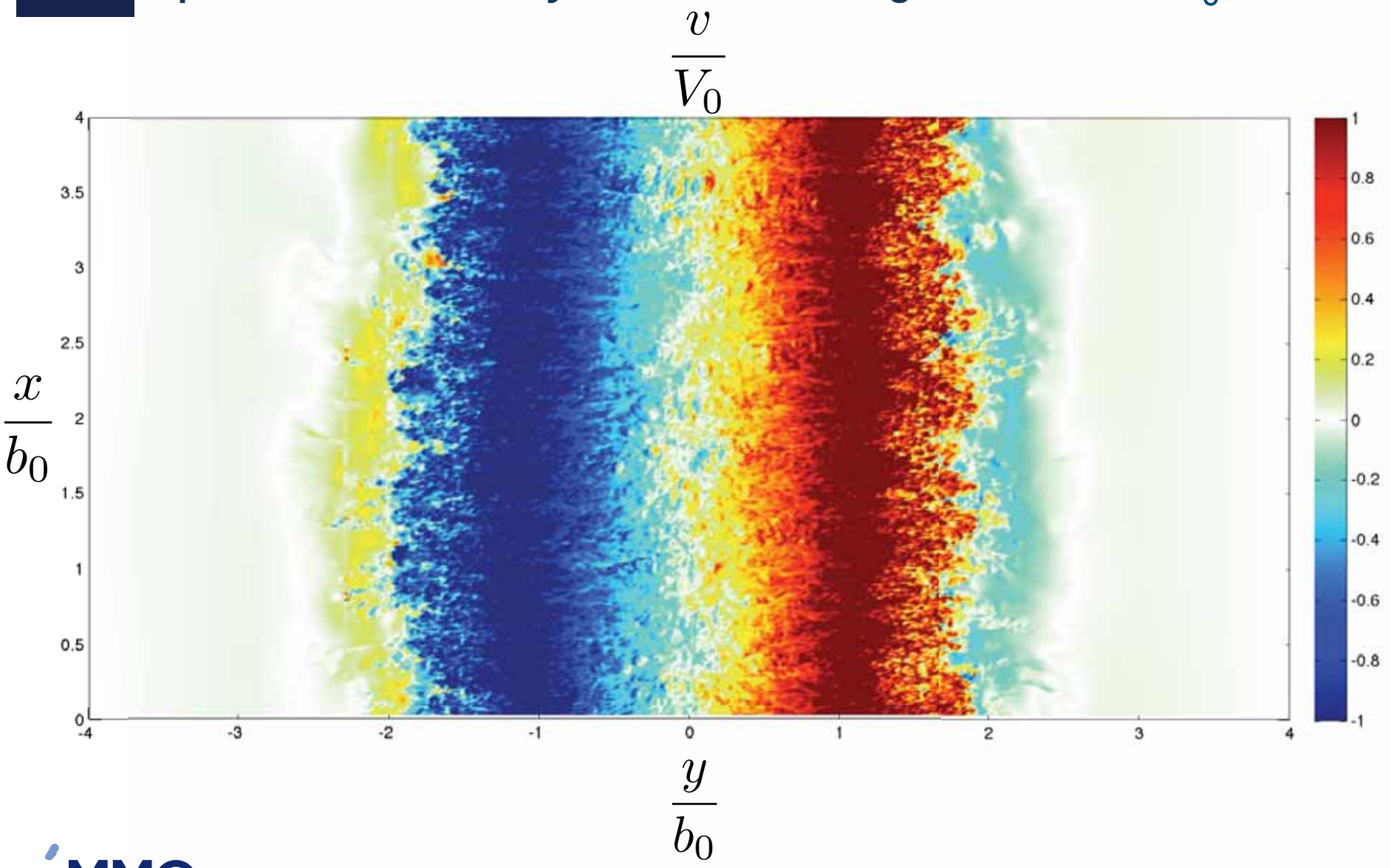
Footprint of the 2VS: spanwise velocity close to the ground at $t/t_0=1$



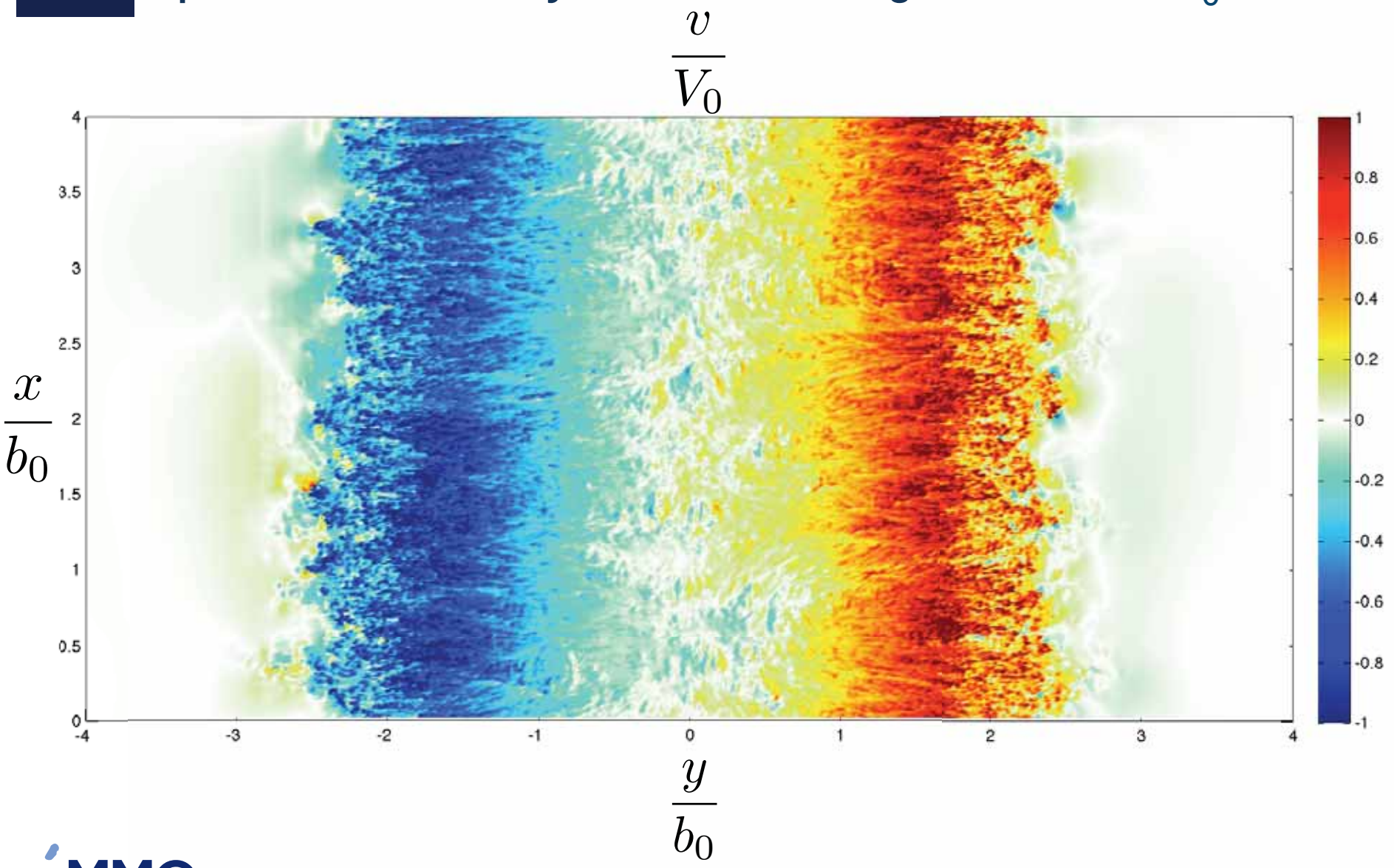
Footprint of the 2VS: spanwise velocity close to the ground at $t/t_0=2$



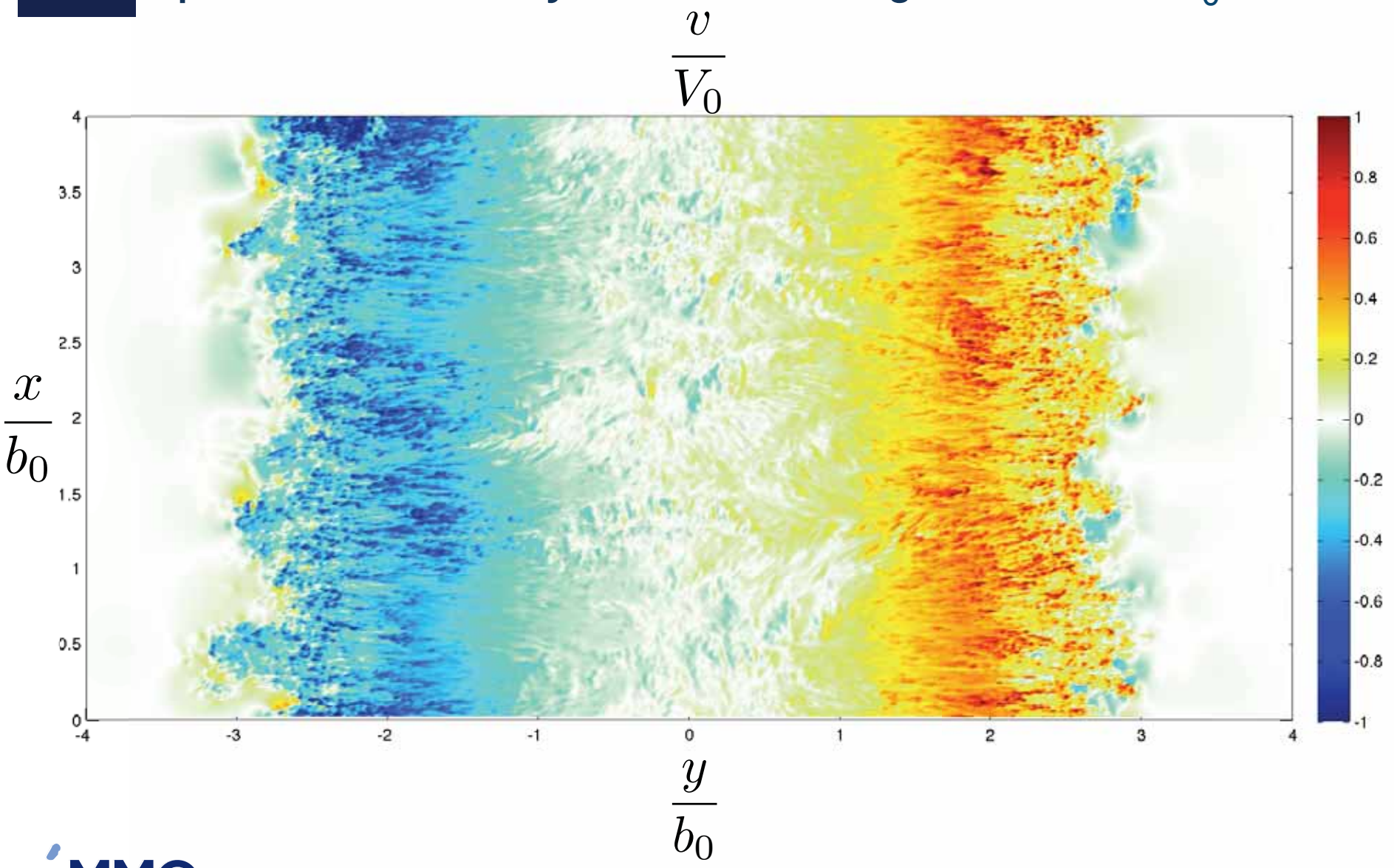
Footprint of the 2VS: spanwise velocity close to the ground at $t/t_0=3$



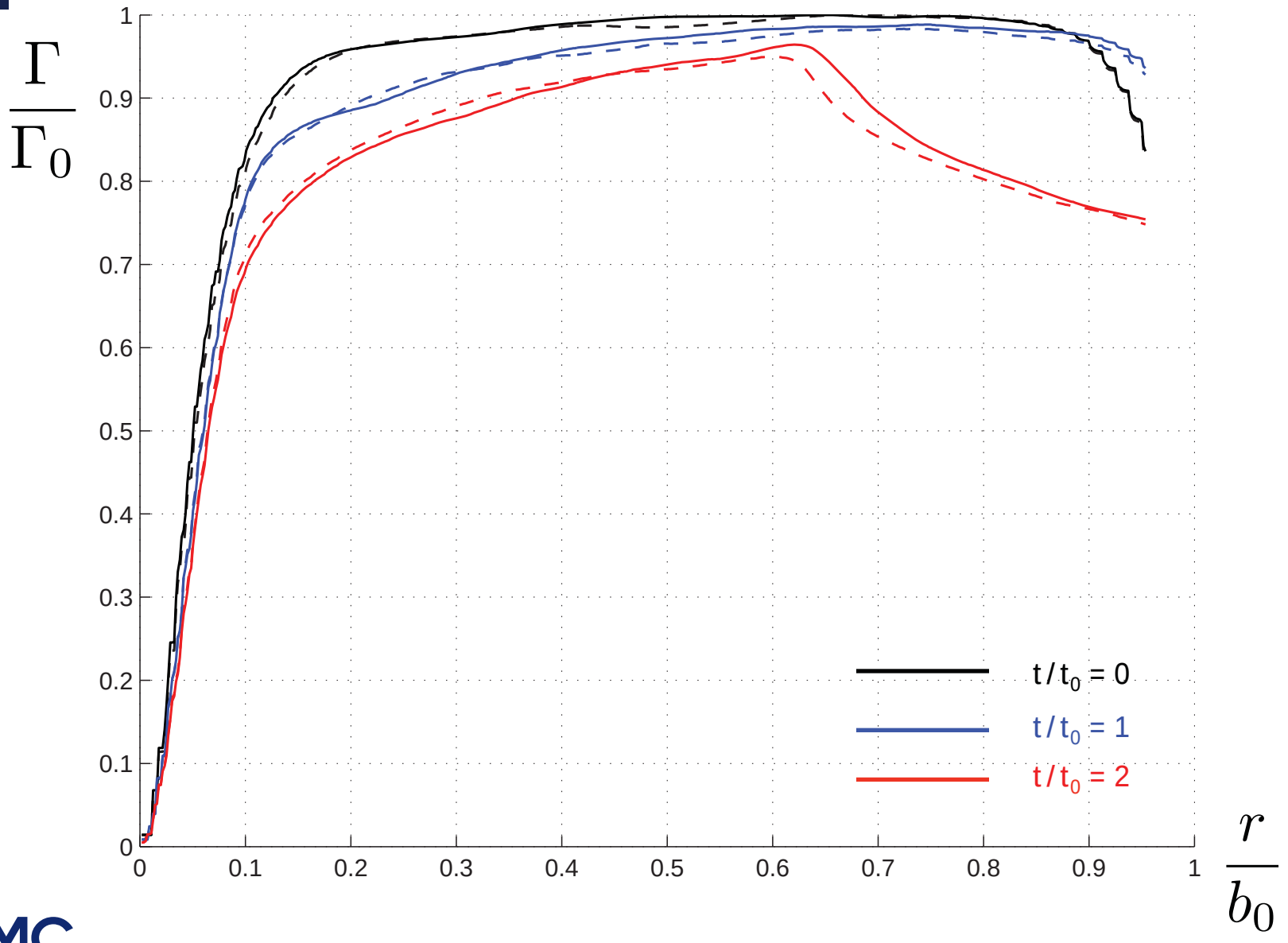
Footprint of the 2VS: spanwise velocity close to the ground at $t/t_0=4$



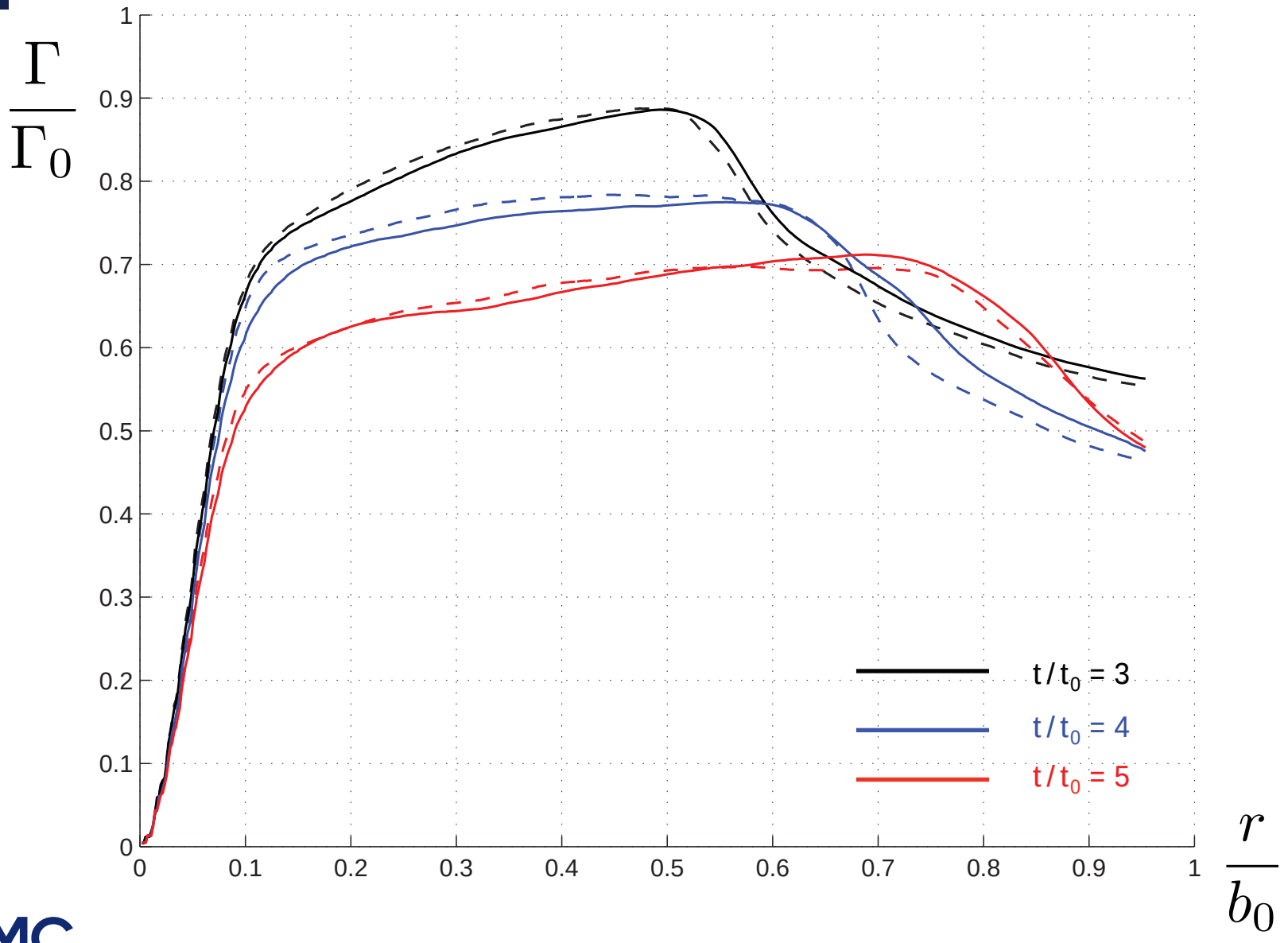
Footprint of the 2VS: spanwise velocity close to the ground at t/t_0=5



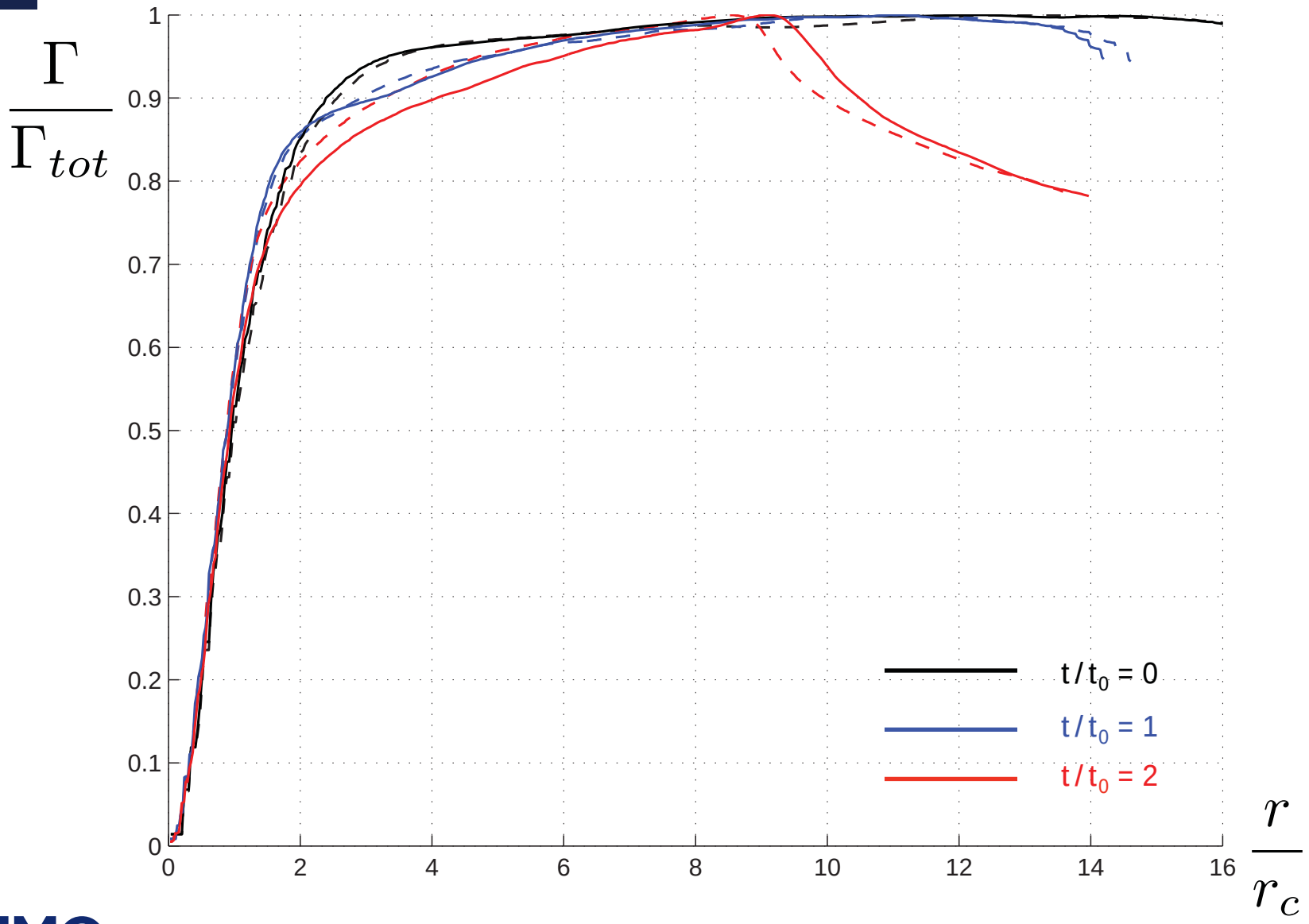
Vortex circulation profile



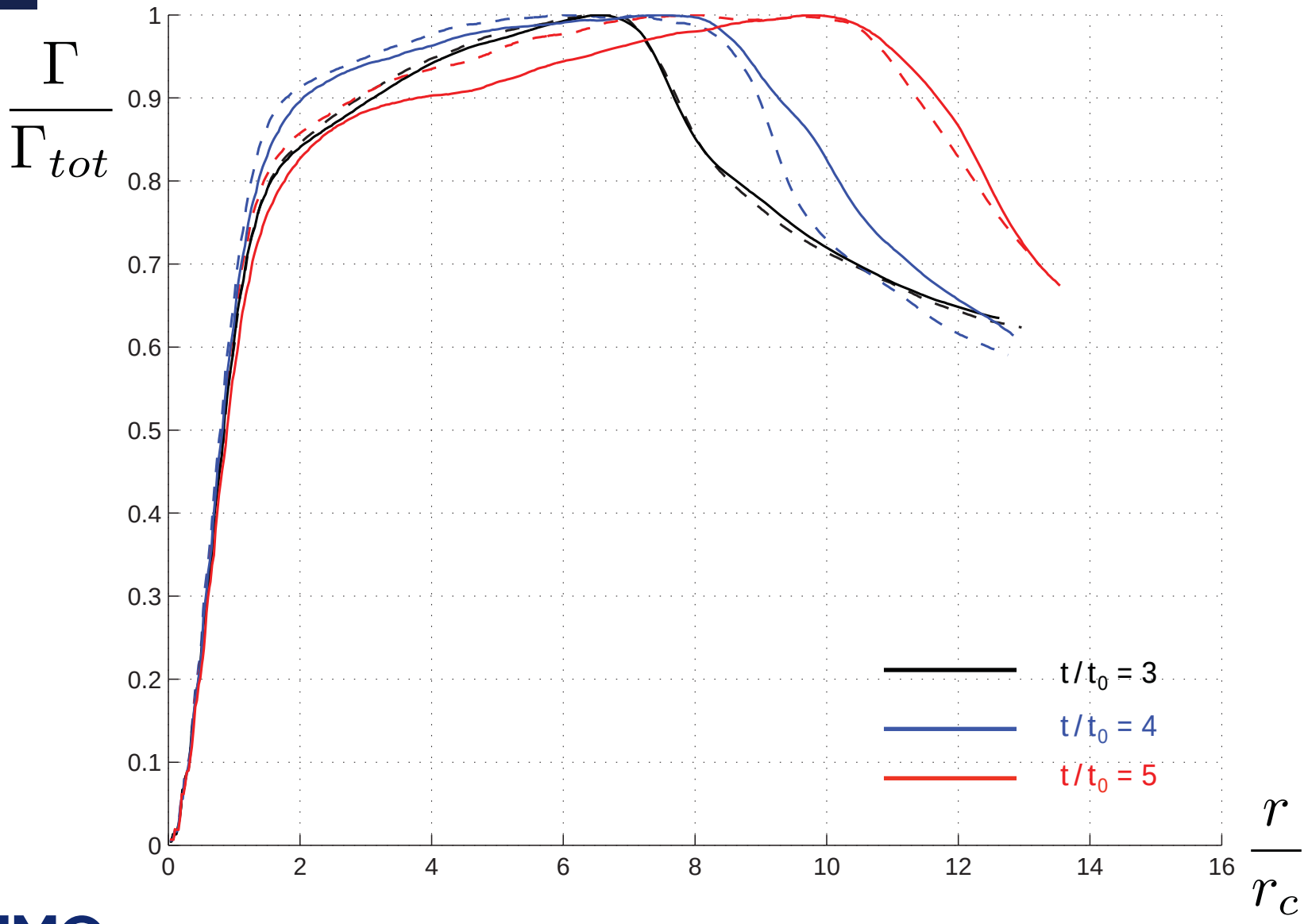
Vortex circulation profile



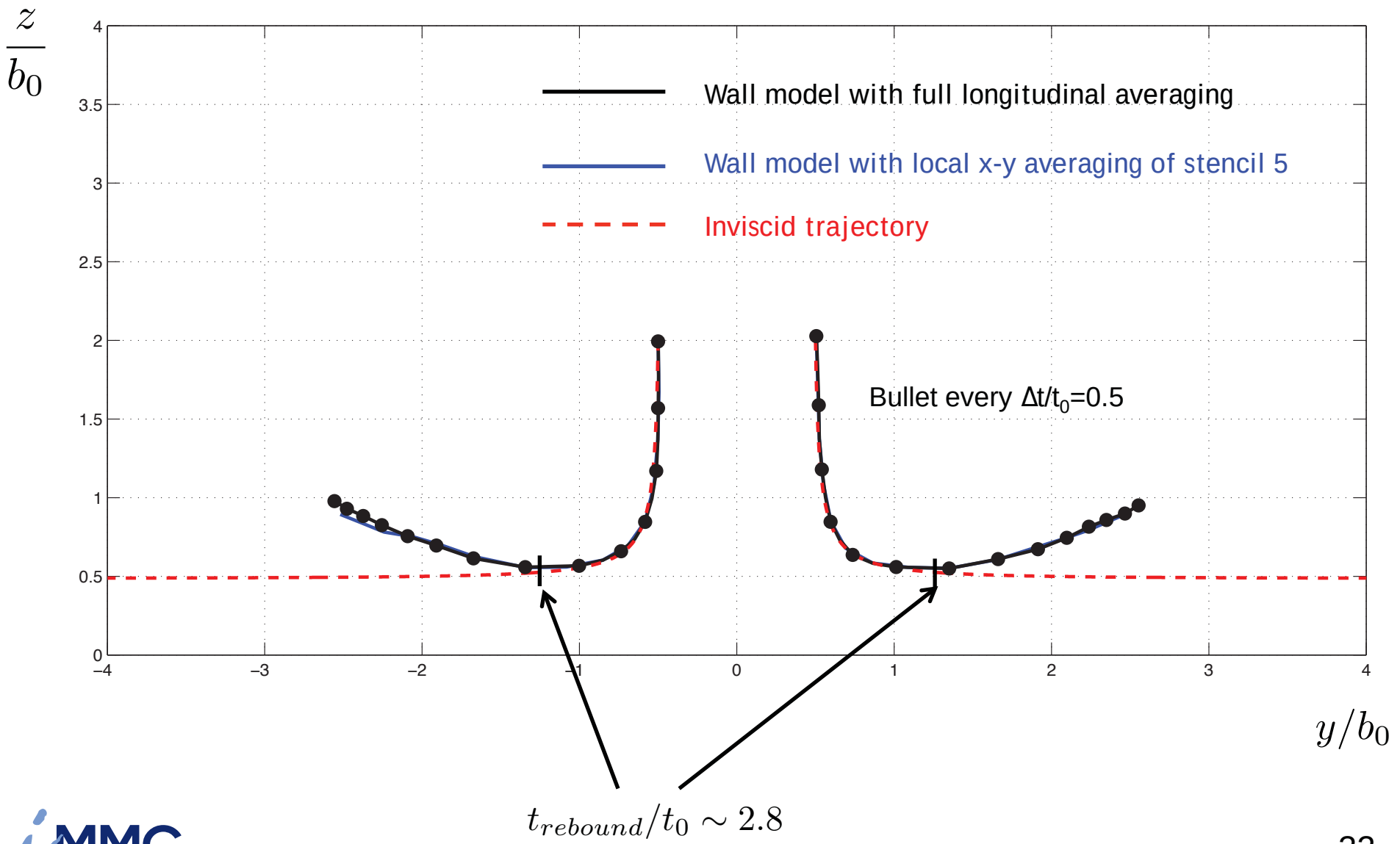
Vortex circulation profile



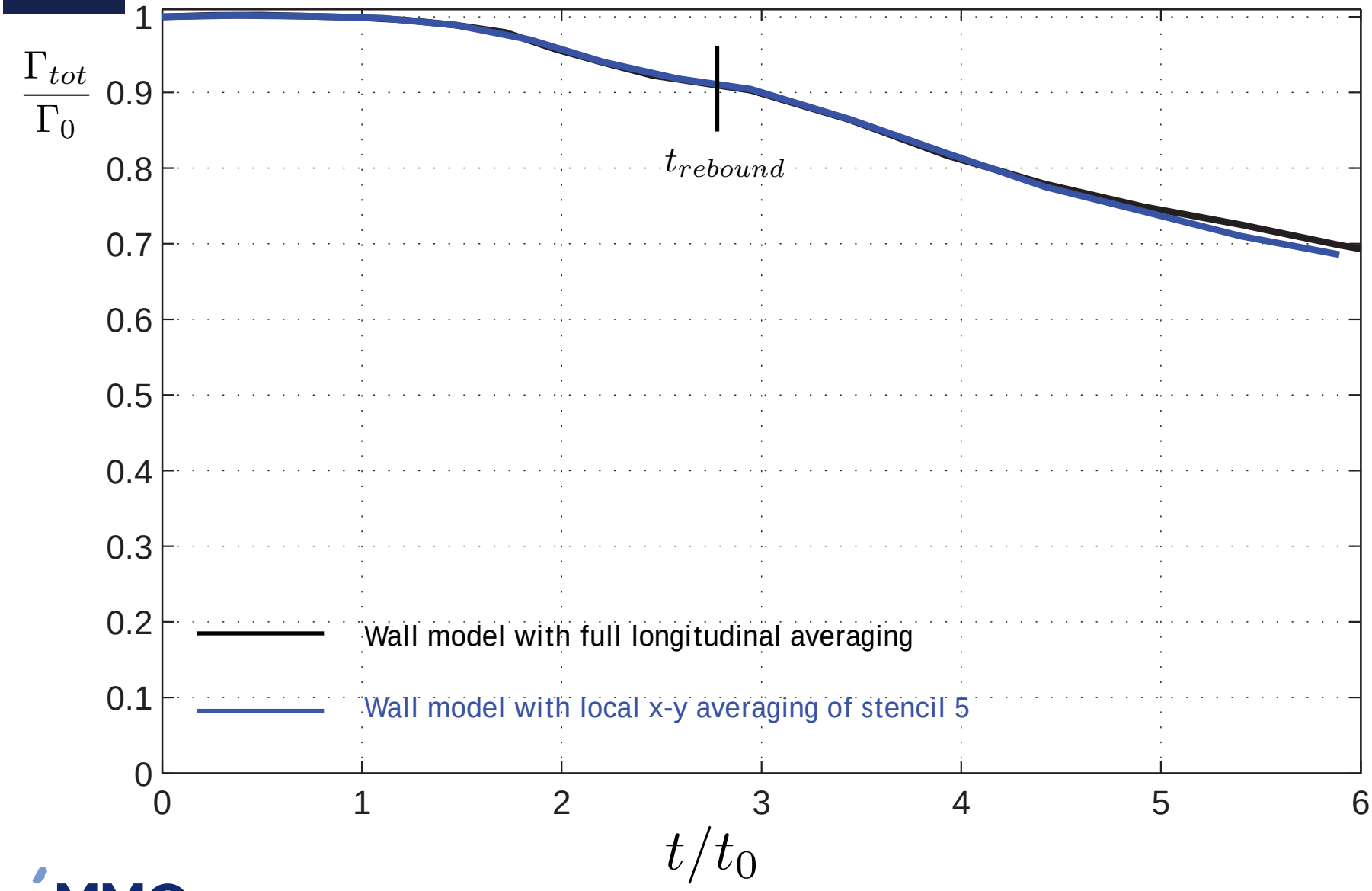
Vortex circulation profile



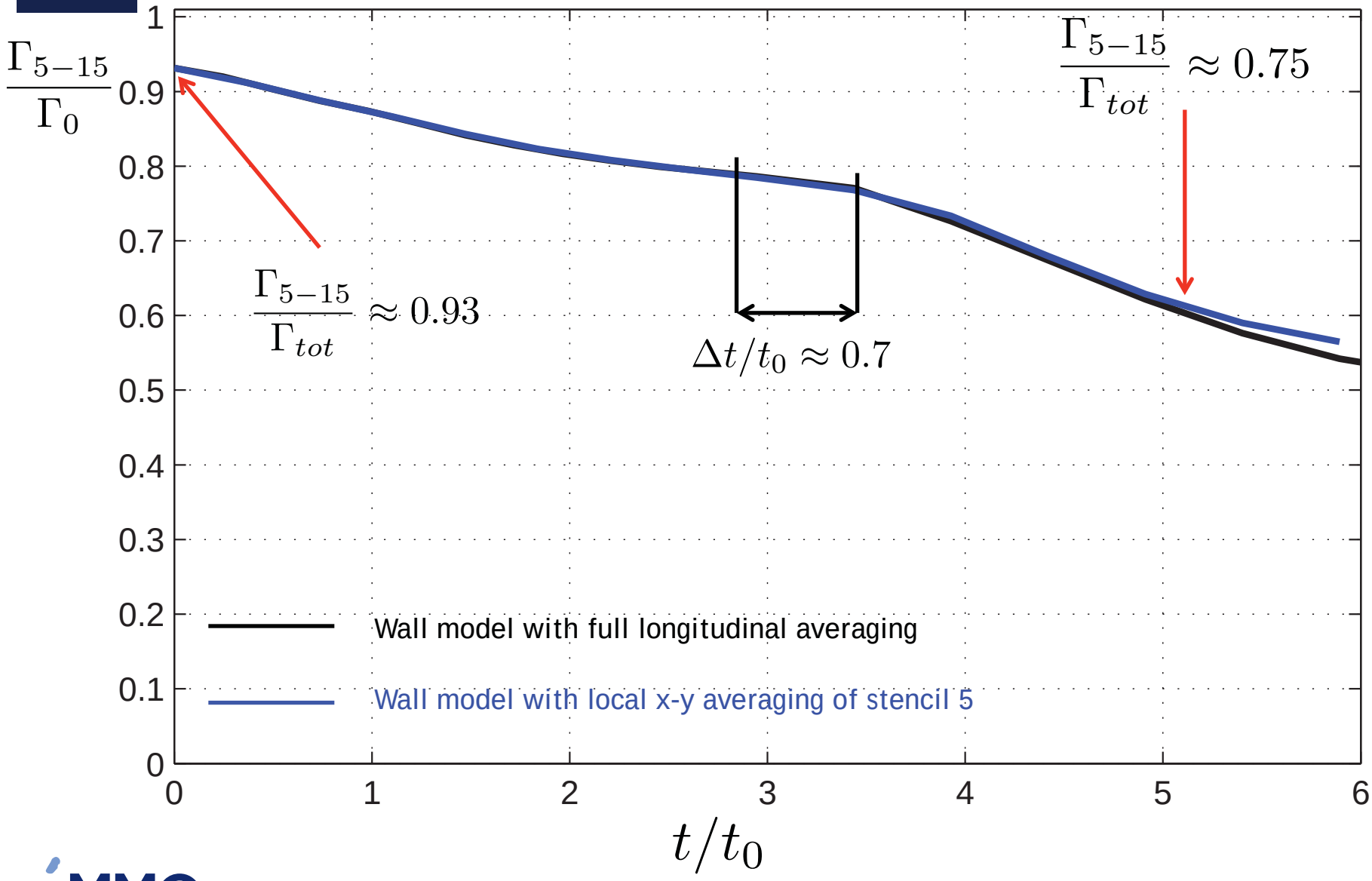
Vortex trajectories



Temporal evolution of vortex circulation

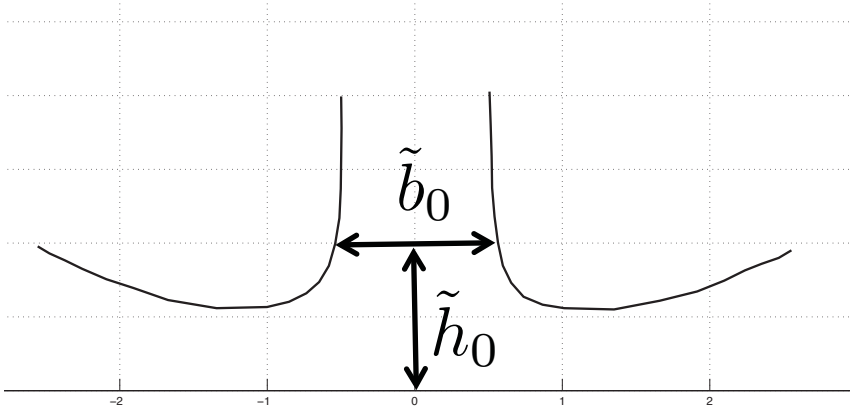


Temporal evolution of vortex circulation



Comparison with previous simulations

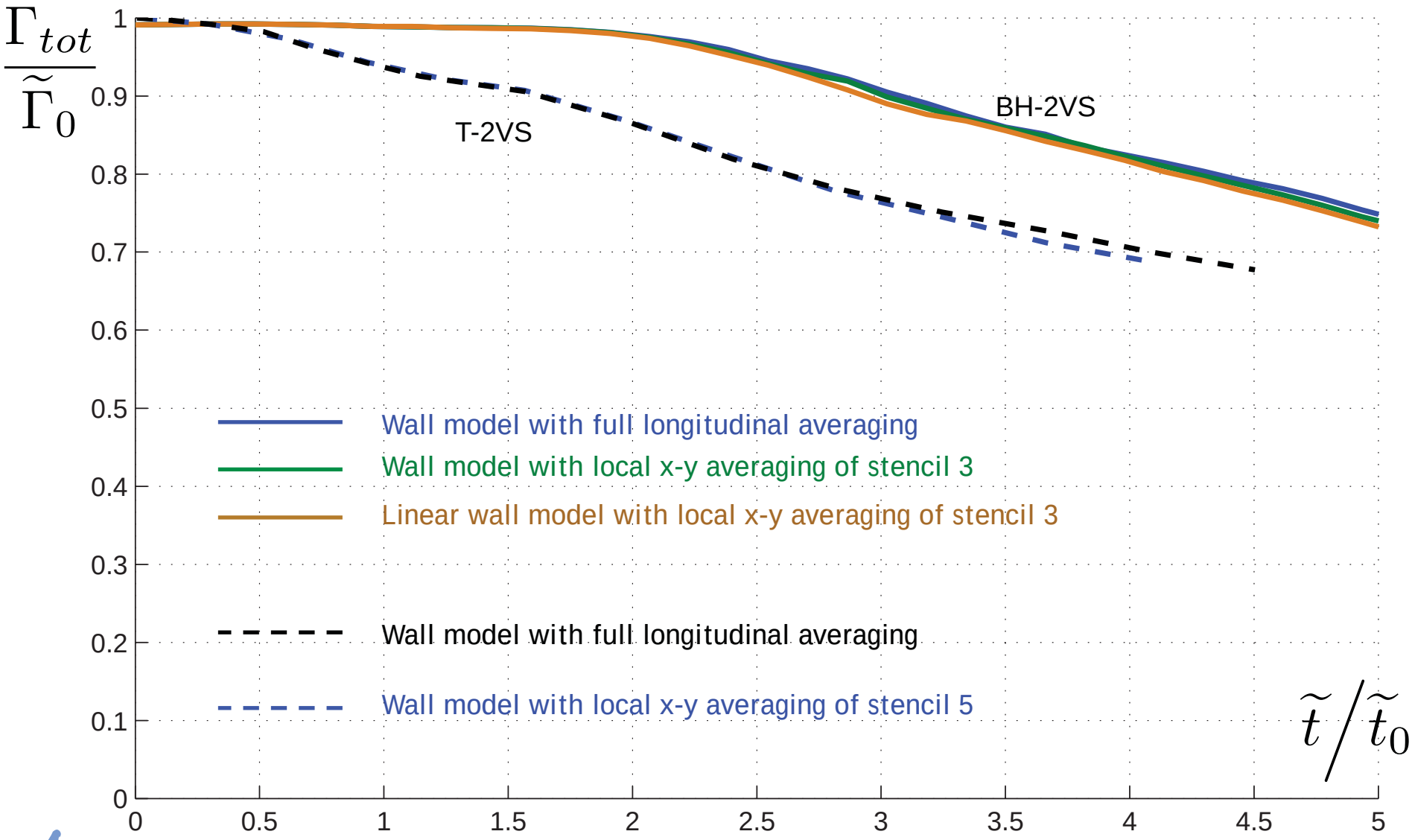
- Compare with previous runs of a BH-2VS released at $h_0 = b_0$
- Shift time such that at $\tilde{t} = 0$, $\tilde{h}_0 = \tilde{b}_0$.



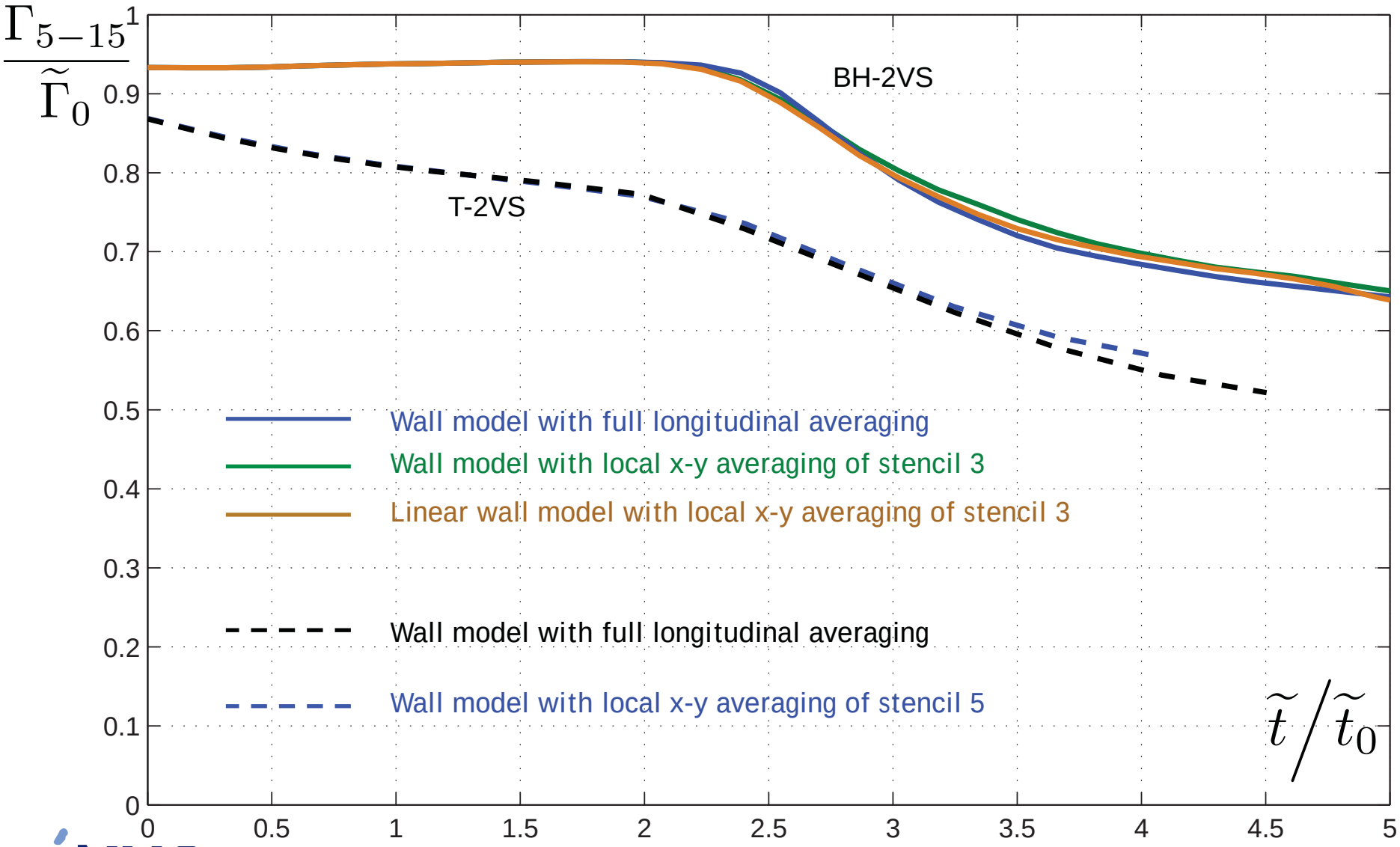
- Define $\widetilde{\Gamma}_0 = \Gamma(\tilde{t} = 0)$

$$\widetilde{V}_0 = \frac{\widetilde{\Gamma}_0}{2\pi \widetilde{b}_0} \quad \Rightarrow \quad \widetilde{t}_0 = \frac{\widetilde{b}_0}{\widetilde{V}_0}$$

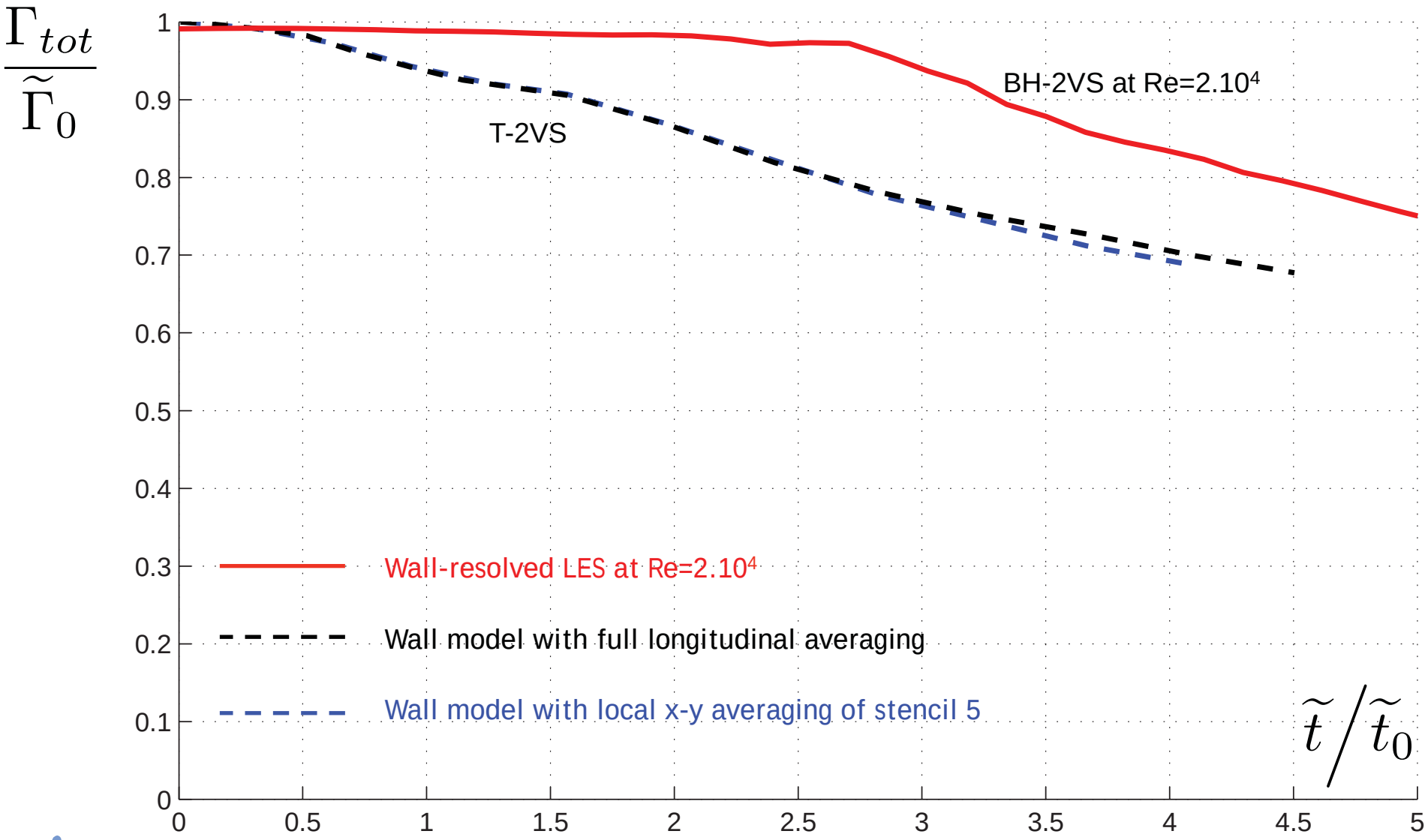
Temporal evolution of vortex circulation



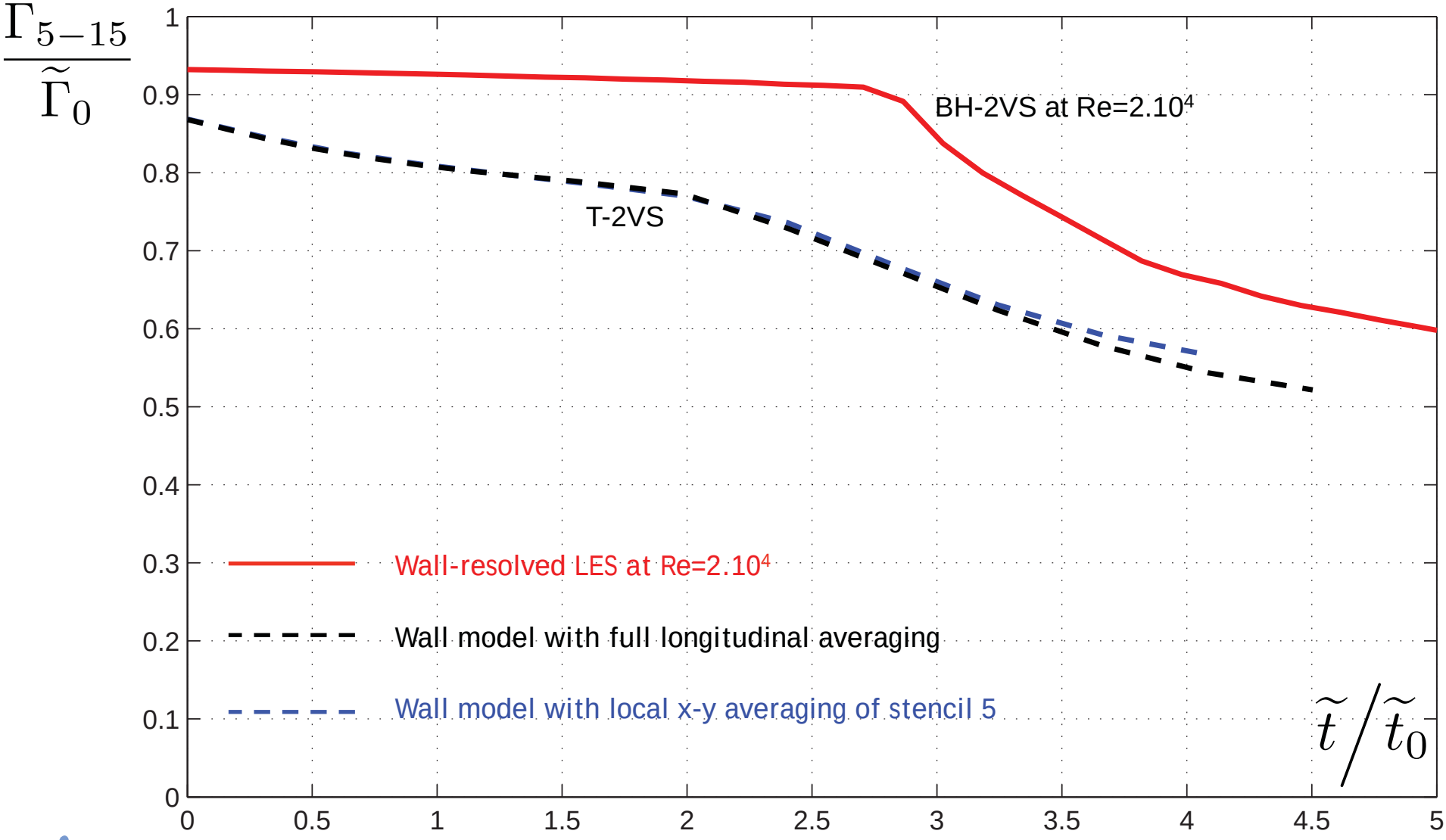
Temporal evolution of vortex circulation



Temporal evolution of vortex circulation



Temporal evolution of vortex circulation



Conclusion

- Simulations of wake vortices IGE have been carried out with:
  - different initial conditions: **realistic turbulent two-vortex system** (T-2VS) versus Burnham-Hallock two-vortex system (BH-2VS)
  - different Reynolds numbers: LES at Re=2.10^4 (as also done in FAR-Wake and beyond, and reported in previous workshops and publications) and new LES **at Re=2.10^5**
- The T-2VS was also **released NGE** (at $h_0=2.b_0$) so as to make sure that it descends naturally towards IGE.
- Circulation profiles have been measured.
- The decay and transport of the vortices IGE has been measured.
- In the « fast decay phase » after rebound:
  - the decay rate of Γ_{tot} is roughly the same as that obtained for the LES at Re=2.10^4 (which is good news)
  - Yet this is not the same for the decay rate of Γ_{5-15}
- This obtained decay should be considered an **absolute lower bound for decay** (no long-wave instability, no wind, no tilting, no background turbulence)
- We also obtain, for late vortices after rebound, that $\frac{\Gamma_{5-15}}{\Gamma_{tot}} \approx 0.75$ (might be useful for LIDAR algorithms)

Acknowledgements & references

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Questions?