Case C3.4
DNS and LES of the flow over a 2D periodic hill

3rd International Workshop on High-Order CFD Methods

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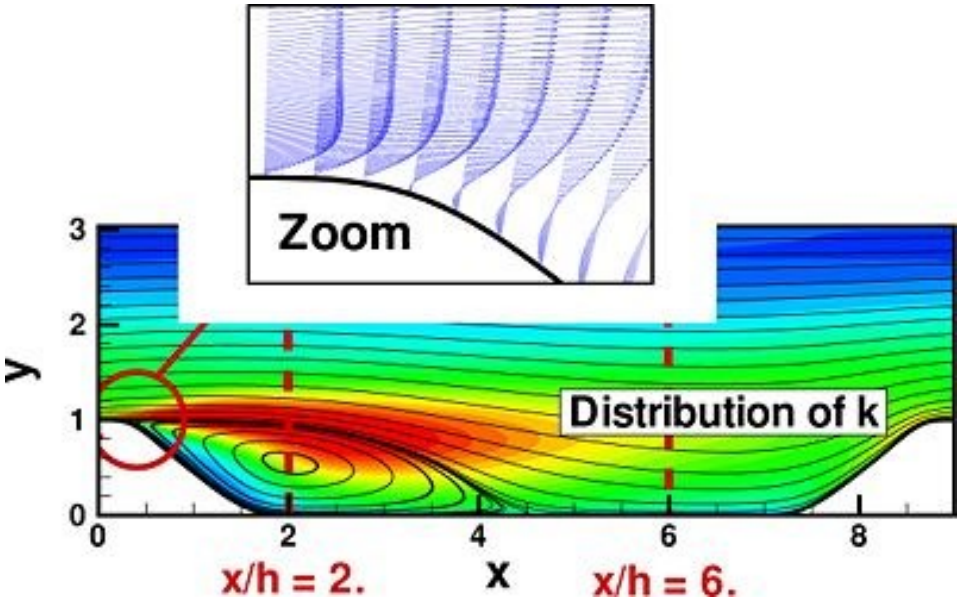
Motivation

- Benchmark for wall-bounded turbulent flows, with smooth separation, recirculation and natural reattachment
- Simple setup: periodic domain, 2D geometry, still close to complexity of industrial configuration
- Numerical and experimental results available at wide range of Reynolds numbers
- Possibility to assess solvers for DNS, LES, WMLES, RANS-LES,…



- Detailed description, data, references,… on the
  [Ercoftac QNET-CFD wiki forum](#) / [2D periodic hill](#)

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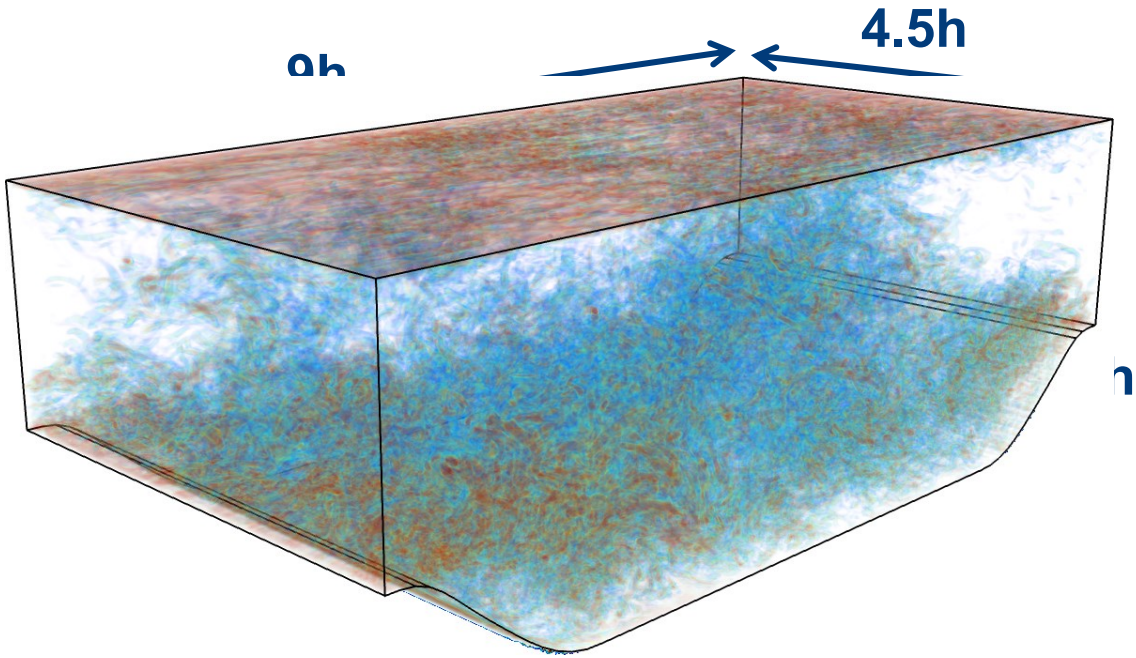
Geometry and flow conditions



- **Periodic domain in streamwise and spanwise directions**
- **Body force to provide the correct mass flow rate:**
- $$u_b = \frac{1}{2.035h}\int_h^{3.035h} u(y)dy \longrightarrow Re_b = \frac{u_b h}{\nu}$$

$$\left(\frac{dp}{dx}\right)^{n+1} = \left(\frac{dp}{dx}\right)^{n+1} - \frac{1}{A_c \Delta t}\left(\dot{m}^* - 2\dot{m}^n + \dot{m}^{n-1}\right)$$

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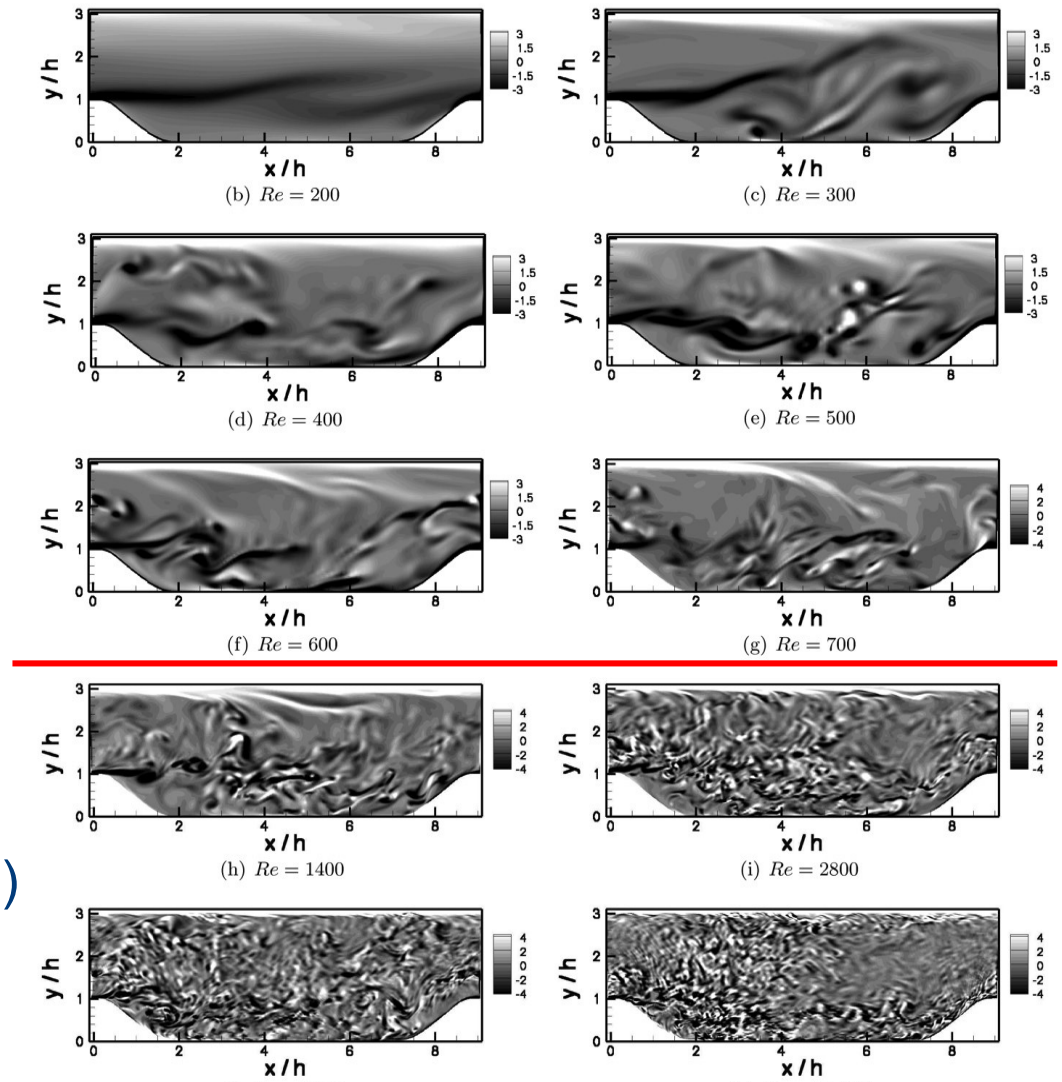
Experimental/numerical results available

- **Experiments:**
  - **Rapp (2009), Munich**
  - **Re = [5.6, 10.6, 19, 37] x 10^3**
  - **Incompressible flow**
  - **PIV and LDA agreement**
  - **Periodicity achieved by using 10 successive hills and 18h in span**
- **CFD:**
  - **Breuer et al. (2009)**
  - **MGLET and LESOCC:**
    - Finite Volume methods (central)
    - Incompressible solvers
    - Explicit time-stepping
  - **DNS and LES up to Re=37k**



Breuer et al. (2009)

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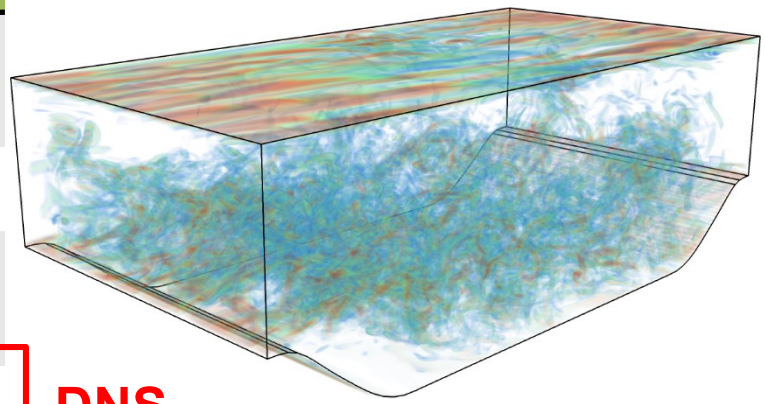
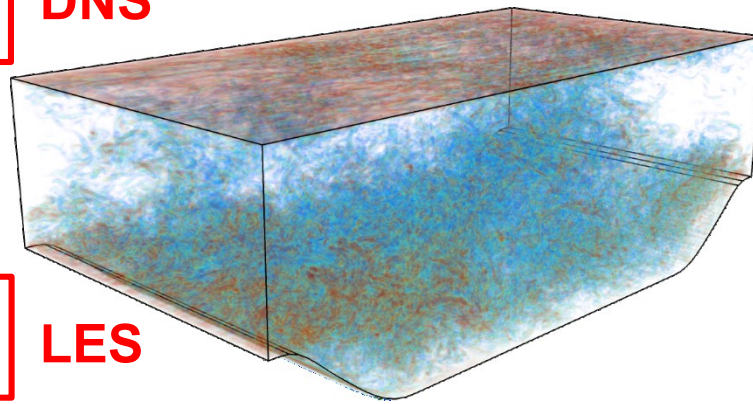
Summary of the reference CFD

Re	Sim.	$N_{tot}/10^6$	N_{span}	$\Delta t/10^{-3}$	T_{avg}	Code
1400	DNS	13.1	200	1.1	1249	LESOCC
1400	DNS	20.0	132	1.5	540	MGLET
2800	DNS	13.1	200	2.0	1249	LESOCC
2800	DNS	48.0	304	1.0	562	MGLET
5600	DNS	13.1	200	2.0	1214	LESOCC
5600	DNS	231.0	404	1.0	343	MGLET
10,595	LES	13.1	200	1.8	1277	LESOCC
10,595	LES	4.1	104	1.0	241	MGLET
37,000	LES	4.1	104	1.0	439	MGLET



DNS



LES

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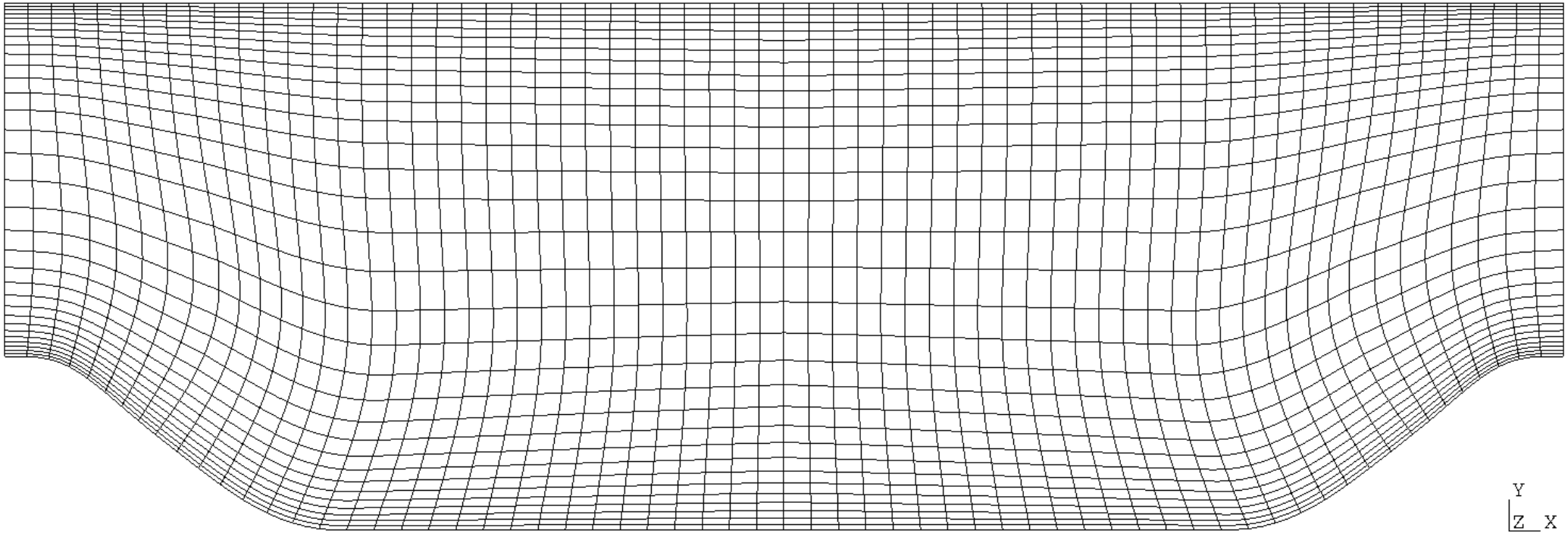
Mesh generated with IGG, curved with Gmsh

CGNS	Gmsh (2nd order)
128 x 64 x 64	64 x 32 x 32
256 x 128 x 128	128 x 64 x 64
512 x 256 x 256	256 x 128 x 128



Participants

- Laslo Diosady, and Scott M. Murman, NASA Ames
- Marta de la Llava Plata and Vincent Couailler, Onera
- Daniel J. Garmann and Miguel R. Visbal, US AFRL
- Corentin Carton de Wiart and Koen Hillewaert, Cenaero
- Jonathan Bull and Antony Jameson, Stanford
- Andrea D. Beck, David Flad, Thomas Bolemann, Claus-Dieter Munz, Stuttgart
- A.F. Antoniadis, Z. Rana, P. Tsoutsanis, D. Drikakis, Cranfield

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Summary of contributions (7 participants, 25 computations)

Participant	Research lab	Code	Method/Order	Temporal scheme	Case/Reynolds	DOF
L. Diosady	NASA	DGM-BR2	DGM-BR2 (8)	Space-Time DG (4th order)	10595 (4)	0.5M – 14M
M. de la Llava Plata	ONERA	Aghora	DGM/SIP (4)	Explicit RK4	2800 (1)	33M
D. Garmann	US AFRL	FDL3DI	Compact FD (6)	Implicit (2nd order)	2800 (3) 10595 (3)	0.5M – 33M
C. Carton de Wiart	Cenaero	Argo DGM	DGM/SIP (4)	Implicit (2nd order)	2800 (2) 10595 (2)	14M – 19M
J. Bull	Stanford	HiFiLES	FR – DGM (3 – 5)	Explicit?	2800 (2) 10595 (4)	2M – 8M
A. D. Beck	IAG Stuttgart	Flexi	DGSEM (4 – 10)	Explicit RK4	2800 (2) 10595 (3)	0.5M – 8M
A.F. Antoniadis	Cranfield	-	-	-	-	-

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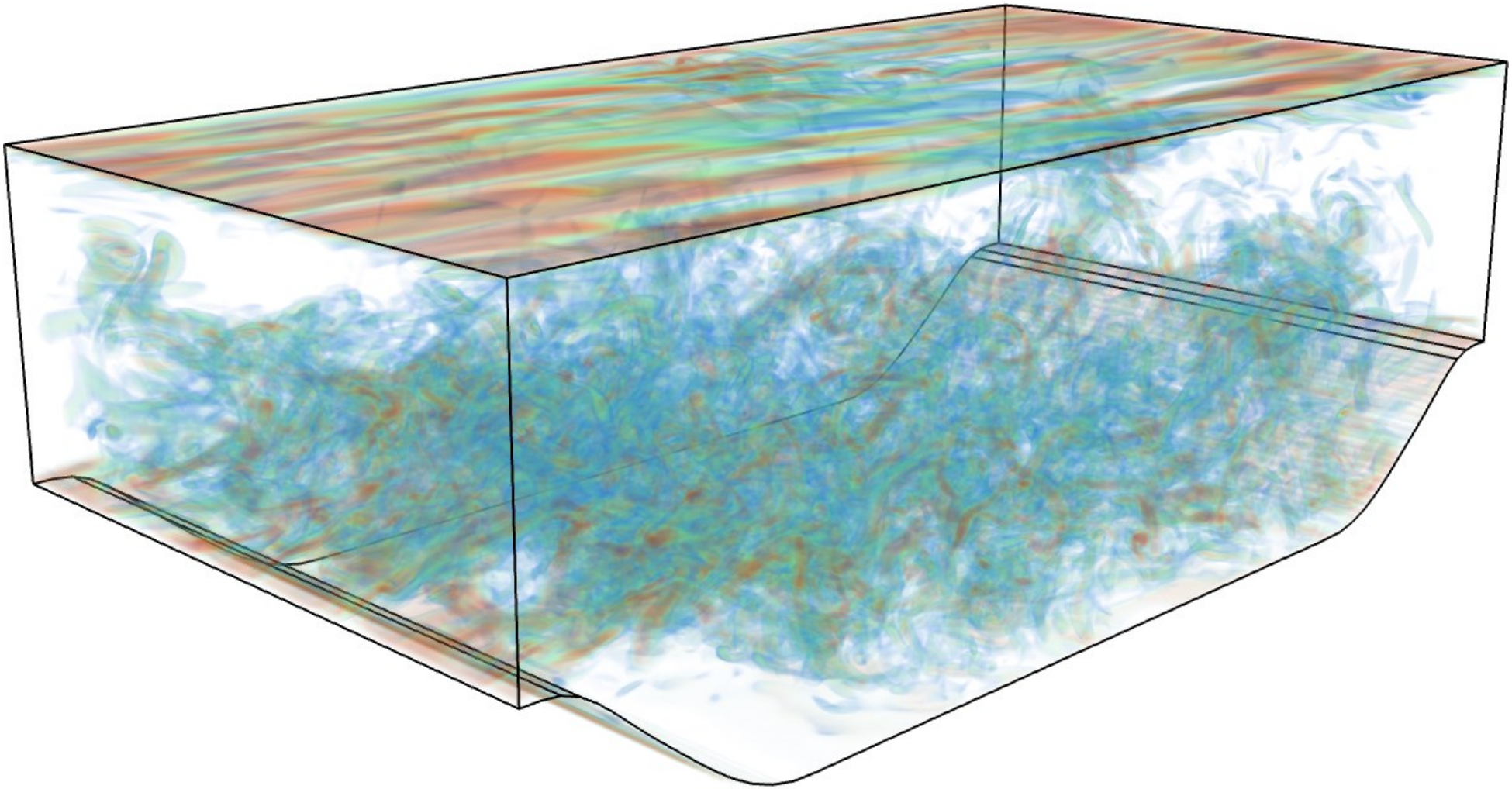
Re=10595, were performed using Implicit LES, i.e. without SGS model

DNS at Reynolds 2800



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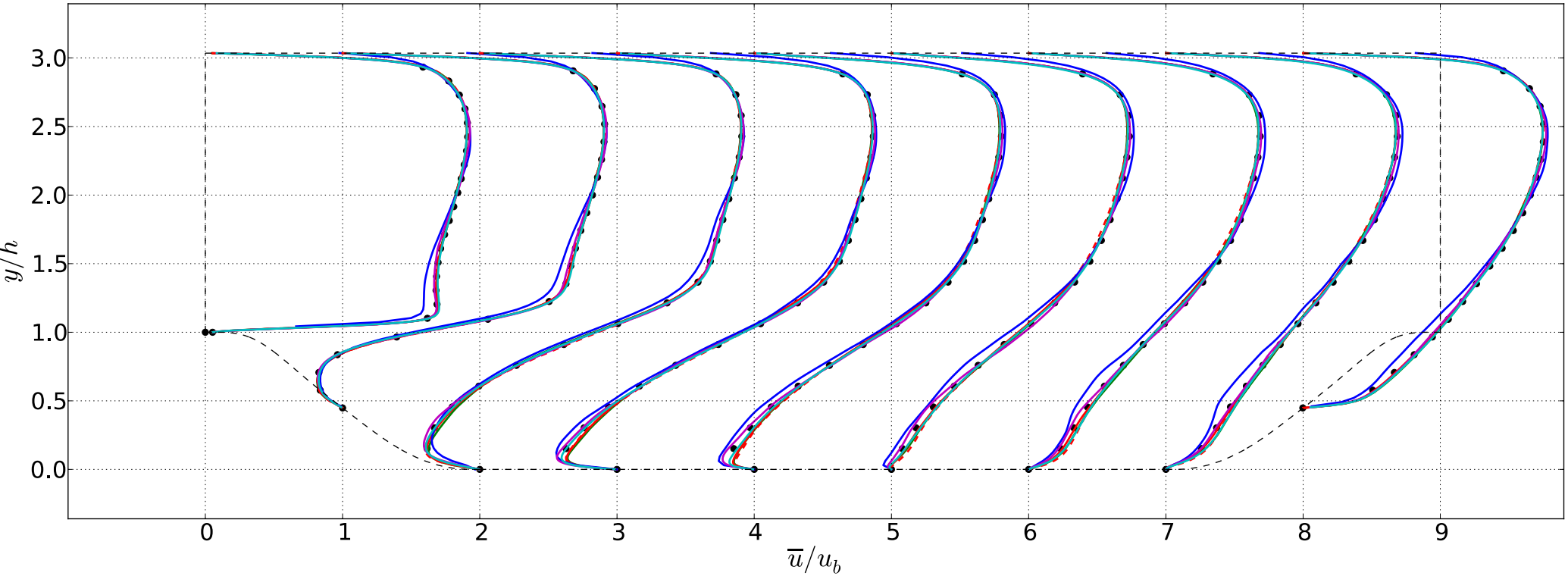
DNS Reynolds 2800 – Mean x-velocity



- MGLET (FVM - 44M)

de la Llava Plata (DG4 - 33M)

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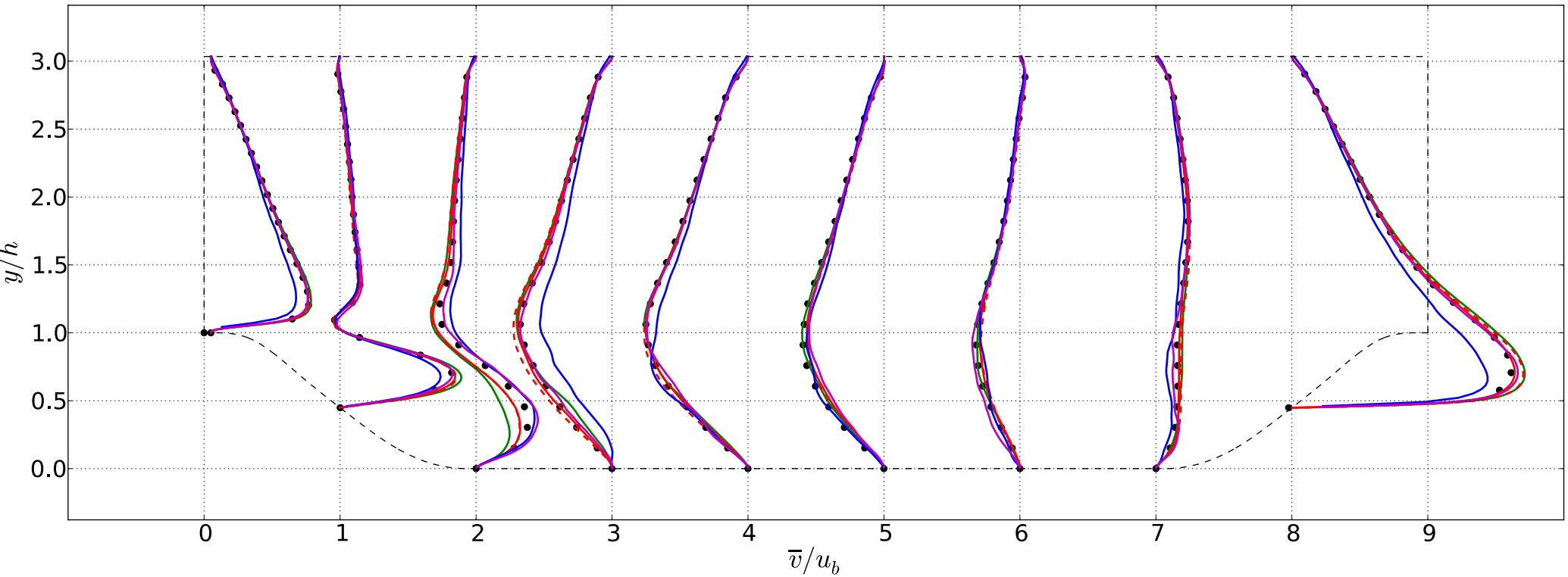

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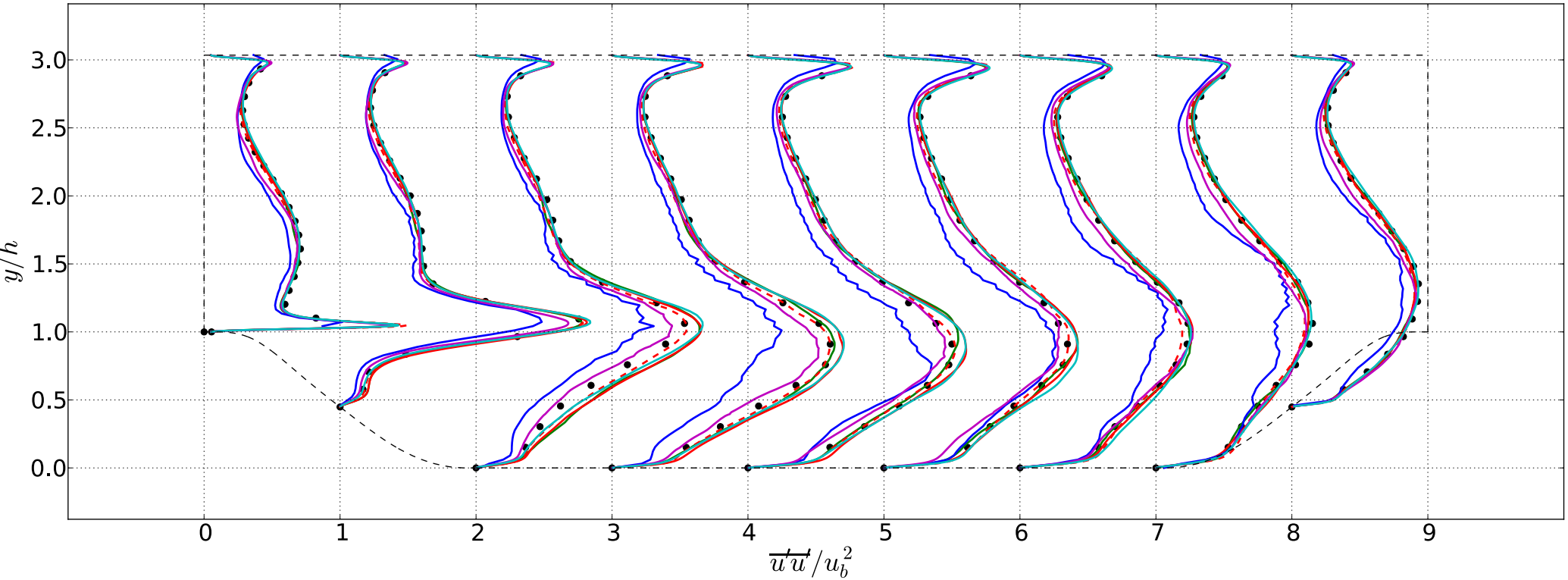
DNS Reynolds 2800 – Averaged u'u' fluctuations



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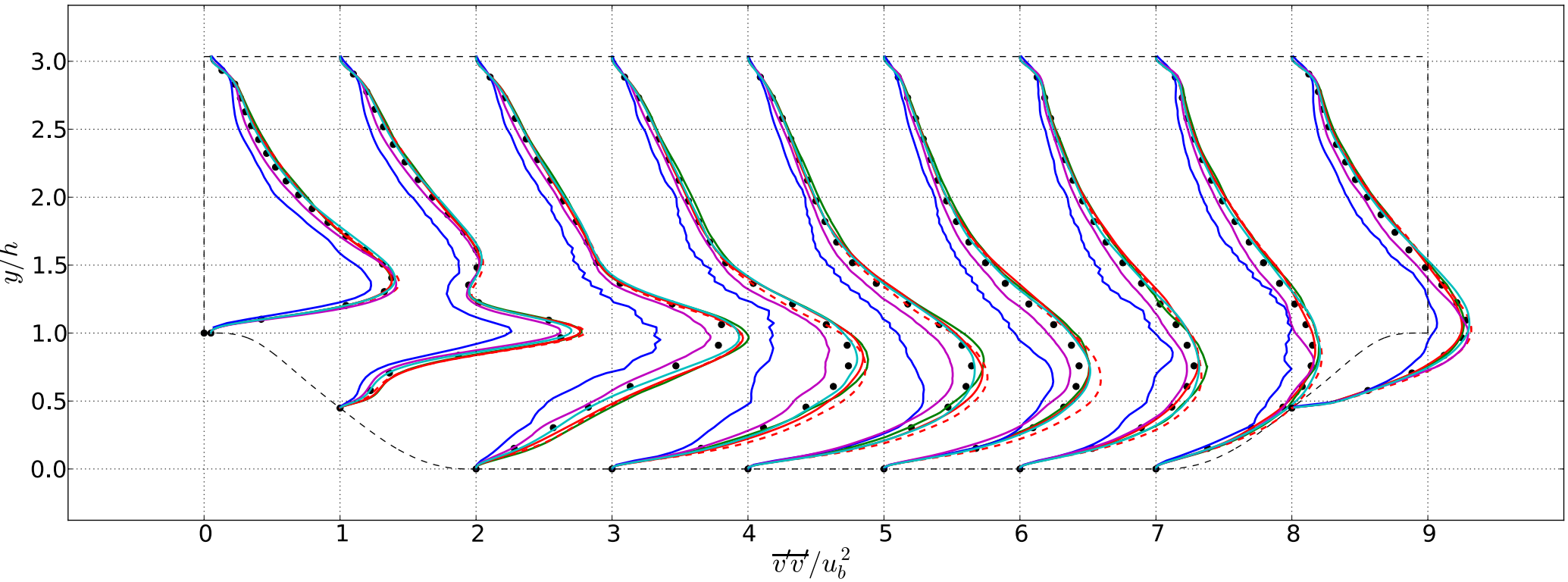

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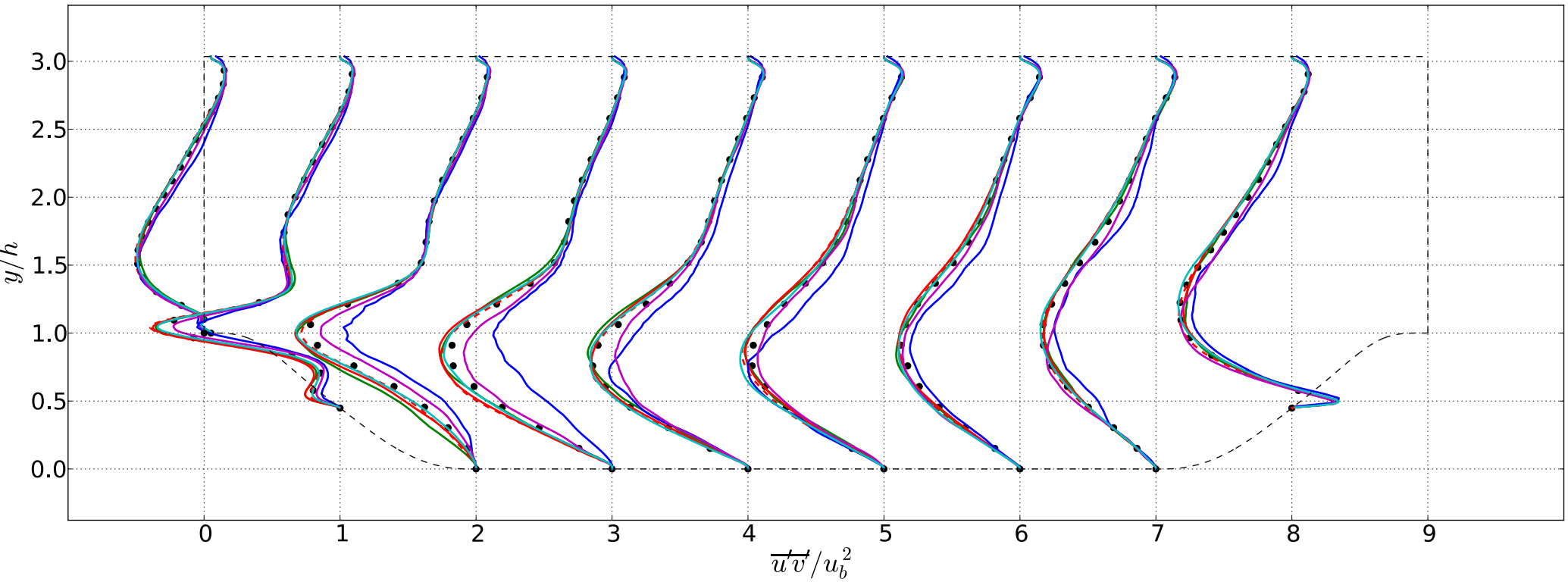

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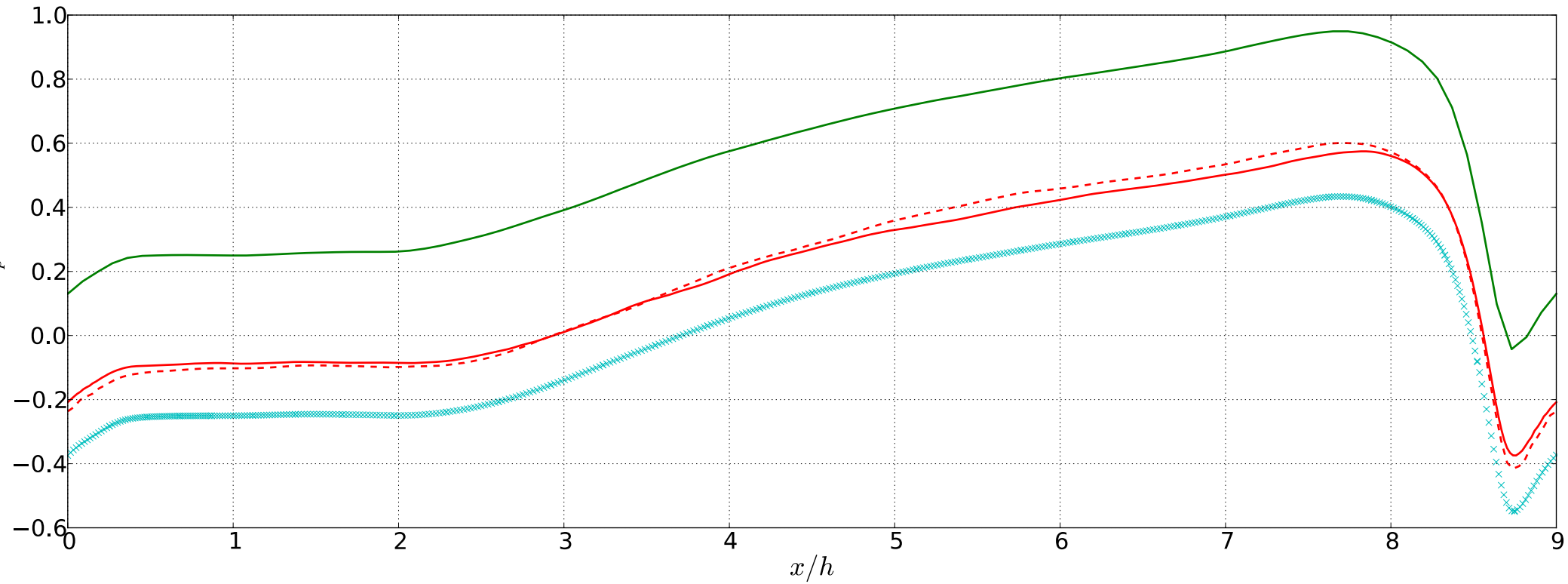
DNS Reynolds 2800 – Averaged Pressure Coefficient



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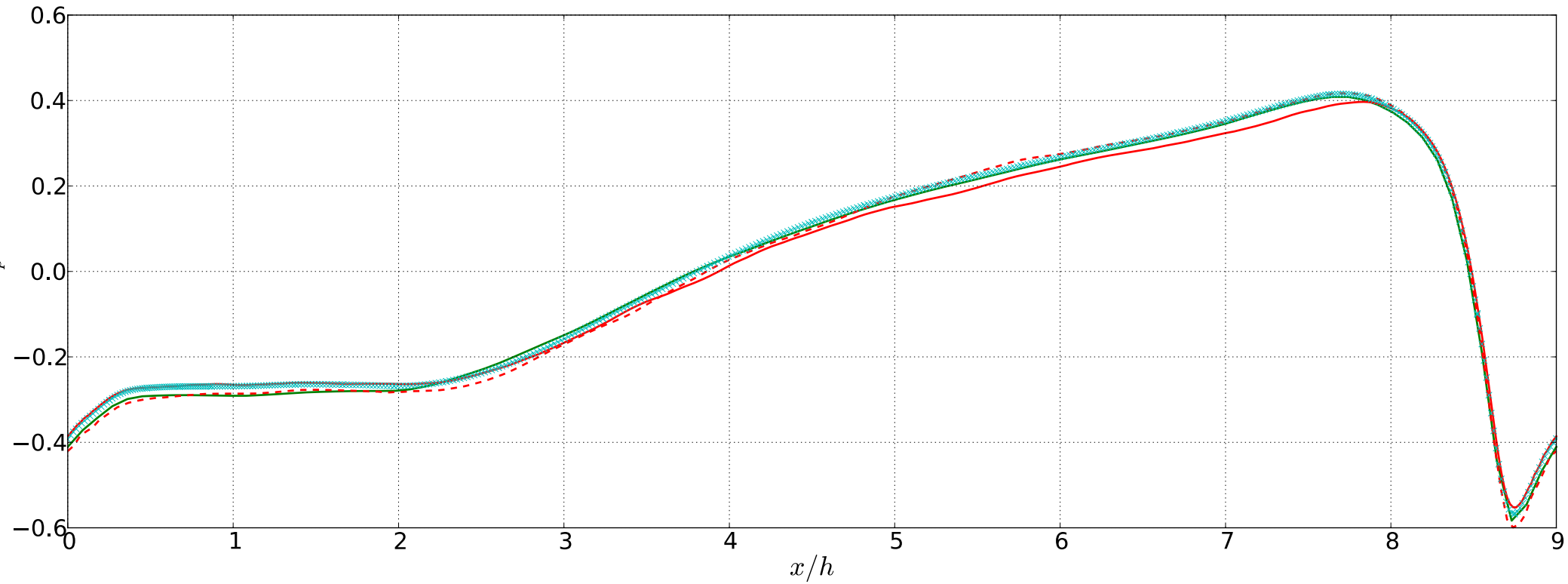

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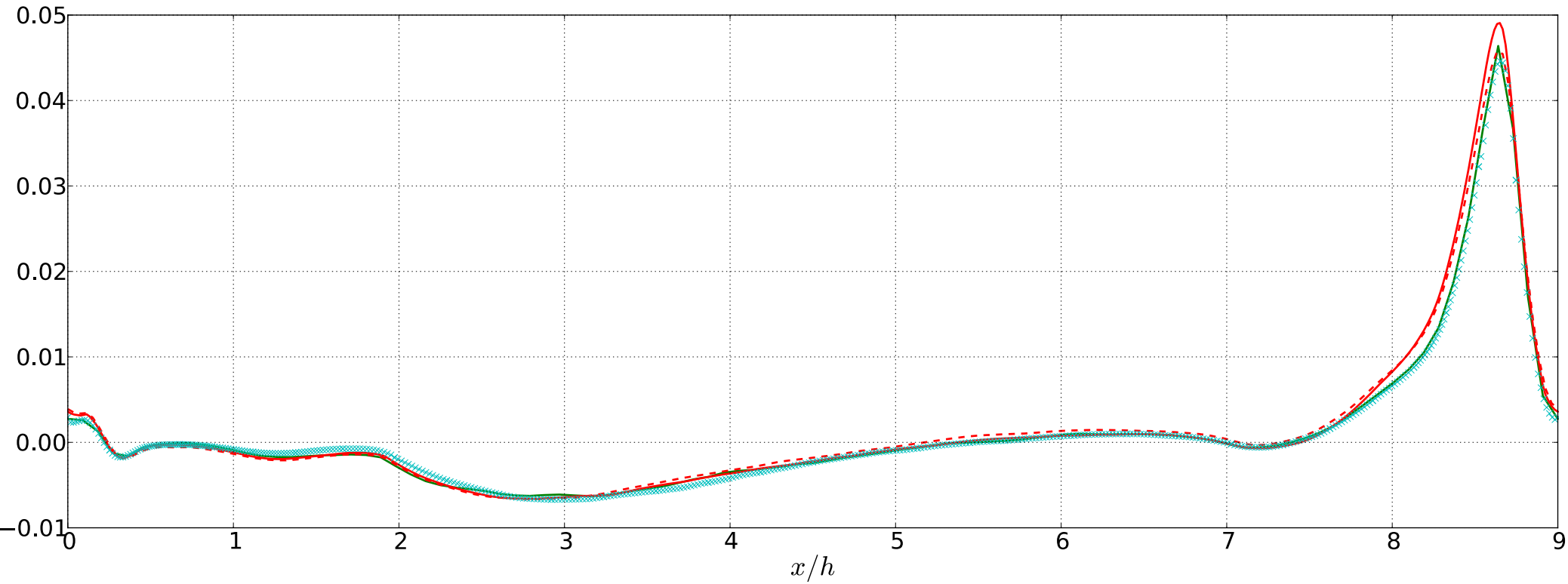
DNS Reynolds 2800 – Averaged Friction Coefficient



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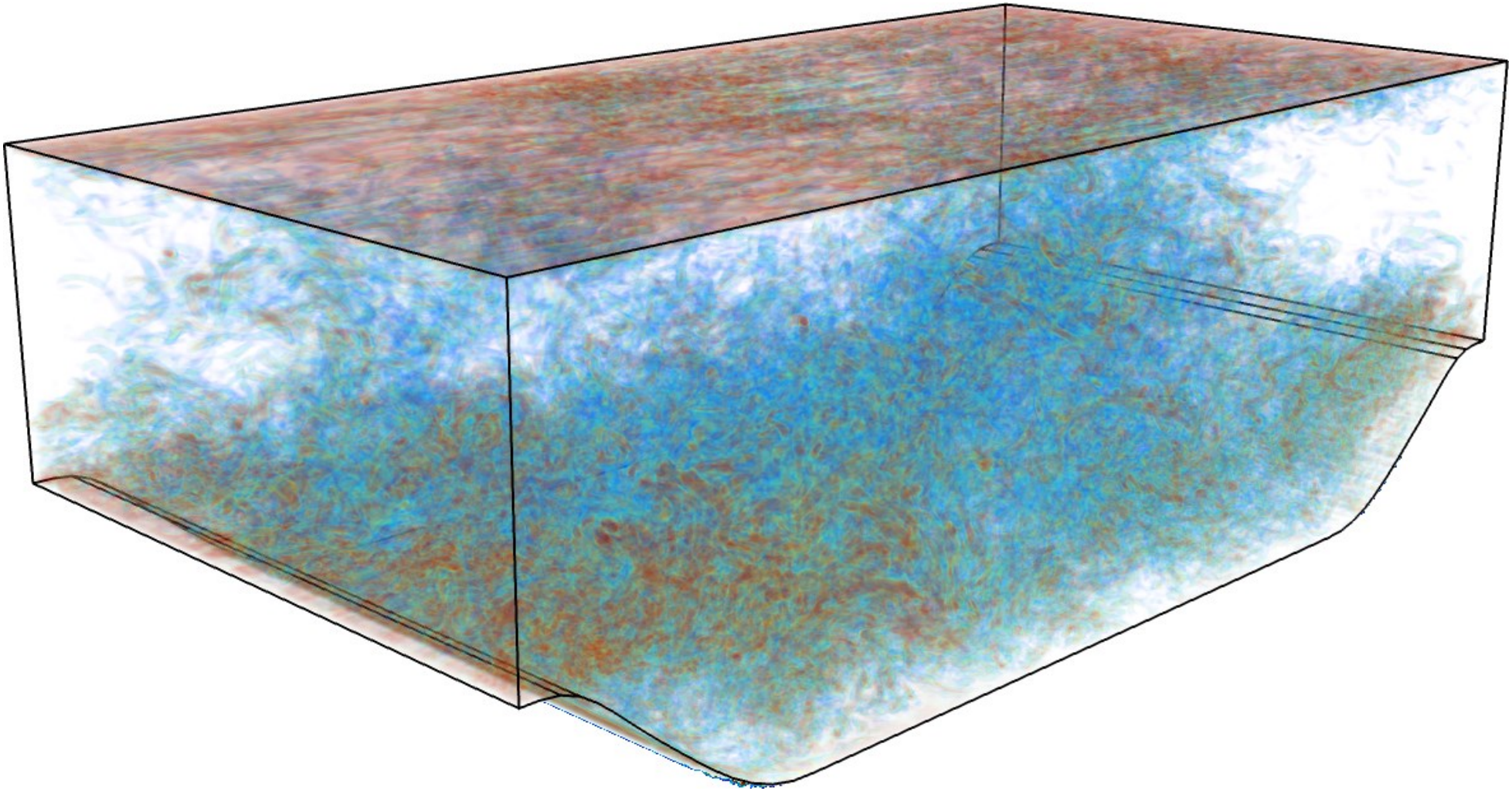
LES at Reynolds 10595



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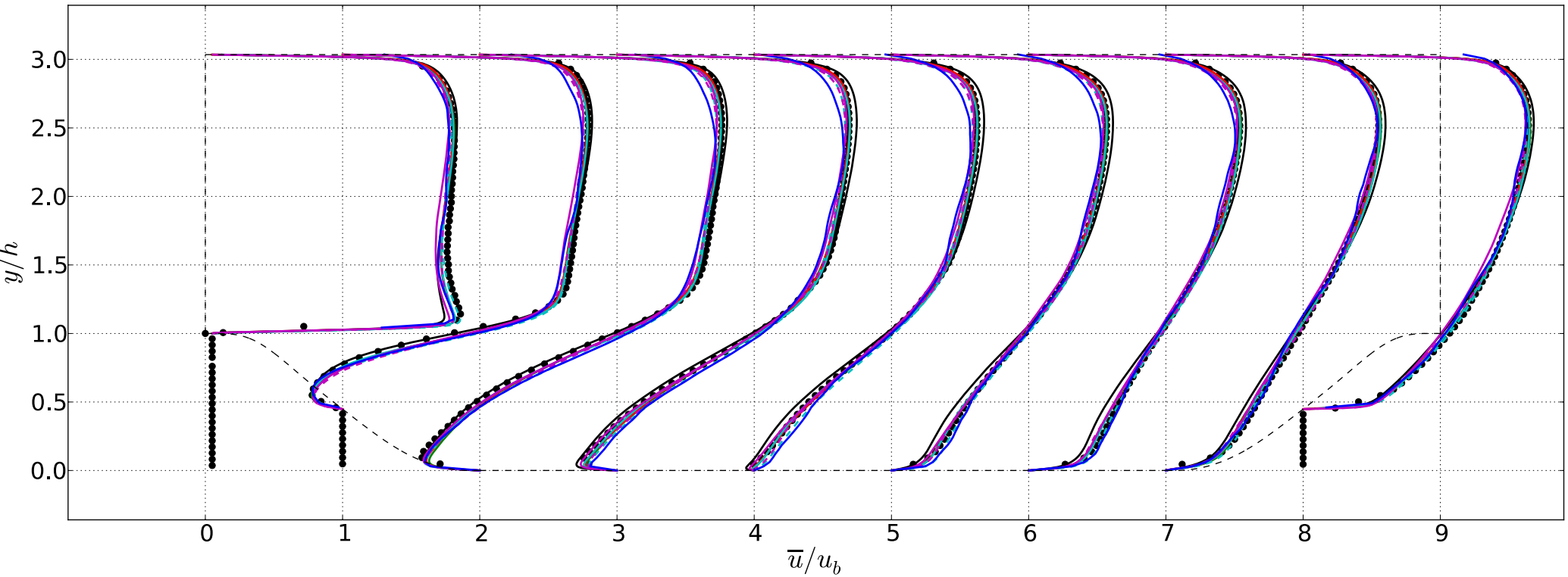
LES Reynolds 10595 – Mean x-velocity



- Experiment

LESOCC (FVM – 13M)

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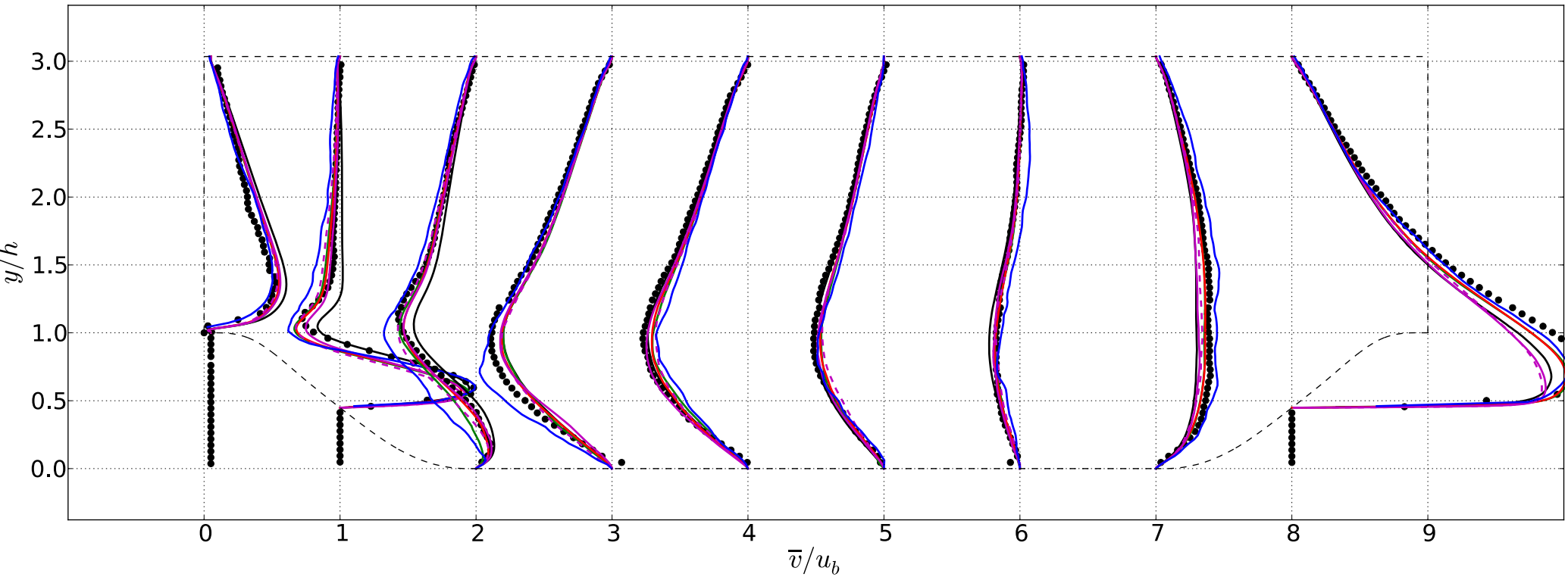

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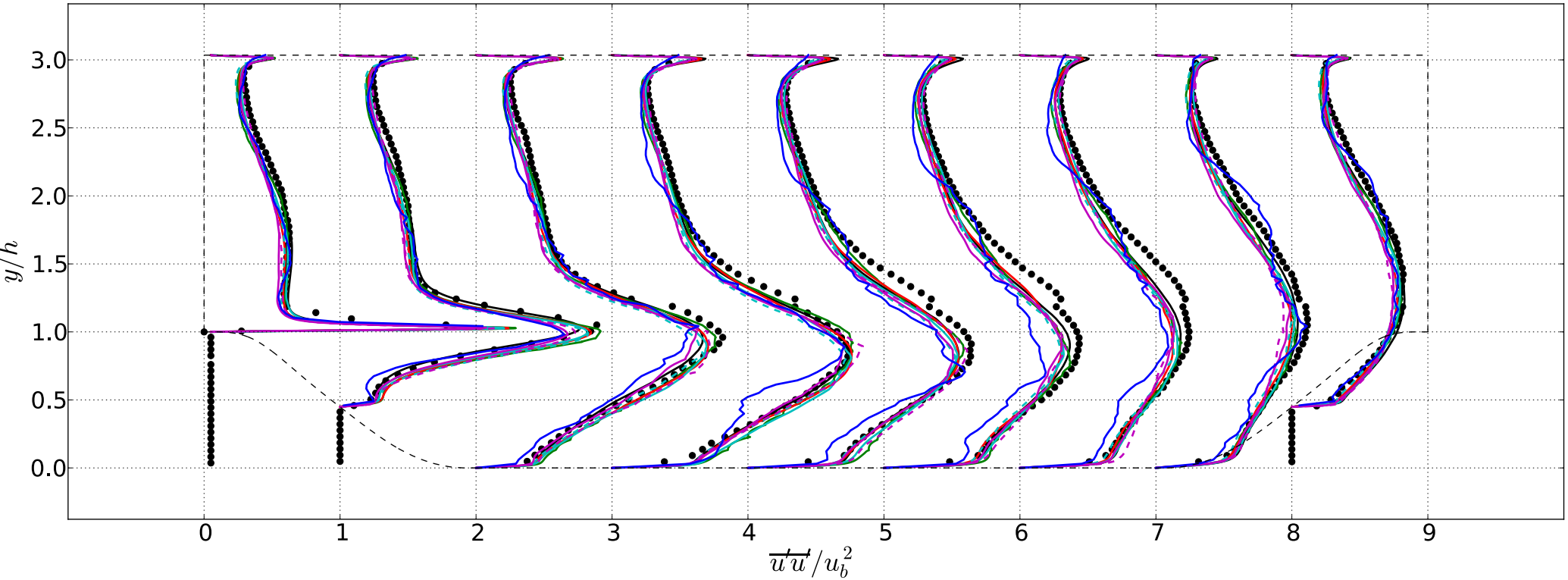

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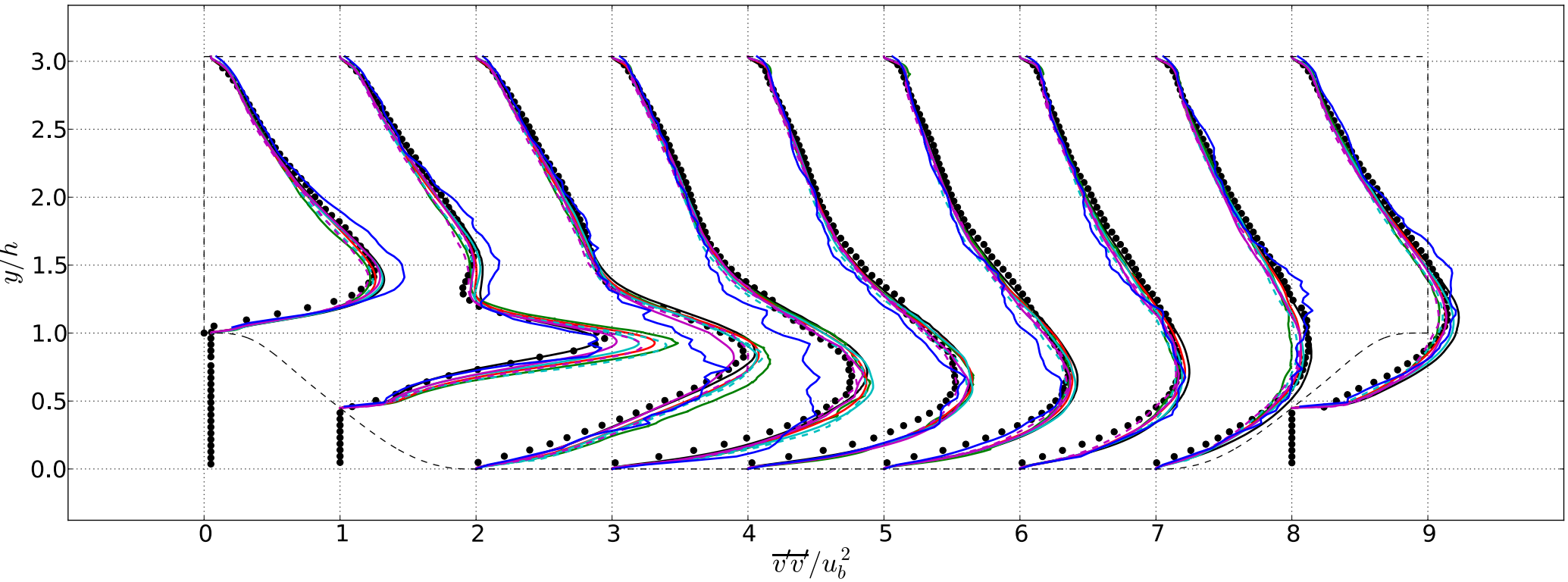

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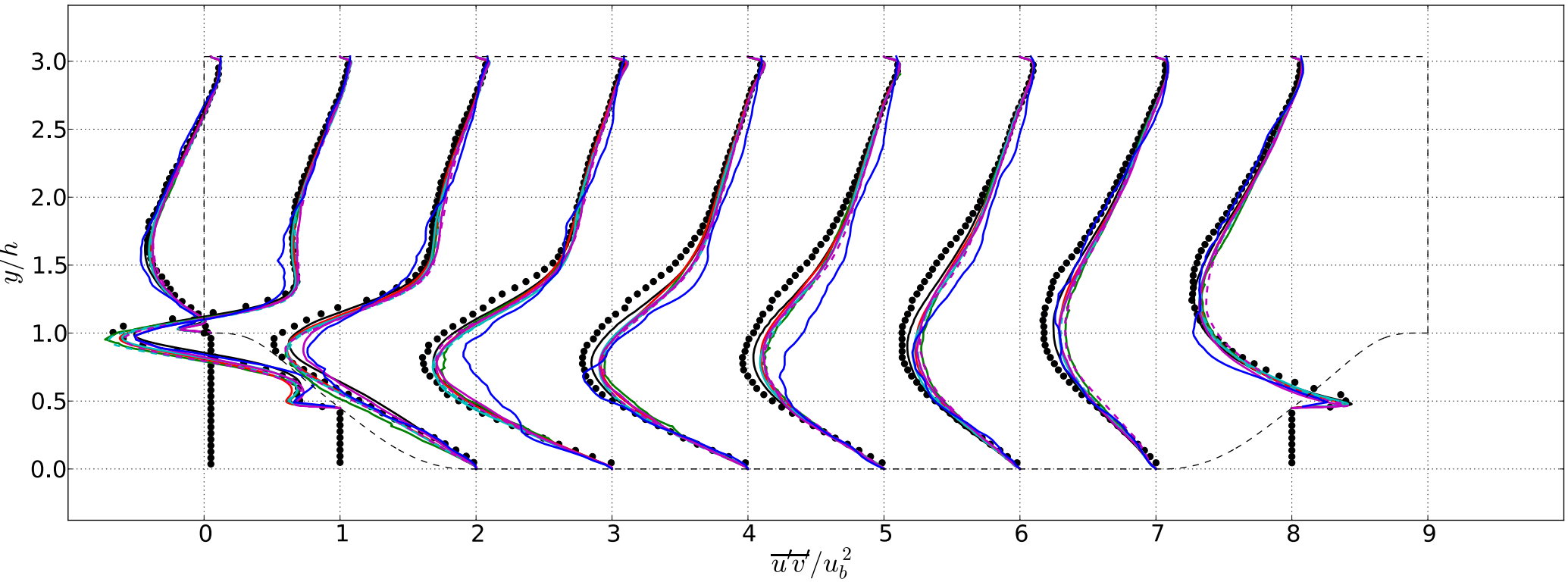

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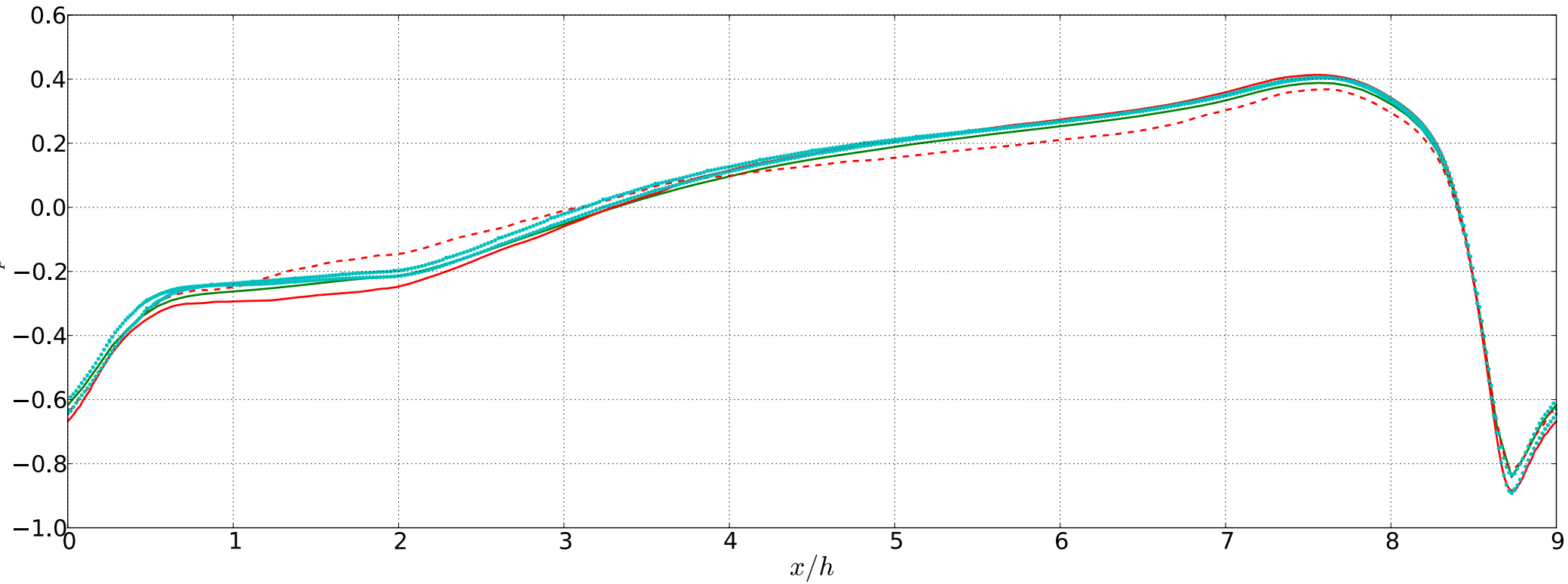
LES Reynolds 10595 – Averaged Pressure Coefficient



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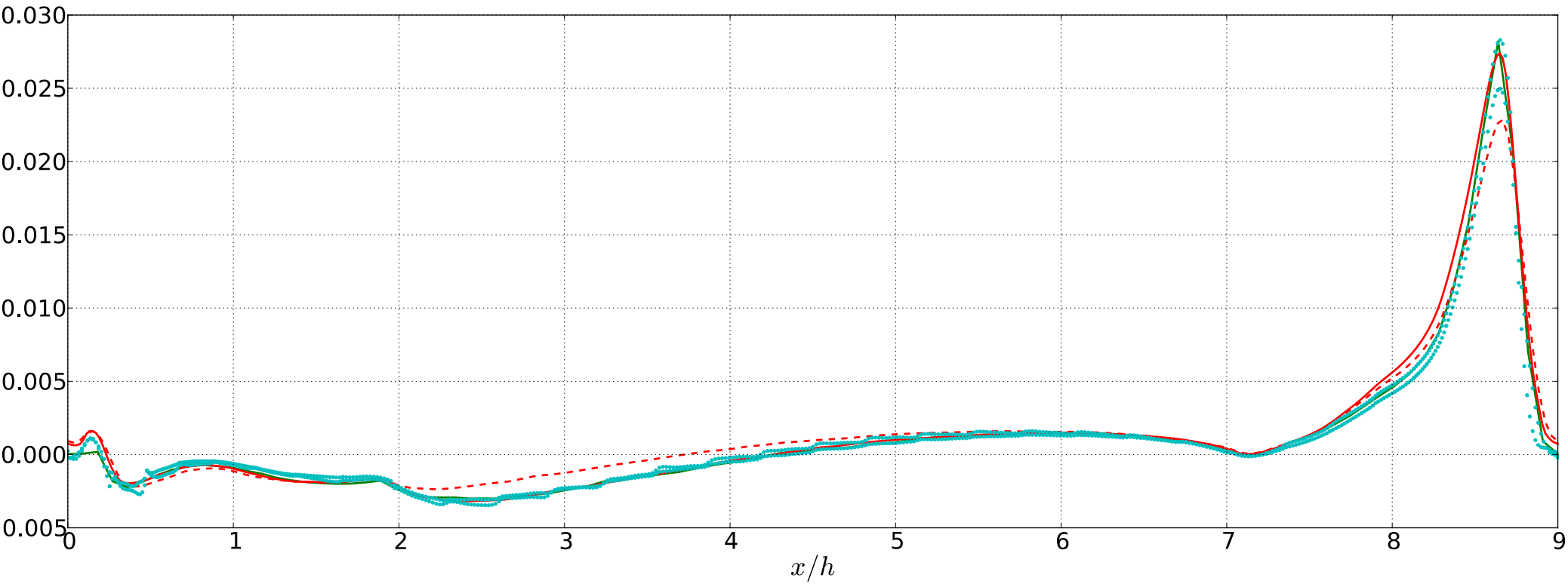

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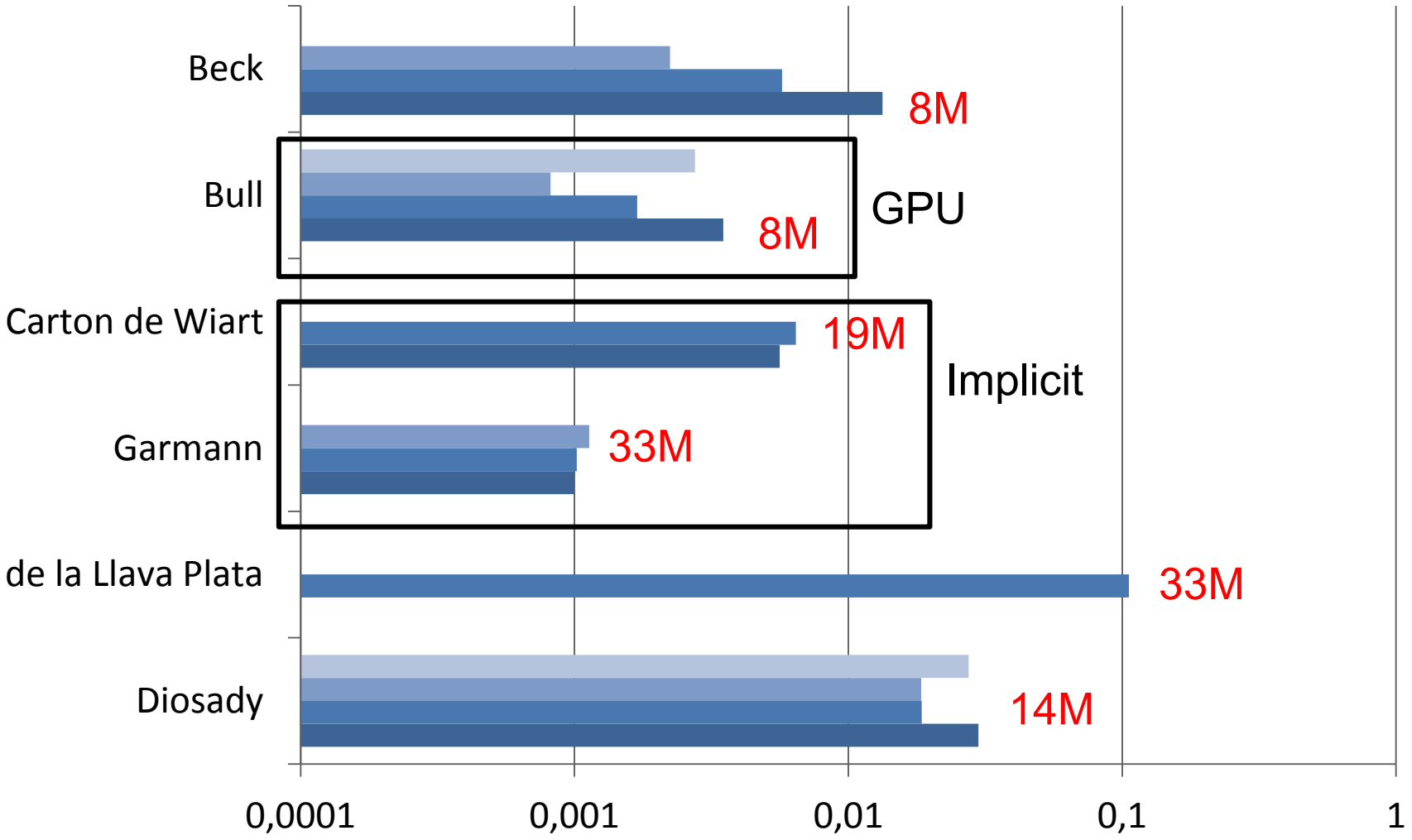
Work units / convective time / dof



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Conclusion

- 2D periodic hill is a very expensive test case… don't compute the flow if you know you don't have enough resources!
- Very good agreement for most participants on the two cases
- Advantages of high-order methods, for both DNS and (I)LES, can be observed
- Grid/order convergence are now available for DGM and Compact FDM
- Study performed on unstructured meshes with DGM offers the same accuracy than structured grids
- Define better suited set of boundary conditions for compressible flows:
  - Need to set pressure/density/temperature
  - Adiabatic vs isothermal walls?
  - Source term for the density and energy equations?