KiSSAM Simulation Software for Additive Manufacturing

Variations in morphology and microstructure caused by different melt pool dynamics in laser powder bed fusion of ultrathin walls

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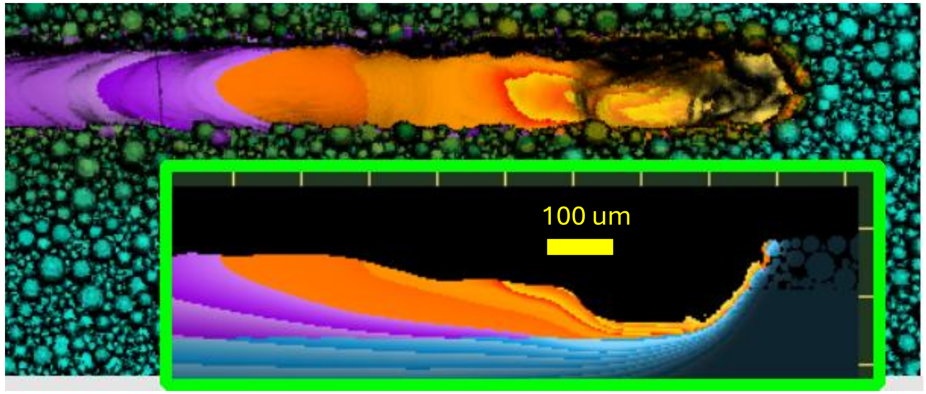
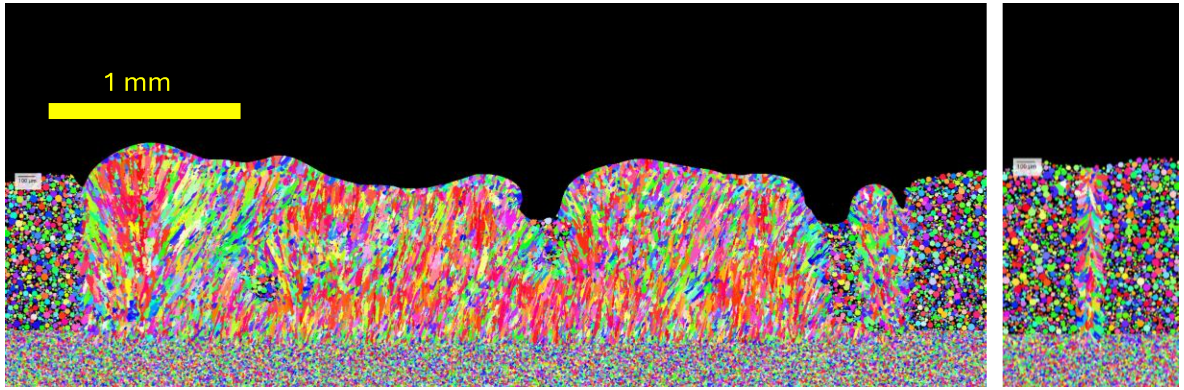
Motivation

Resolve:

- **Melt pool at the mesoscale**



- **Microstructure and morphology at the part scale**



- <u>Aim:</u>
  - Demonstrate the link between the process parameters, morphology and microstructure <u>**for a complete part by the mesoscale simulation**</u>
- <u>Choice of the part geometry:</u>
  - Ultrathin wall (single laser pass per layer) is a simplified model of lightweight/lattice part, essential for innovative lightweight structures

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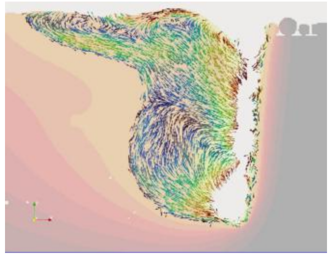
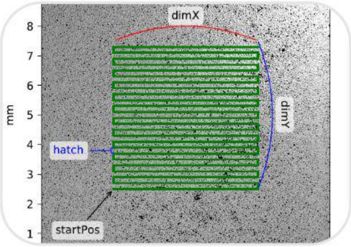
KiSSAM: A high-fidelity simulation at the mesoscale

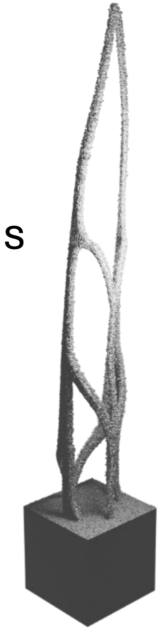


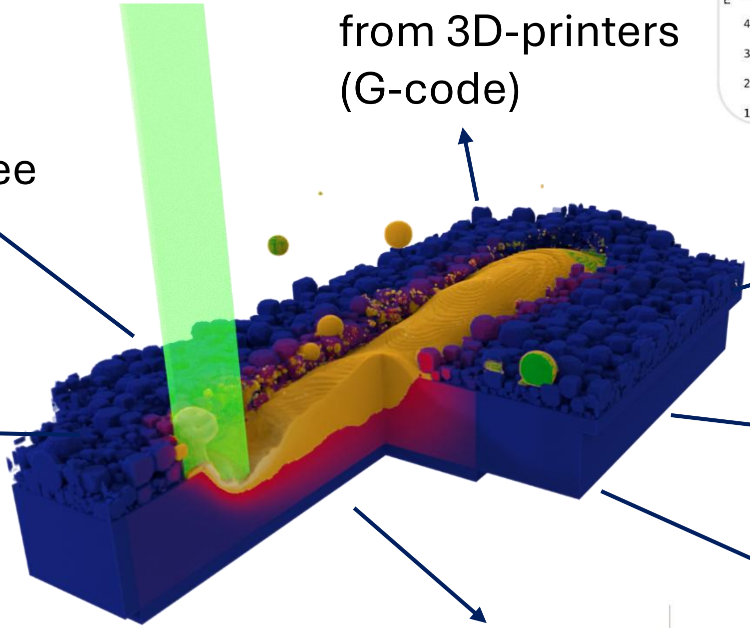
Solver: Temperature Lattice Boltzmann Method (LBM) with free surface tracking

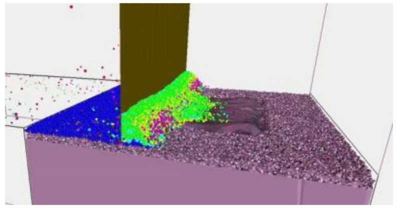
Scanning strategy import directly from 3D-printers (G-code)



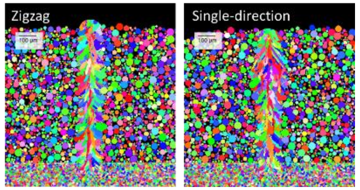
Full part simulations



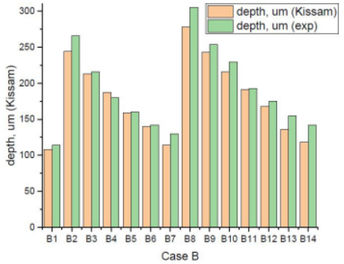




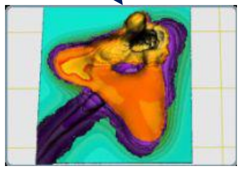
Powder coating simulation



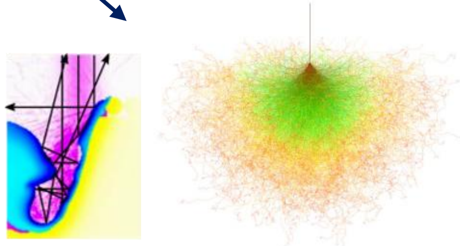
microstructure



Verified material library

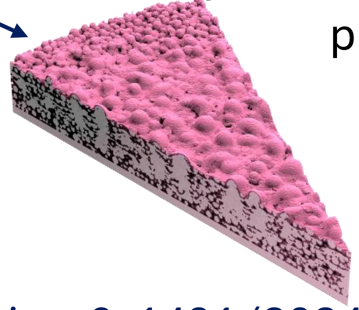


Beam shaping



Laser and electron beam

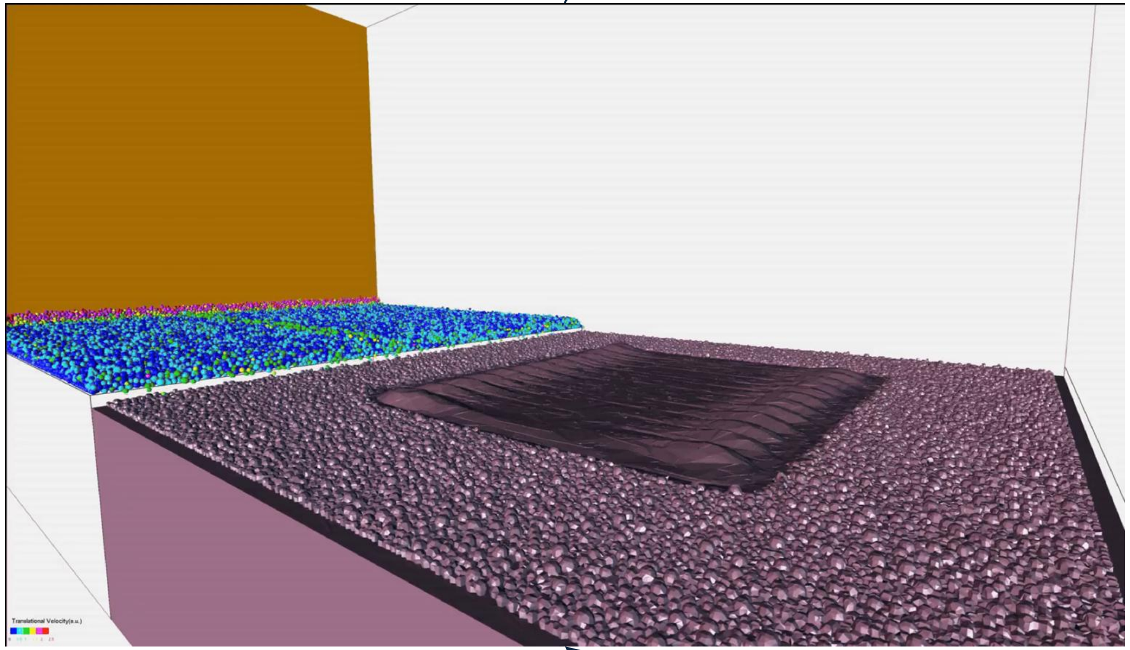
Porosity and roughness prediction

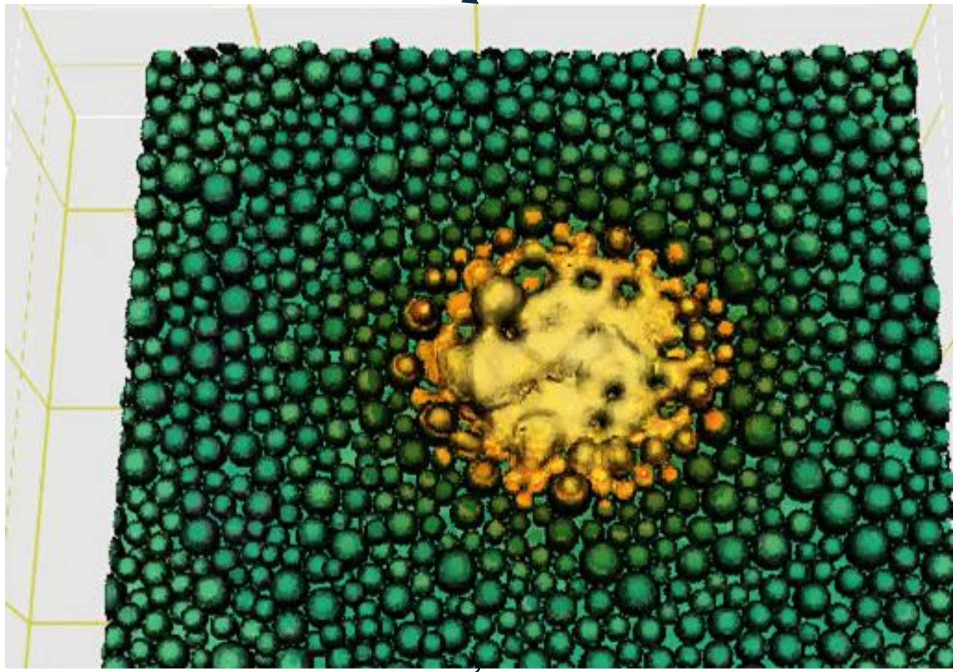


A. Zakirov et.al. *Additive Manufacturing*, *35*, 101236 (2020); *Progress in Additive Manufacturing*, *9*, 1491 (2024).

Multilayer simulations with KiSSAM

powder particles are loaded to KiSSAM main simulation module





New layer surface is loaded to PowDEM for next powder spreading

KiSSAM DEM module PowDEM to simulate powder spreading

KiSSAM LBM simulation of selective melting

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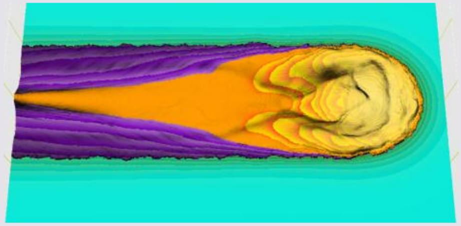
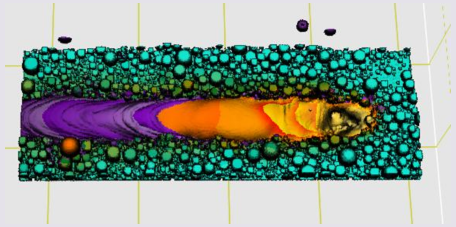
Some performance figures

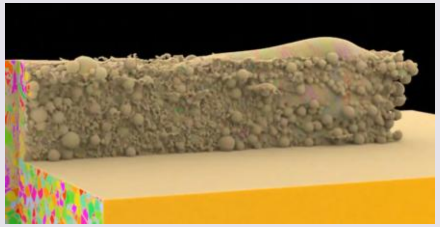
- KiSSAM is a high performance software implemented on CUDA C++ for NVIDIA GPUs.
- Typical performance is **0.5 – 1 hr per 1 ms** of scanning time.
- Here are some sample setups modeled on a single GeForce RTX 3090 24 GB GPGPU and total simulation times.



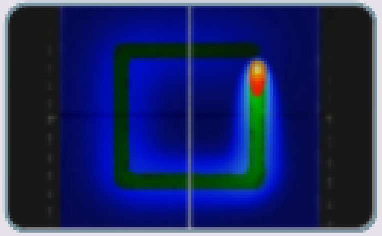
Single tracks on a plate
~ 0.5-1 h



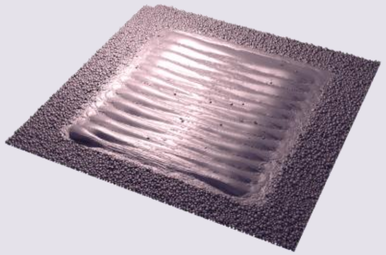
Single tracks on powder
~ 0.5-1 h



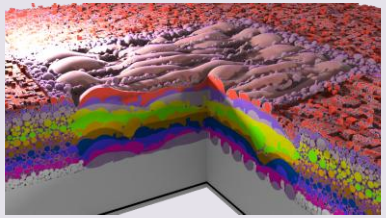
Thin walls
~ 1-3 days



Contours
~ 2-4 h



Single layers
~ 6-12 h



Bulk samples
~ 1-2 weeks

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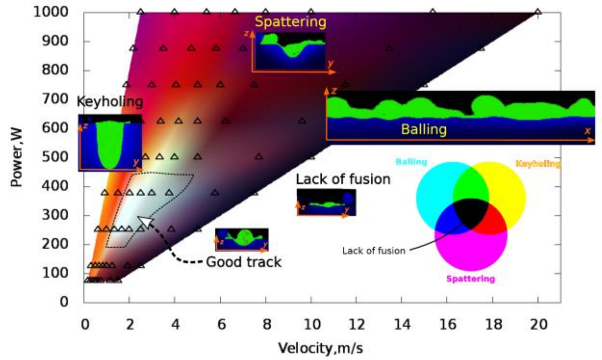
Previously with KiSSAM…

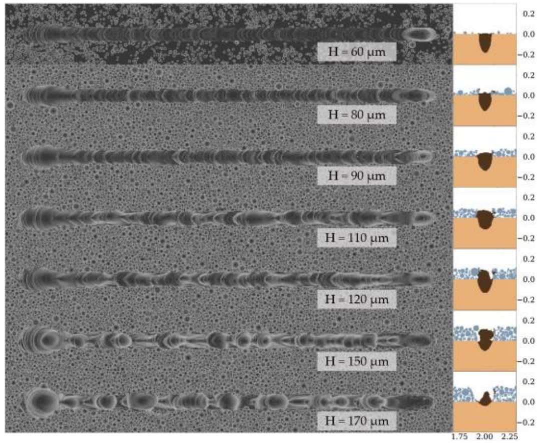
- Process map generation

  D. Nakapkin et.al., Sim-AM 2019: II International Conference on Simulation for Additive Manufacturing (pp. 297-308). CIMNE (2019).



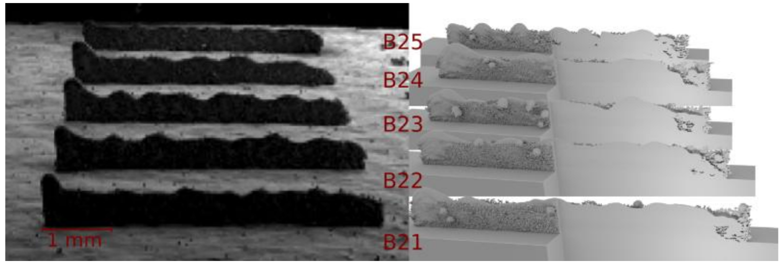
- Study of thicker powder layers as a means to increase productivity of PBF

  M. Bogdanova et.al., Journal of Manufacturing and Materials Processing, 8(1), 7 (2024).



- Prediction of the thin wall morphology at the mesoscale

  B. Korneev et.al., Additive Manufacturing, 74, 103705 (2023).



Microstructure modeling in KiSSAM

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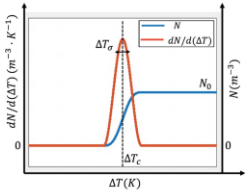
- Cellular automata method (CA) is used (***Anderson et al. (1984). Acta Metall. 32, 783-791)*** for grain microstructure calculation:
    - CA uses the same grid as LBM
    - model parameters:
        - grain growth velocity as function of undercooling:

$$v = K_1 \Delta T + K_2 \Delta T^2 + K_3 \Delta T^3$$

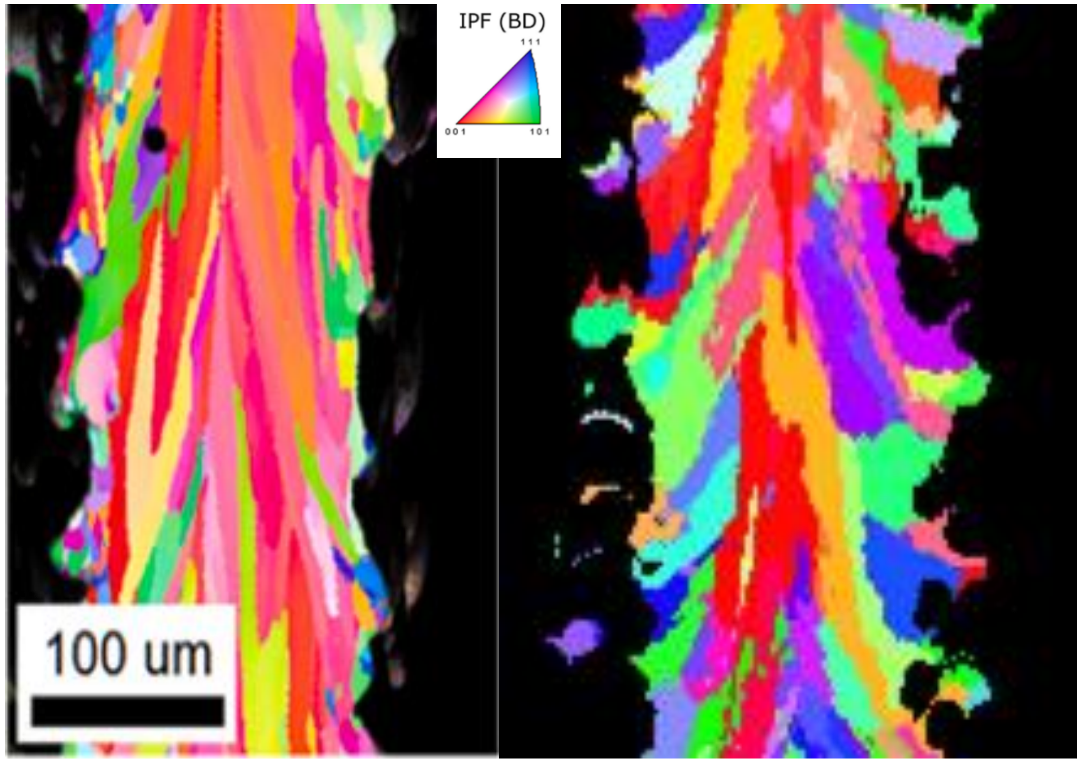
        - grains nucleation parameters



    - initial grain structure is defined randomly with given mean grain size or can be loaded from the previous layer
- CA model is coupled with the LBM

Model validation on thin walls (SS316L)

Left: experimental data of ***Wrobel et al. (2024). Mater. Des. 238, 112652.***, right: KiSSAM simulation



Study objectives

- How is the morphology and microstructure of ultrathin walls affected by:
  - The scanning strategy:

Single direction

Zigzag

  - The printing regime:
    - Laser power
    - Scan speed

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Study setup: ultrathin wall

Parameters of the wall:

- Single pass thin wall
- Wall length is 5 mm
- Material is Inconel 625
- Powder is spherical, size in the range 15-45 um

Laser parameters and scanning strategies

Case ID	Strategy	V, mm/s	P, W	layers
S-V600-P195	Single direction	600	195	24
S-V1058-P349	Single direction	1058	349	13
S-V1600-P500	Single direction	1600	500	10
Z-V600-P195	Zig-zag	600	195	24
Z-V1058-P349	Zig-zag	1058	349	16
Z-V1600-P500	Zig-zag	1600	500	17

Additional process parameters:

- Beam size $D_{4\sigma} = 100\ um$
- Platform step is 40 um

Single direction

Zigzag

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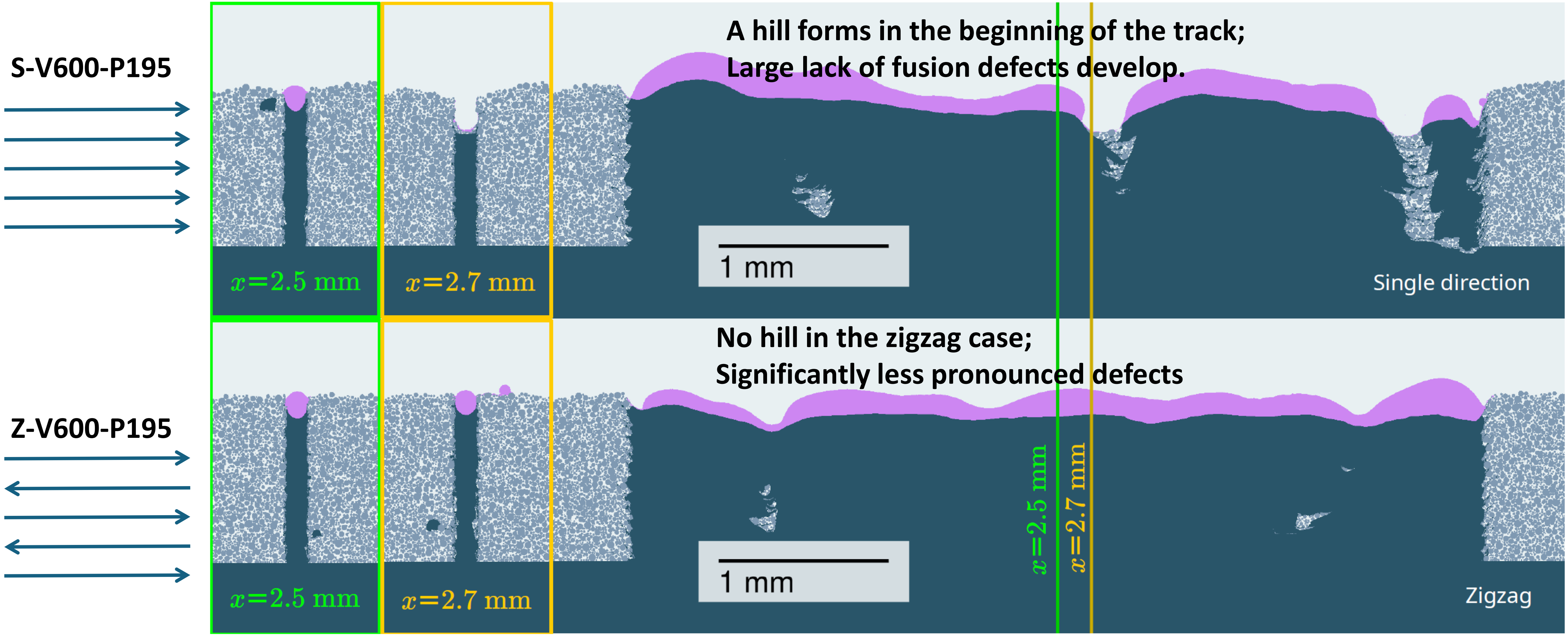
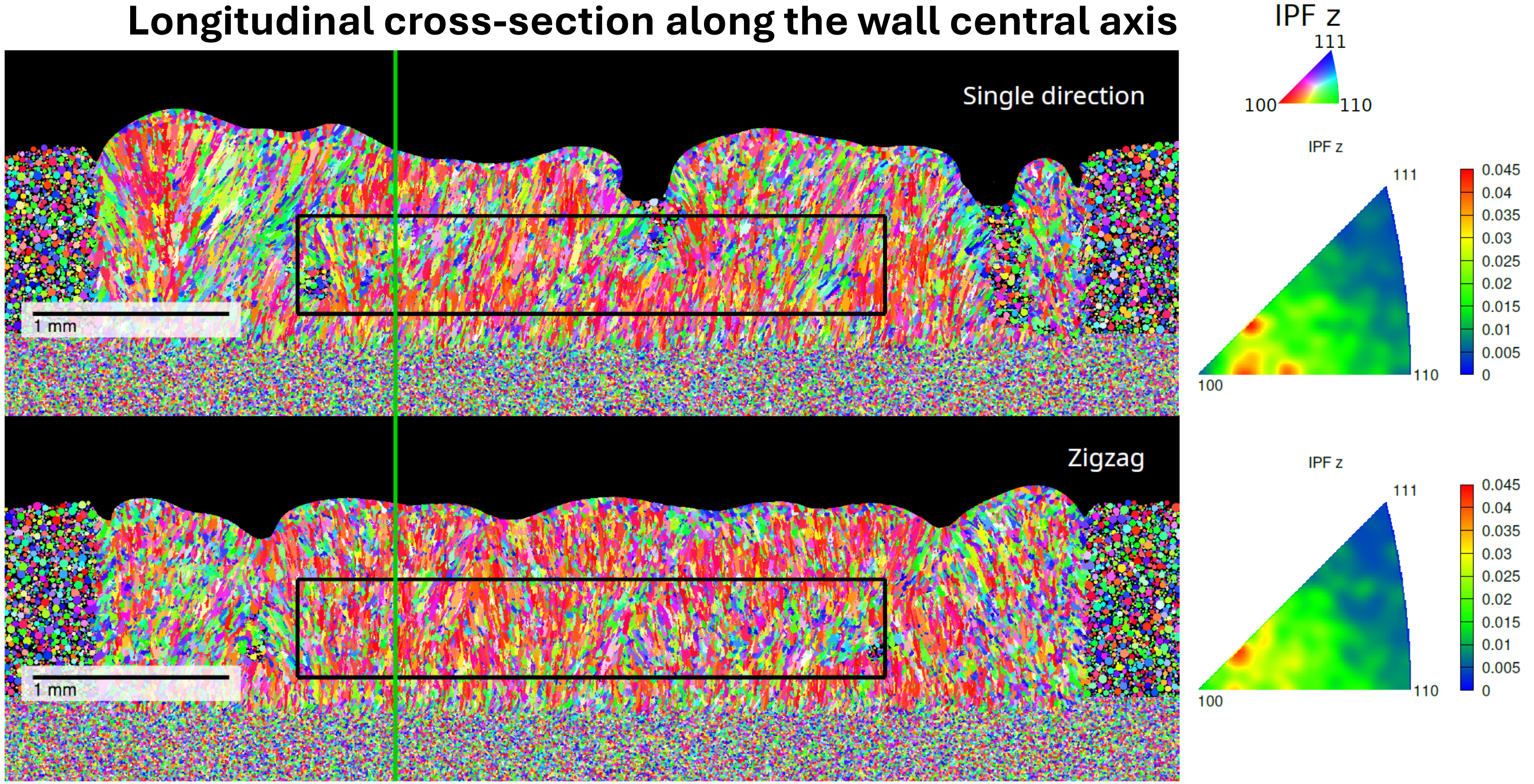
Impact of the scanning strategy on morphology



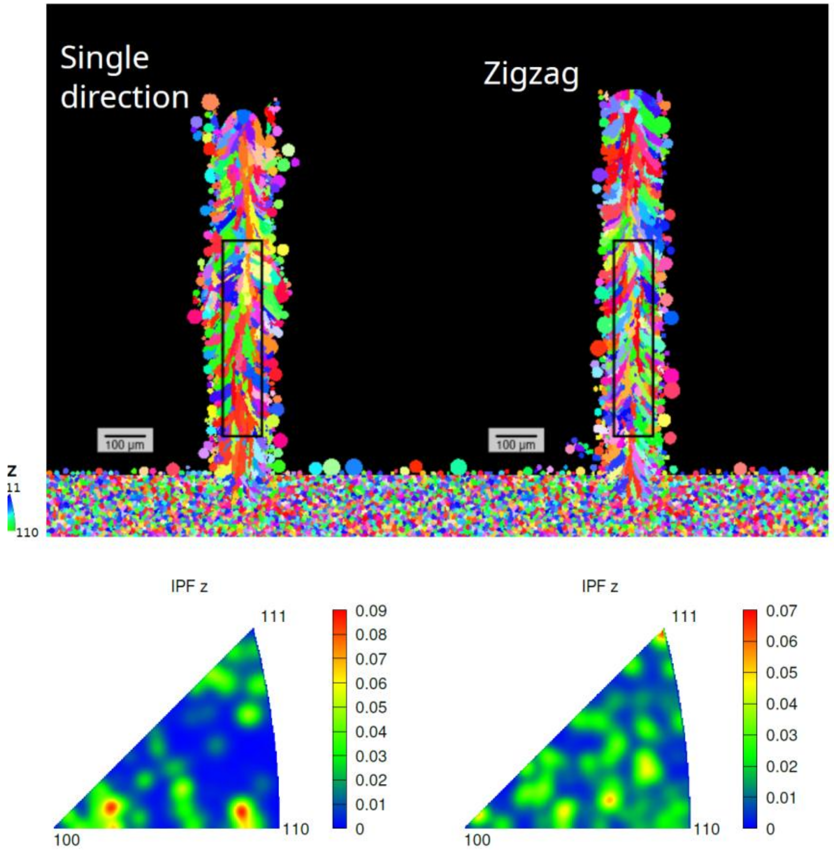
- Scanning strategy drastically affects the morphology: zigzag strategy is preferable

Impact of the scanning strategy on microstructure

Longitudinal cross-section along the wall central axis



Transverse cross-section along green line



- On the other hand, melt pool fragmentation during the thin wall build results in the microstructure, which is relatively unaffected by the scanning strategy

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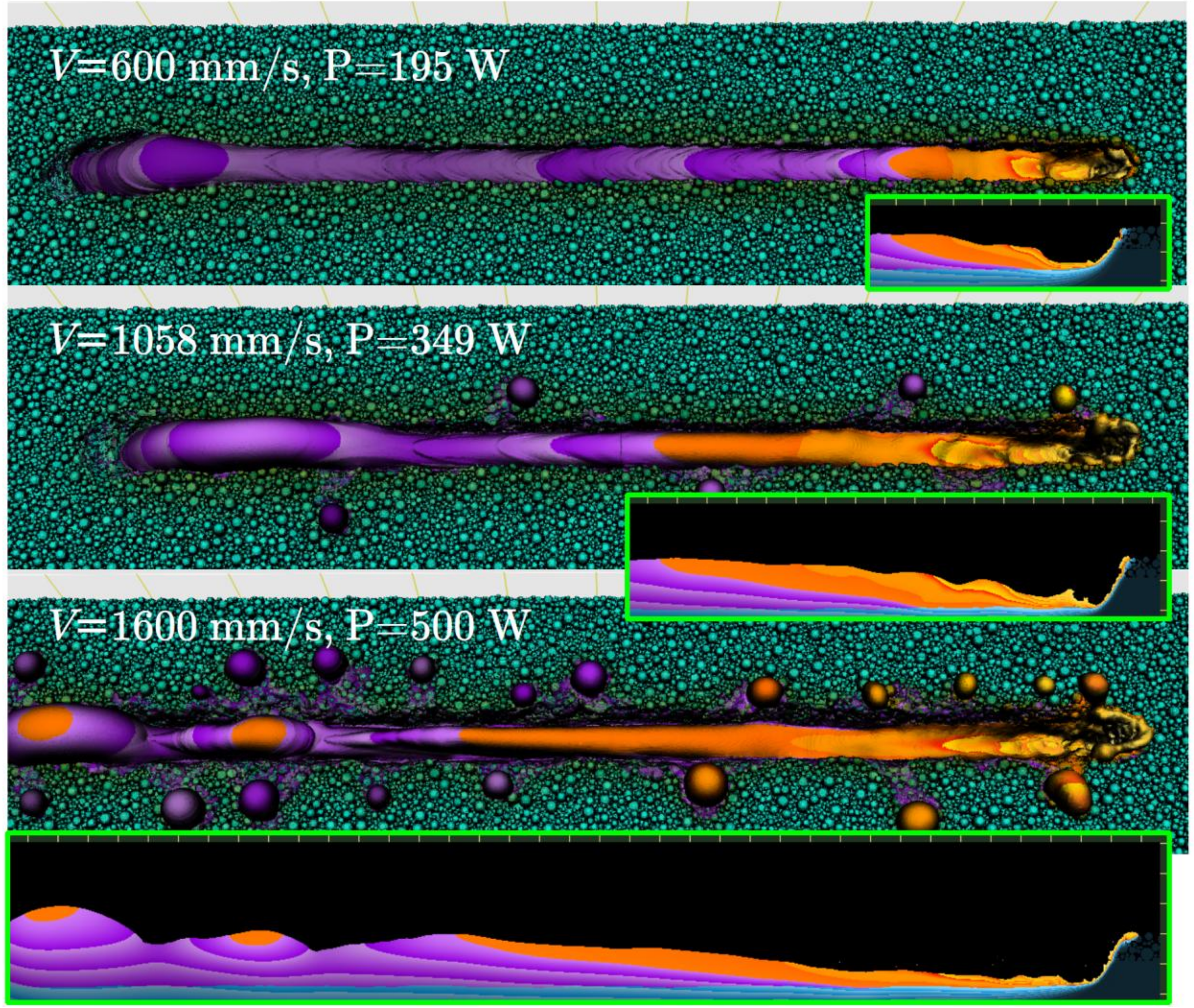
Impact of the printing regimes

- Track printing regimes are based on the AFRL benchmark* for Inconel 625
- The laser power and scan speed are optimized to keep the melt depth approximately the same (~100 um), but allowing melt pool length manipulation
- Longer melt pool tends to fragment, leading to a less uniform morphology

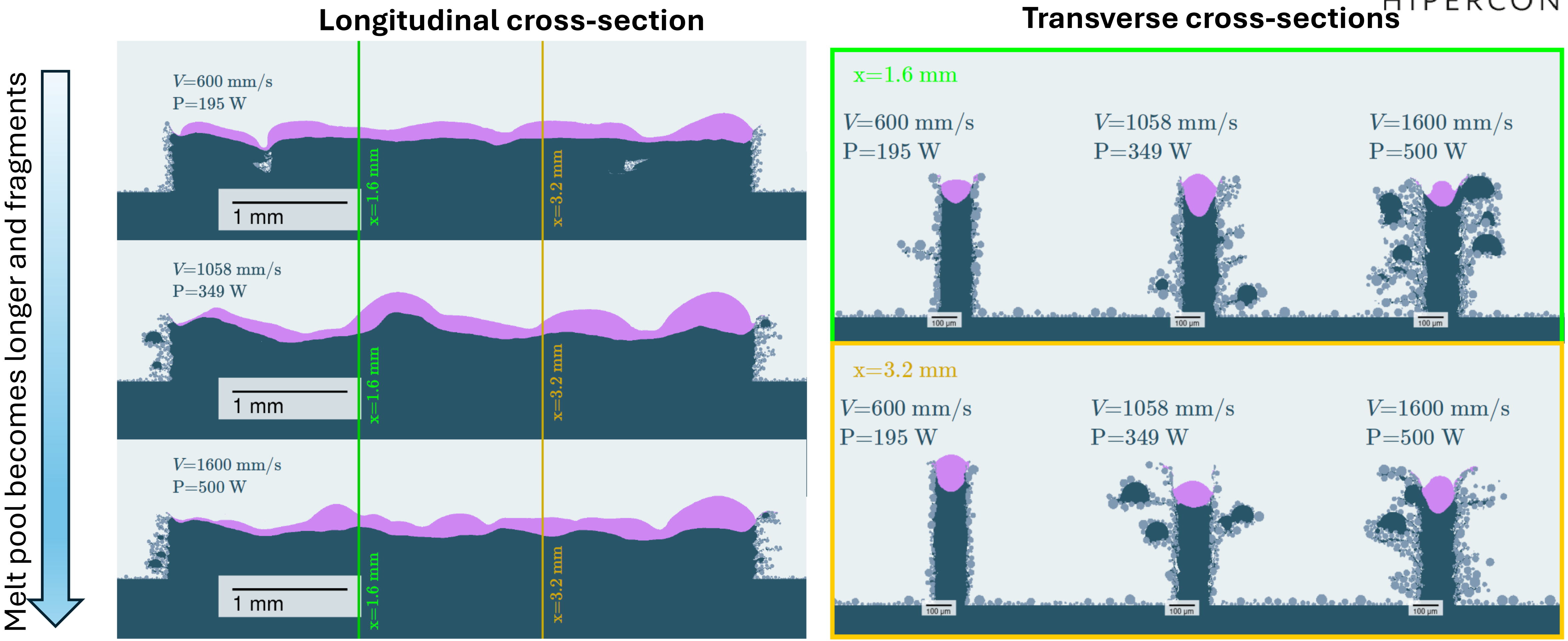
Melt pool parameters

	600 mm/s, 195 W	1058 mm/s, 349 W	1600 mm/s, 500 W
Melt pool depth, μm	71	105	86
Melt pool width, μm	116	120	118
Melt pool length, mm	0.84	1.7	2.0



[*] Air Force Research Laboratory (AFRL) Additive Manufacturing (AM) Modeling Challenge Series, 2020. URL: https://materials-datafacility.github.io/MID3AS-AM-Challenge/.

Impact of the printing regime on morphology



- Longer melt pool leads to more droplets ejected due to instability
- Lateral sides of the wall become more rough

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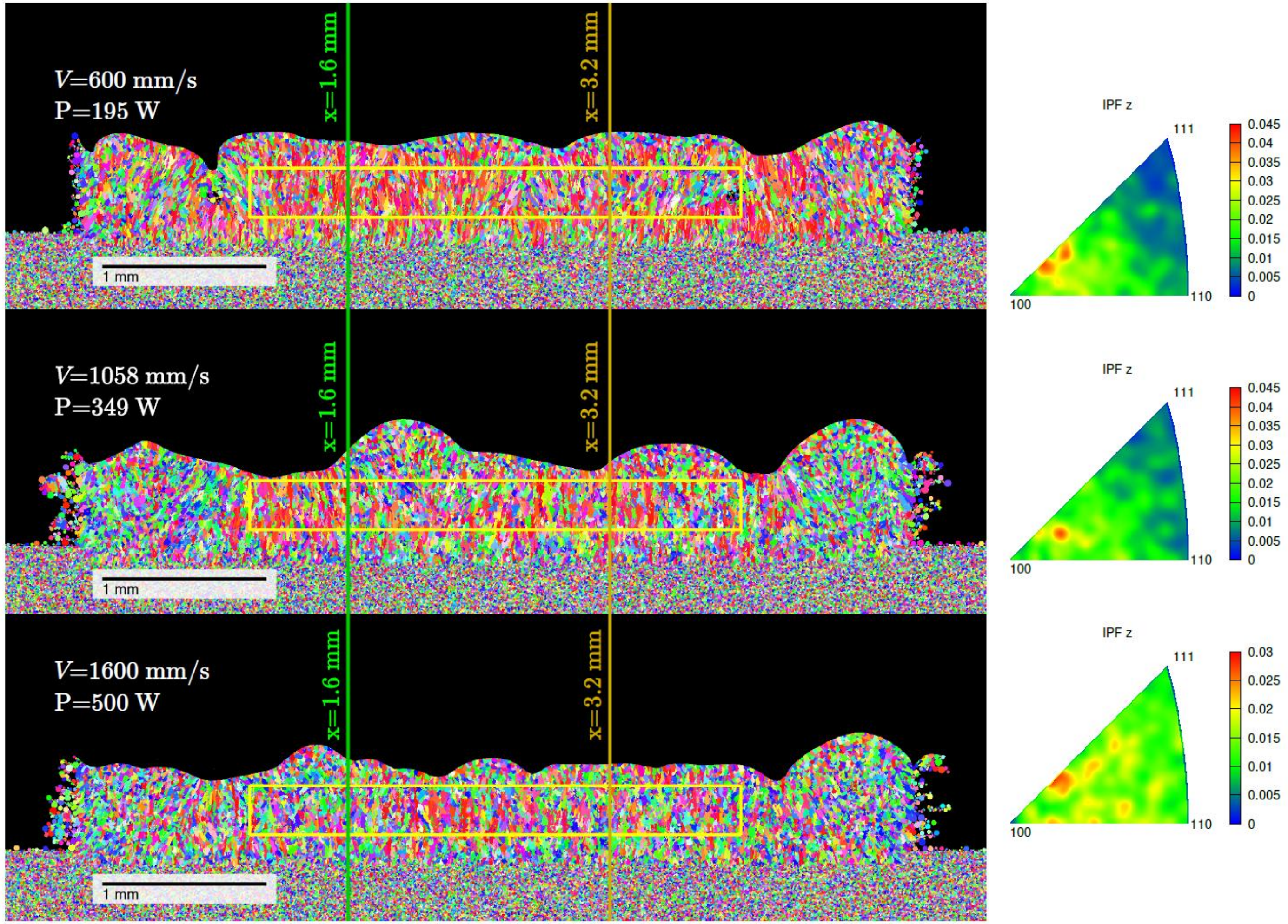
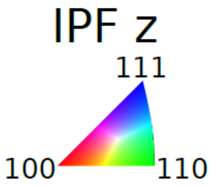
Impact of the printing regime on microstructure

Longitudinal cross-section

Melt pool becomes longer and fragments



Less 100 grains



- Significantly less long grains with <100> crystallographic orientation at higher speeds

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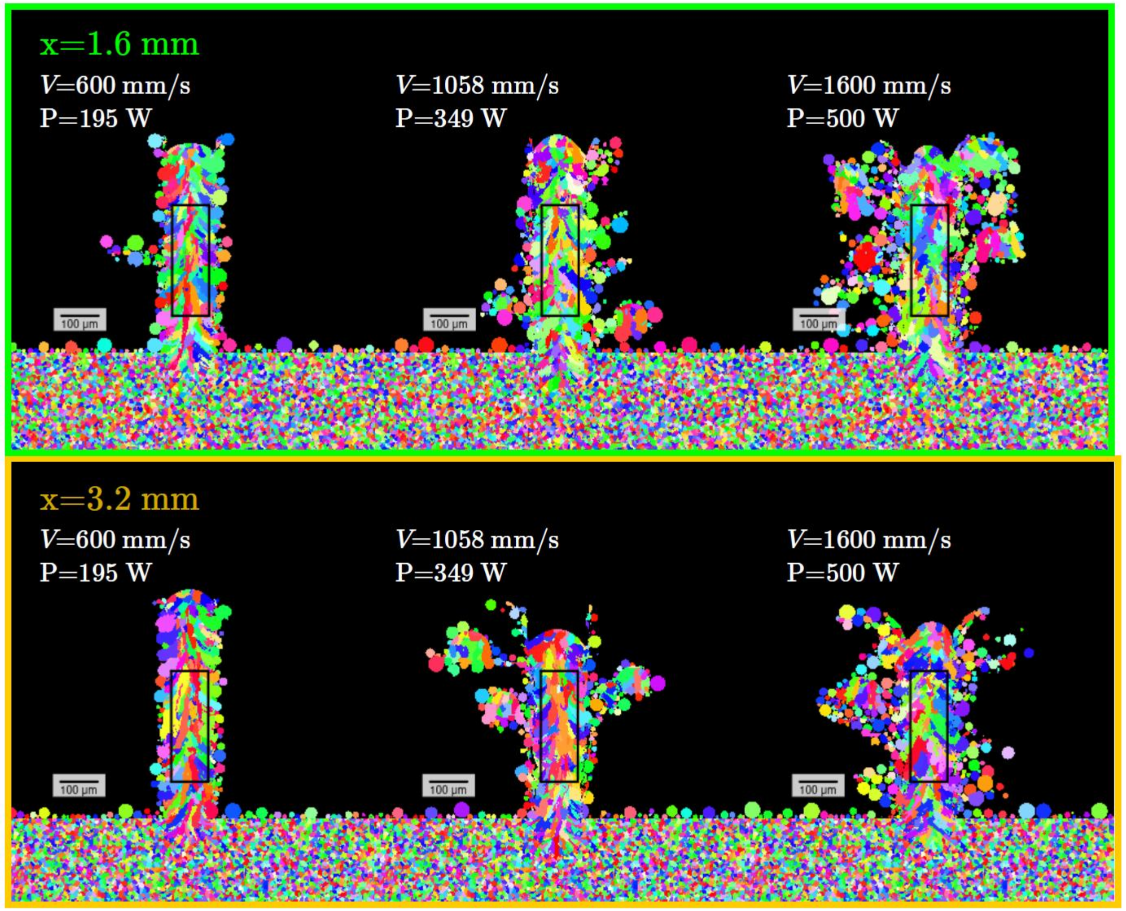
Impact of the printing regime on microstructure

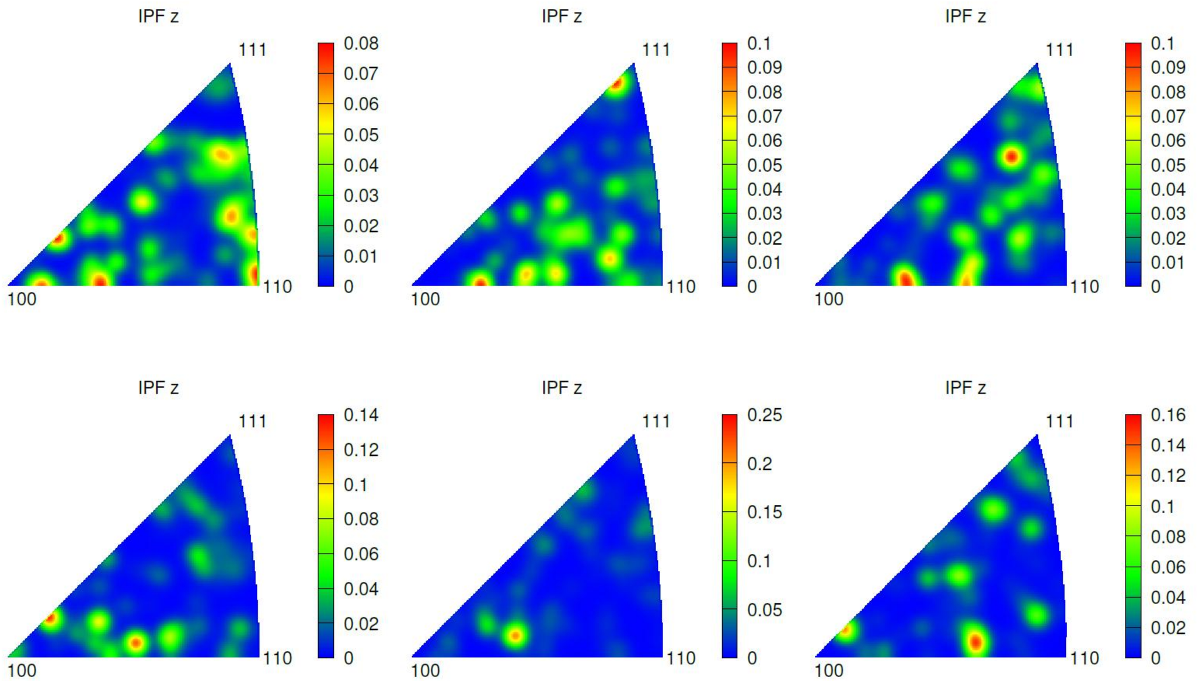
Transverse cross-sections

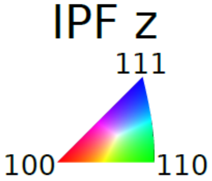


V = 600 mm/s
P = 195 W

V = 1058 mm/s
P = 349 W

V = 1600 mm/s
P = 500 W

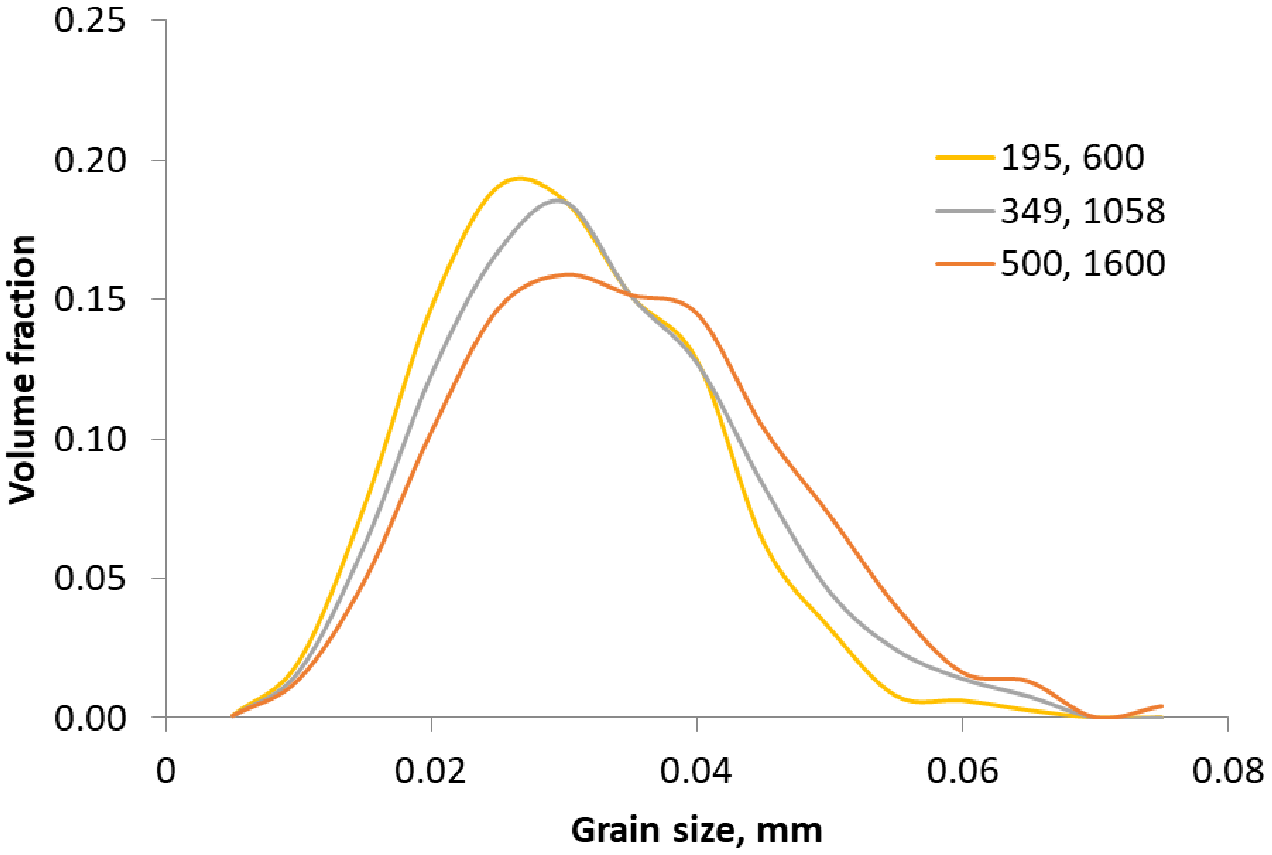




- Powder particles on the wall sides initiate new grains
- The grains near the central axis of the wall are few due to the low thickness of the wall
- Thus, no apparent effect is seen on the grain crystallographic orientation

Grain size distribution

- Grains in the 3x0.1x0.3 mm^3 volume centered at the wall axis are analyzed
- There is a slight increase in the volume fraction of the bigger grains at the higher scan speeds



Conclusions and outlook

- Wall morphology can be manipulated separately from the microstructure for the thin walls.
- Microstructure can be manipulated by adjusting the printing regime (laser power, scan speed etc.), but the morphology is also affected.
- Melt pool length affects its stability: increasing the length leads to disordered grain growth due to the melt pool instability.
- Higher scan speeds lead to the droplets ejected on the sides of the wall, which can strongly impact the microstructure.
- The grain structure can be used as an input in the mechanical models. Thus, this study can be used as a starting point for mechanical evaluation of thin walls and similar structures.

Thank you for your attention!
Grazie!

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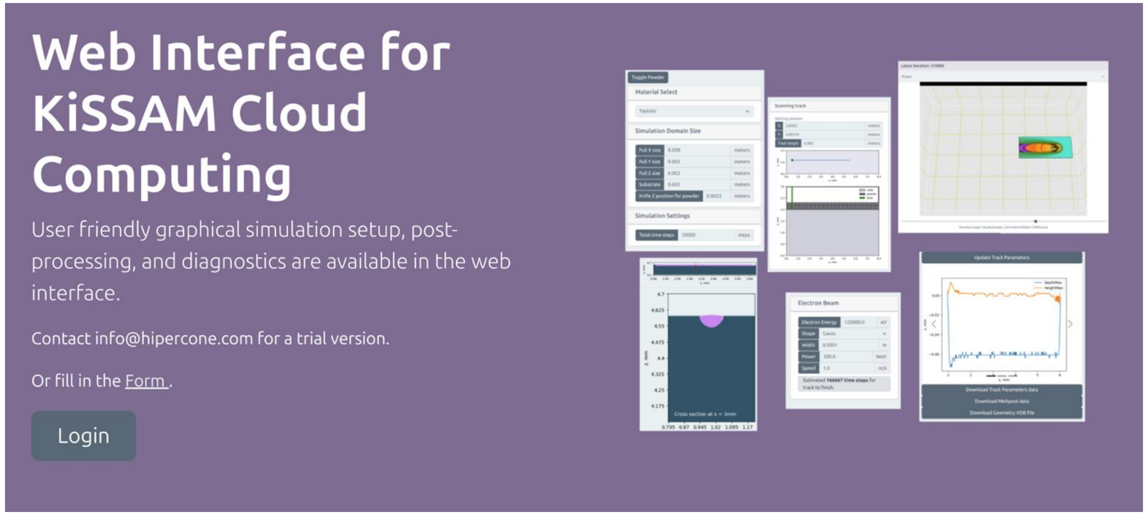

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