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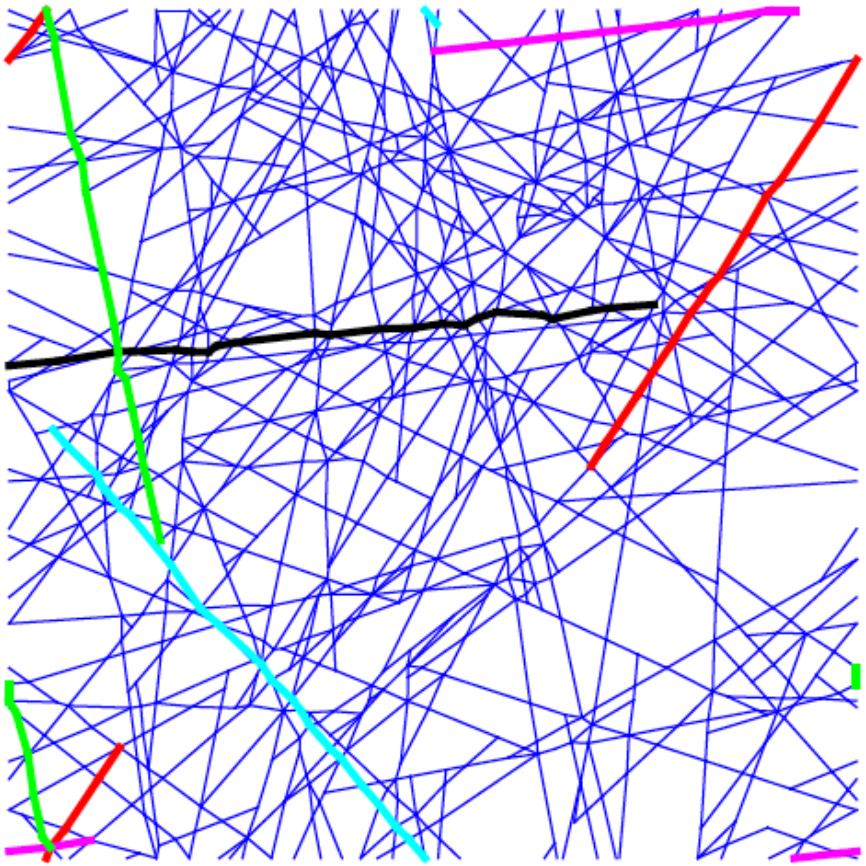
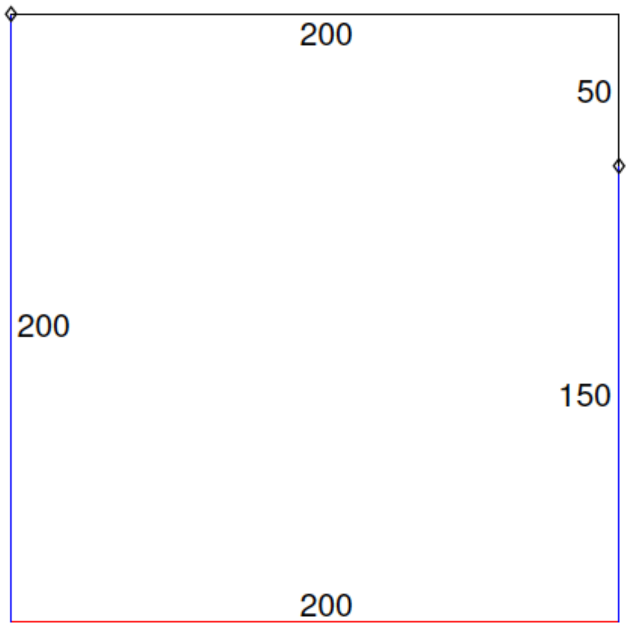
An equation-free multiscale method applied to discrete networks

Lars Beex   University of Luxembourg
Pierre Kerfriden   Cardiff University

Setup



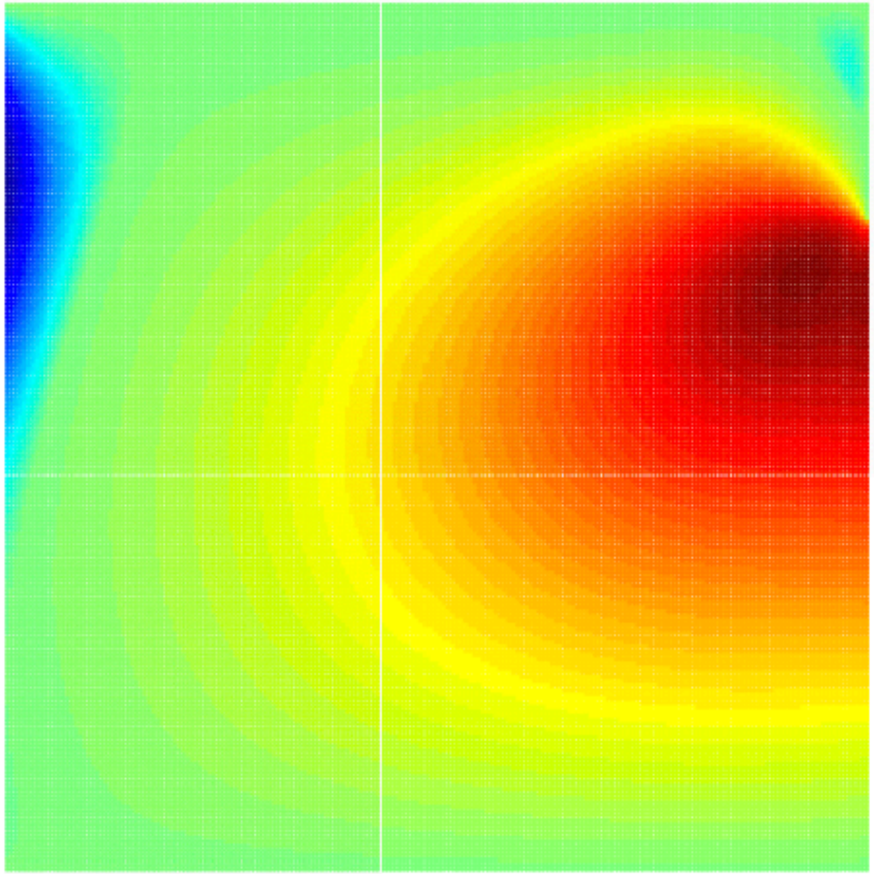
Planar unit cell of LE EB beams inc damage ($1x1mm^2$)

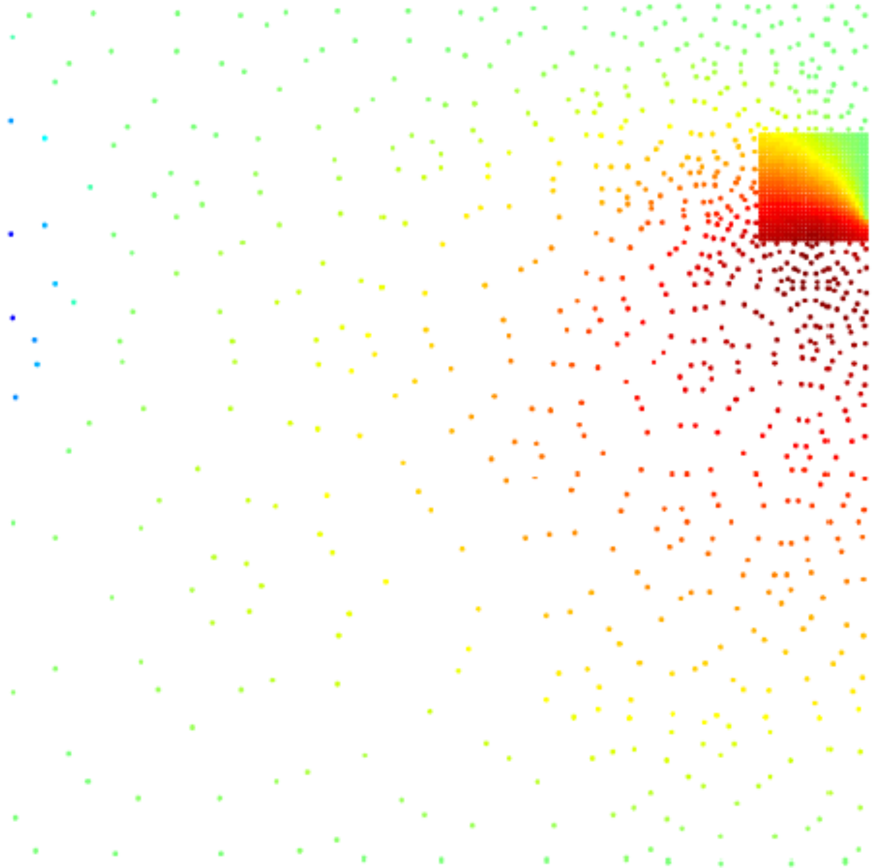


Macroscale problem

Result

Rotation around vertical axis



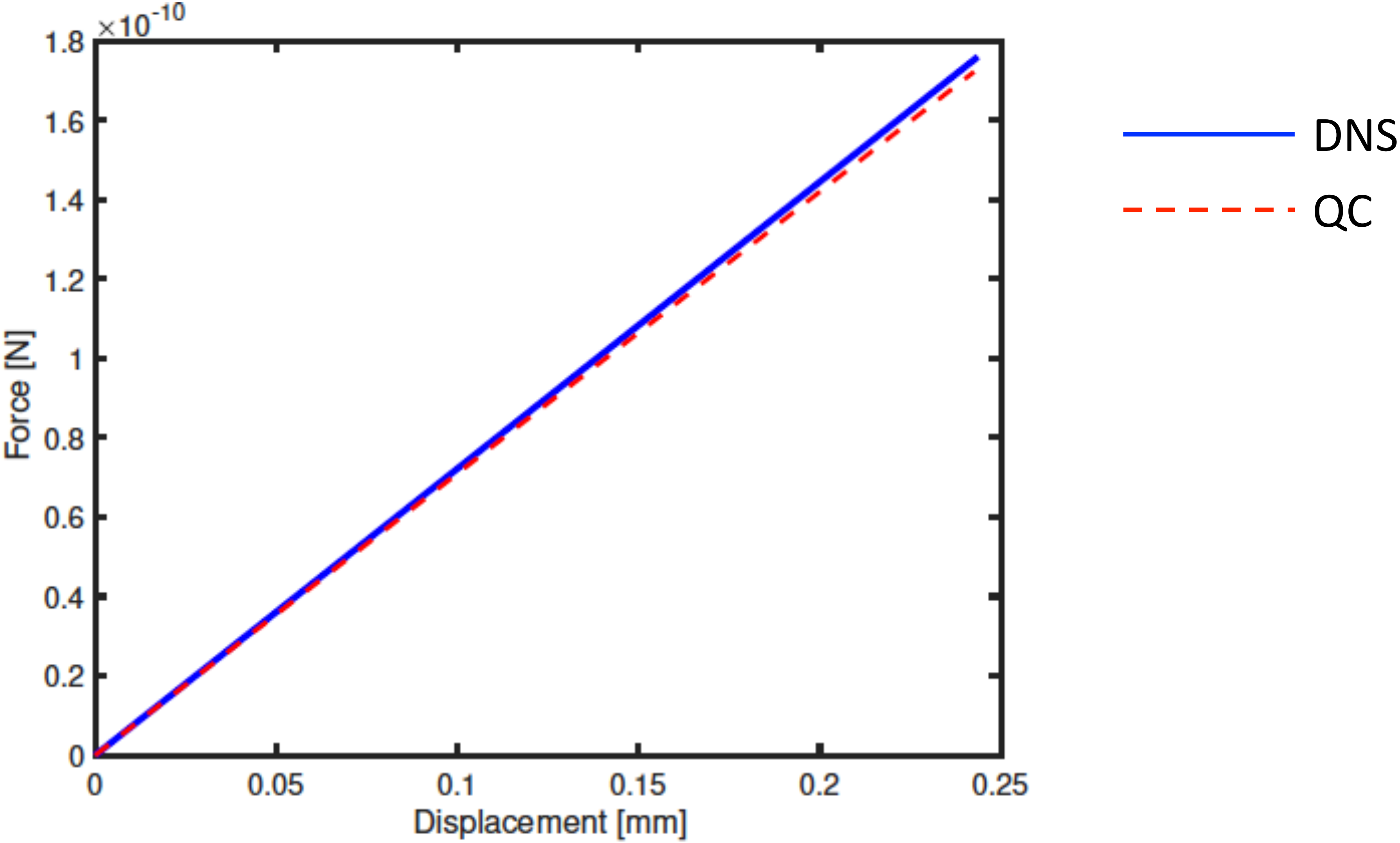


DNS:
- 80M beams
- 233M DOFs

QC:
- 29x less beams
- 42x less DOFs

Result

Force-displacement response



Main points of the method

Condition:

Unit cell must be periodic.

Advantages compared to other nested multiscale methods:

1. Higher-order macroscale interpolations are as easy to treat as linear ones

2. No scale-separation

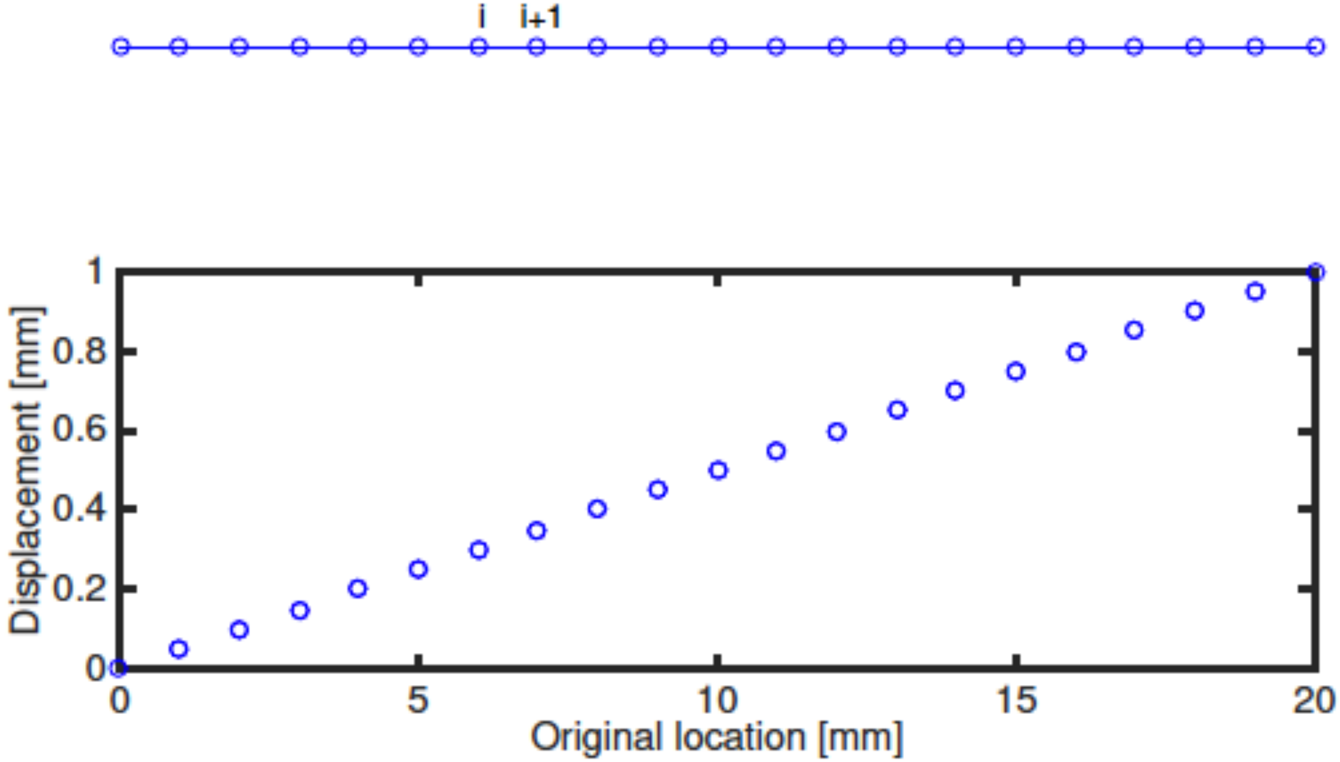
Disadvantages compared to other nested multiscale methods:

1. All DOFs in one system, instead of subdivided over the unit cells and the macroscale elements

2. More unit cells required

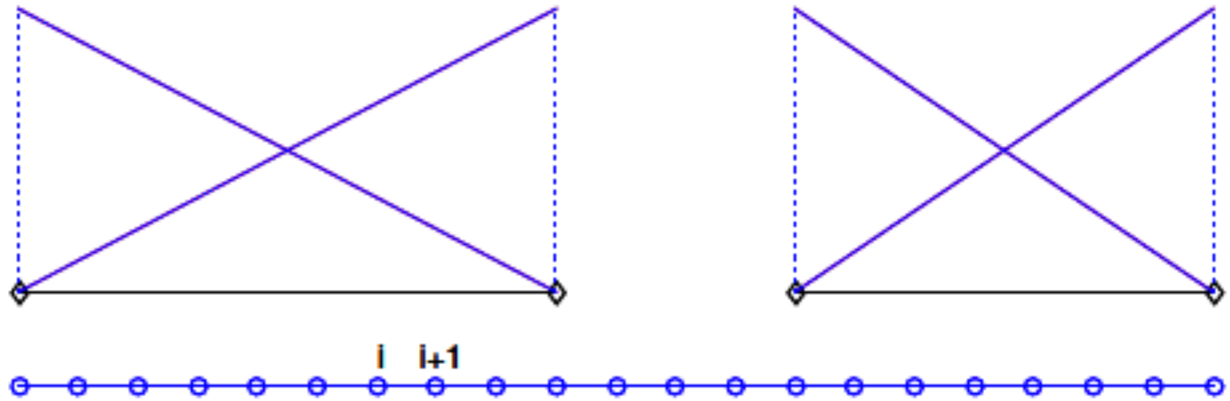
The method's ansatz explained

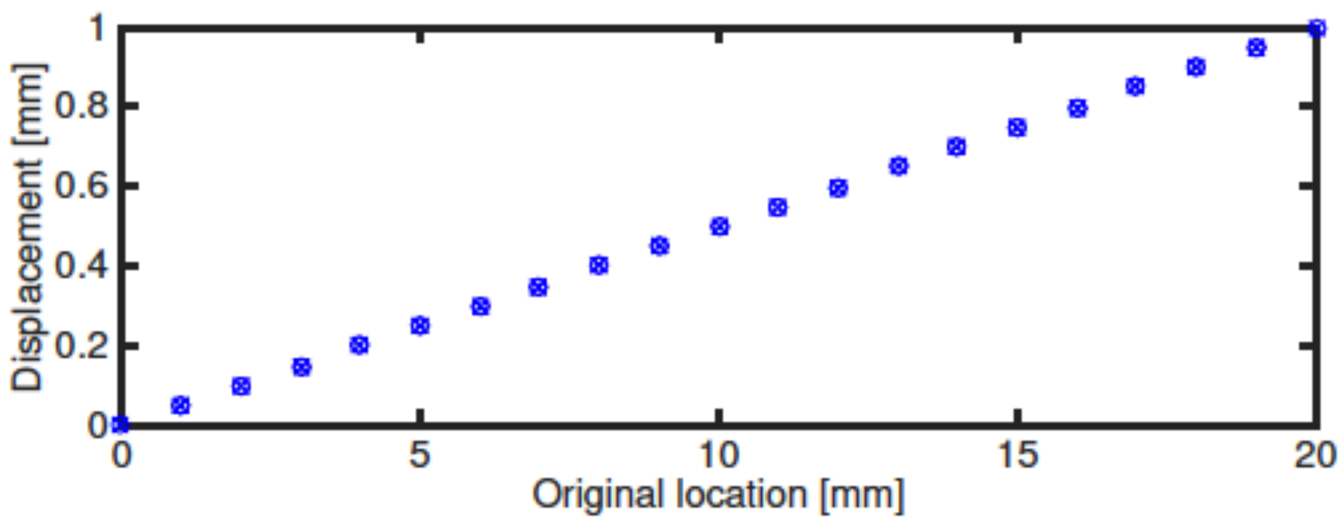
1D string of LE springs: DNS



The method's ansatz explained

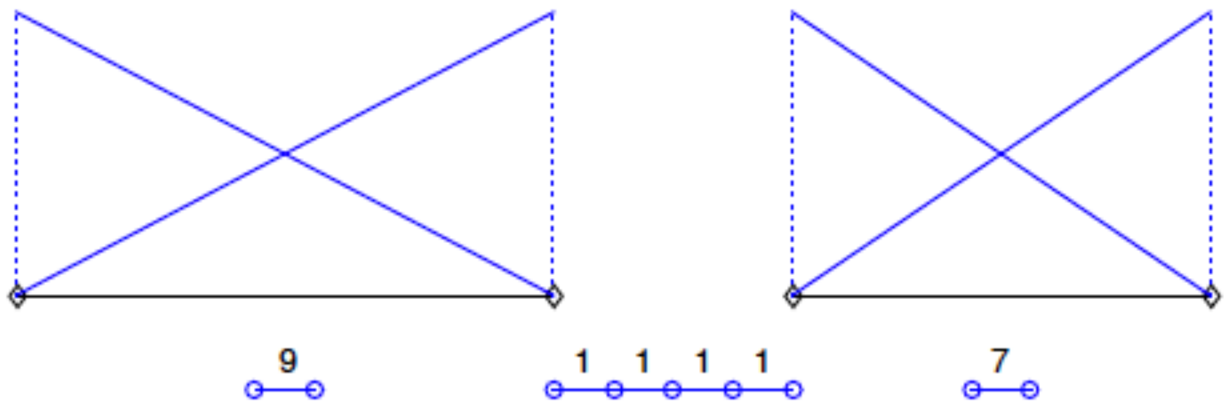
1D string of LE springs: Interpolation

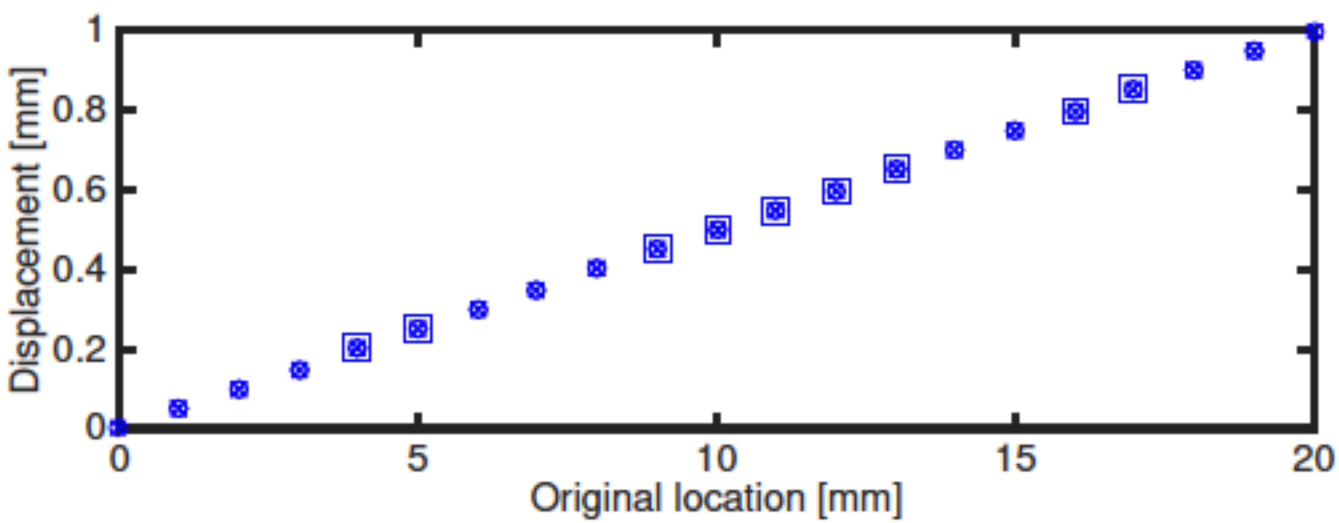




The method's ansatz explained

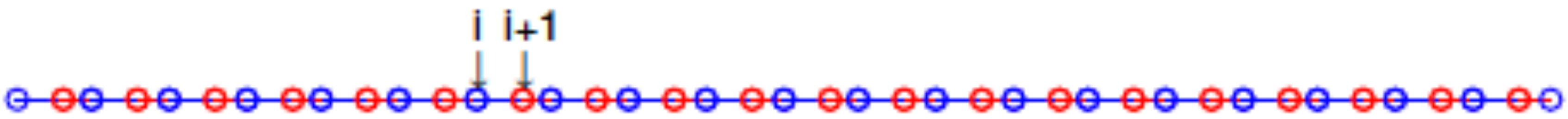
1D string of LE springs: Interpolation + Sampling

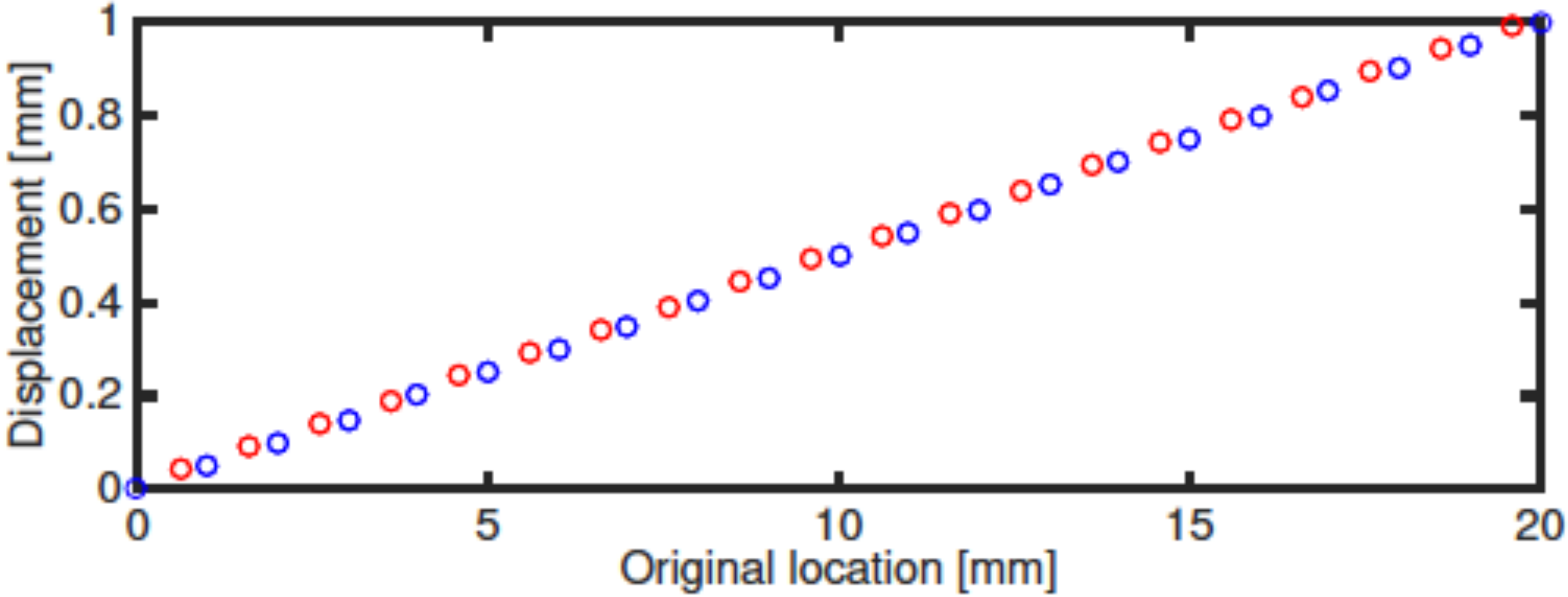




The method's ansatz explained

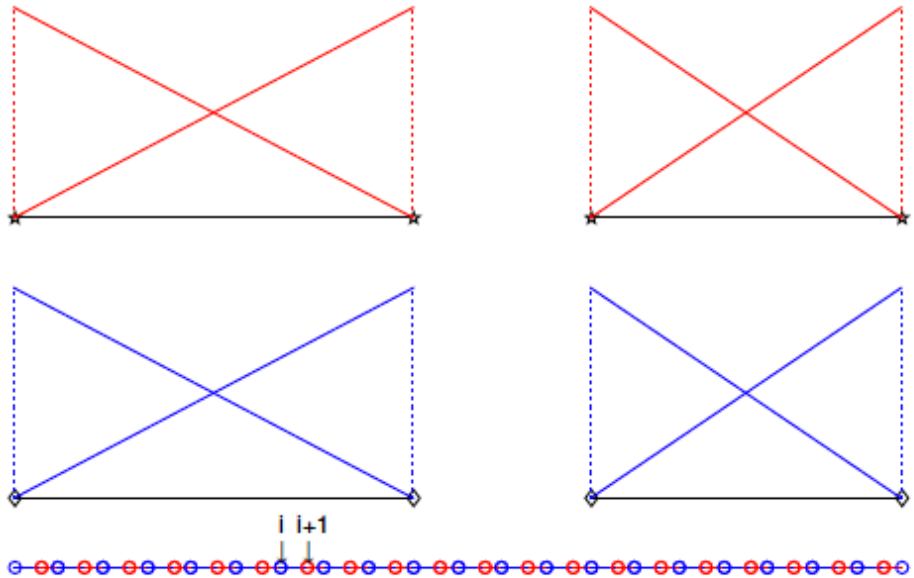
1D string of 2 types of LE springs: DNS

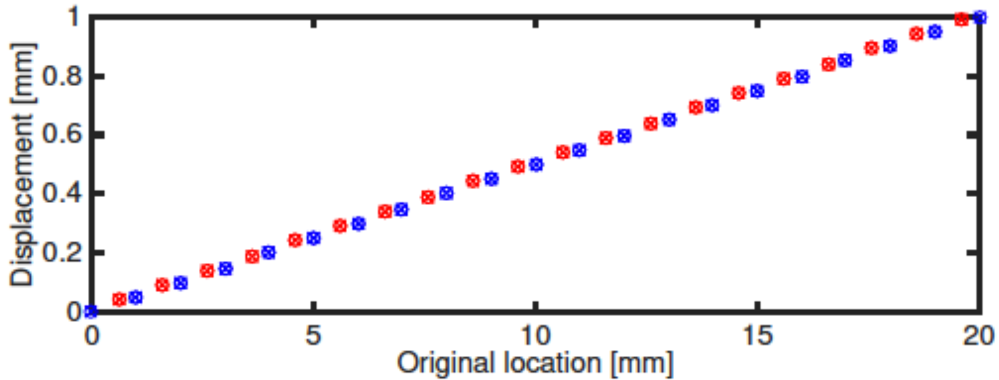




The method's ansatz explained

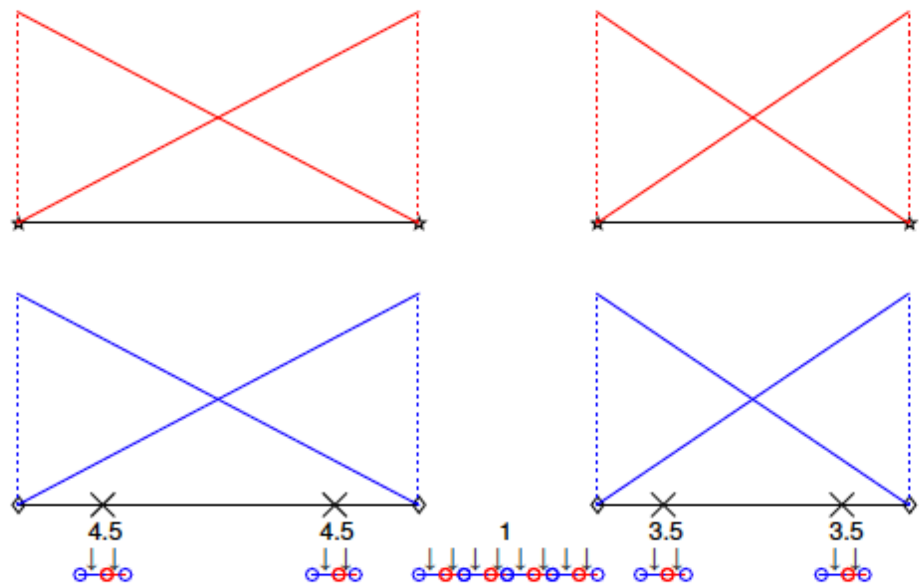
1D string of 2 types of LE springs: Interpolation

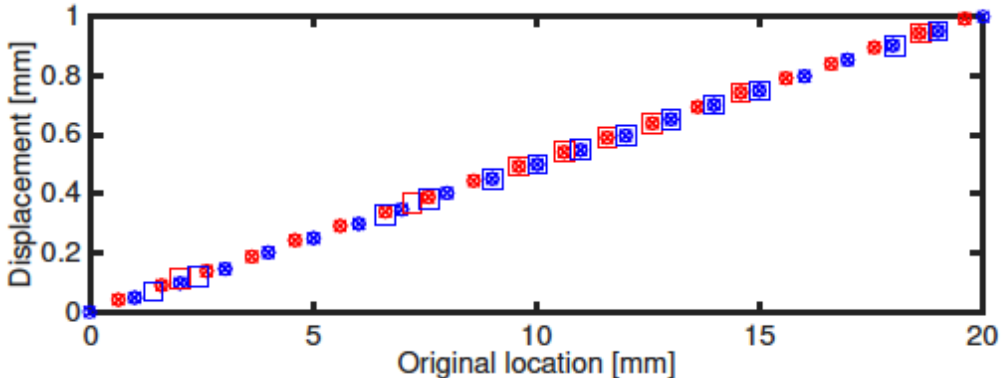




The method's ansatz explained

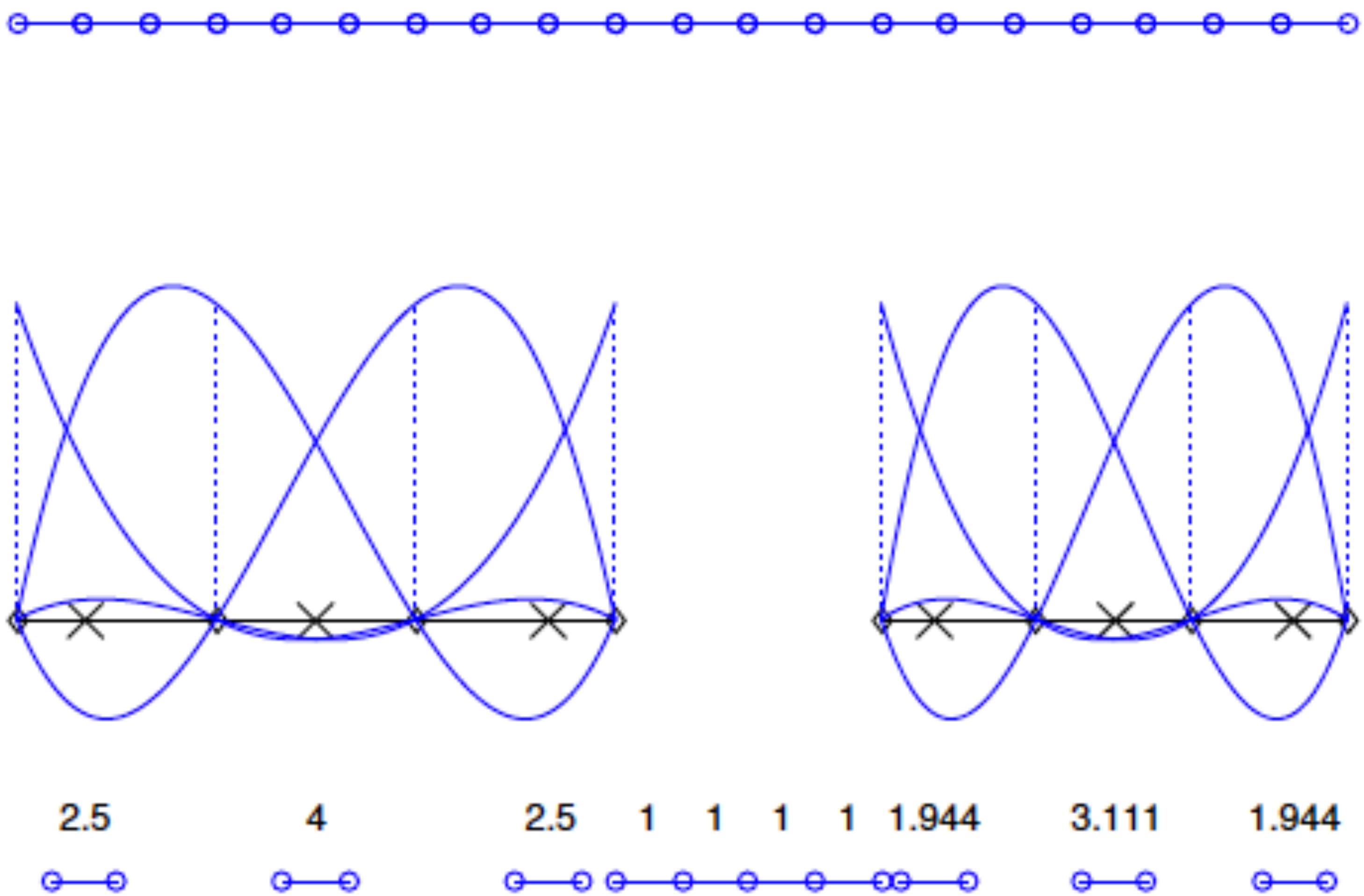
1D string of 2 types of LE springs: Interpolation + Sampling





The method's ansatz explained

String of LE beams: Interpolation + Sampling



The method's ansatz explained

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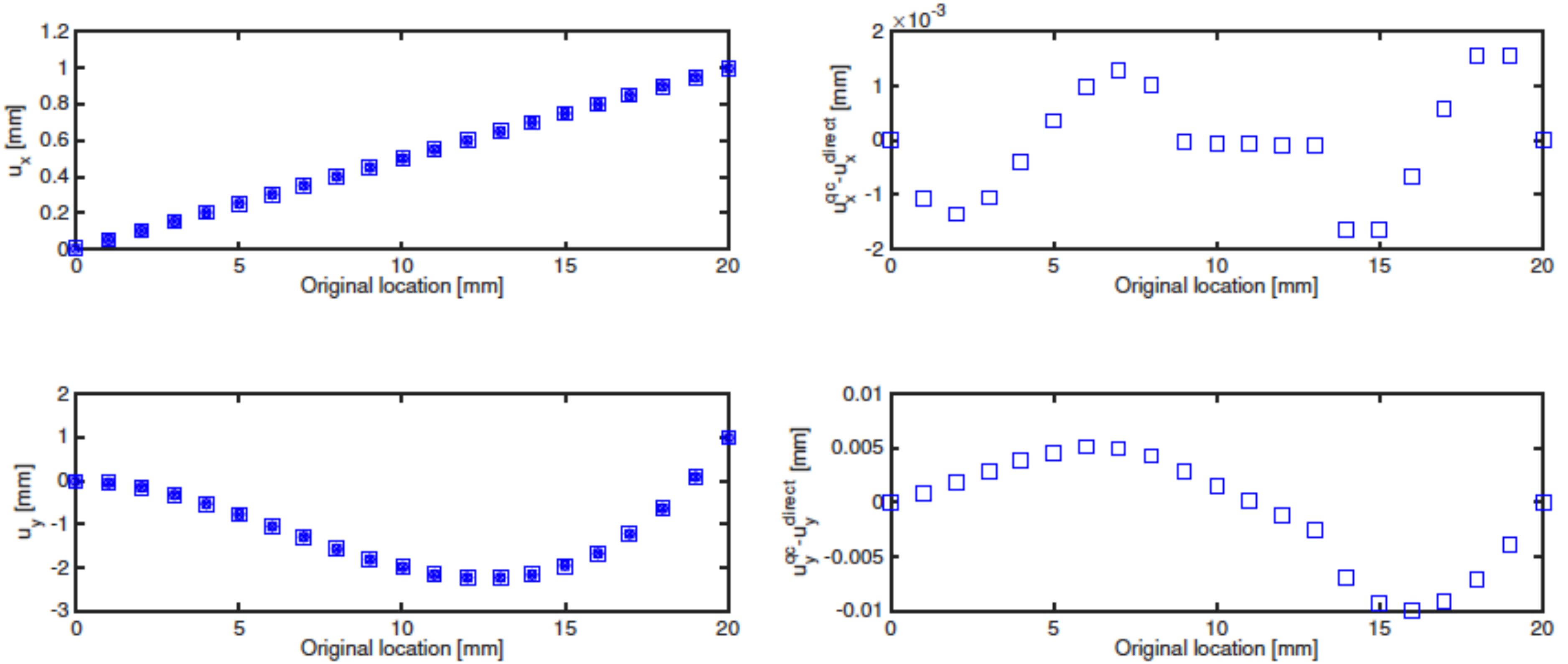
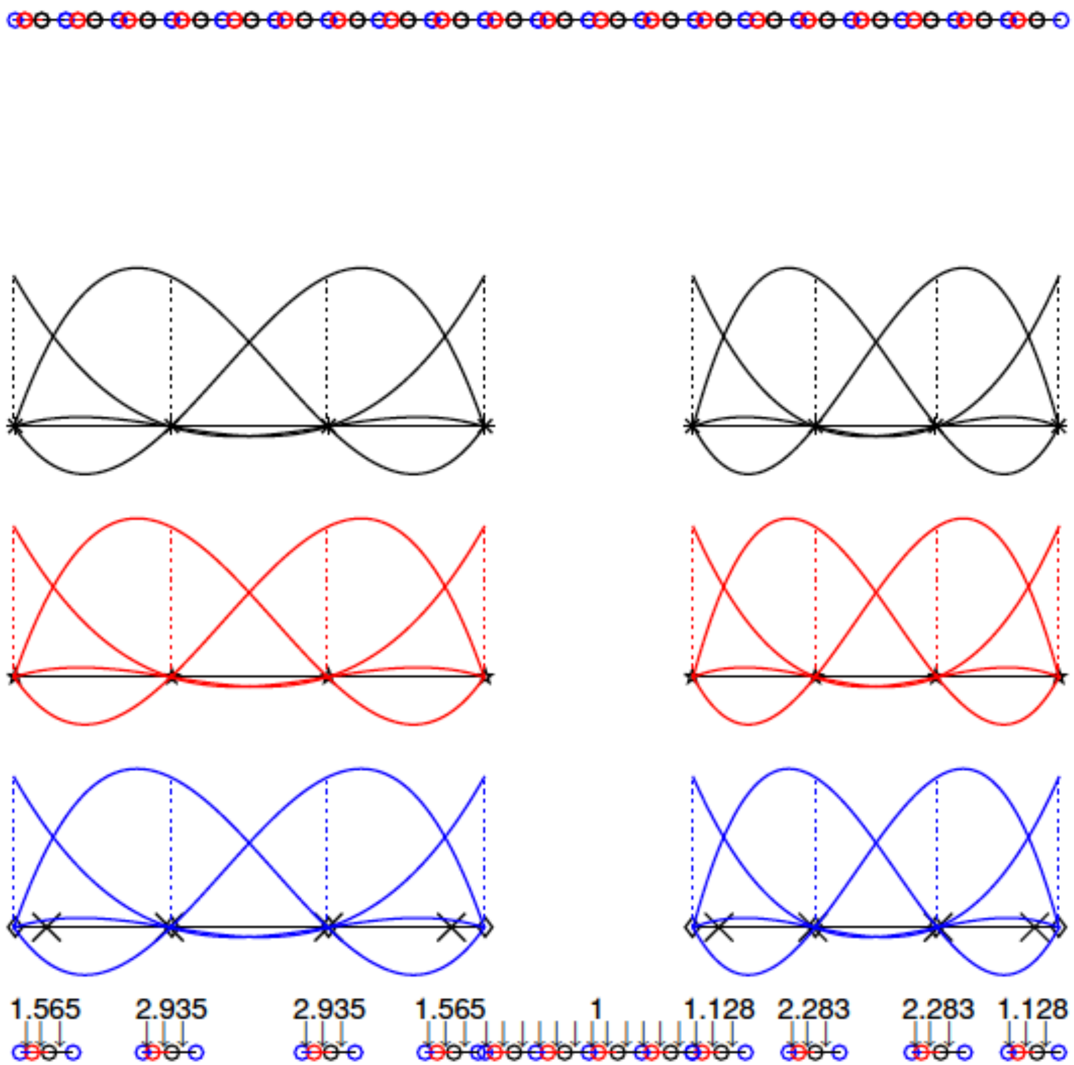
String of LE beams: Interpolation + Sampling



The method's ansatz explained

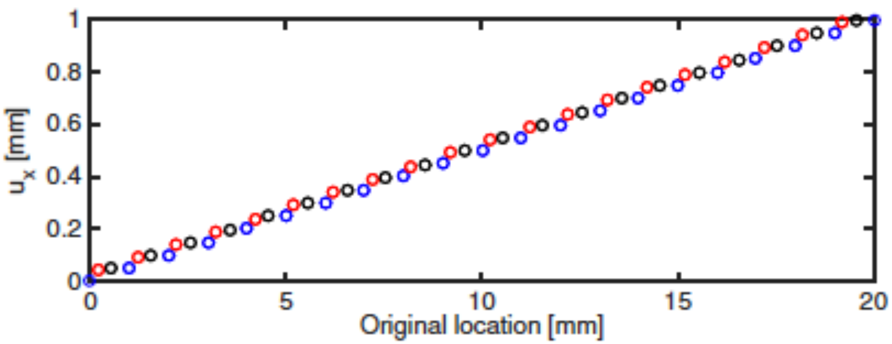
String of 3 types of LE beams: Interpolation + Sampling

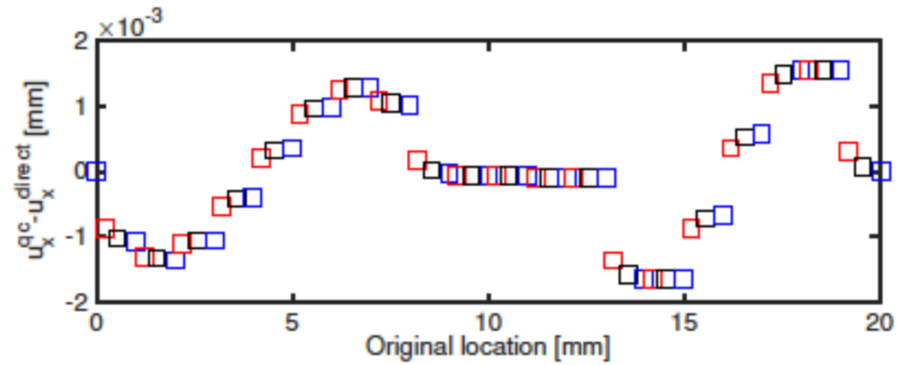


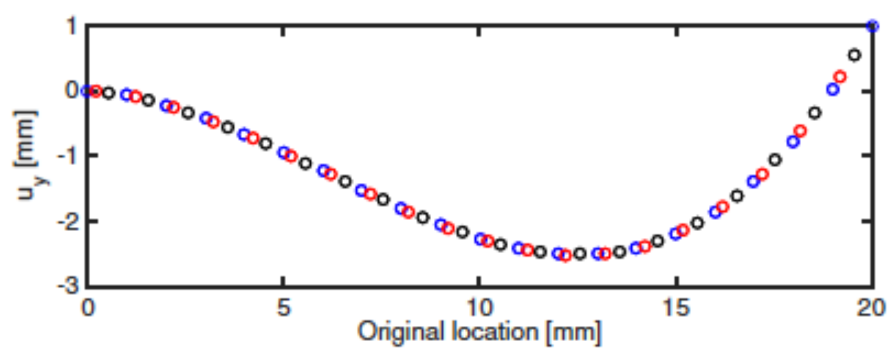
The method's ansatz explained

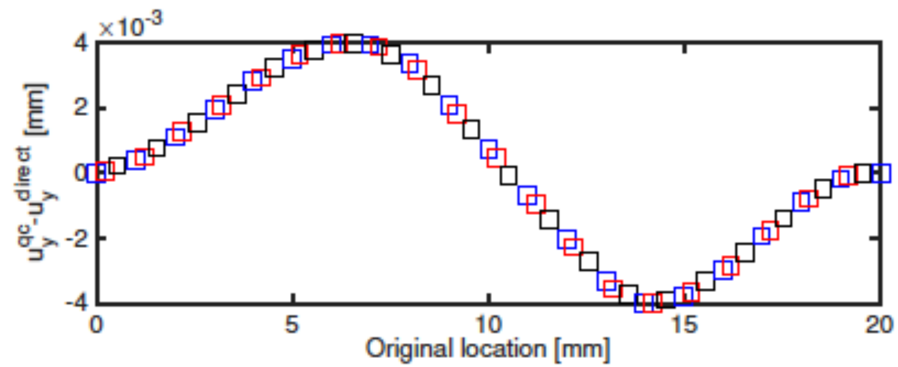
String of 3 types of LE beams:

Interpolation + Sampling

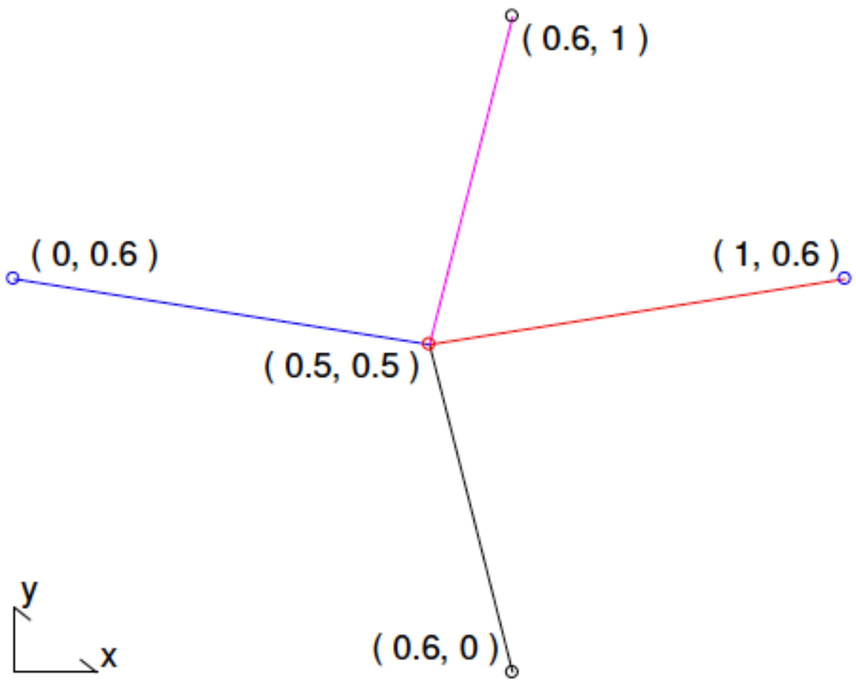






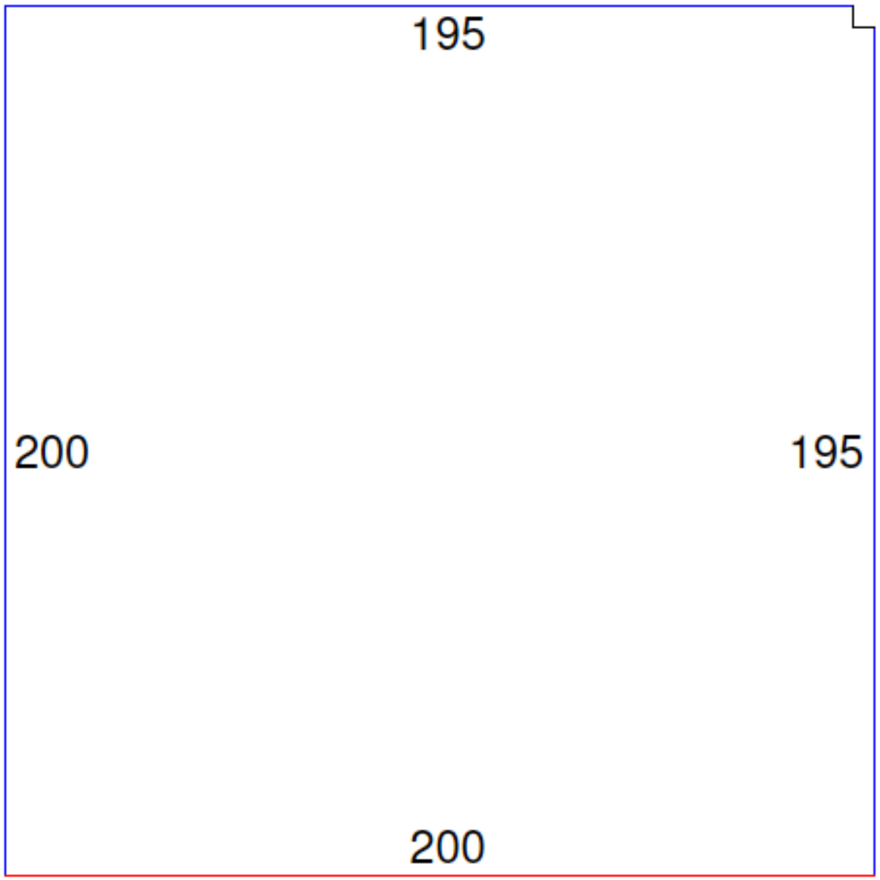


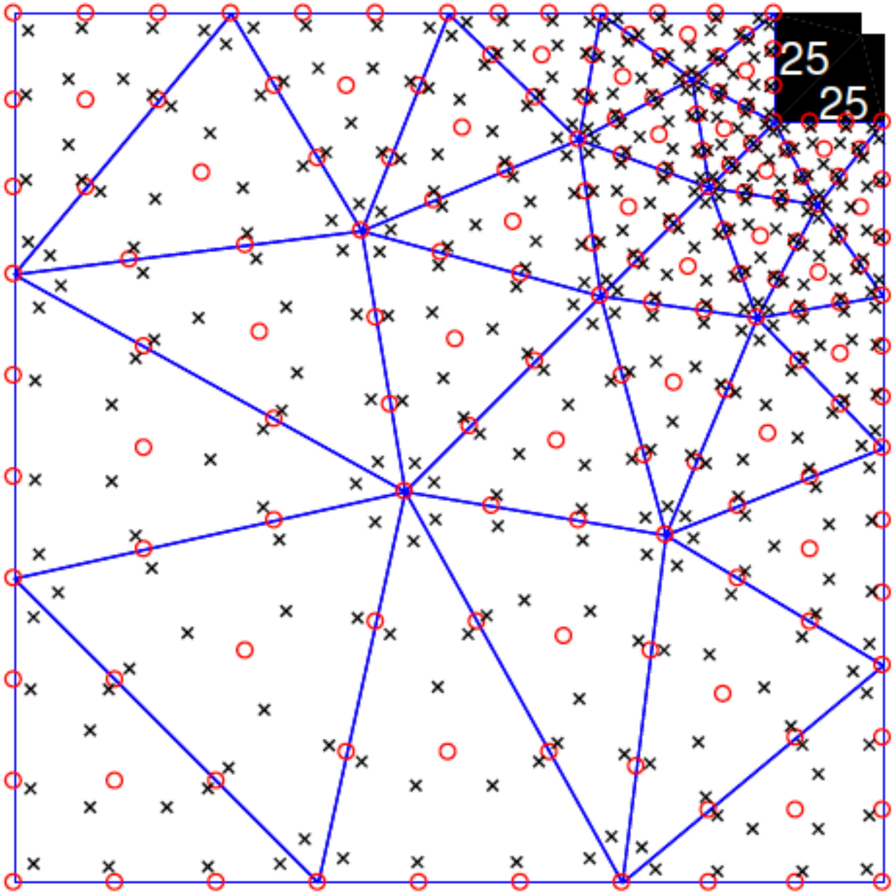
Simple planar unit cell: Setup



	Blue	Red	Black	Purple	
Area	1	3	9	27	[m^2] ($x10^{-9}$)
Y. Modulus	1	5	25	125	[MPa]
P. ratio	0.1	0.2	0.3	0.4	[-]
Failure str.	10	1	2	70	($x10^{-5}$)

Simple planar unit cell: Setup





DNS:
- 160k beams
- 722k DOFs

QC:
- 42x less beams
- 52x less DOFs

Simple planar unit cell: Results

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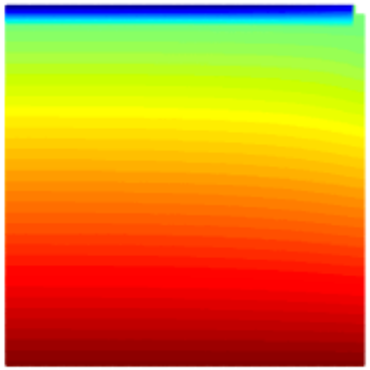
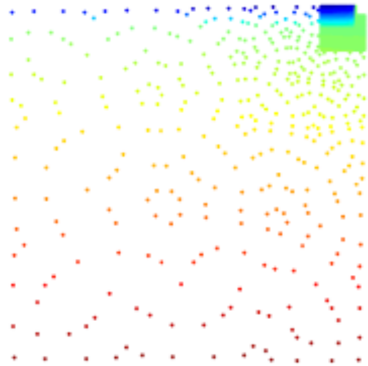
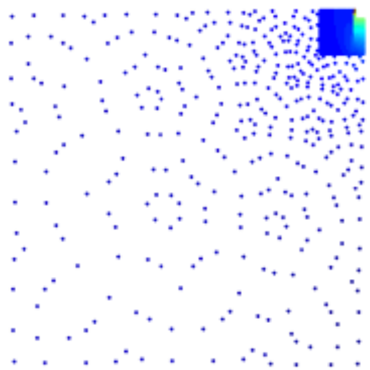
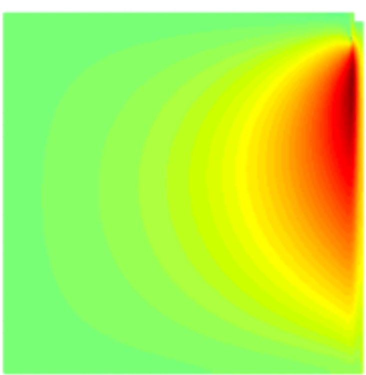


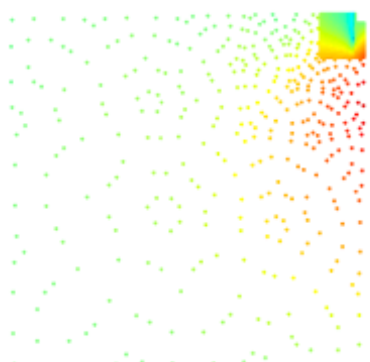


Out-of-plane displacement



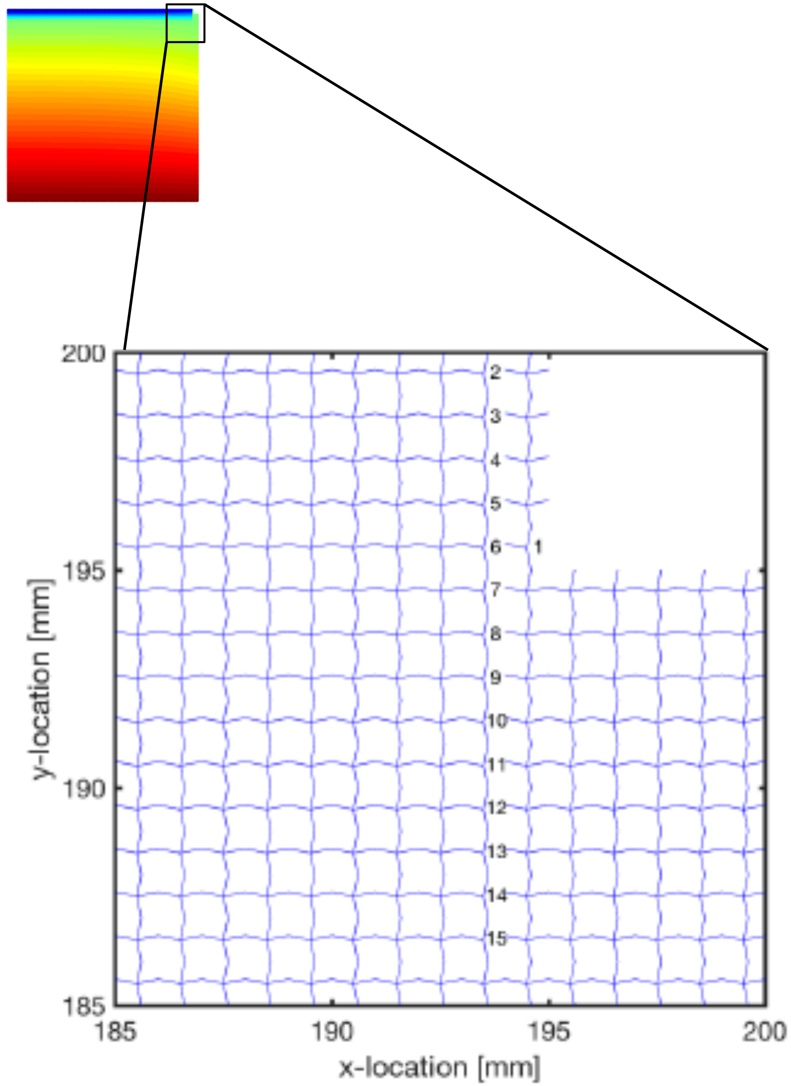
Rotation around horizontal axis

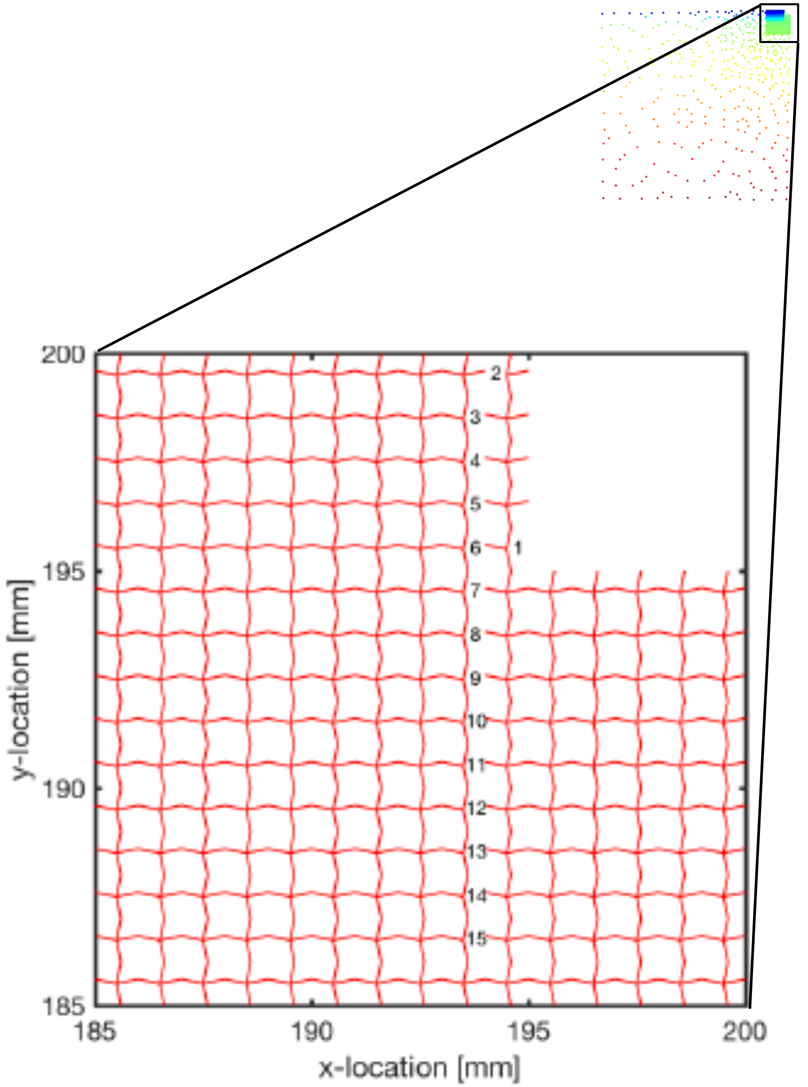




Rotation around vertical axis

Simple planar unit cell: Results





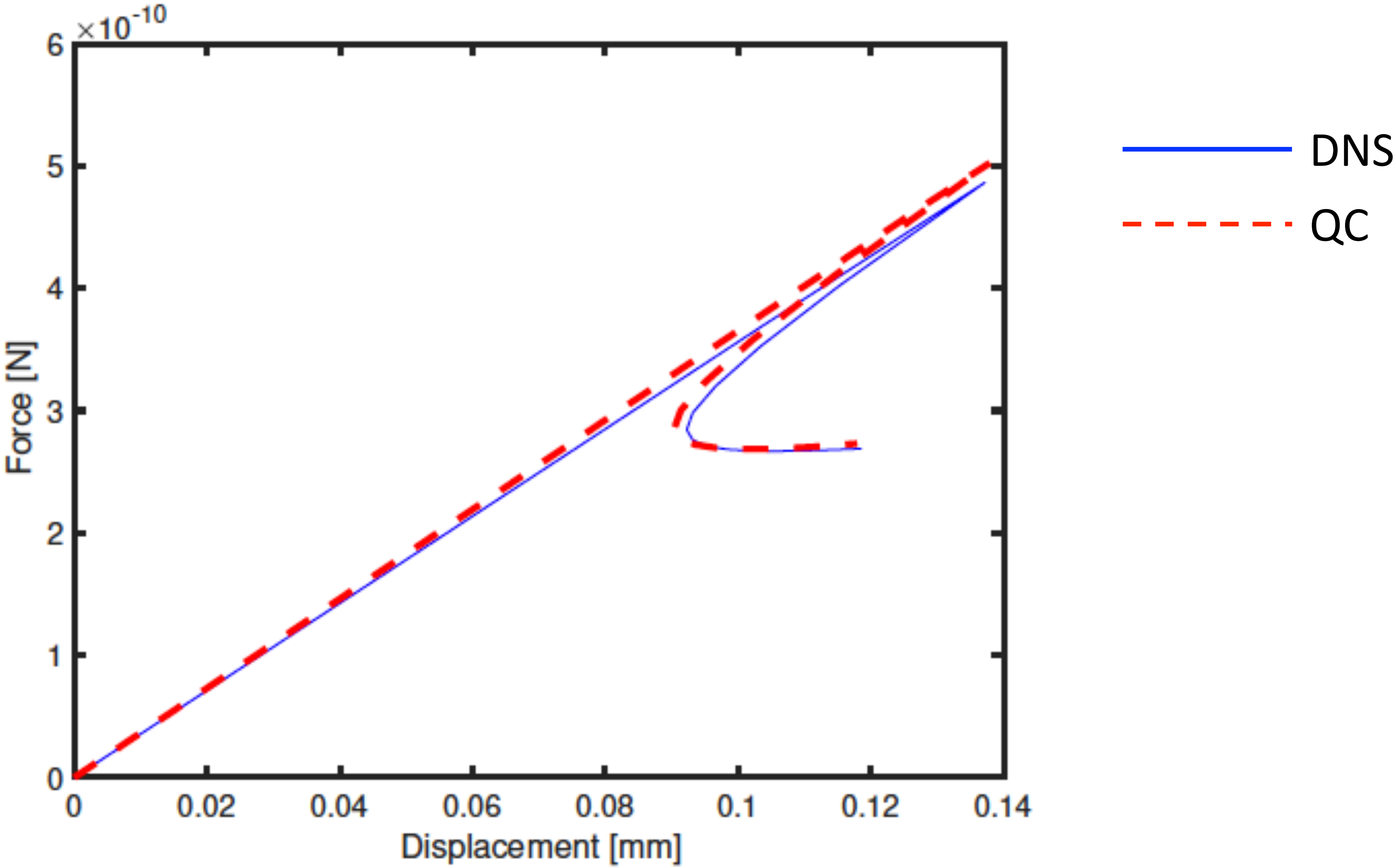
DNS

QC

Failed beams, inc. sequence

Simple planar unit cell: Results

Force-displacement response



Simple planar unit cell: New setup + Result

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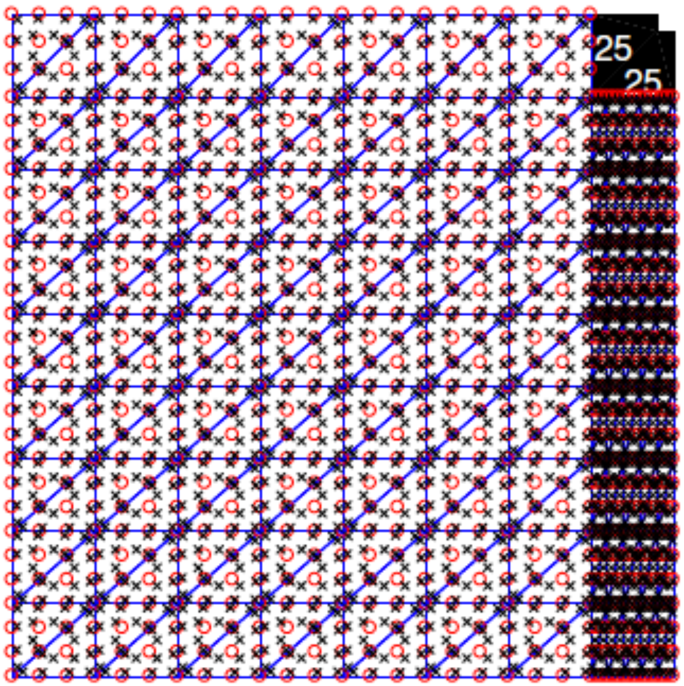
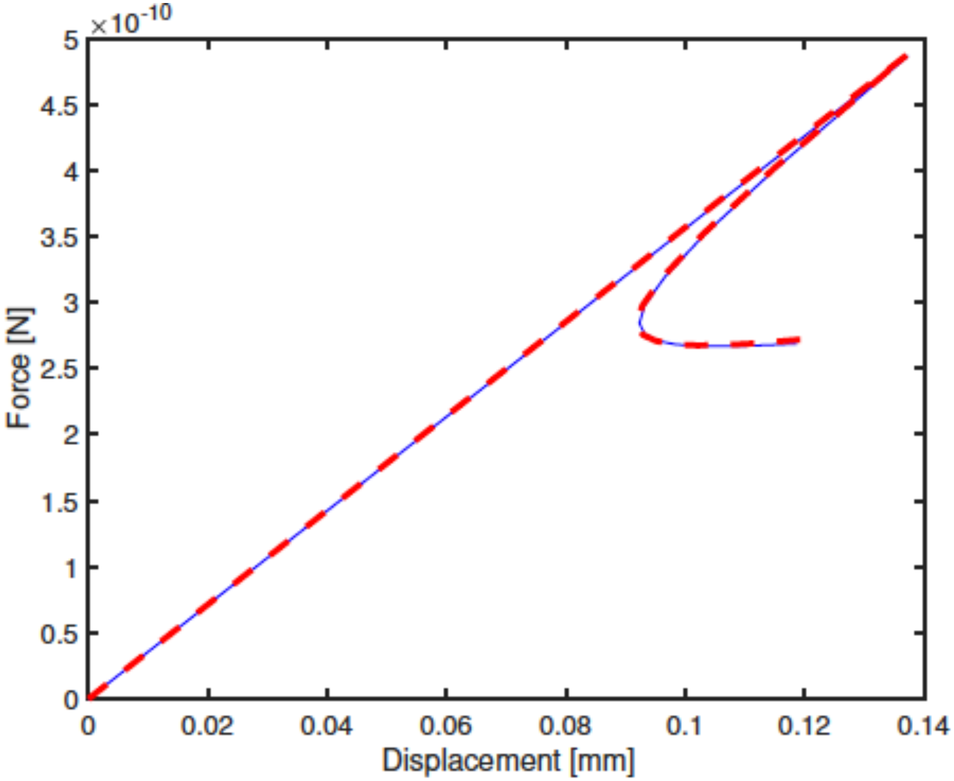




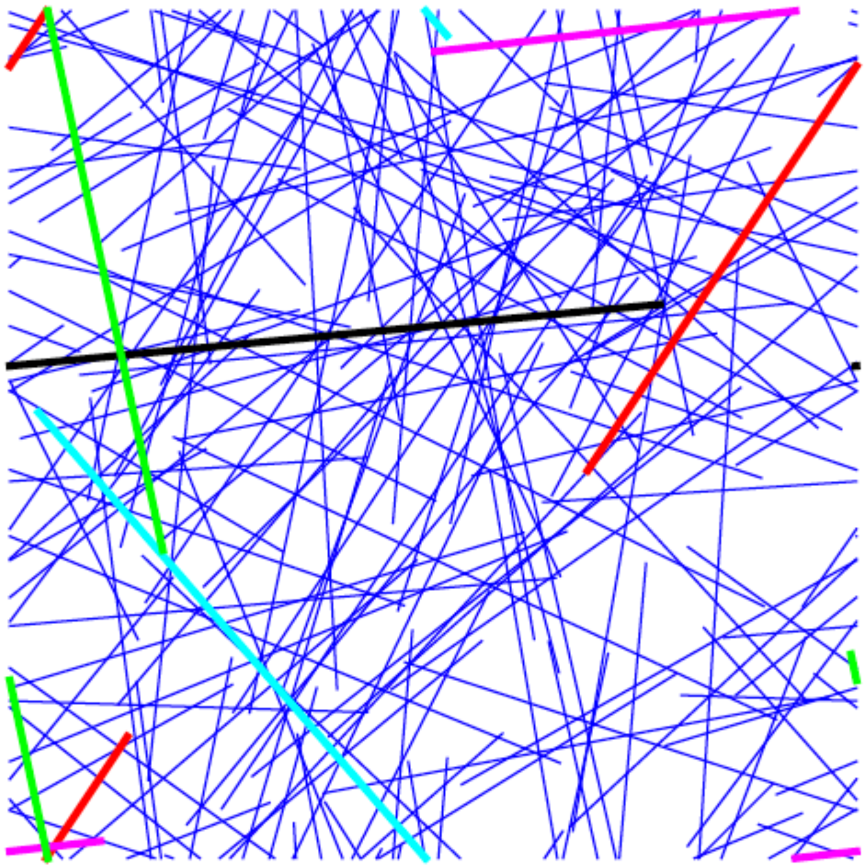
DNS

QC

QC:

- 13x less beams
- 25x less DOFs

Fibrous unit cell: Small setup

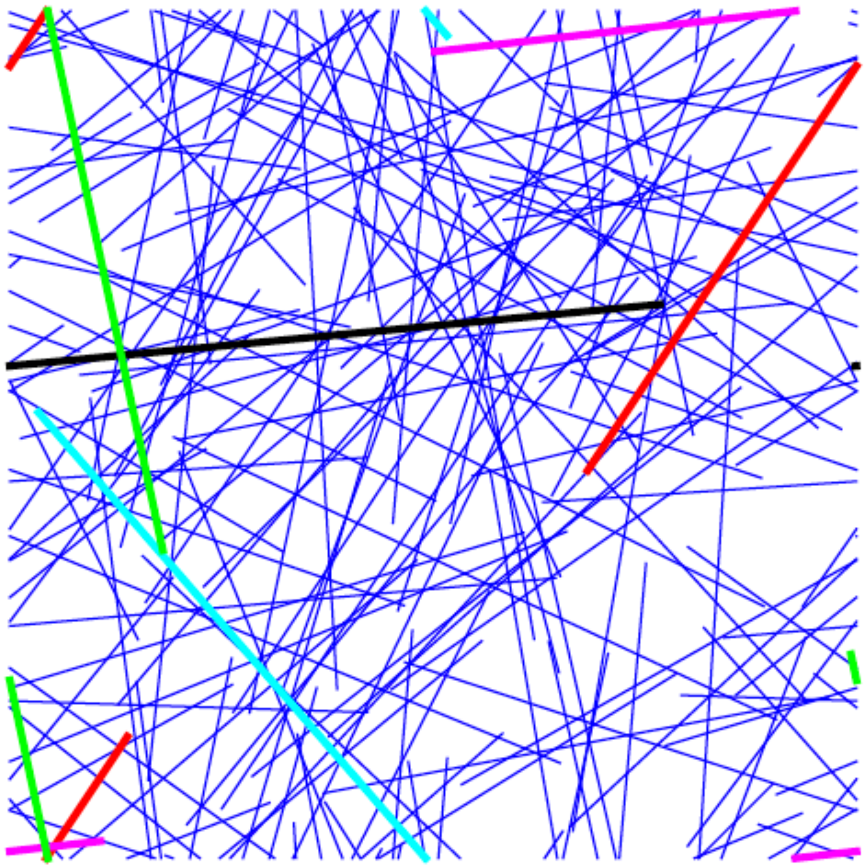


Periodic, planar unit cell of fibres (1x1mm^2)

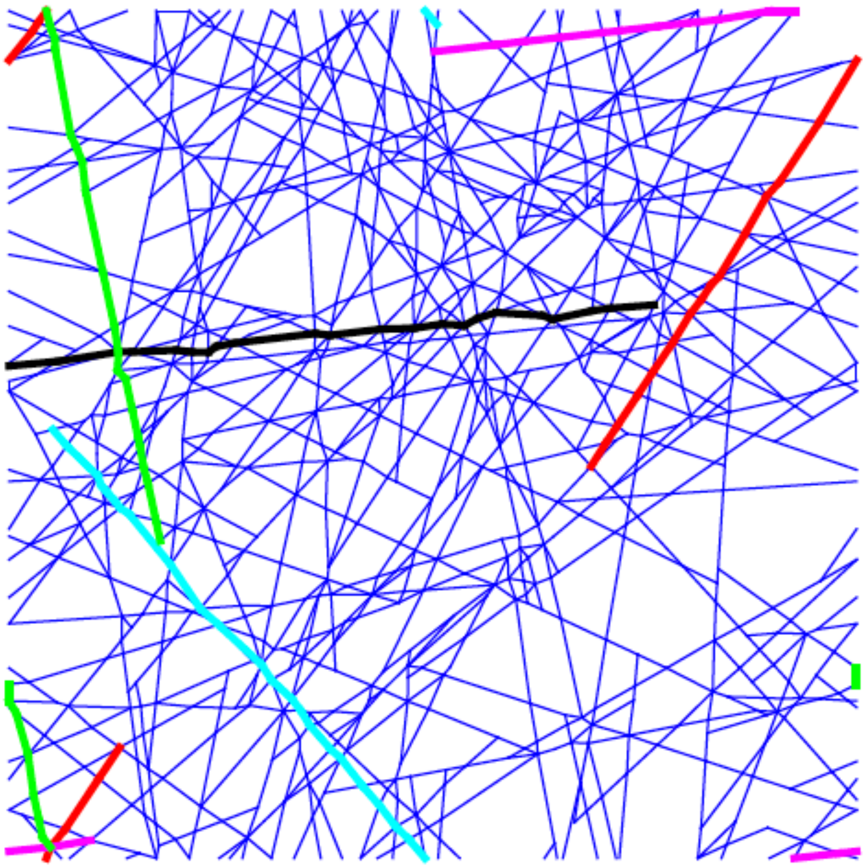
Parameters taken from U(a,b)

	a	b	
L	0.6	0.9	[mm]
A	1	2	[m^2] (x10^{-9})
E	1	2	[MPa]
ν	0.2	0.4	[-]
Failure str.	1	2	(x10^{-5})

Fibrous unit cell: Small setup



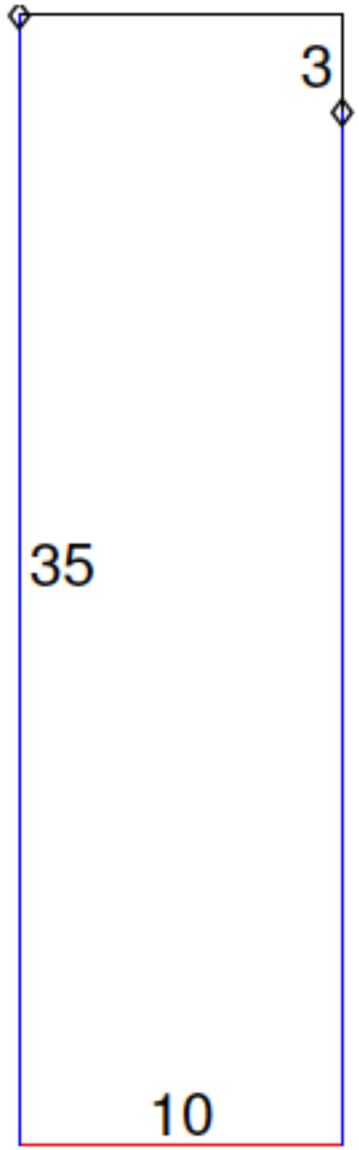
Periodic, planar unit cell of fibres (1x1mm^2)

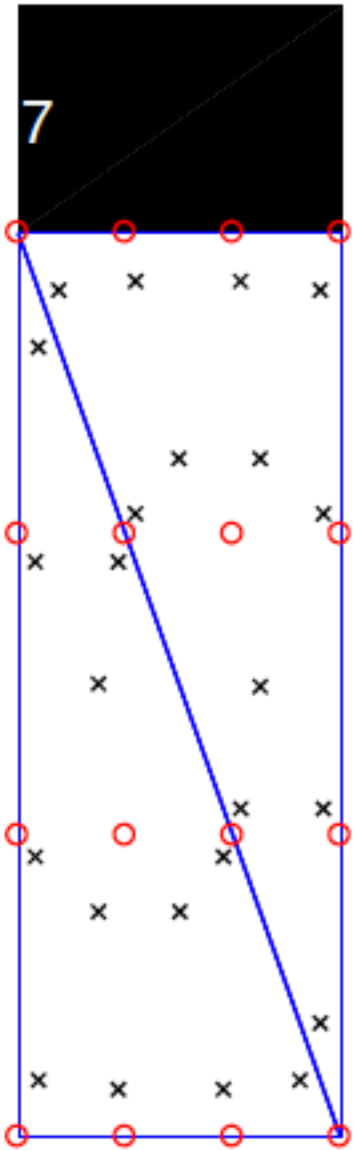


Beam discretisation
(LE EB beams with brittle damage)

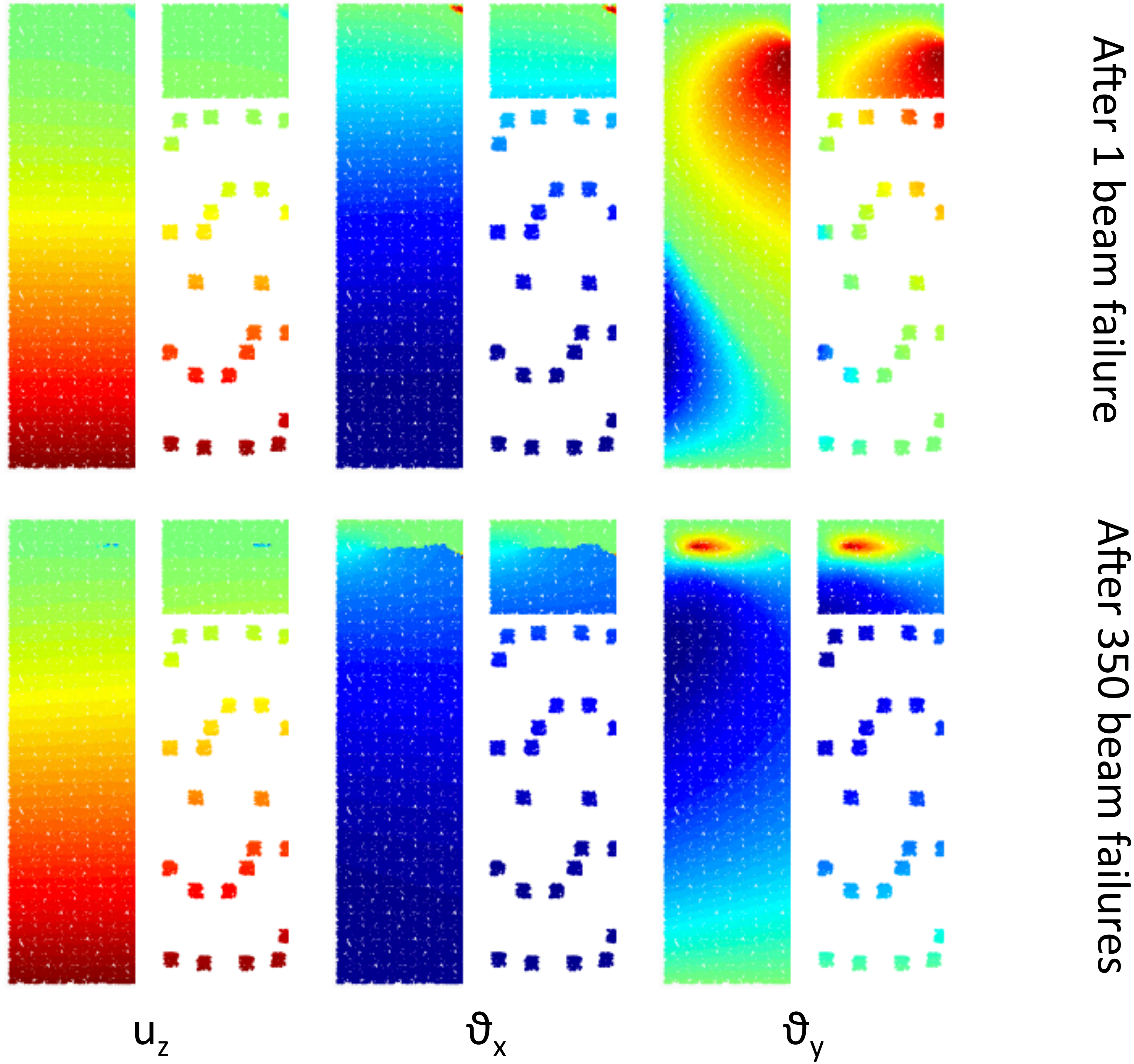
Fibrous unit cell: Small setup

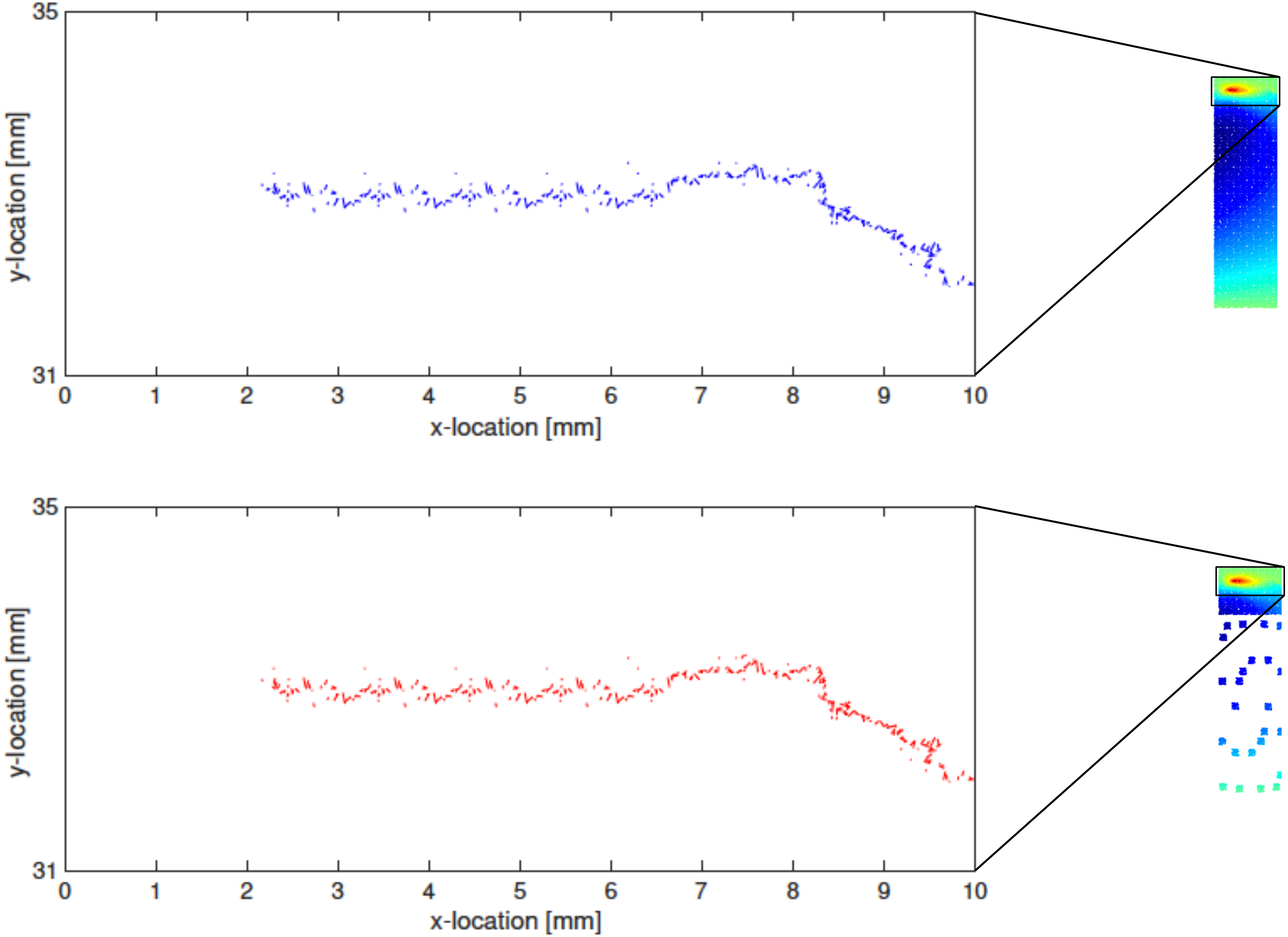
DNS:
- 700k beams
- 2M DOFs





QC:
- 4 less beams
- 4 less DOFs

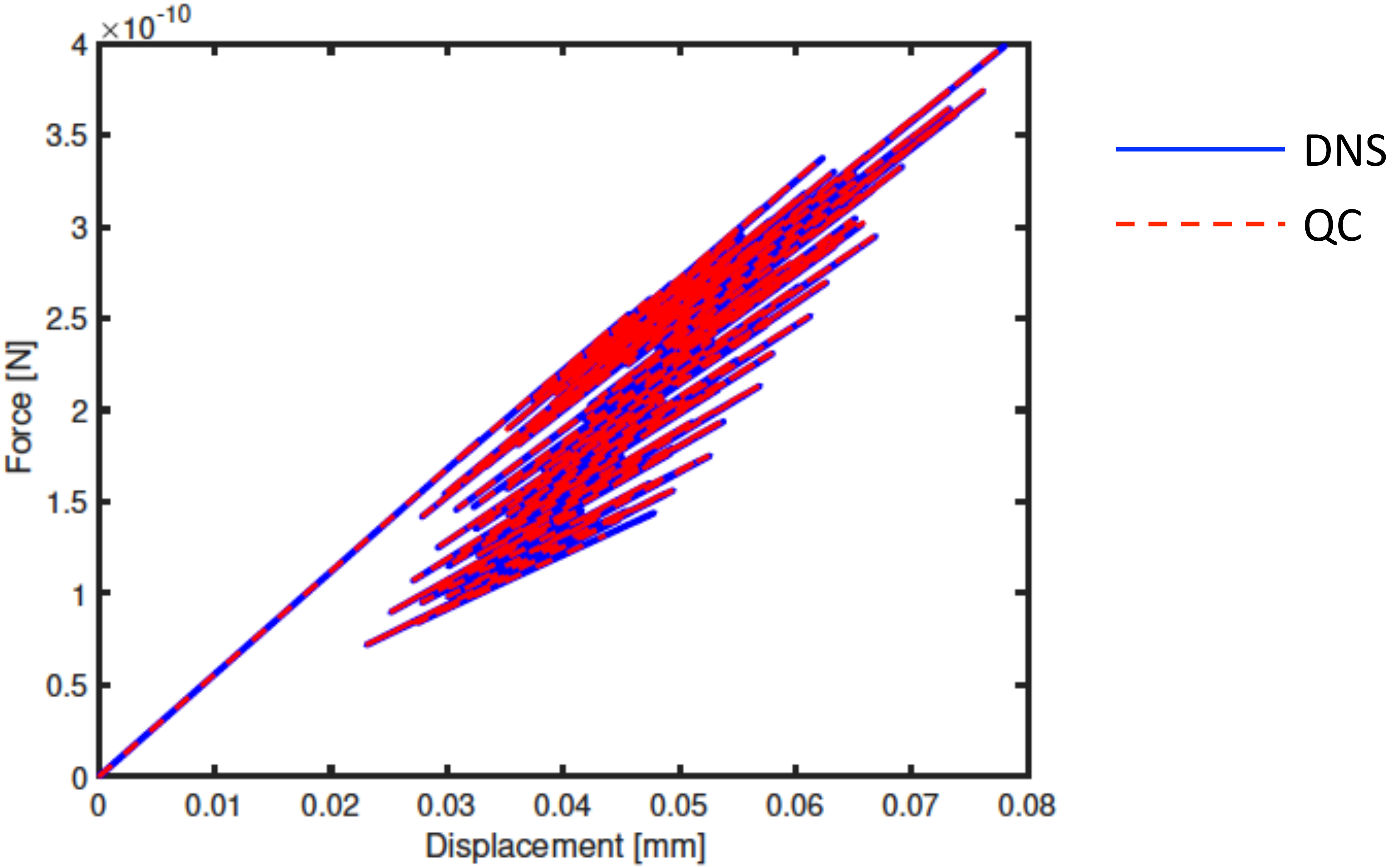

After 1 beam failure
After 350 beam failures
u_z
ϑ_x
ϑ_y



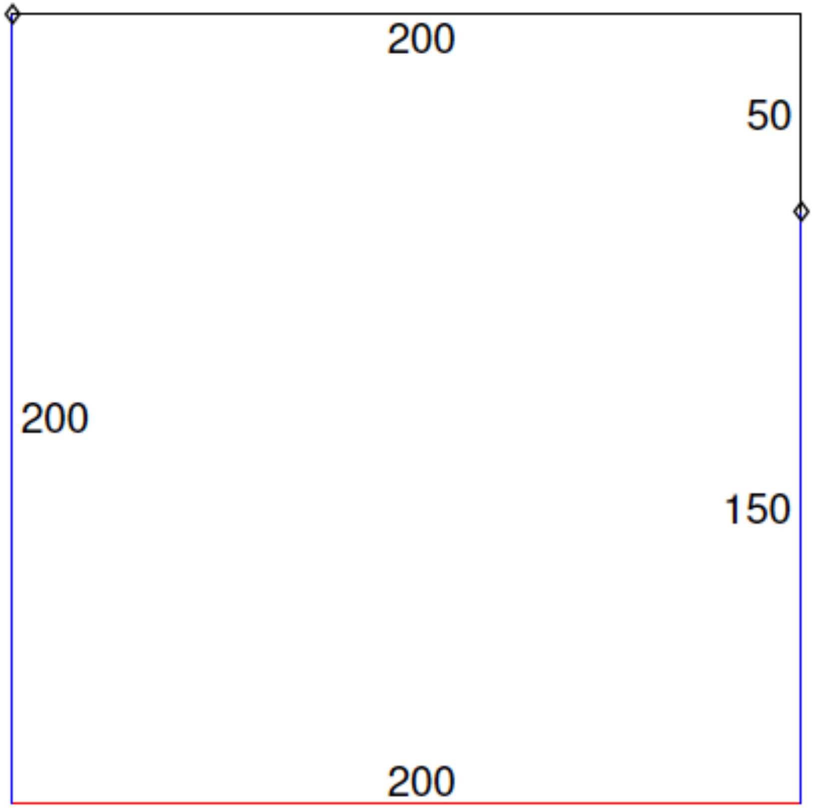
Failed beams

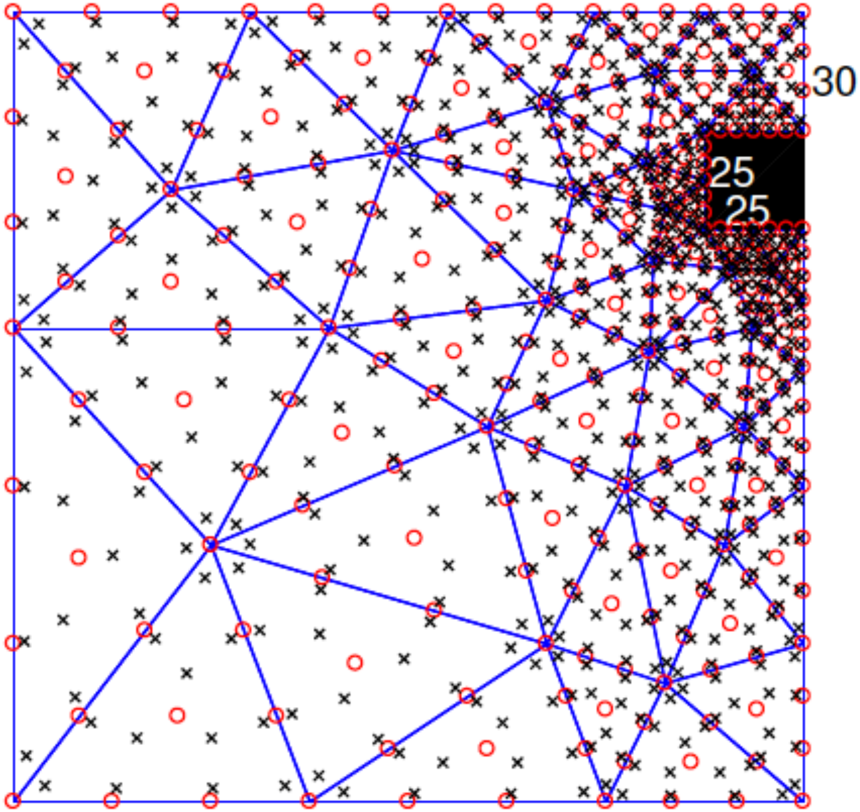
Fibrous unit cell, small setup: Results

Force-displacement response



Fibrous unit cell: Large setup





DNS:
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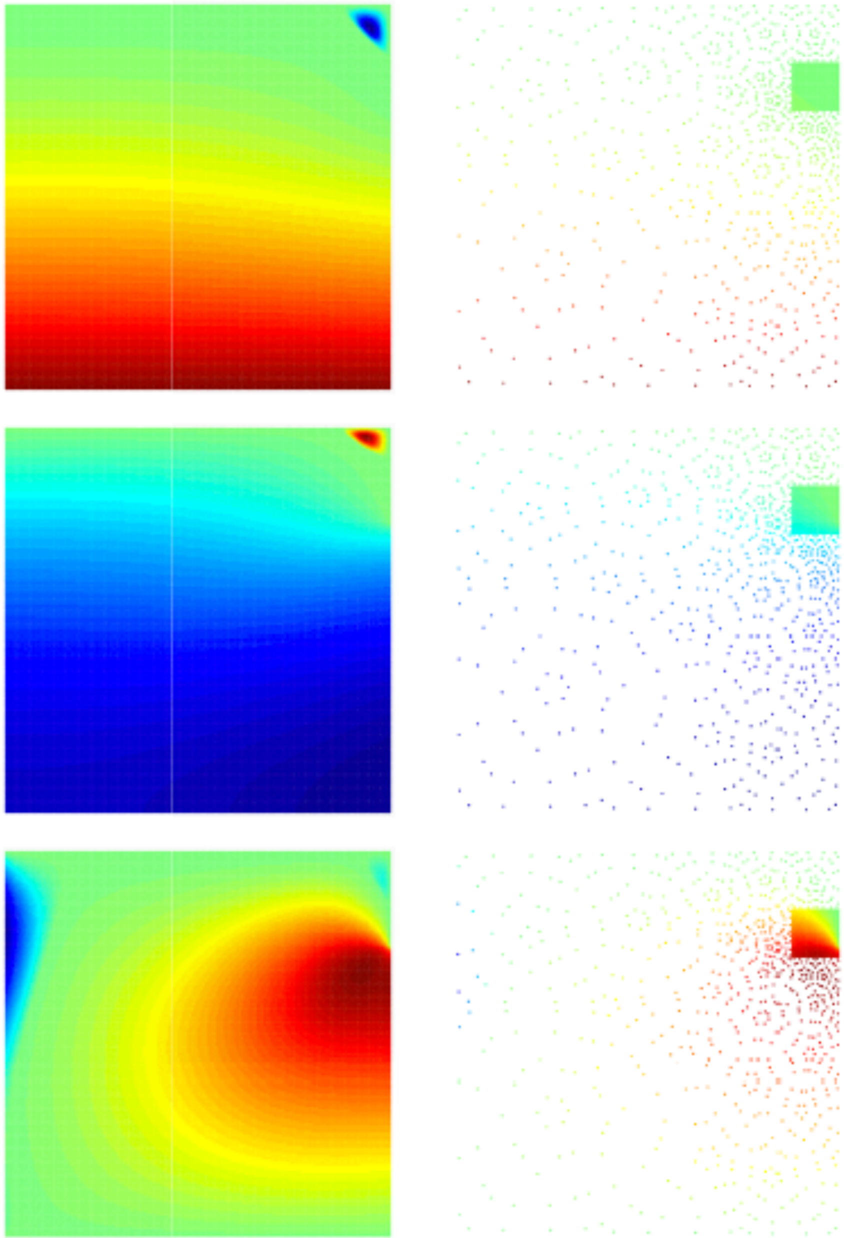
- 233M DOFs

QC:
- 29x less beams
- 42x less DOFs

Fibrous unit cell, large domain: Results



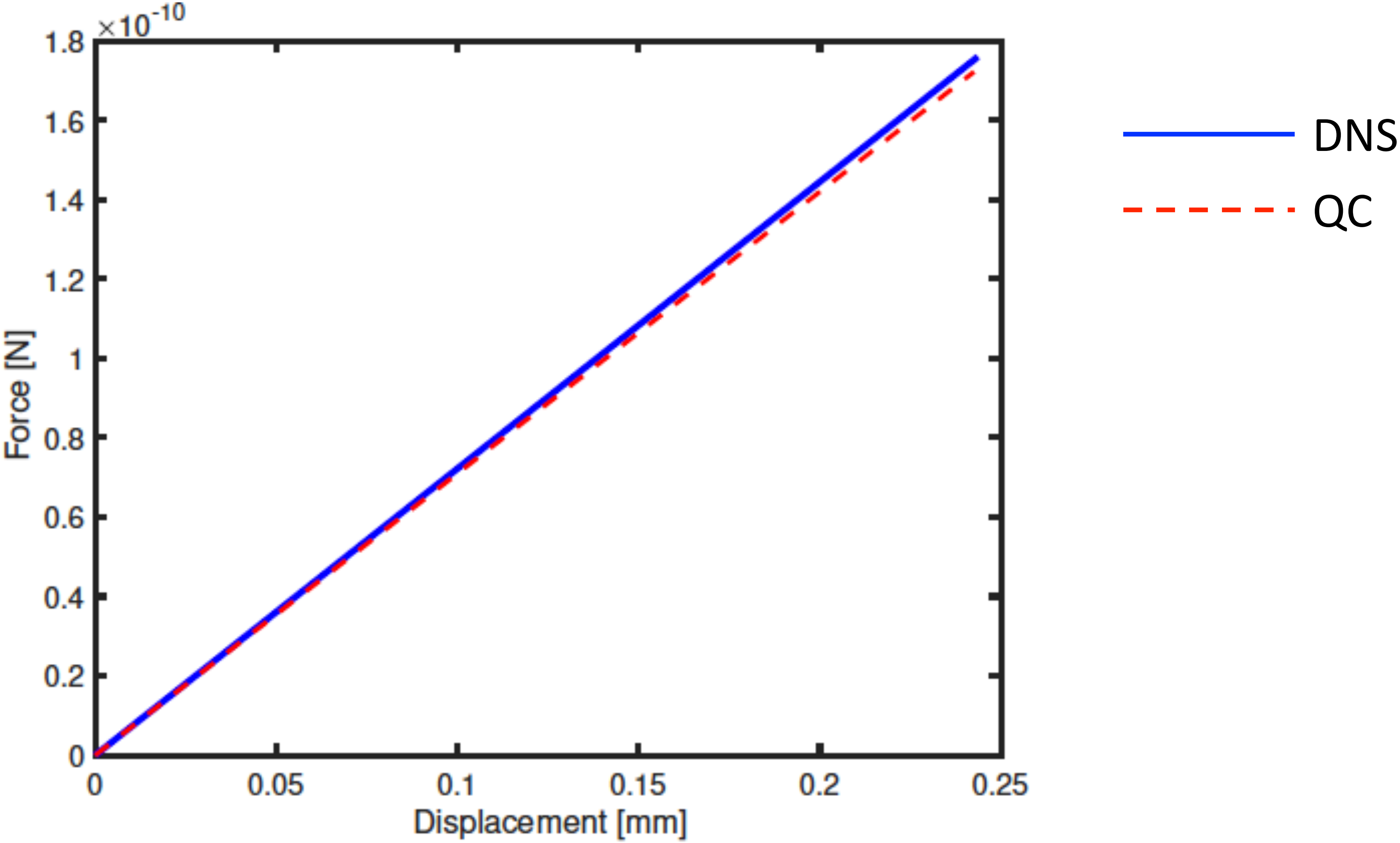
Out-of-plane displacement

Rotation around horizontal axis

Rotation around vertical axis

Fibrous unit cell: Large setup

Force-displacement response



Main points of the method

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Condition:

Unit cell must be periodic.

Advantages compared to other nested multiscale methods:

1. Higher-order macroscale interpolations are as easy to treat as linear ones
2. No scale-separation

Disadvantages compared to other nested multiscale methods:

1. All DOFs in one system, instead of subdivided over the unit cells and the macroscale elements
2. More unit cells required

Future work

Ongoing:

Apply to matrix material + inclusions (geom. NL + mat. NL)

Future:

Apply to real materials (e.g. PAPER/CARDBOARD??)

(Goal-oriented) adaptivity

Add randomness to structure in the fully resolved region