

Quantification and Morphological Analysis of Nanofibres for Material Characterisation Purposes using SEM and Advanced Image Processing

15.03.23

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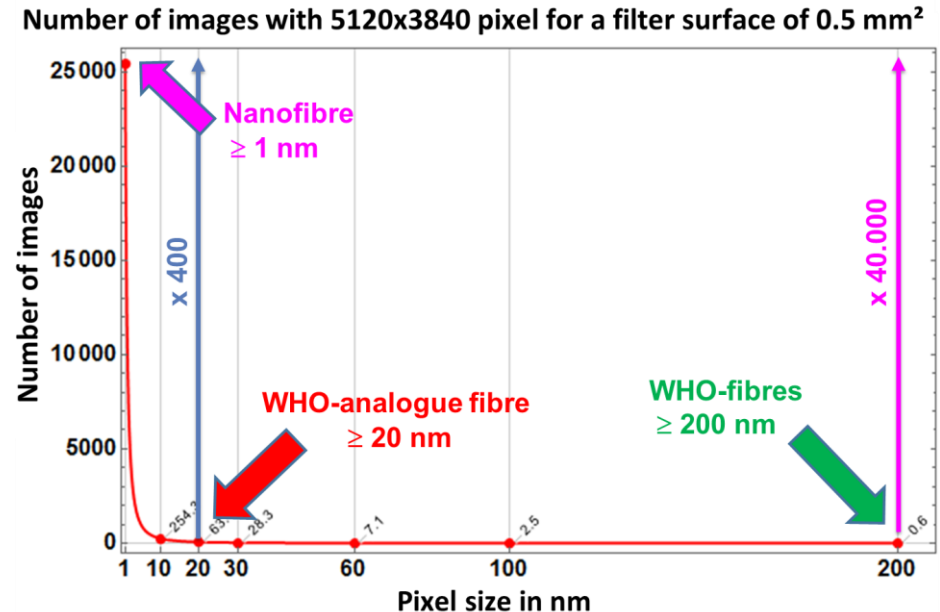
Automated evaluation for nanofibre exposure control

Recommended nanofibre exposure limit compliance testing requires the examination of a given air volume that corresponds to a specific filter area after air sampling and SEM/TEM imaging.

Number of images to be evaluated increases **quadratically** with decreasing fibre diameter.

Therefore, automated evaluation becomes necessary.

References: [TRGS 572], [doi: 10.3390/atmos11111254]



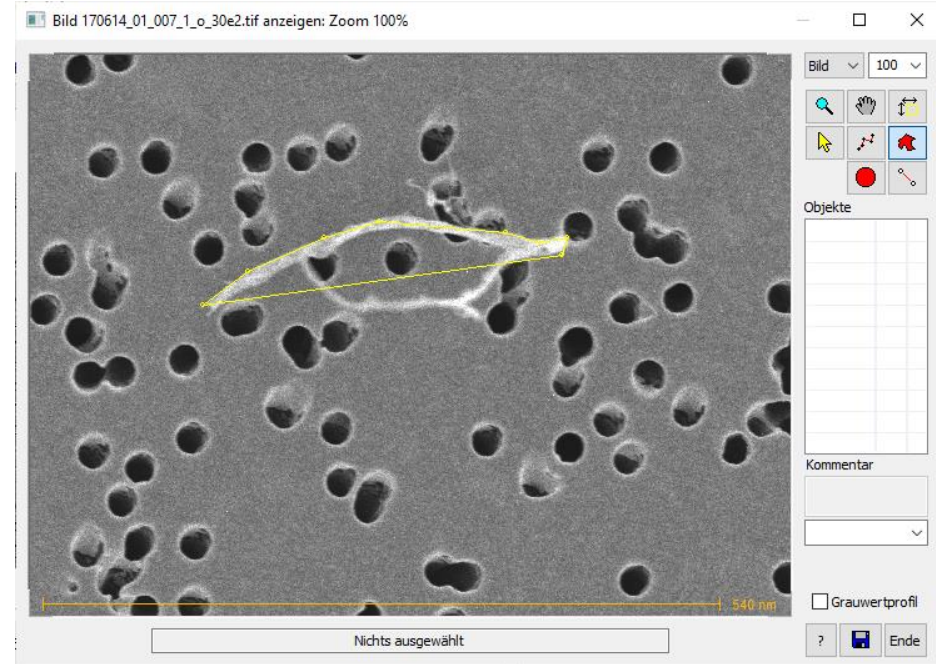
Manual evaluation using a computer-assisted measurement tool

Time spent for one workplace sample:

- 80-650 micrographs (20 MPX each)
- 150 micrographs on average
- about 3 min per micrograph

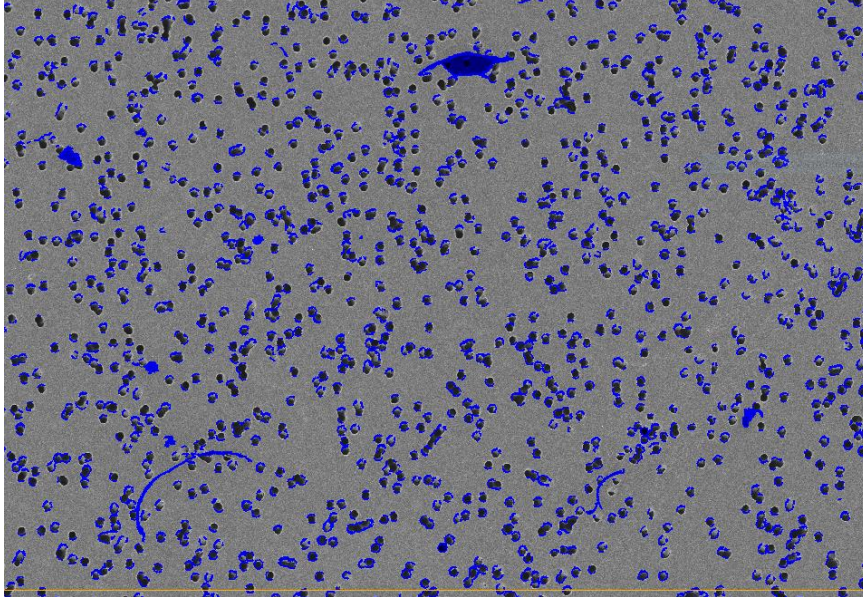
 **450 min. = 7.5 h**

**Very laborious &
Work load difficult to estimate!**

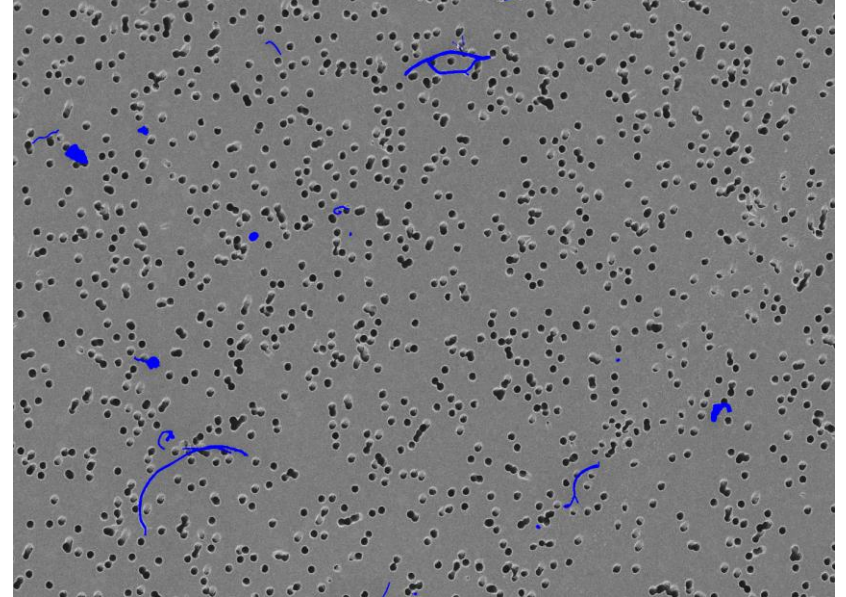


Classic image processing vs. convolutional neural networks (CNNs)

Classic image processing by greylevel thresholding



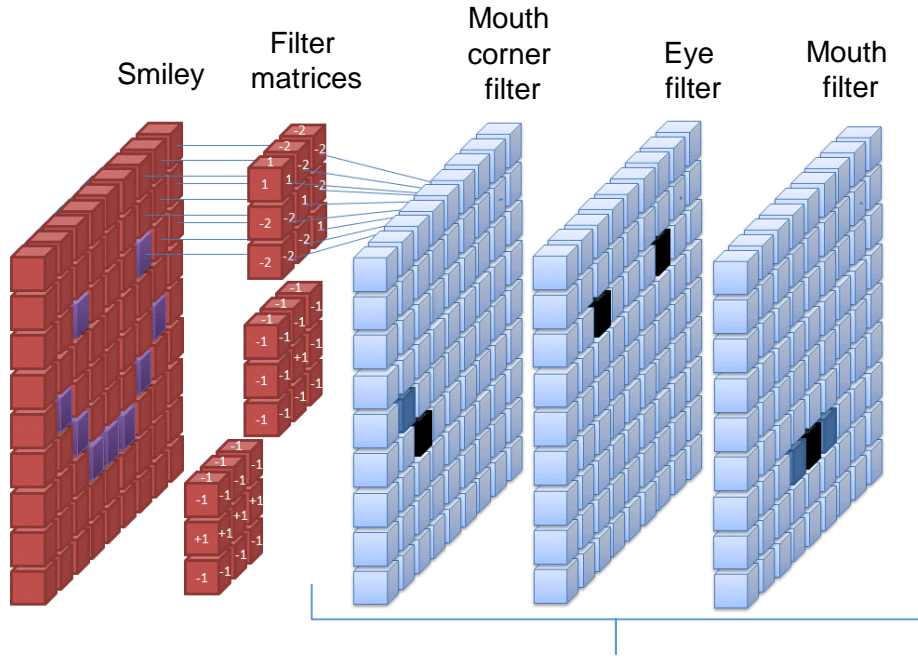
CNN



Computation time: ~1 second per
micrograph (GPU)

How do CNNs work?

Convolutional image filter matrices in neural networks



Each convolutional filter matrix produces a „feature map“.
Training aims at optimising the filter matrix' parameters to obtain “useful” feature maps.

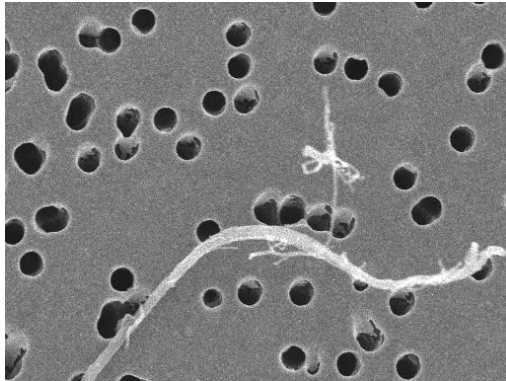
Picture: https://commons.wikimedia.org/wiki/File:3_filters_in_a_Convolutional_Neural_Network.gif

Training data set

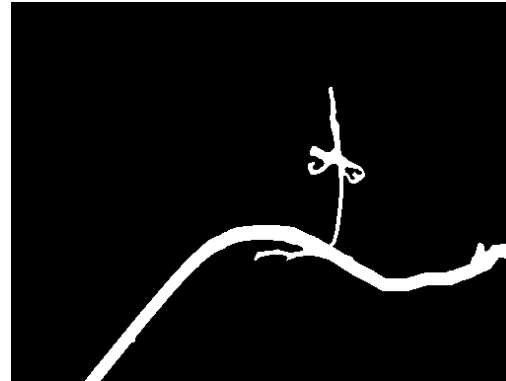
Data set used for supervised training

- 1080 manually evaluated and annotated SEM-micrographs (5120x3840 pixels)
- 108.000 training images (512x384 pixels)
- Mainly CNT-materials, few images of other fibre materials
- 7/8 of the data is used for training, the rest is used for validation

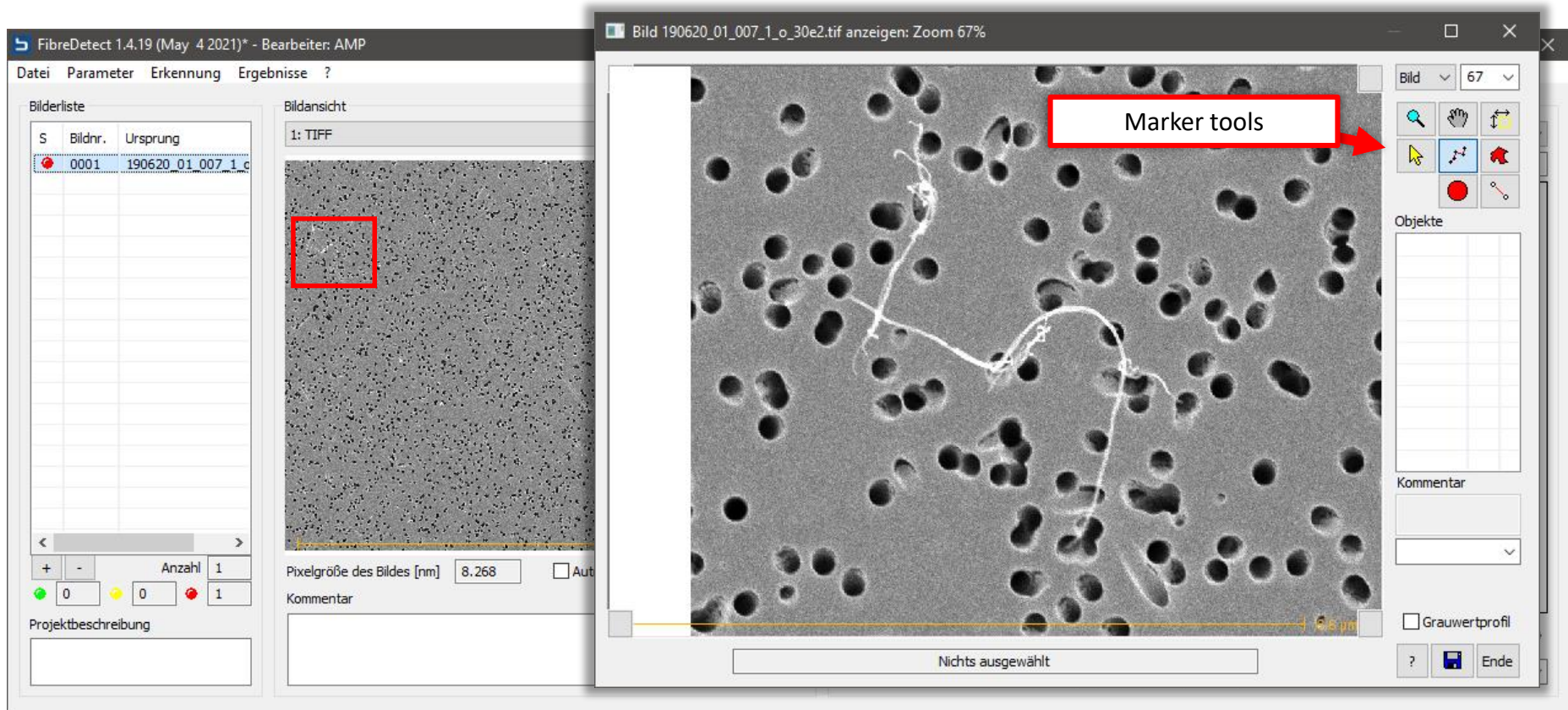
SEM image section



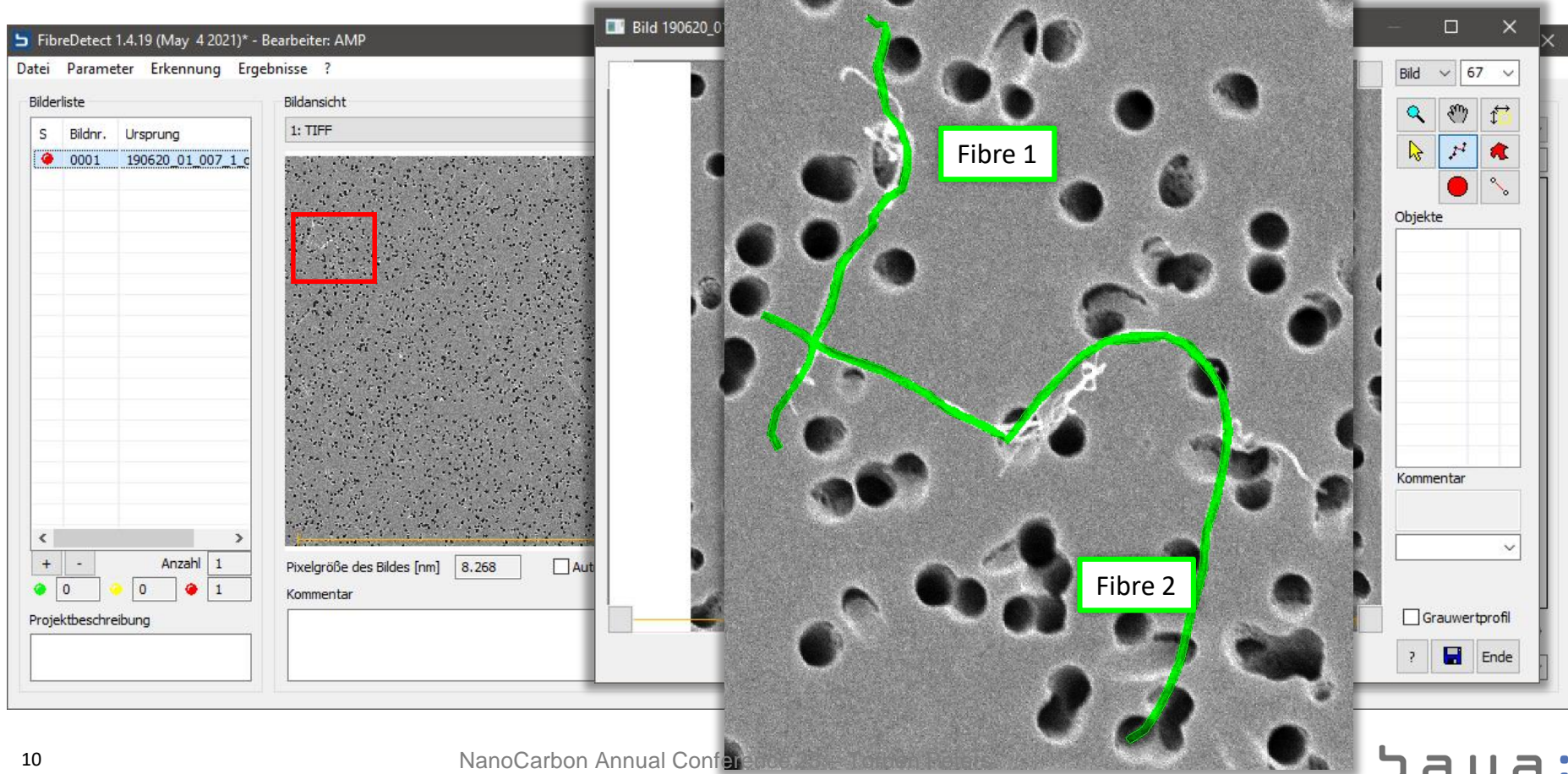
Ground Truth



Manual fibre evaluation



Manual fibre evaluation



FibreDetect 1.4.19 (May 4 2021)* - Bearbeiter: AMP

Datei Parameter Erkennung Ergebnisse ?

Bilderliste

S	Bildnr.	Ursprung
●	0001	190620_01_007_1.c

Bildansicht

1: TIFF


Pixelgröße des Bildes [nm] 8.268 ☐ Aut

Kommentar

Objekte

Kommentar

☐ Grauwertprofil

?  Ende

Fibre 1

Fibre 2

Automated fibre evaluation

FibreDetect 1.4.34 (Feb 20 2023)* - User: Unet_rx1q

File Parameters Detection Results ?

List of images

S	No#	Source
1	0001	190620_01_007_1_c

View: 1: TIFF

Objects segmented by CNN

Pixel size [nm]: 8.268 ☐ Auto contrast

Comment

Classification

Cl	Type	Status	Le...	Width	Se
1	unknown	none	0	0	00
2	unknown	none	0	0	00
3	unknown	none	0	0	00
4	unknown	none	0	0	00
5	unknown	none	0	0	00
6	unknown	none	0	0	00
7	unknown	none	0	0	00
8	unknown	none	0	0	00
9	unknown	none	0	0	00
10	unknown	none	0	0	00
11	unknown	none	0	0	00
12	unknown	none	0	0	00
13	unknown	none	0	0	00
14	unknown	none	0	0	00
15	unknown	none	0	0	00
16	unknown	none	0	0	00

Section from the image of detection 1:(none)

Segment: 0001 from image: 0001:1 of Unet_rx1q

Length: Width: [nm]

Ratio: Splines: 0 unknown (new) v

Count: 16 selected: 1 ?

Algorithmic fibre tracing - vectorisation

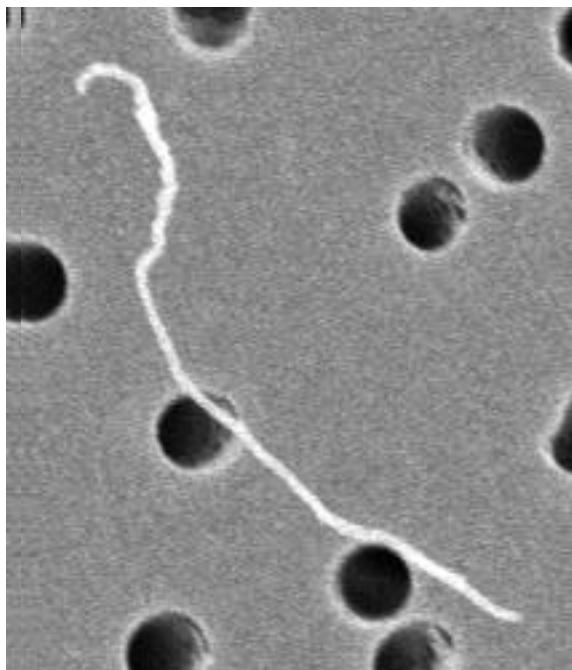
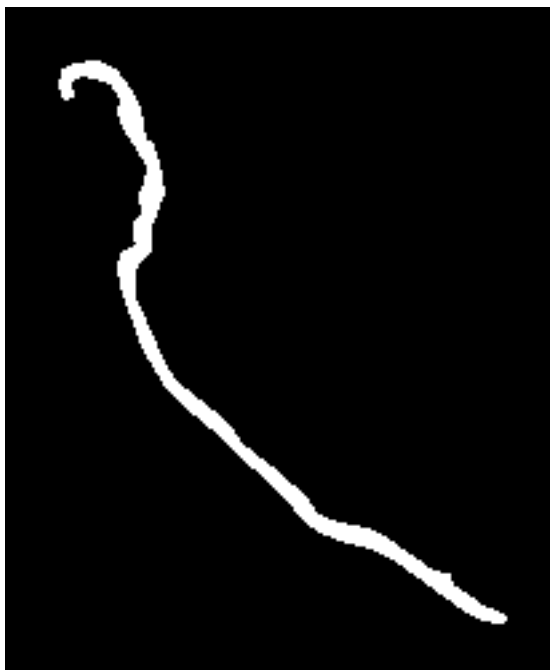
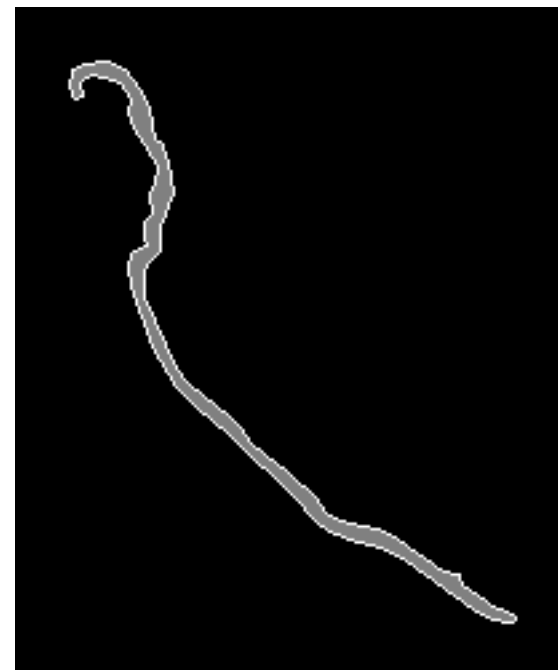


Image section

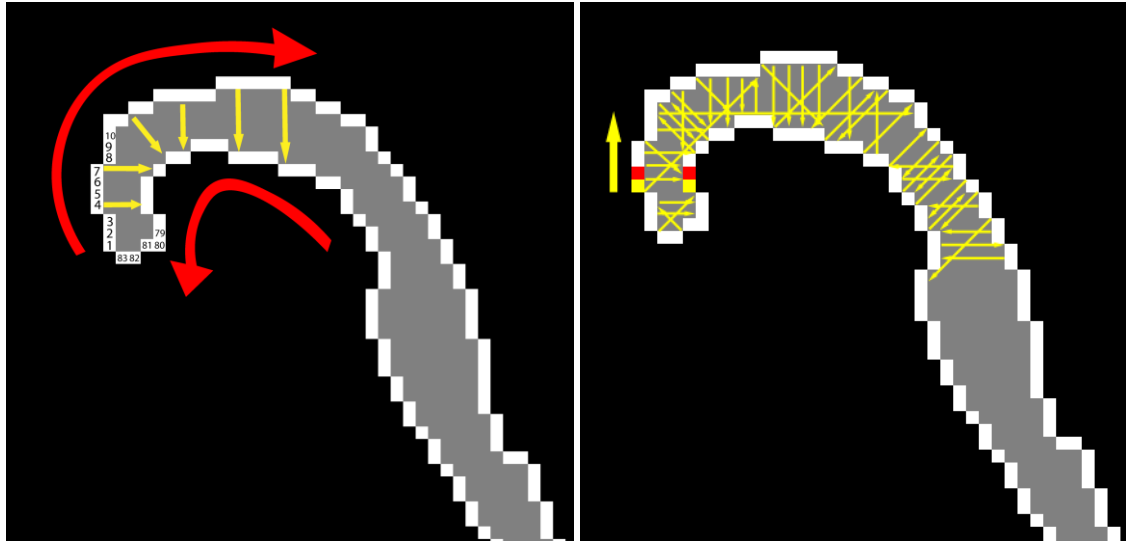


Binary Mask



Vectorisation (Polygon)

Algorithmic fibre tracing – width determination

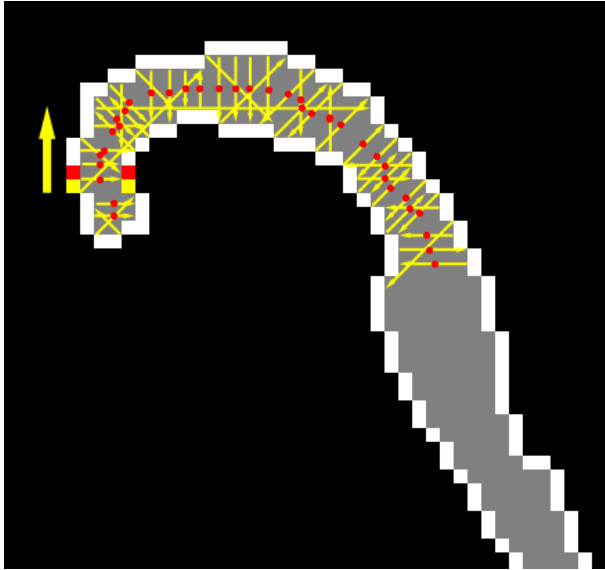


Adjacent points: Orthometric distances to opposite edge

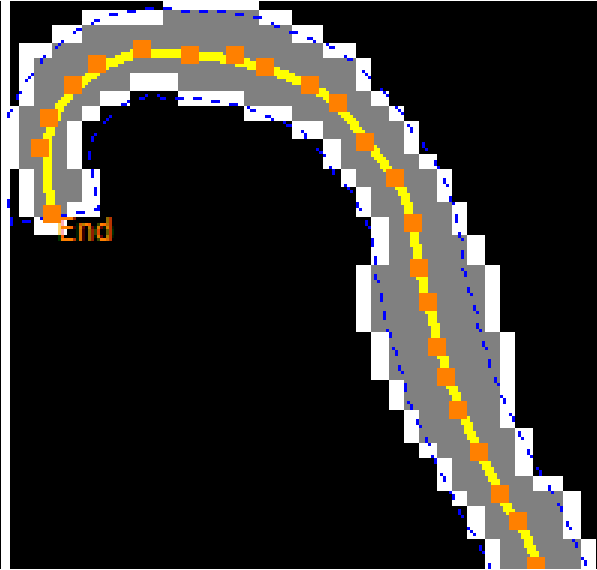


Width histogram:
maximum = fibre width
Green area = width tolerance

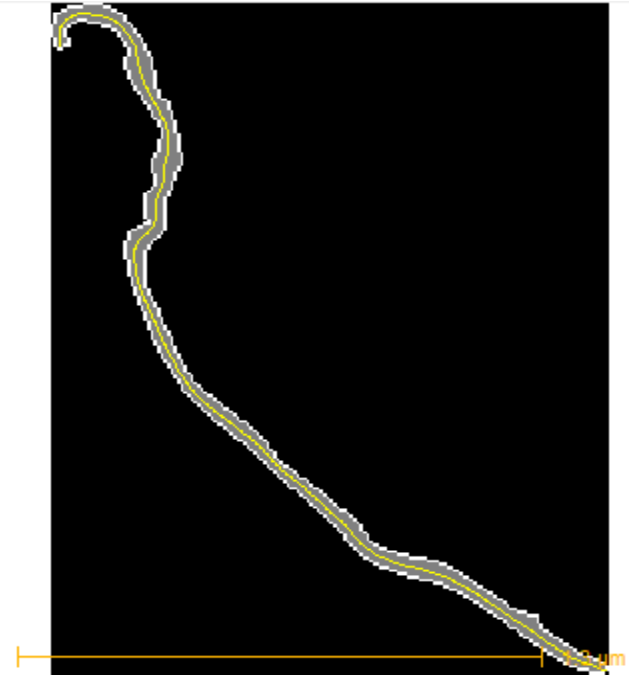
Algorithmic fibre tracing – spline computation



Half distances to the edge:
Support points of the fibre
axis within width tolerance



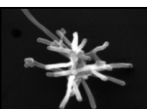


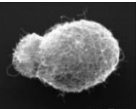
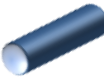
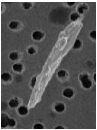

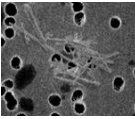


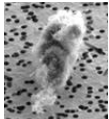

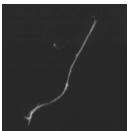




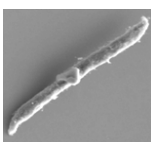


Compute support
points of spline



Fibre length and width

General morphological classification scheme for particles and fibres

	Individual Object	Cluster		Agglomerate		
		Particulate	Fibrous	Particulate	Fibrous	
Low-Aspect Ratio	LARPO Individual Particle Object	LARC (GBS-Cluster) Agglomerated and Countable		LARA (GBS-Agglomerate) Agglomerated and Un-countable		Low-Aspect Ratio
		LARPC	LARFC	LARPA	LARFA	
			 		 	
High-Aspect Ratio	HARFO Individual Fibre Object	HARC HAR-Cluster		HARA HAR-Agglomerate		High-Aspect Ratio
		HARPC	HARFC	HARPA	HARFA	
		 	 		 	
Satisfies WHO-Definition	WHOFO Individual WHO-Fibre Object	WHOC WHO-Cluster		WHOA WHO-Agglomerate		Satisfies WHO-Definition
		WHOPC	WHOFC	WHOPA	WHOFA	
		 	 		 	

LAR stands for **Low-Aspect Ratio** and is defined by a longitudinal to lateral dimension smaller than 3.

HAR stands for **High-Aspect Ratio** and is defined by a longitudinal to lateral dimension greater than 3.

WHO stands for HAR longitudinal dimensions greater than 5 µm and lateral dimensions smaller than 3 µm.

O stands for **Object**, i.e., particle, tube, rod or fibre. **C** for **Cluster**. **A** for **Agglomerate**.

Clusters are characterized by a low number of objects that could be individually distinguished, whereas **Agglomerates** contain objects in a higher concentration such that they overlap and can predominantly not be distinguished individually.

Algorithmic measurement of CNN-detected objects

FibreDetect 1.4.34 (Feb 20 2023)* - User: Unet_rxlq

File Parameters Detection Results ?

List of images

S	No#	Source
●	0001	190620_01_007_1_c

View: 1: TIFF

Objects detected by CNN

Pixel size [nm]: 8.268 ☐ Auto contrast

Comment

Classification

Cl	Type	Status	Le...	Width	Se
●	HARFO (F)	Auto	10...	45	00
●	HARFO (F)	Auto	2540	37	00
●	HARFO (F)	Auto	2516	45	00
●	HARFO (F)	Auto	1095	33	00
●	HARFO (F)	Auto	956	33	00
●	HARFO (F)	Auto	946	33	00
●	HARFO (F)	Auto	736	37	00
●	HARFO (F)	Auto	624	29	00
●	HARFO (F)	Auto	593	33	00
●	HARFO (F)	Auto	586	33	00
●	Object (O)	Auto	436	33	00
●	HARPA (E)	Auto	358	17	00
●	HARPA (E)	Auto	206	29	00
●	Object (O)	Auto	167	29	00
●	Object (O)	Auto	126	21	00
●	Object (O)	Auto	59	21	00

Count: 16 selected: 1 ?

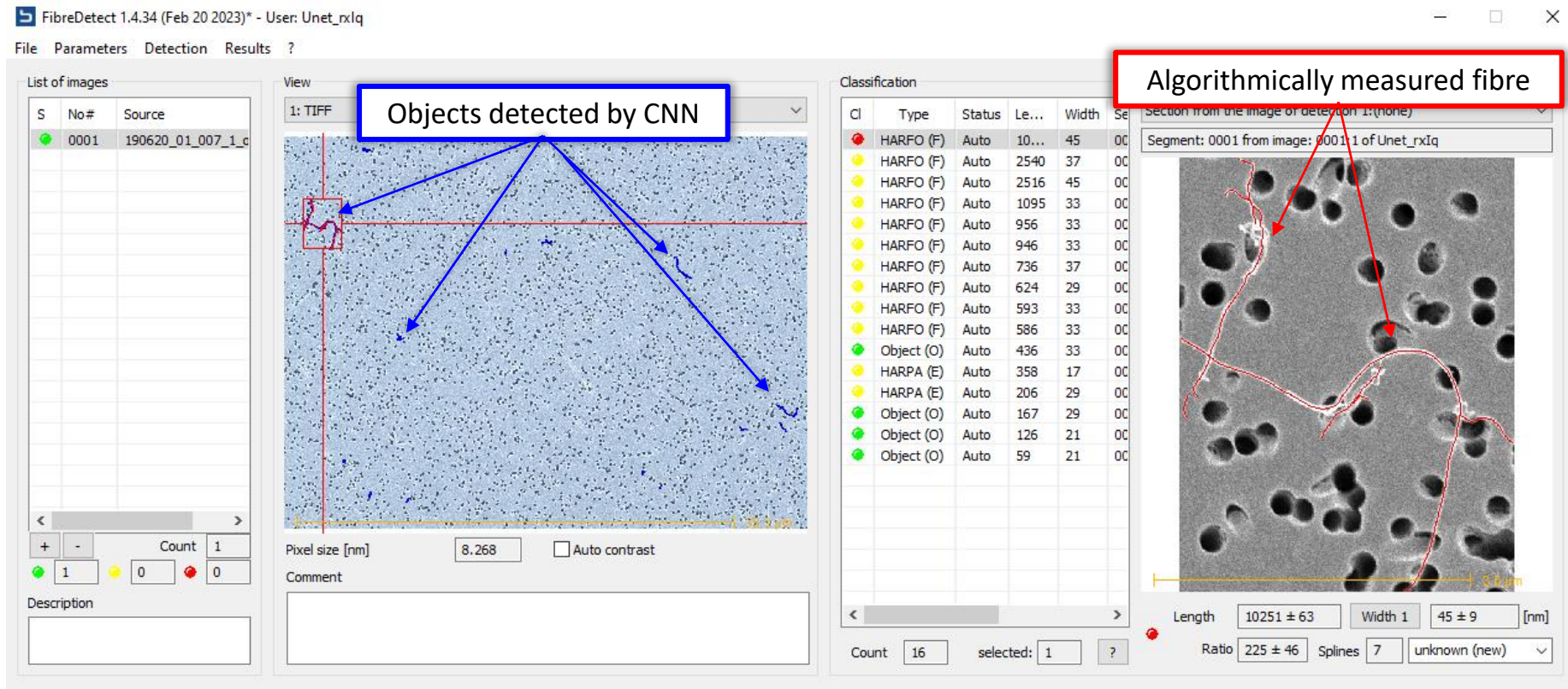
Algorithmically measured fibre

Section from the image of detection 1: (none)

Segment: 0001 from image: 0001_1 of Unet_rxlq

Length: 10251 ± 63 Width 1: 45 ± 9 [nm]

Ratio: 225 ± 46 Splines: 7 unknown (new)



Algorithmic measurement of CNN-detected objects

FibreDetect 1.4.19 (May 4 2021) - Unet_auswertung.fib - Bearbeiter: AMP

Datei Parameter Erkennung Ergebnisse ?

Bilderliste

S	Bildnr.	Ursprung
0049	190620_01_049	
0050	190620_01_050	
0051	190620_01_051	
0052	190620_01_052	
0053	190620_01_053	
0054	190620_01_054	
0055	190620_01_055	
0056	190620_01_056	
0057	190620_01_057	
0058	190620_01_058	
0059	190620_01_059	
0060	190620_01_060	
0061	190620_01_061	
0062	190620_01_062	
0063	190620_01_063	
0064	190620_01_064	
0065	190620_01_065	
0066	190620_01_066	

Pixelgröße des Bildes [nm] 8.268 ☐ Autokontrast

Kommentar

Objekt 0053 anzeigen: Zoom 10.48%

Algorithmically measured fibre

Object detected by CNN

Spines

001	
002	
003	
004	
005	
006	
007	
008	
009	
010	
011	
012	
013	

Kommentar

unbekannt (neu)

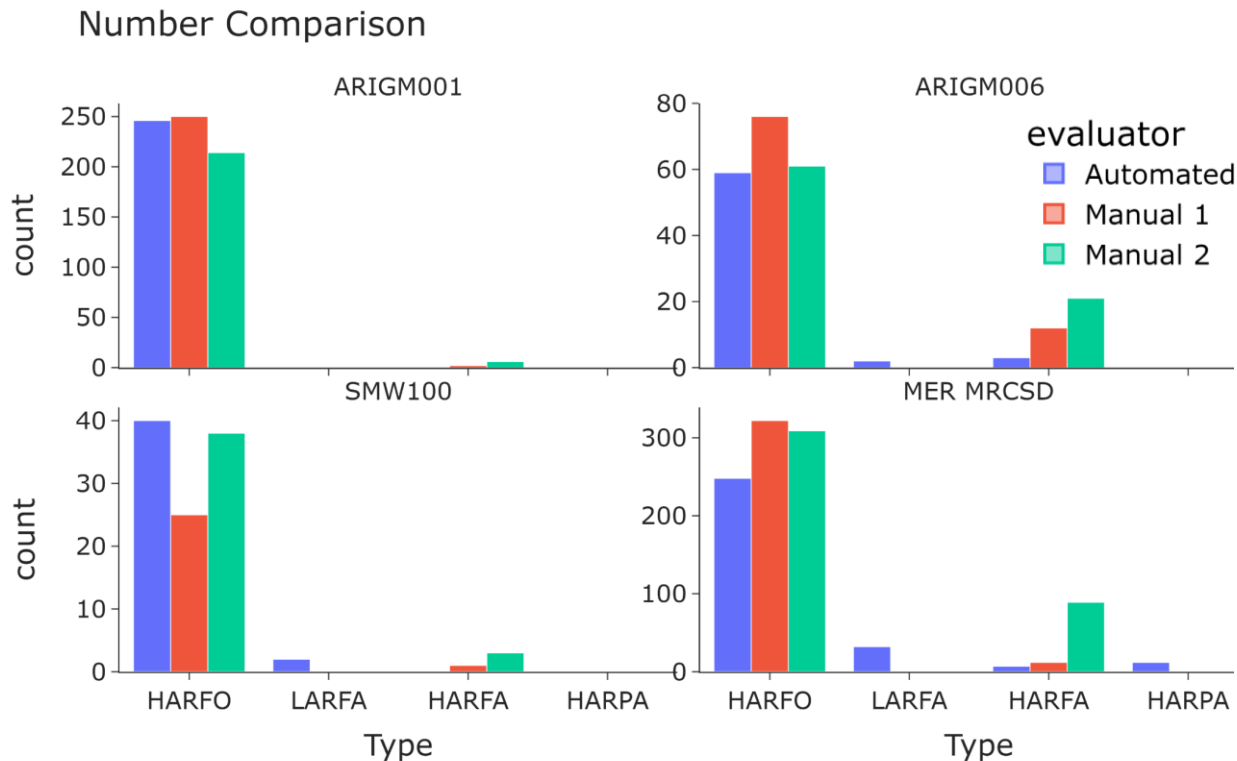
☒ Faserpolygon

☐ Faserhüllen

☐ Krümmungen

Nichts ausgewählt

Evaluation comparison – Counted objects



ARIGM006:

- wide length distribution
- often agglomerated

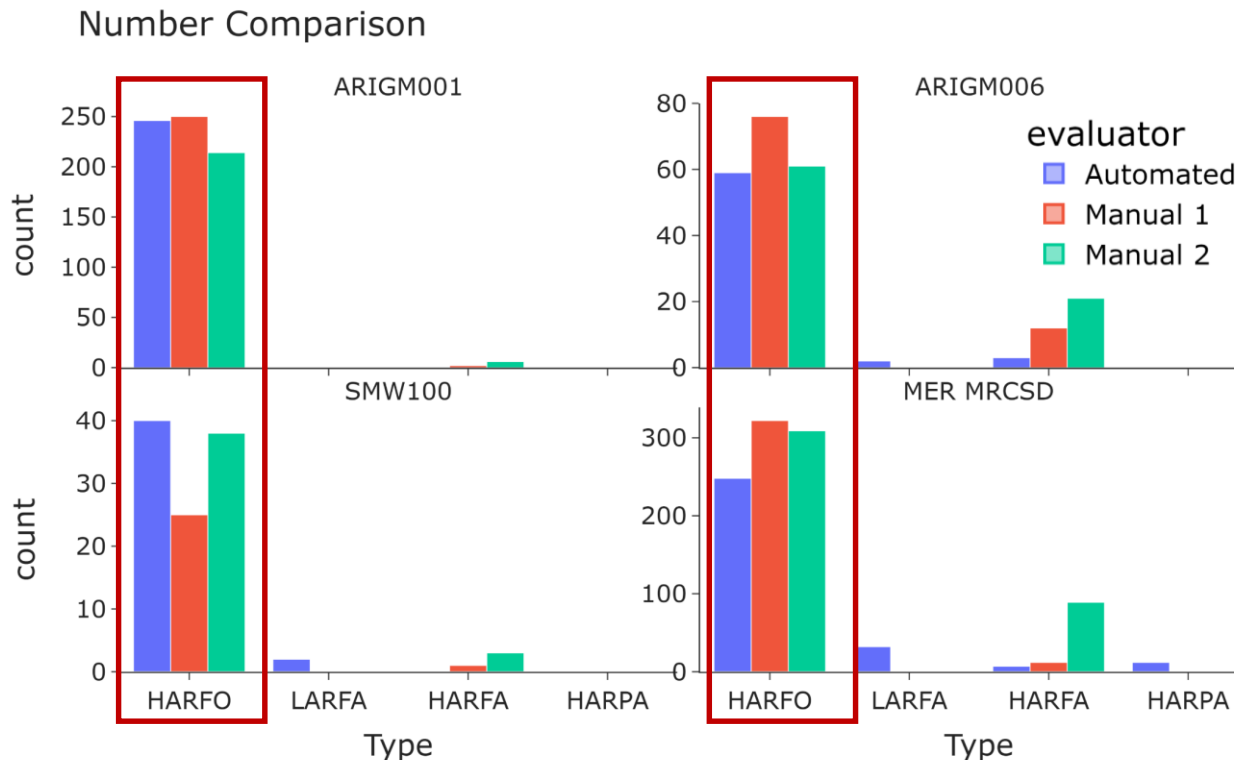
MER MRSCD:

- very long fibres
- often agglomerated

SMW 100:

- short fibres
- low filter occupancy

Evaluation comparison – Counted objects



ARIGM006:

- wide length distribution
- often agglomerated

MER MRSCD:

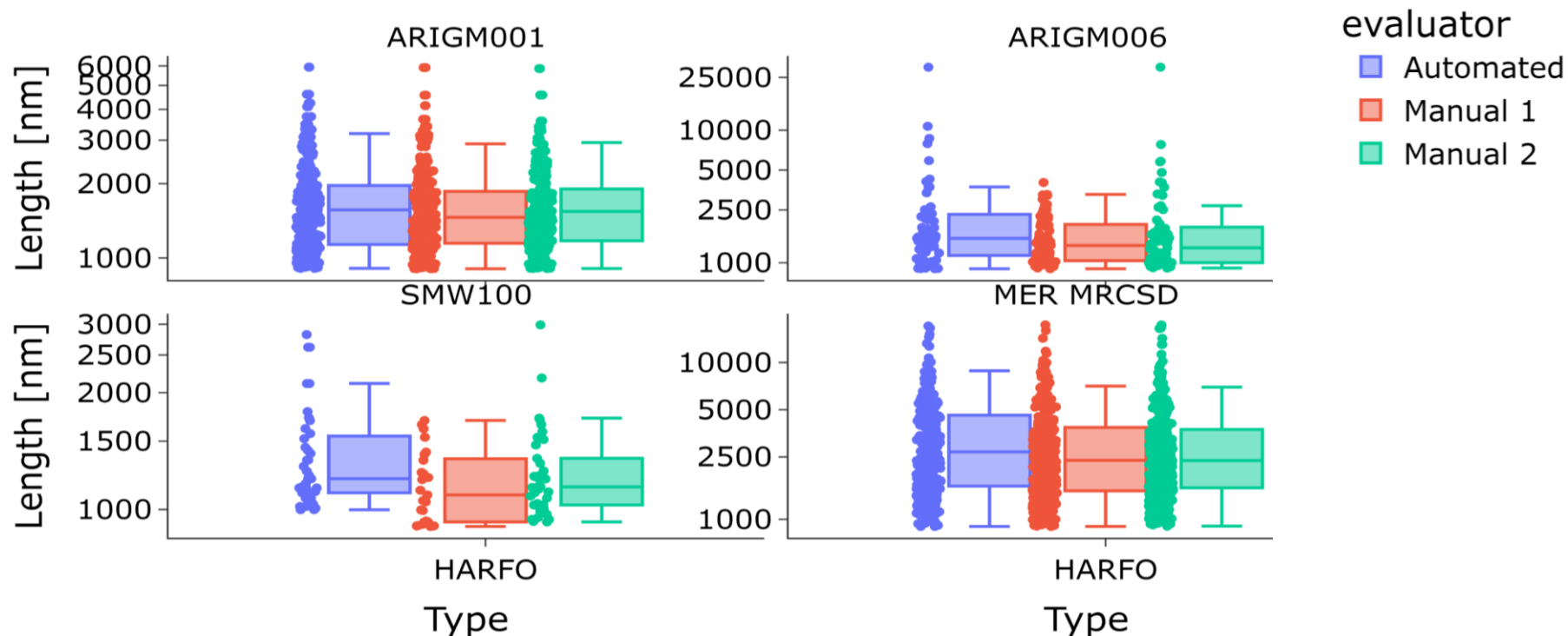
- very long fibres
- often agglomerated

SMW 100:

- short fibres
- low filter occupancy

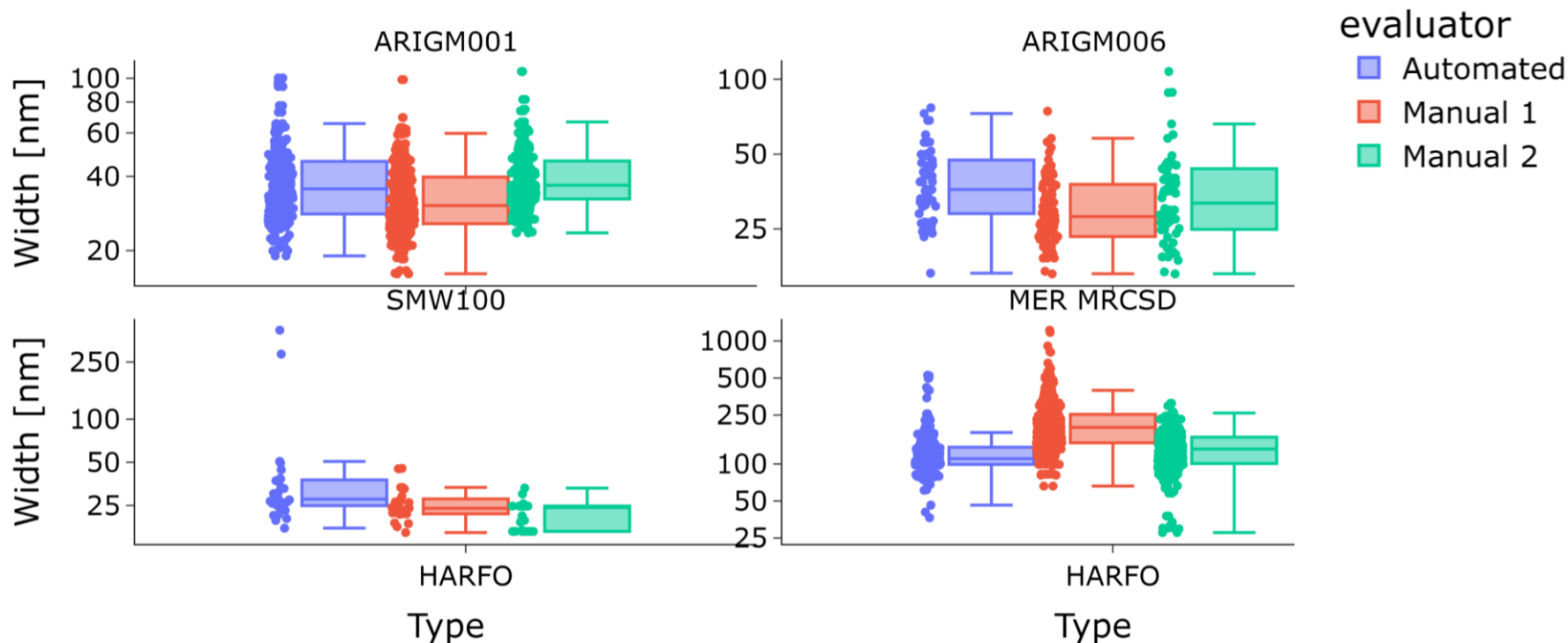
The number of counted HARFOs agrees with the manual evaluation.

Evaluation comparison - length



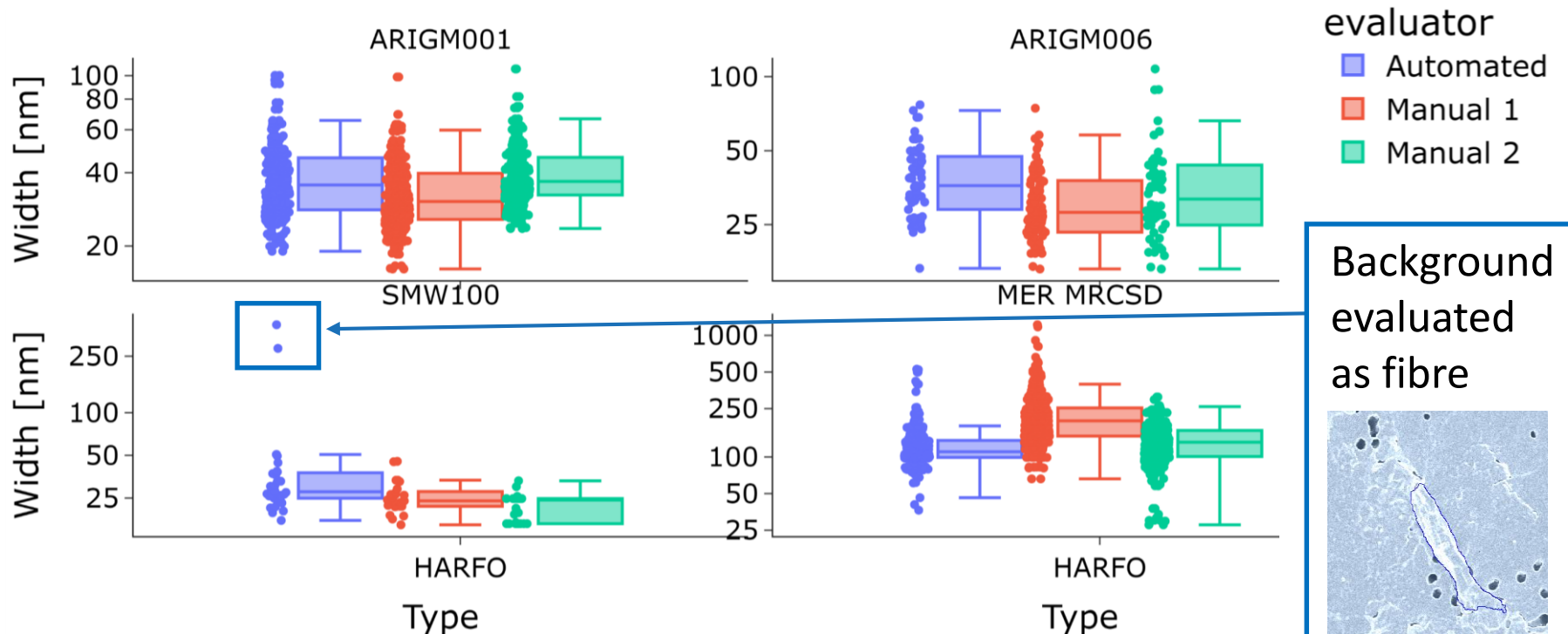
Automated evaluation is in agreement with manual evaluation.

Evaluation comparison - width



Automated evaluation is in agreement with manual evaluation.

Evaluation comparison - width



Automated evaluation is in agreement with manual evaluation.

Summary

- Counts comparison (HARFOs): fits
- Length comparison (HARFOs): fits
- Width comparison (HARFOs): fits

Recommended
compliance testing for
nanofibre limits becomes
feasible!

- Algorithmic classification of object morphology
is **not always reliable**
 - Can a neural network do a better job?

Thank you for your attention!

Contact

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