ROBUSTNESS, ACCURACY AND EFFICIENCY OF DGSEM UNDER LOCAL MESH REFINEMENT

STAB Symposium

November 13, 2024

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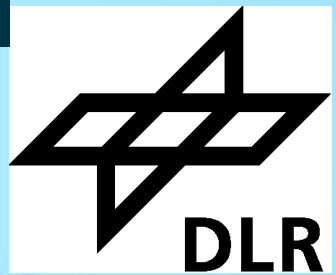


MOTIVATION

Towards industrial LES via DGSEM

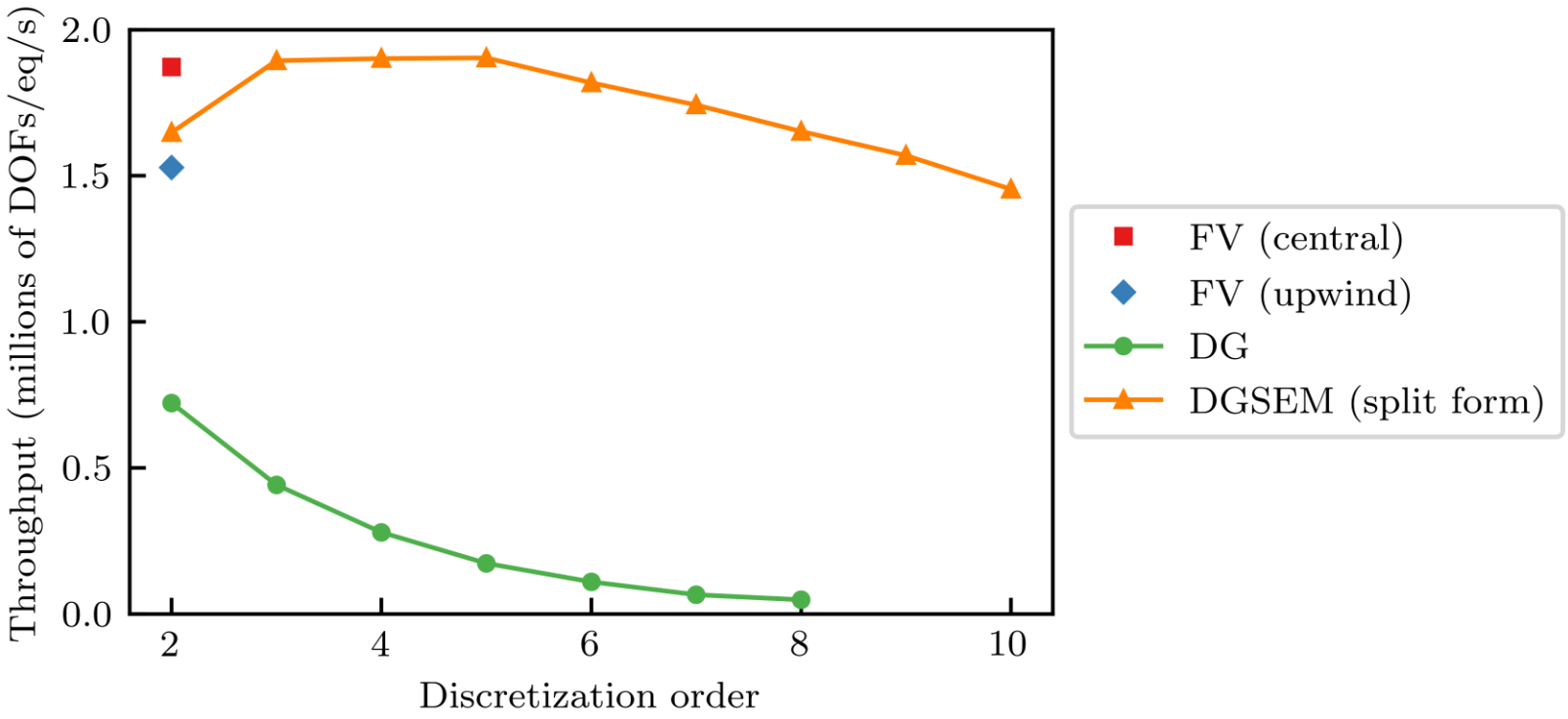
Available in CODA, the CFD software of ONERA, DLR and Airbus

High order of accuracy

Robustness

High throughput

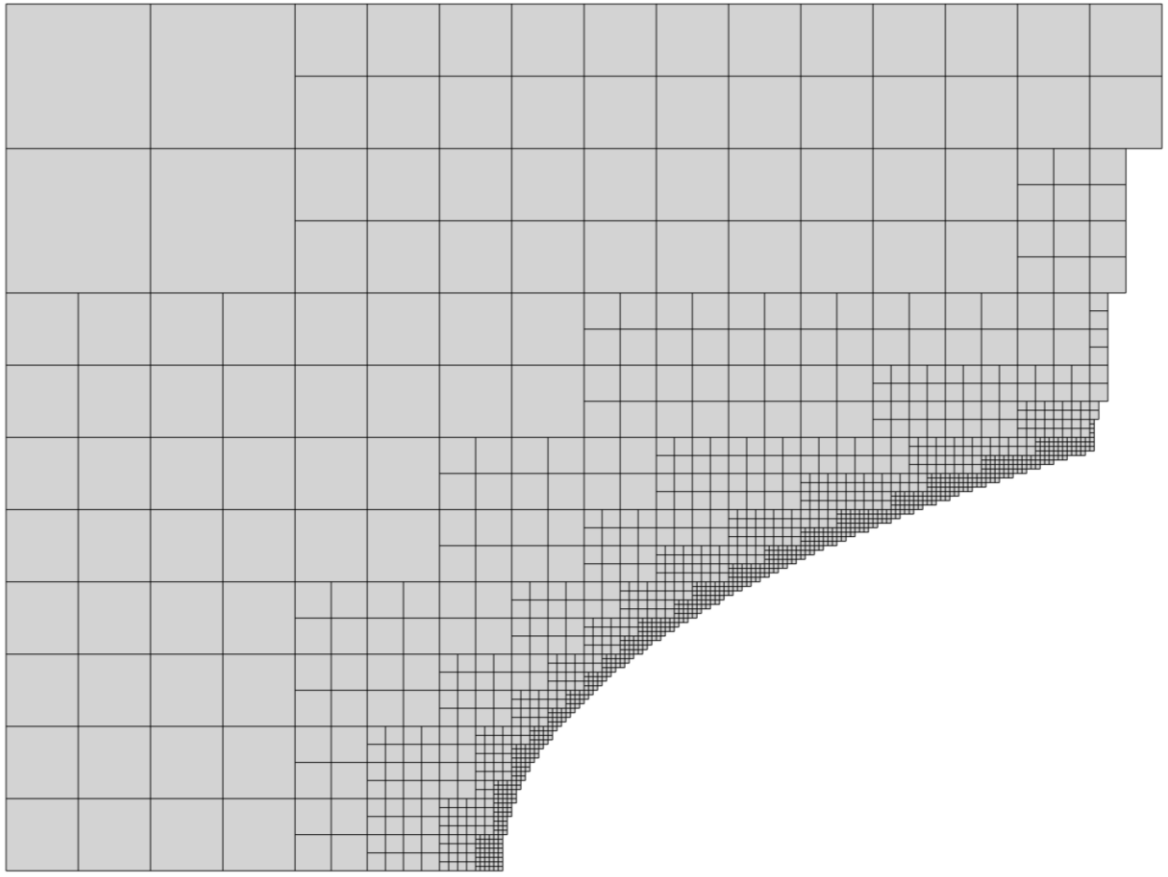
} Higher order → fewer DOFs → lower cost?

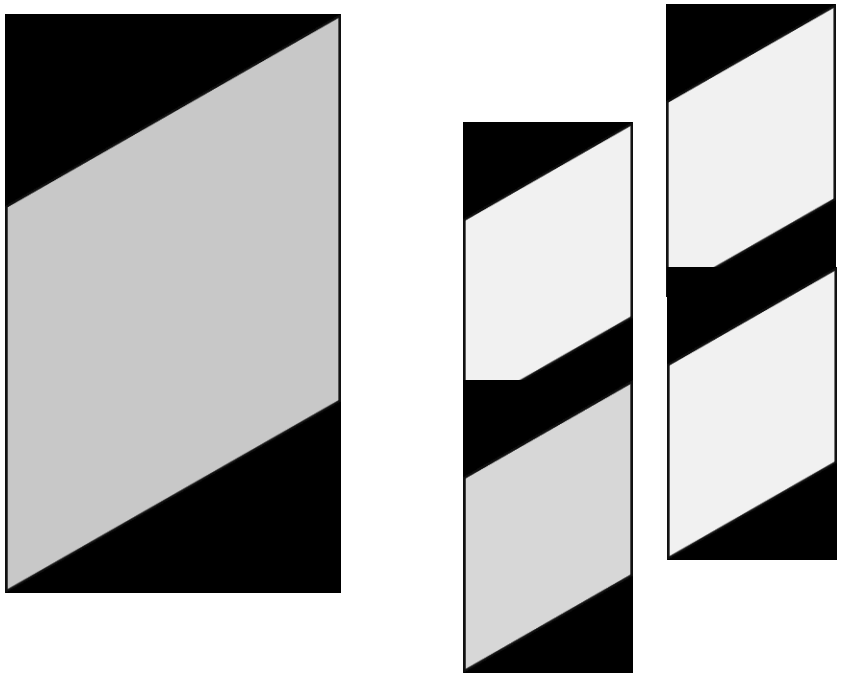


Nonconforming hexahedra meshes

Local isotropic grid refinement

Automatic mesh generation?





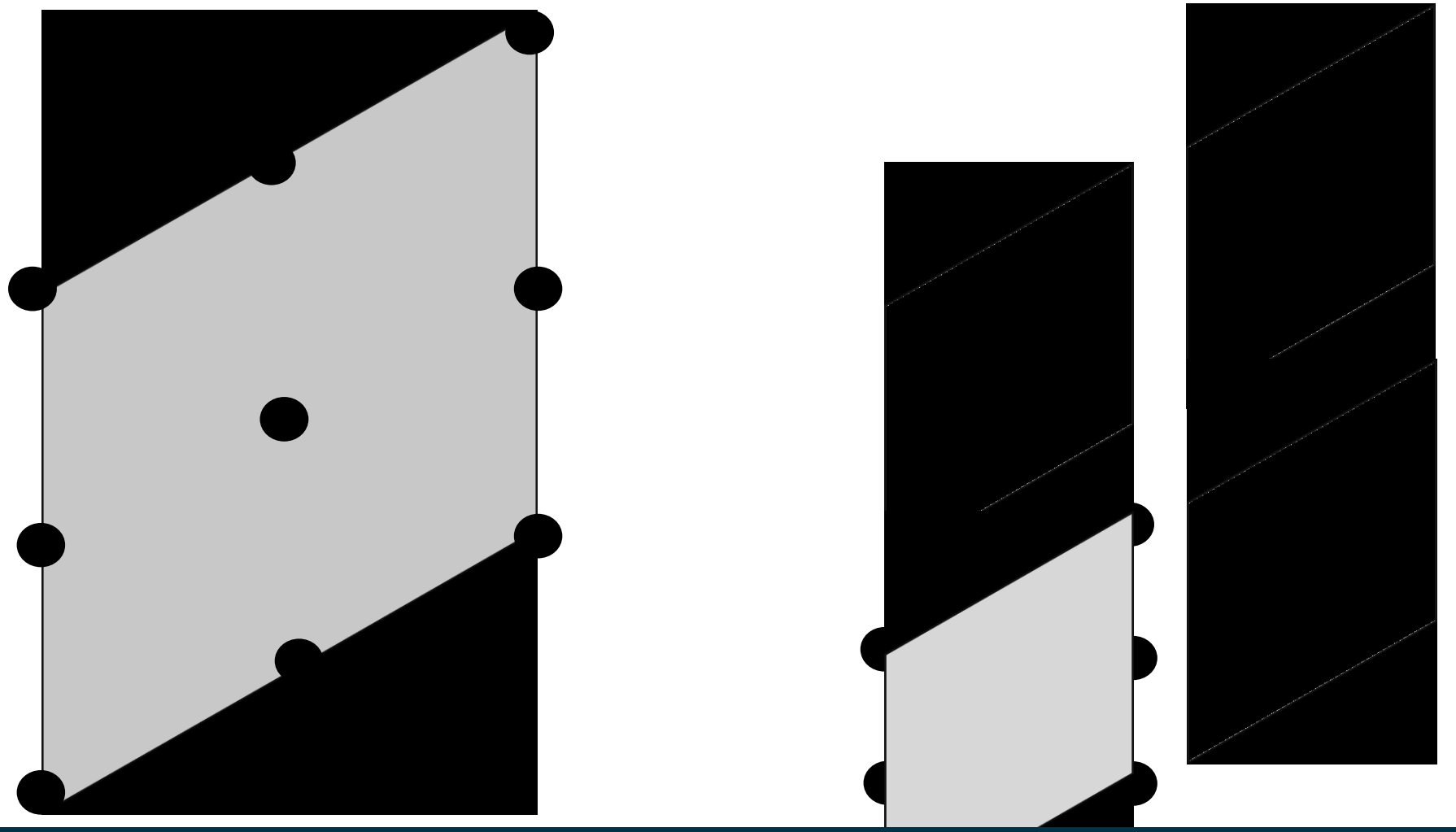
Current status & today's talk

We have extended DGSEM in CODA to nonconforming hexahedra meshes

We verified robustness and accuracy using two LES benchmark cases

- Taylor Green vortex
- Periodic hill

Here is what we found



METHODOLOGY

DGSEM

Legendre-Gauss-Lobatto (LGL) quadrature

Collocated Lagrange polynomial basis

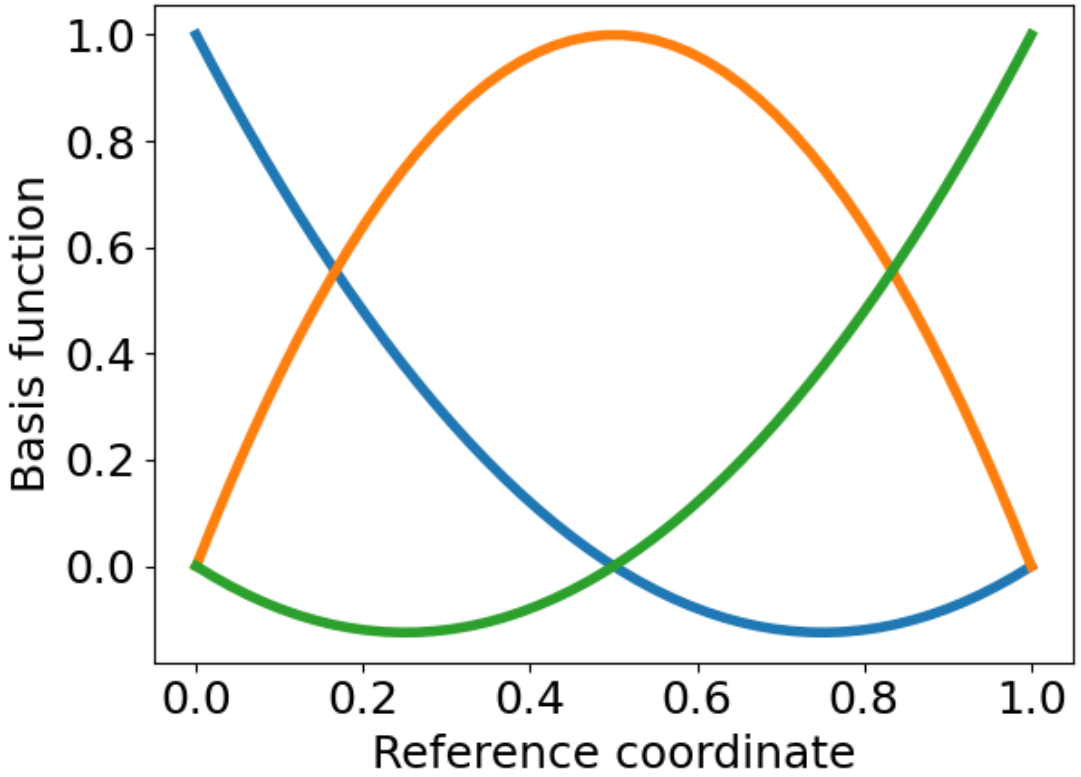
Metric terms of Kopriva (2006)

Split-form a la Gassner et al. (2016)

Two-point EC volume flux of Chandrashekar (2013)

Roe upwind convective scheme

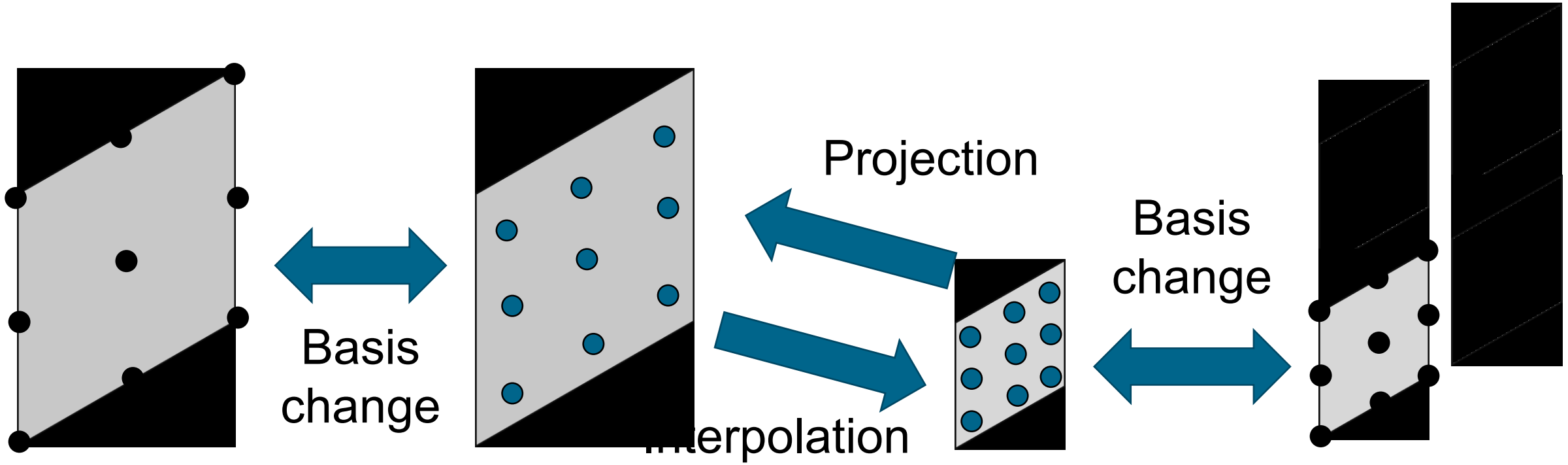
BR2 gradient lifting



Nonconforming face treatment

Standard mortar method a la Kopriva (1996)

Gauss (**not** collocated) quadrature



Time scheme

Low-storage explicit Runge-Kutta of Niegemann et al. (2012)

4^{th} order

14 stages per time step

Constant time step size

Physical model

Compressible Navier-Stokes equations

No explicit subgrid-scale model

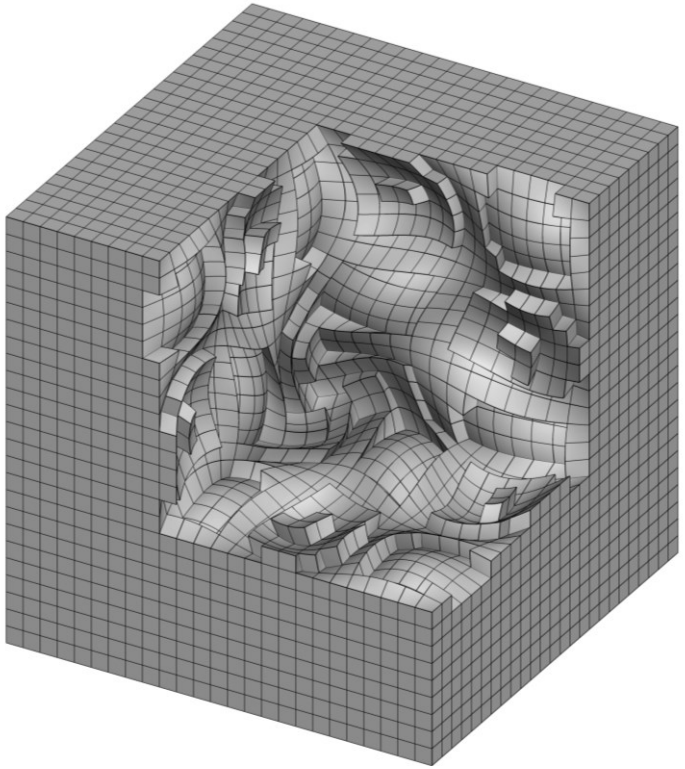
Perfect gas, air

TAYLOR-GREEN VORTEX

Meshes & resolutions (Taylor-Green vortex)

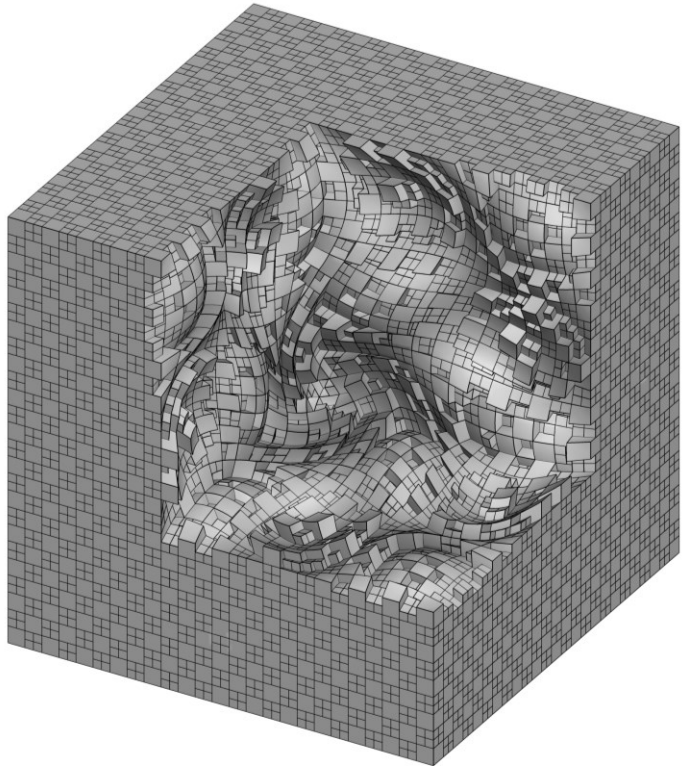
Parent

25^3 elements
200^3 DOFs/eq



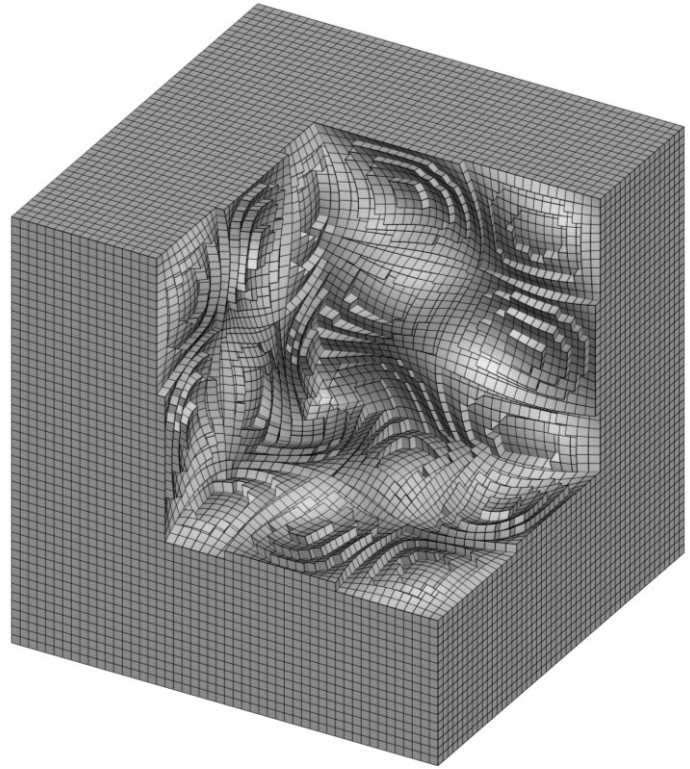
Locally refined

~41^3 elements
~330^3 DOFs/eq

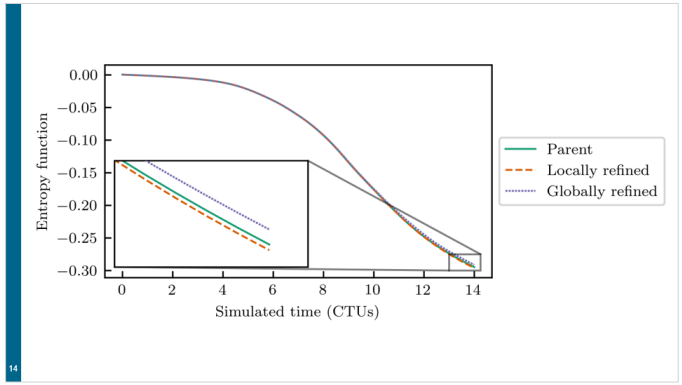


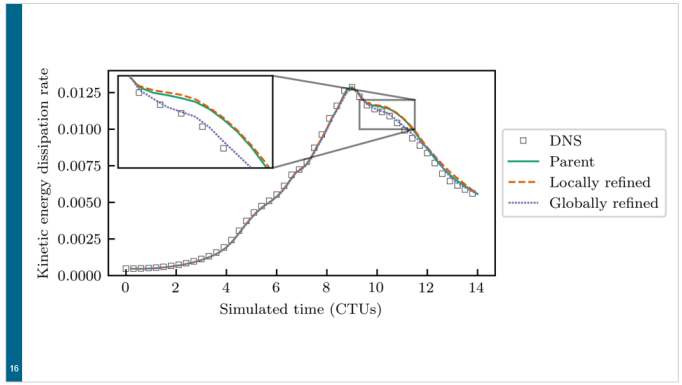
Globally refined

50^3 elements
400^3 DOFs/eq

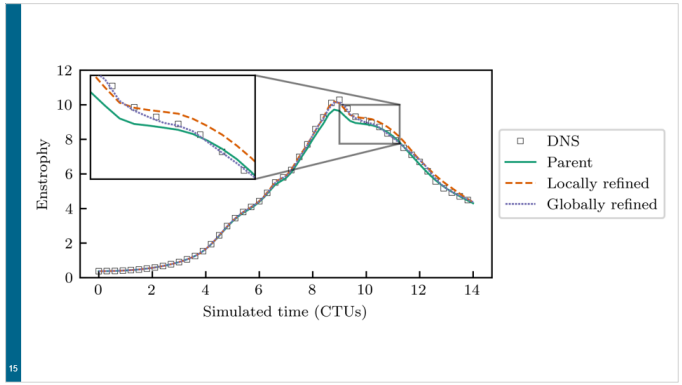


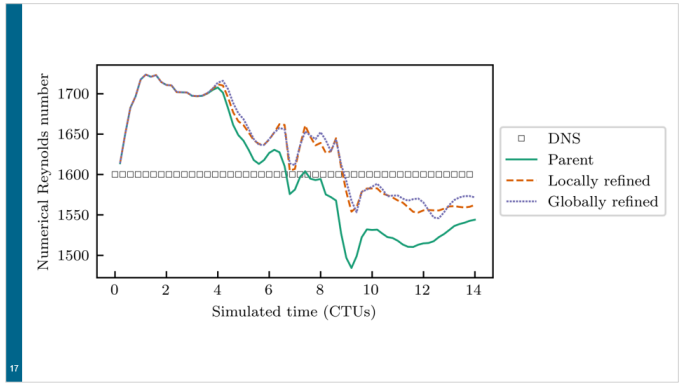
Results (Taylor-Green vortex; Re = 1600, Ma = 0.1)

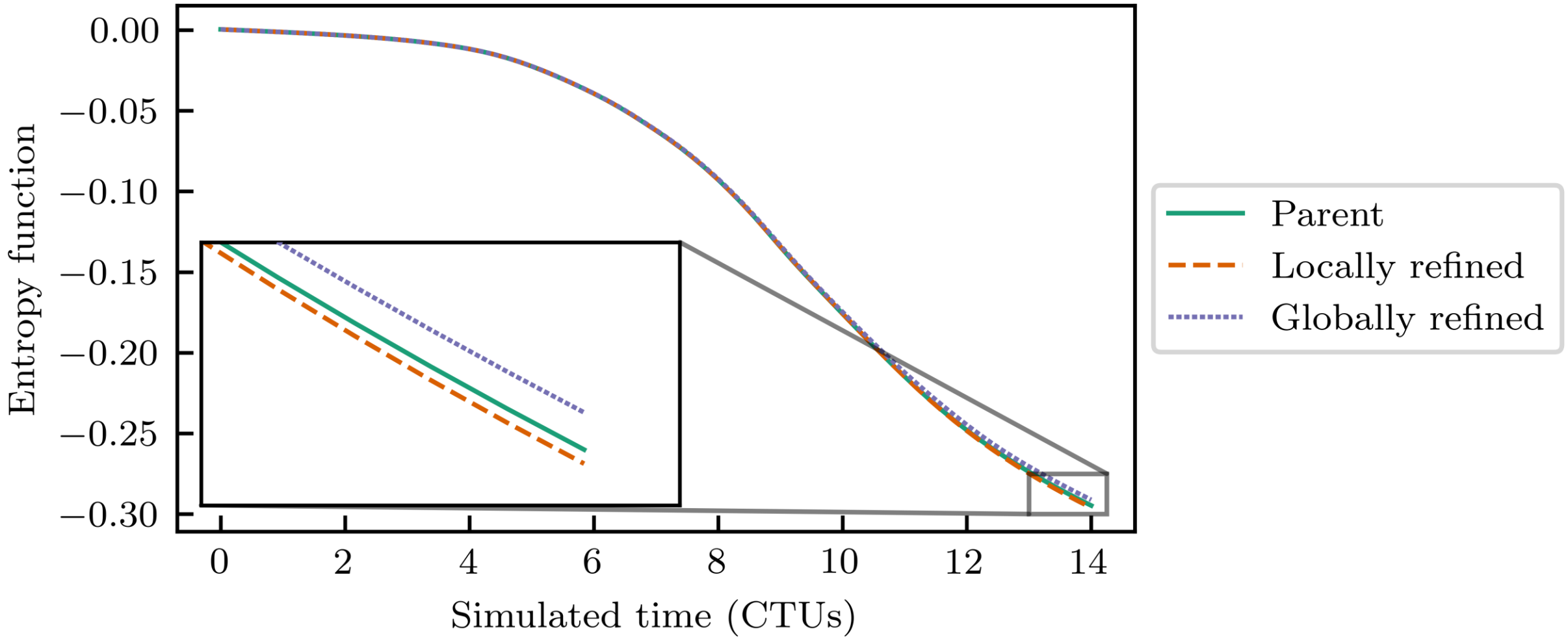


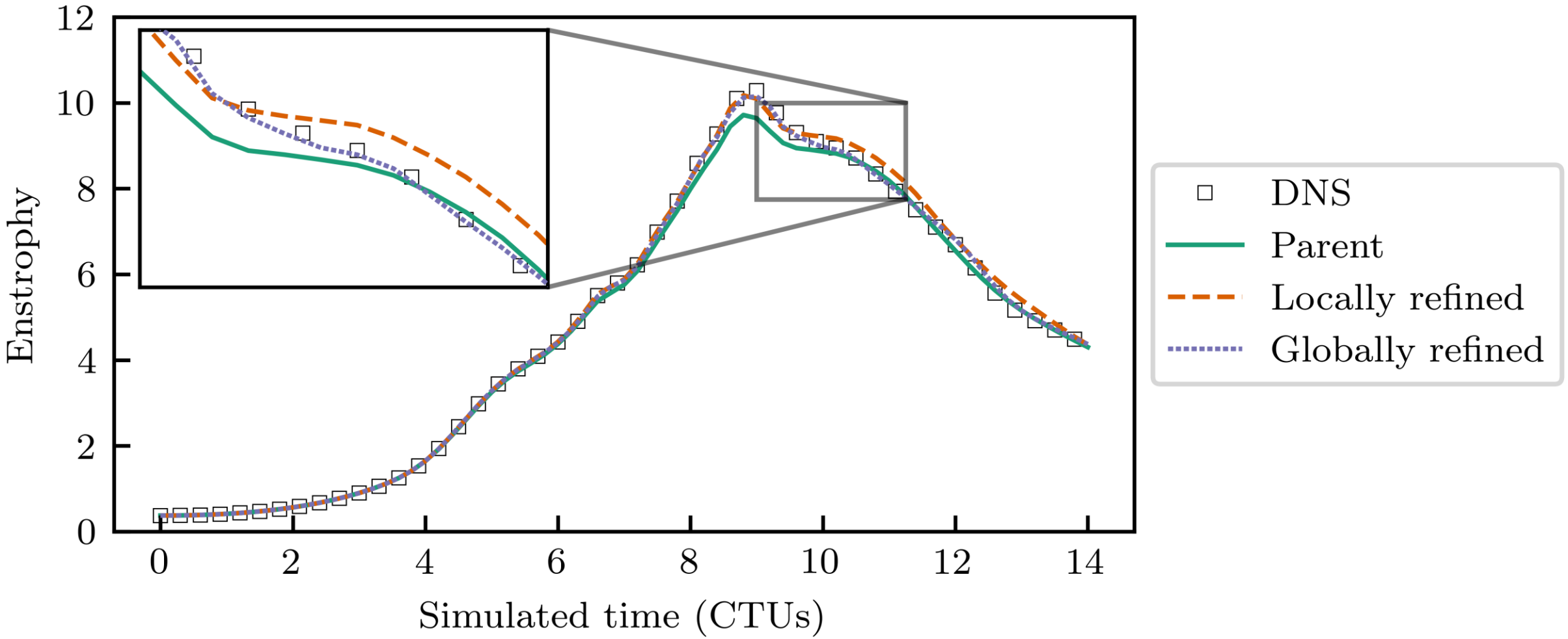


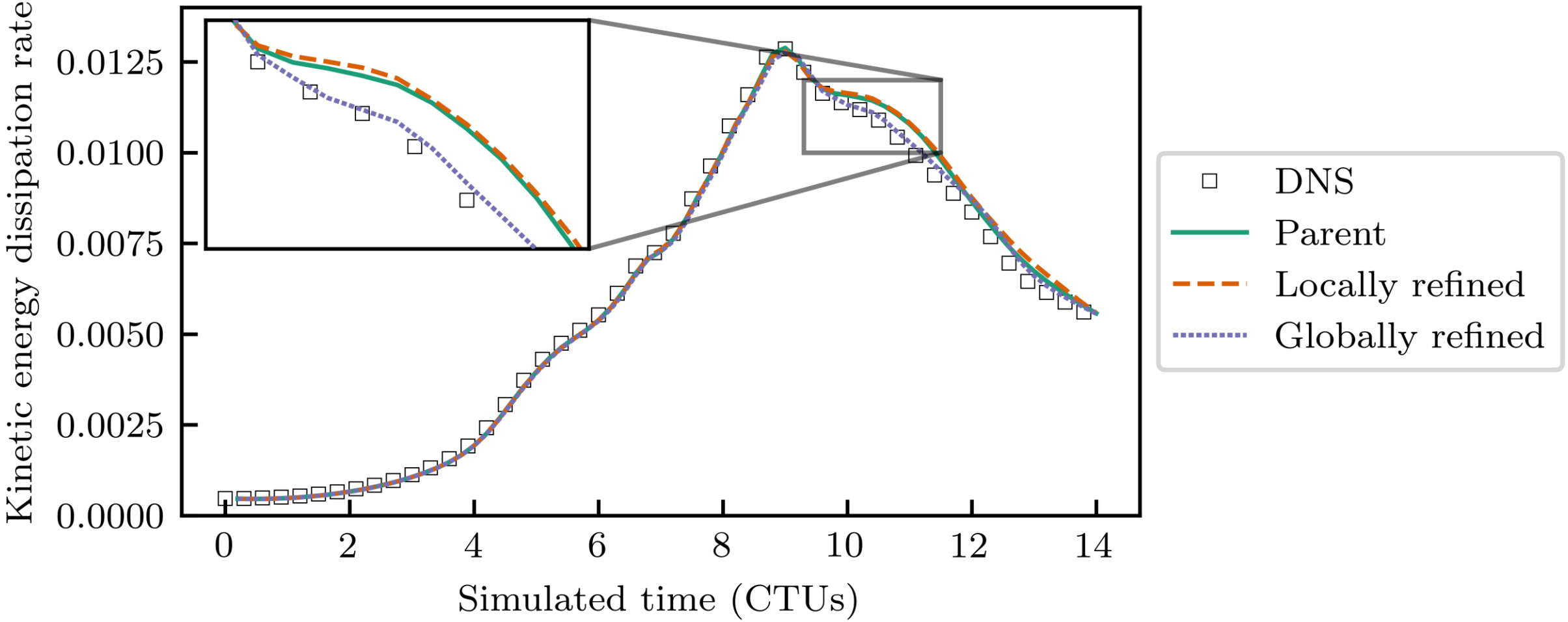
Relative to globally refined…	Parent	Locally refined
…CPU time	17%	140%
…# of DOFs	13%	56%
…# of faces	13%	74%

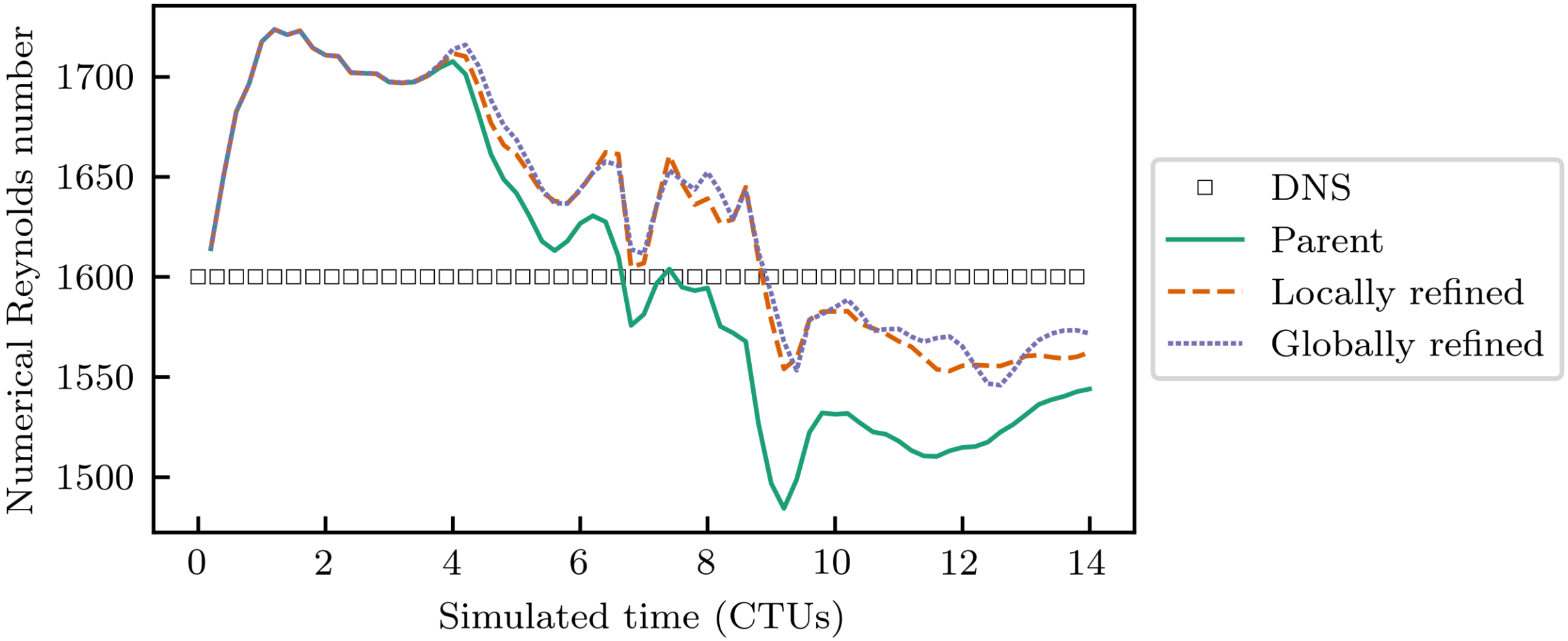




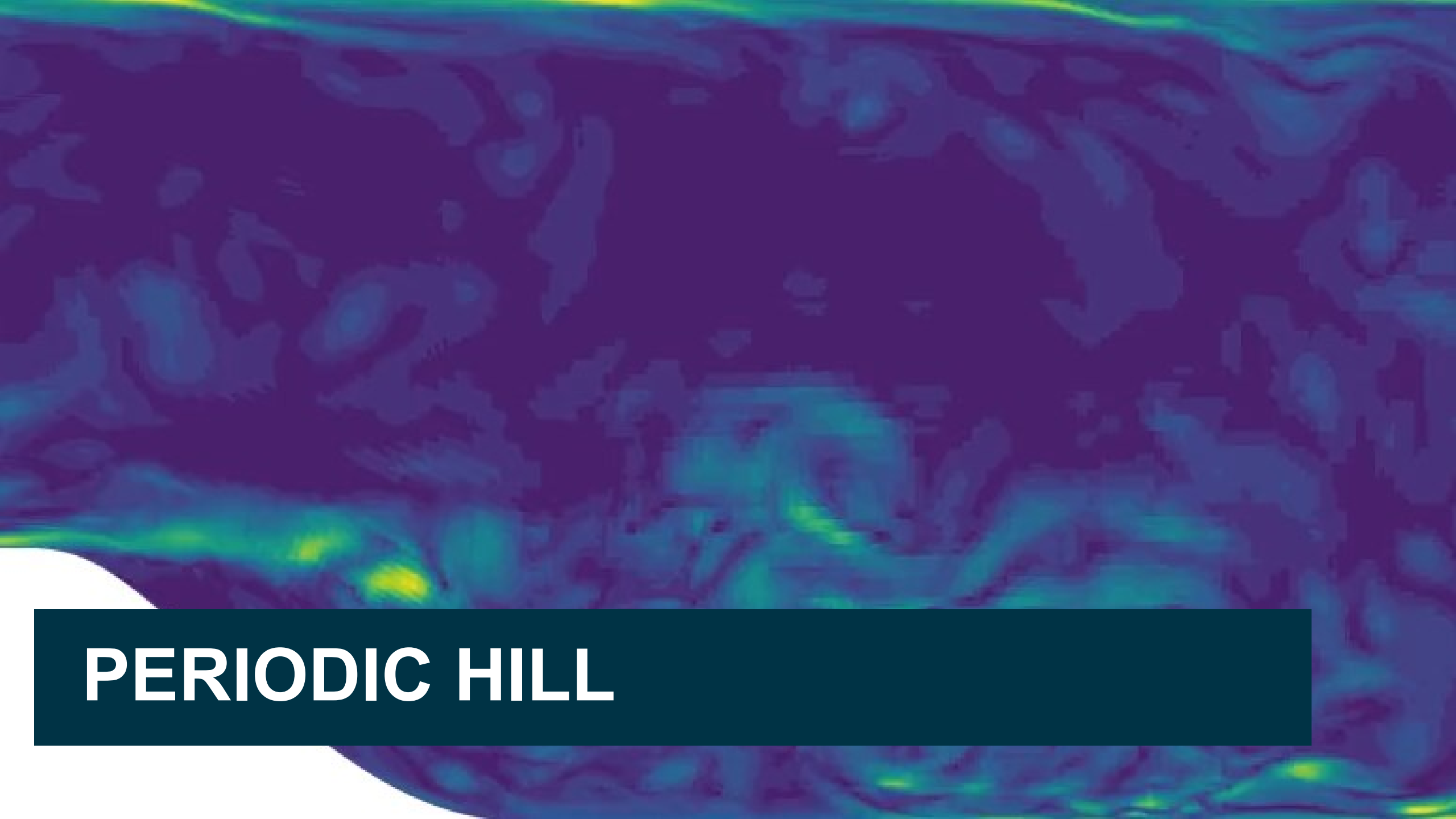

0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
Entropy function
0
2
4
6
8
10
12
14
Simulated time (CTUs)
Parent
Locally refined
Globally refined


Enstrophy
Simulated time (CTUs)
0
2
4
6
8
10
12
14
DNS
Parent
Locally refined
Globally refined


Kinetic energy dissipation rate
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
0
2
4
6
8
10
12
14
Simulated time (CTUs)
DNS
Parent
Locally refined
Globally refined


Numerical Reynolds number
1700
1650
1600
1550
1500
0
2
4
6
8
10
12
14
Simulated time (CTUs)
DNS
Parent
Locally refined
Globally refined

Relative to globally refined…	Parent	Locally refined
…CPU time	17%	**140%**
…# of DOFs	13%	56%
…# of faces	13%	74%



PERIODIC HILL

Meshes & resolutions (periodic hill)

Parent

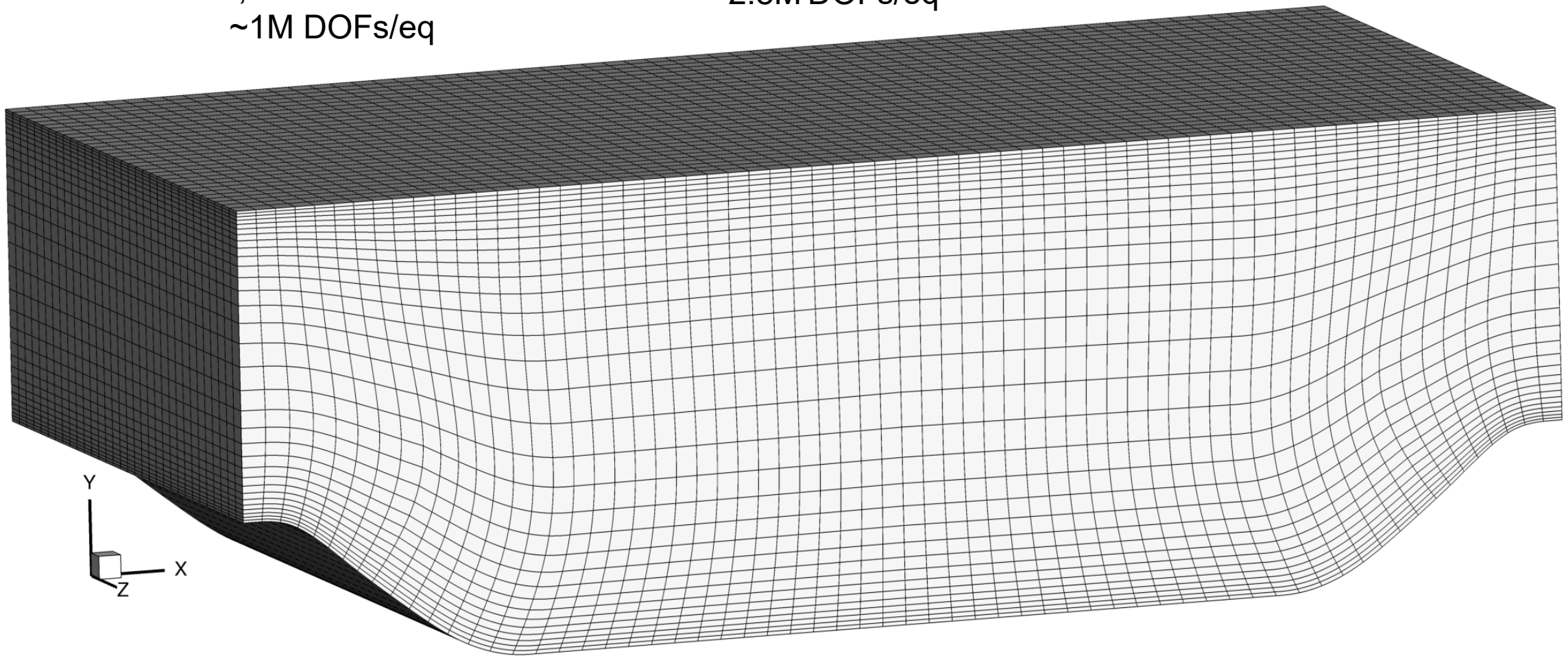
8,192 elements
~1M DOFs/eq

Locally refined

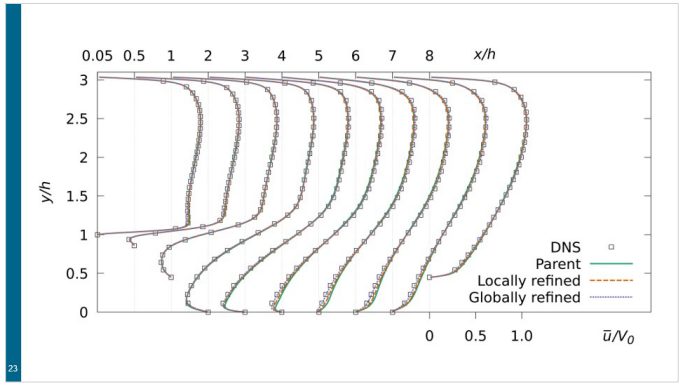
22,528 elements
~2.8M DOFs/eq

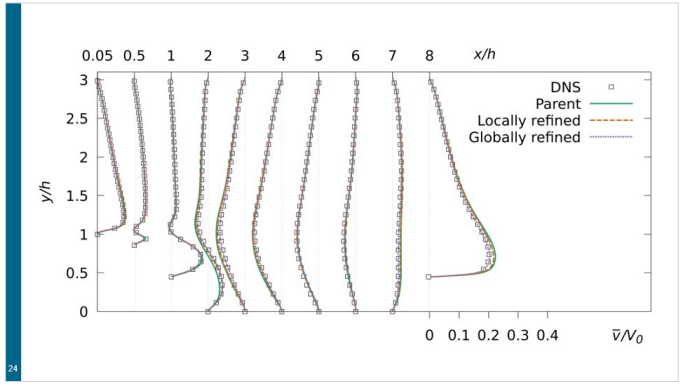
Globally refined

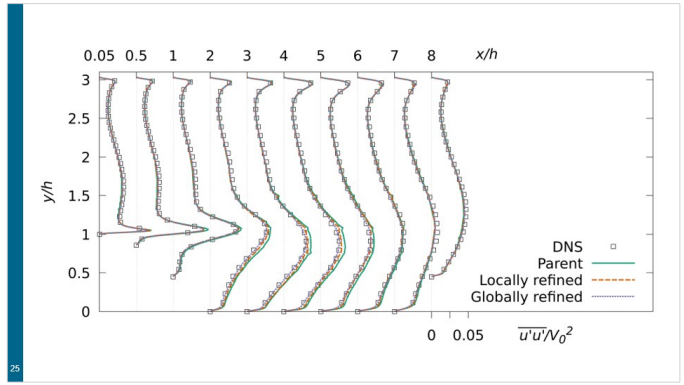
65,536 elements
~8.2M DOFs/eq

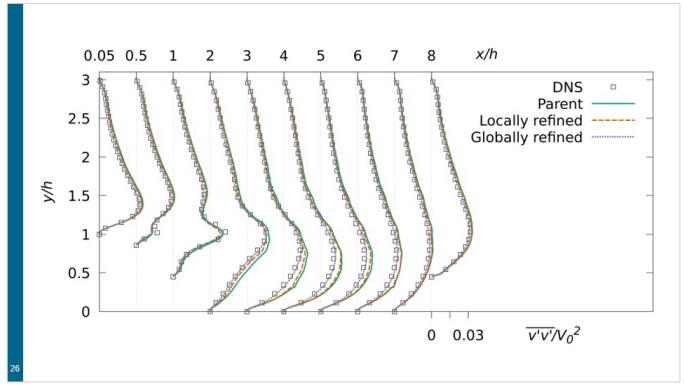


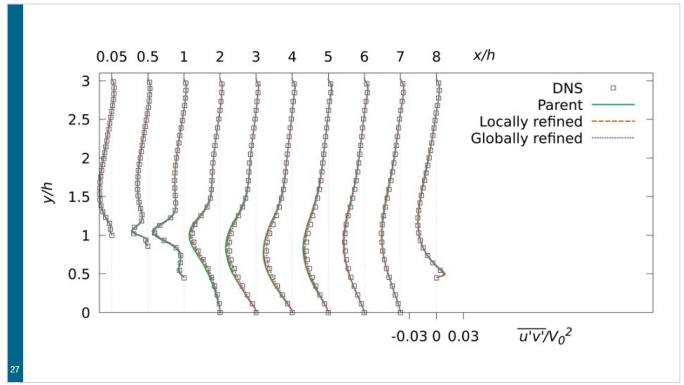
Results (periodic hill; Re = 2800, Ma = 0.1)





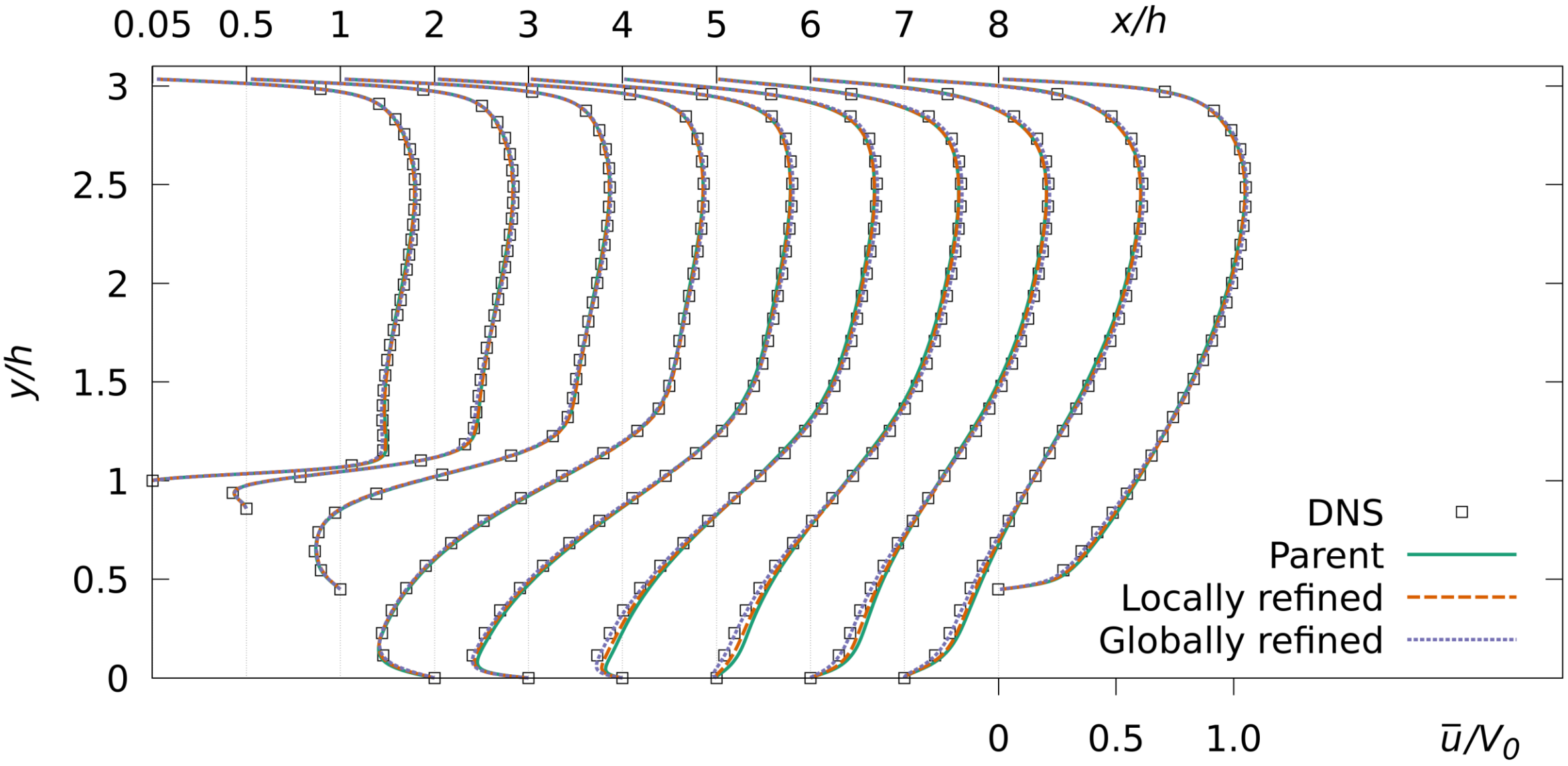


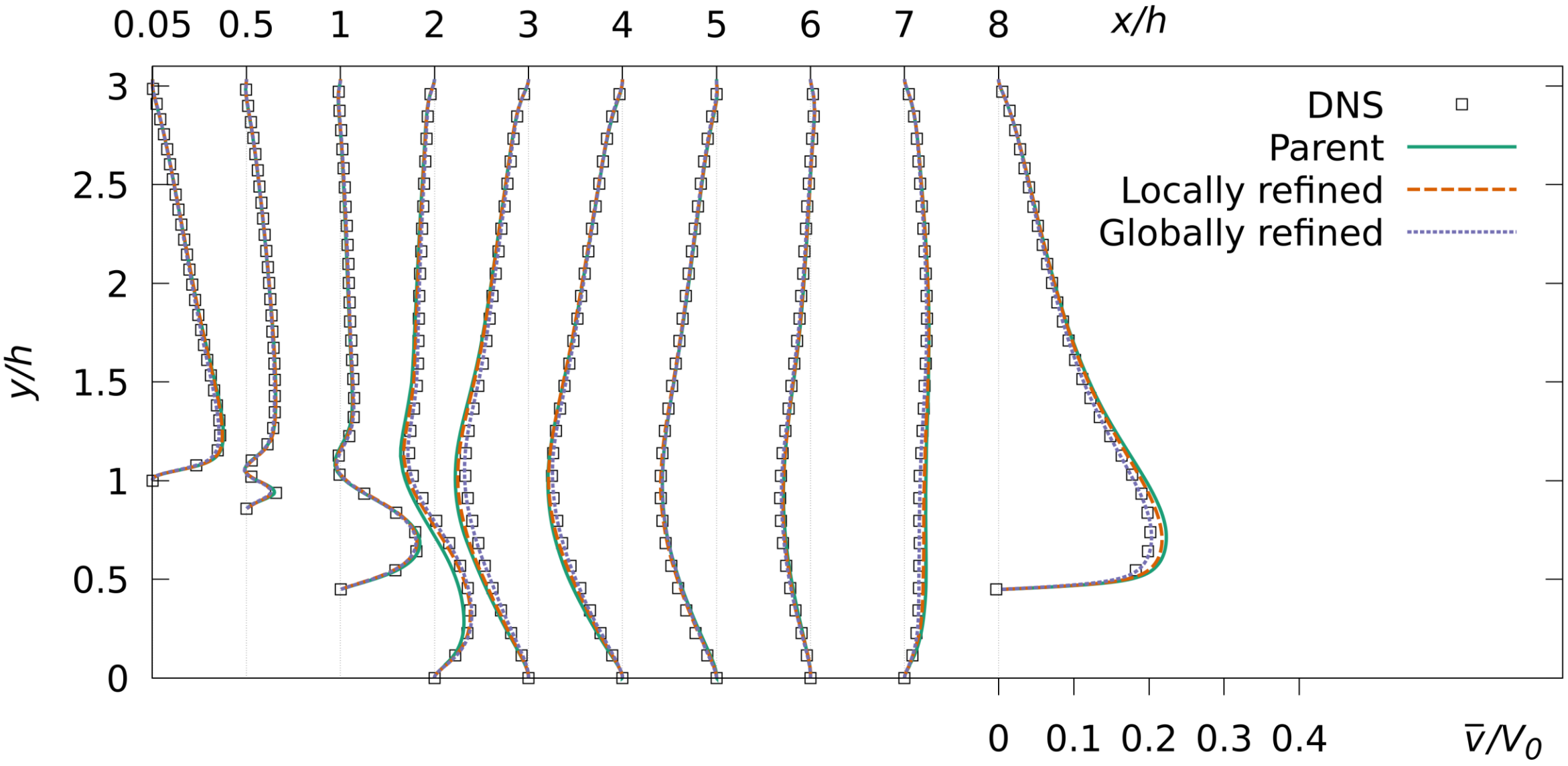


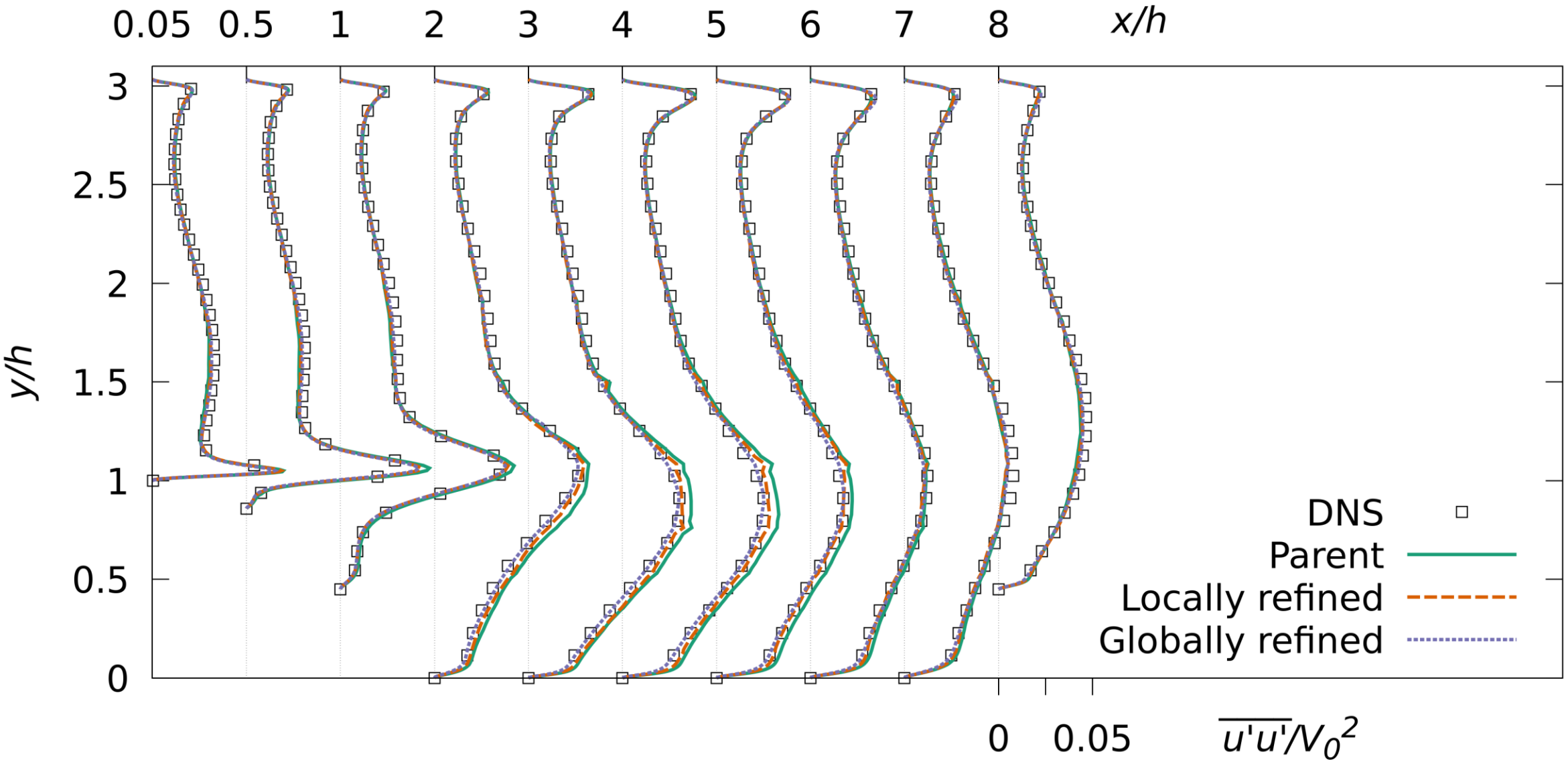


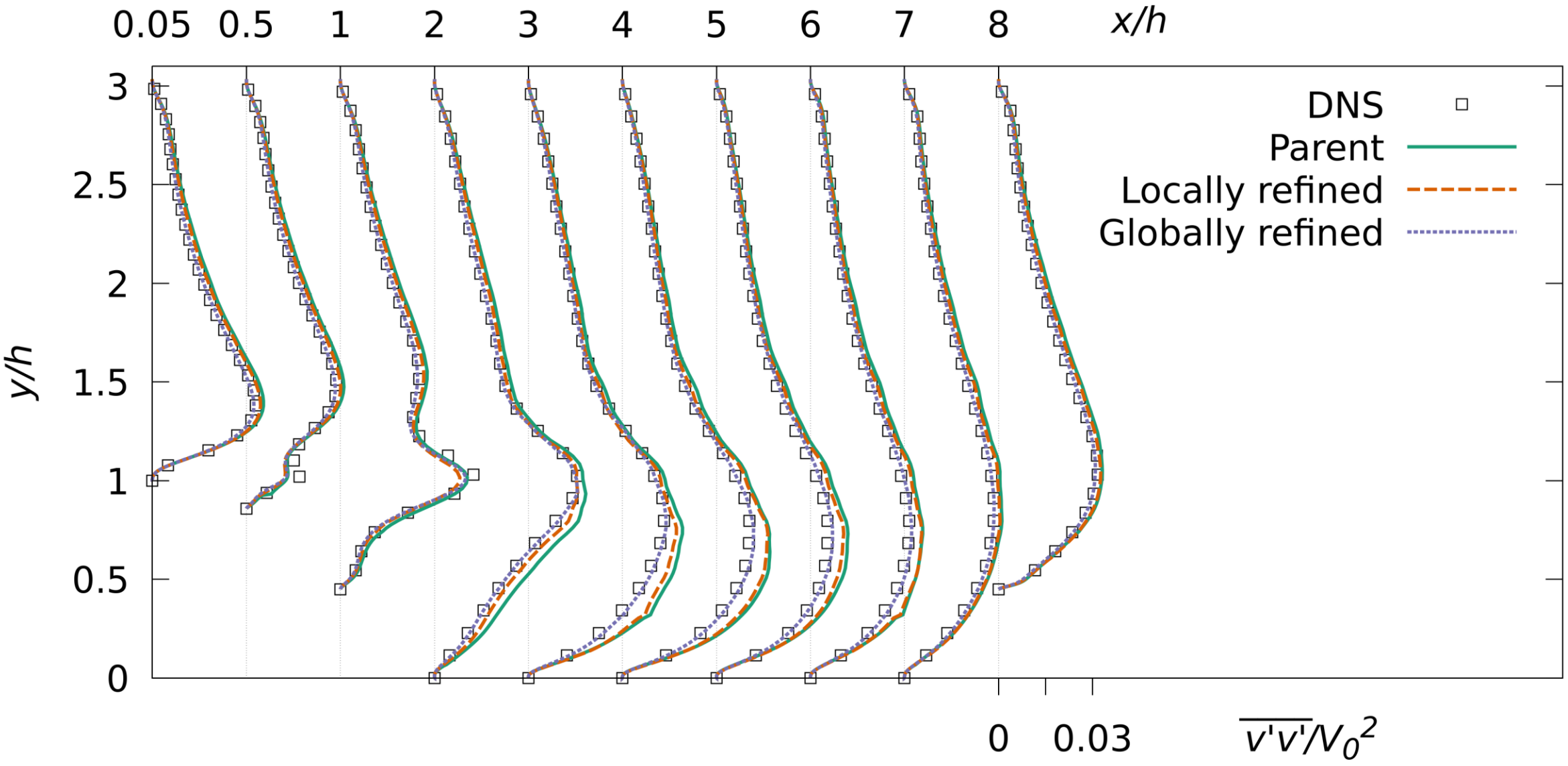
Relative to globally refined…	Parent	Locally refined
…CPU time (averaging period only)	19%	54%
…# of DOFs	13%	34%

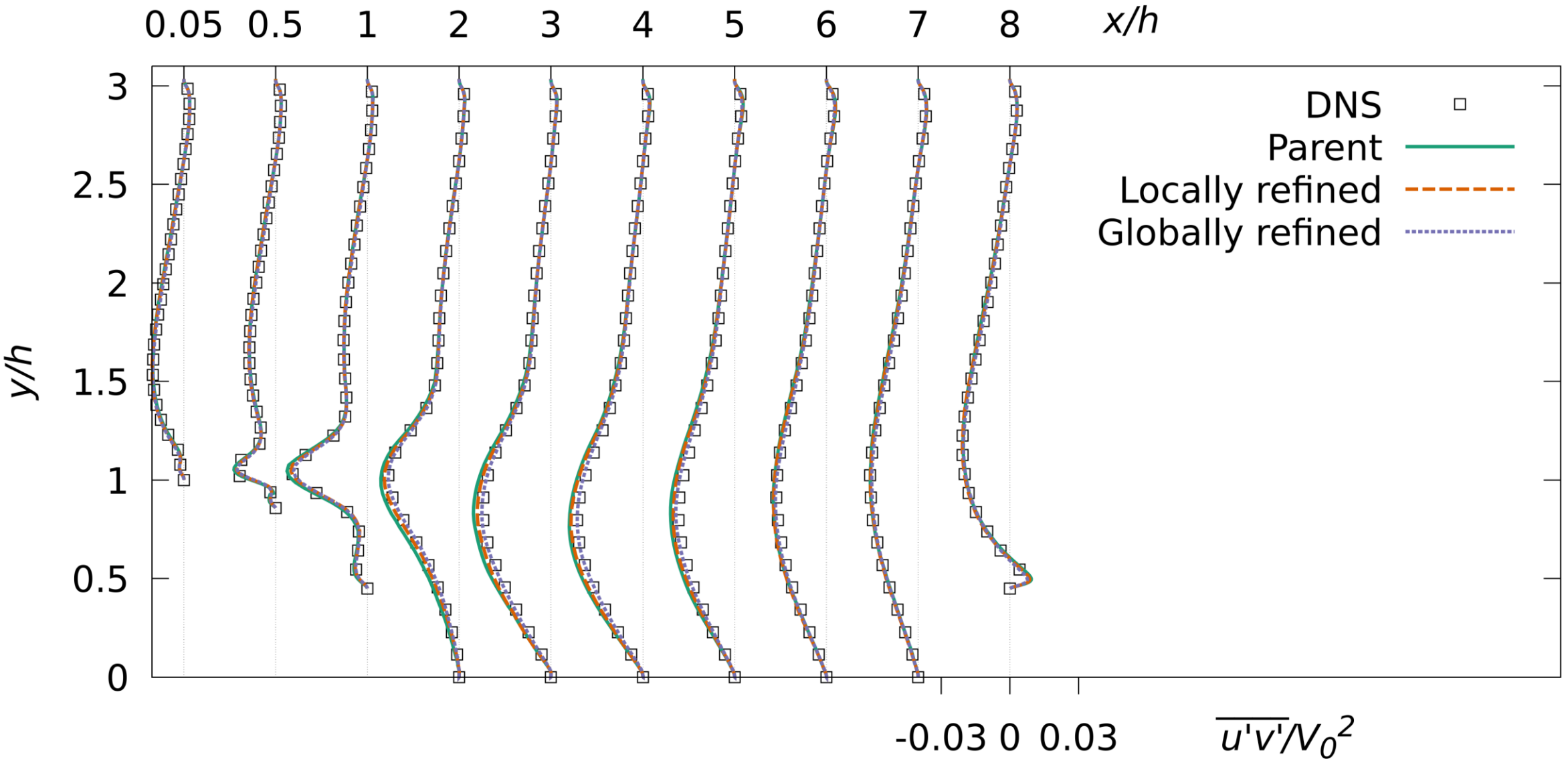
29


0.05
0.5
1
2
3
4
5
6
7
8
x/h
3
2.5
2
1.5
1
0.5
0
y/h
DNS
Parent
Locally refined
Globally refined
0
0.5
1.0
$\bar{u}/V_0$


0.05
0.5
1
2
3
4
5
6
7
8
x/h
3
2.5
2
1.5
1
0.5
0
y/h
DNS
Parent
Locally refined
Globally refined
0
0.1
0.2
0.3
0.4
$\bar{v}/V_0$


0.05
0.5
1
2
3
4
5
6
7
8
x/h
3
2.5
2
1.5
1
0.5
0
y/h
DNS
Parent
Locally refined
Globally refined
0
0.05
$\overline{u'u'}/V_0^2$


0.05
0.5
1
2
3
4
5
6
7
8
x/h
3
2.5
2
1.5
1
0.5
0
y/h
DNS
Parent
Locally refined
Globally refined
0
0.03
$\overline{v'v'}/V_0^2$


0.05
0.5
1
2
3
4
5
6
7
8
x/h
3
2.5
2
1.5
1
0.5
0
y/h
DNS
Parent
Locally refined
Globally refined
-0.03
0
0.03
$\overline{u'v'}/V_0^2$

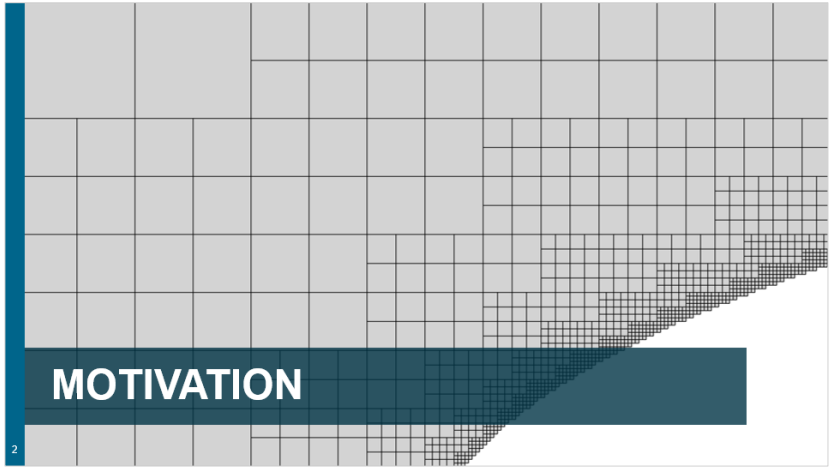
Relative to globally refined…	Parent	Locally refined
…CPU time (averaging period only)	19%	54%
…# of DOFs	13%	34%

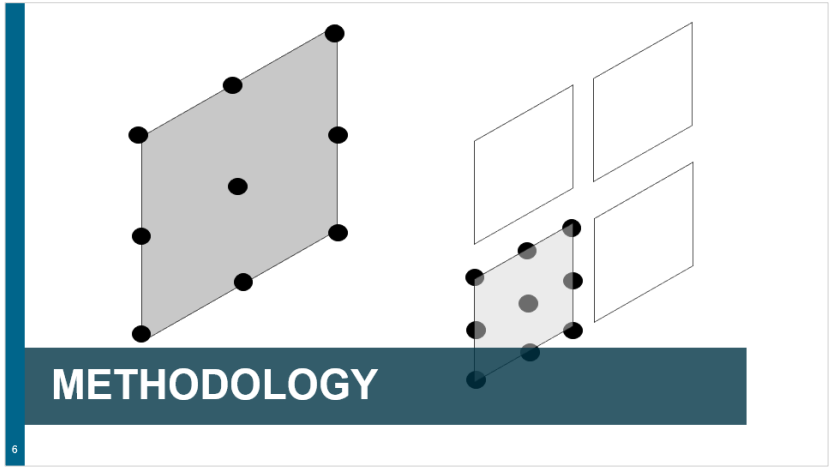
CONCLUSIONS

Robustness ✔

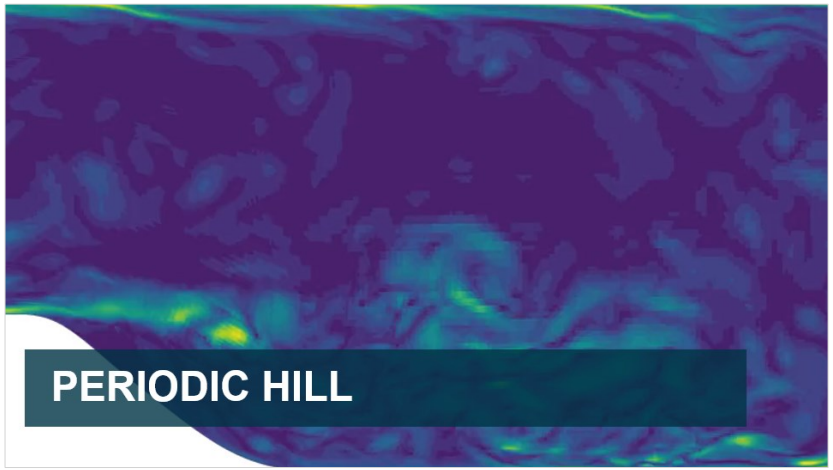
Accuracy ✔

Efficiency ⚠


MOTIVATION
2


METHODOLOGY
6

TAYLOR-GREEN VORTEX
11


PERIODIC HILL

QUESTIONS?