

KiSSAM Simulation Software for Additive Manufacturing

High-Fidelity Mesoscale Simulation of Melt-Pool Dynamics in Powder Bed Fusion using the KiSSAM Simulation Software for Additive Manufacturing

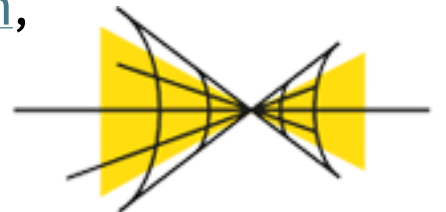
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B. Korneev, A. Zakirov, B. Potapkin

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<https://hipercone.com>

<https://kissam.cloud>

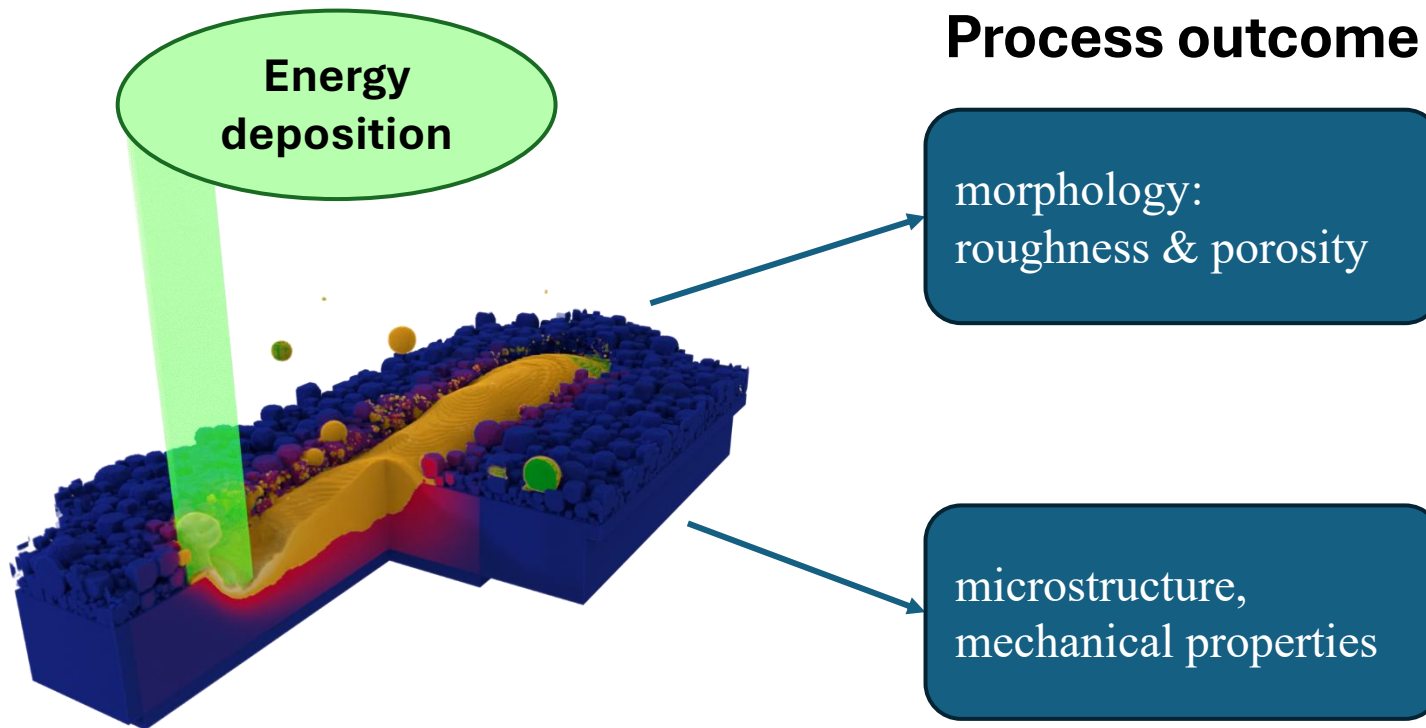


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Contents

- Motivation
- KiSSAM multiphysics model
- Materials and validation
- Selected applications

Motivation



Melt pool level simulation of the process:

- melting
- hydrodynamics
- solidification
- temperature history

Process outcome

morphology:
roughness & porosity

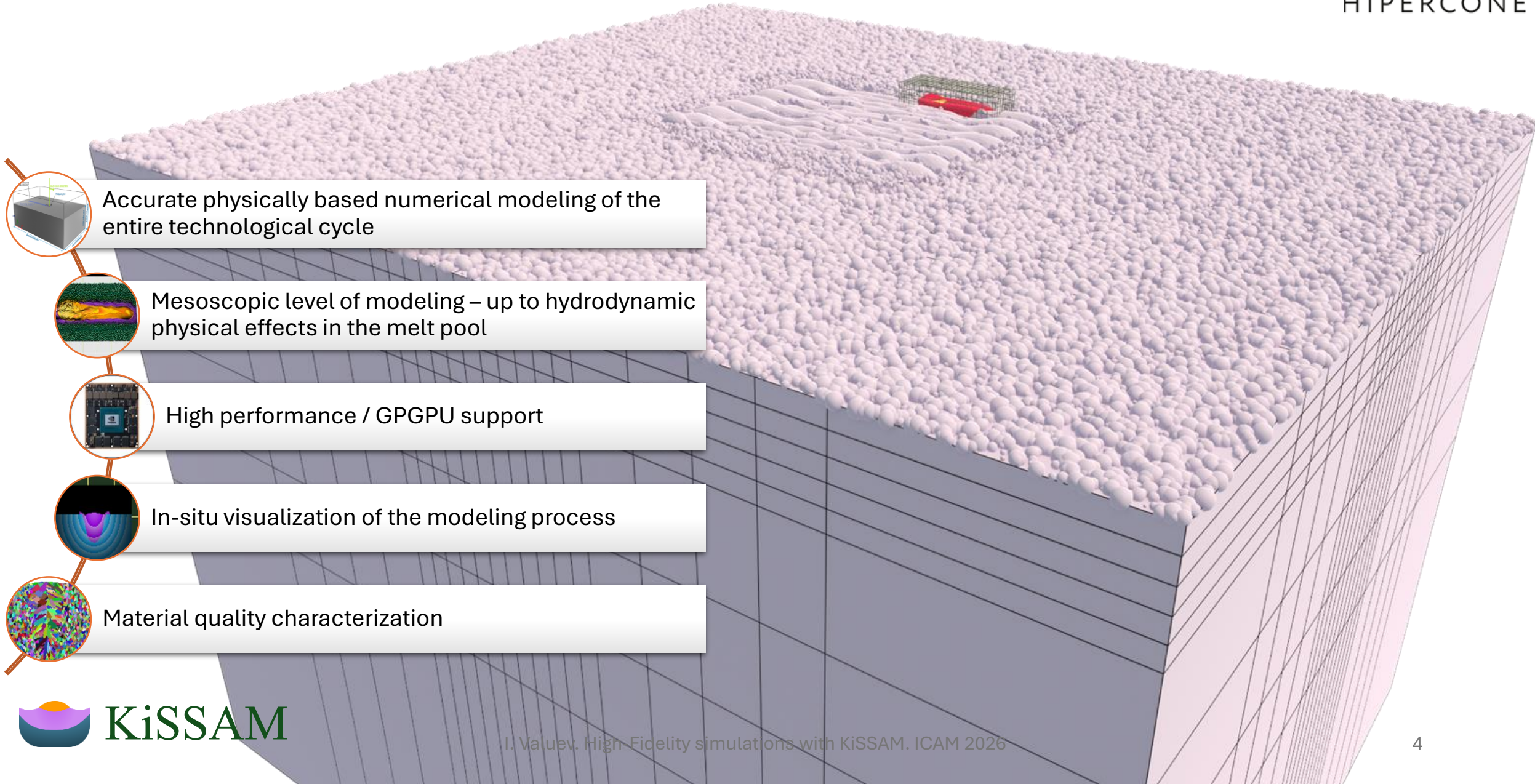
microstructure,
mechanical properties

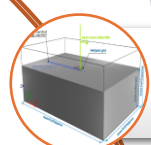
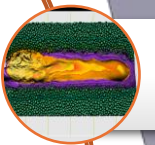
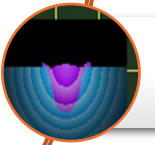
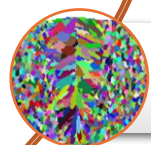
Experiment?

- Process parameter space is multidimensional
- Process parameters adjustment is time-consuming...
- Some things are hard to measure
- High costs...

Why don't we go for...
simulation?

Replacing experiment with simulation



-  Accurate physically based numerical modeling of the entire technological cycle
-  Mesoscopic level of modeling – up to hydrodynamic physical effects in the melt pool
-  High performance / GPGPU support
-  In-situ visualization of the modeling process
-  Material quality characterization

High-fidelity simulation based on the multiphysics models capturing all the essential phenomena



Hydrodynamic solver based on thermal lattice Boltzmann method with volume of fluid free surface tracking

- Phase transition solid / liquid
- Surface tension and wetting
- Marangoni convection
- Drag force in mushy zone
- Recoil pressure, mass and energy losses due to the strong evaporation from the liquid surface
- Radiation cooling
- Convection cooling
- Evaporated metal and chamber gas flow tracking
- Multicomponent evaporation

Heat conduction in the bulk far from the melt-pool

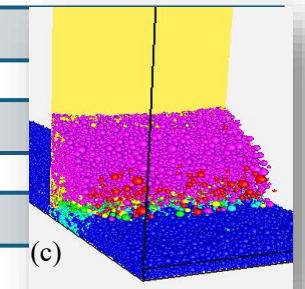
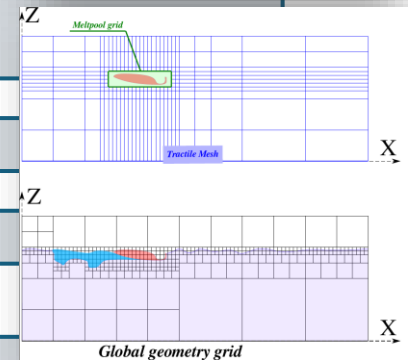
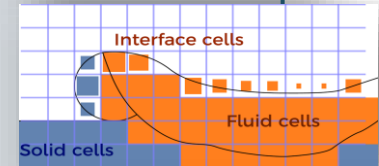
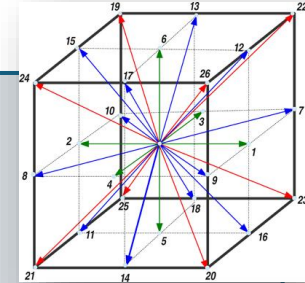
Ray tracing with multiple reflections (for laser beam)

MC simulation of electron trajectories with elastic and inelastic scattering in metal (for electron beam)

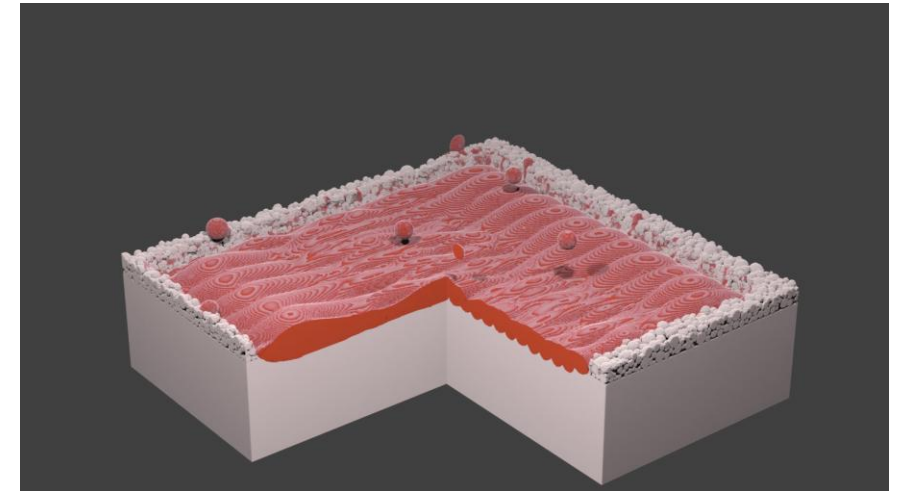
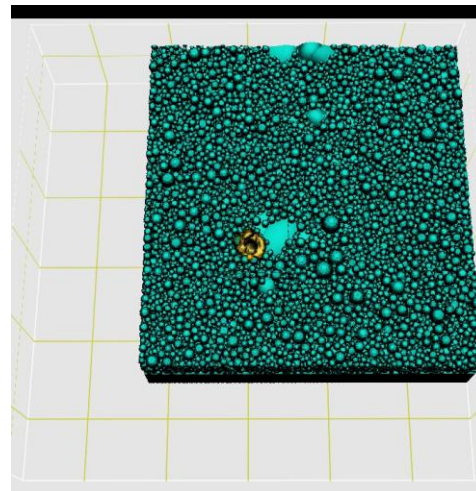
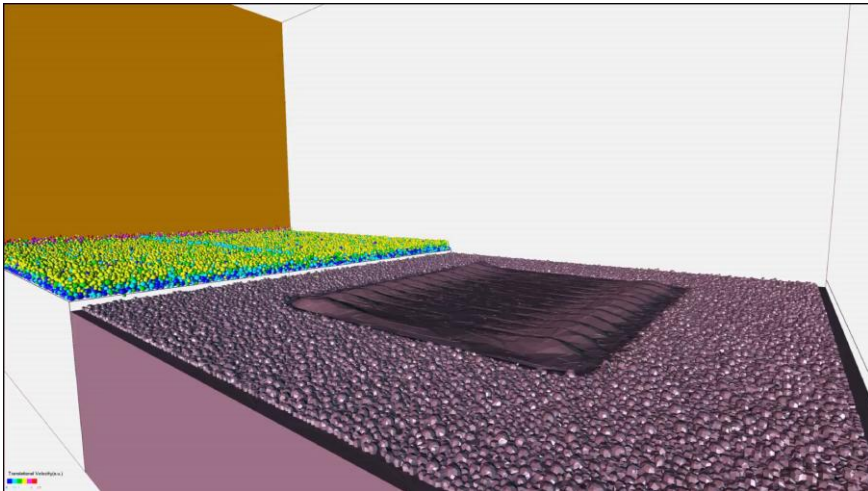
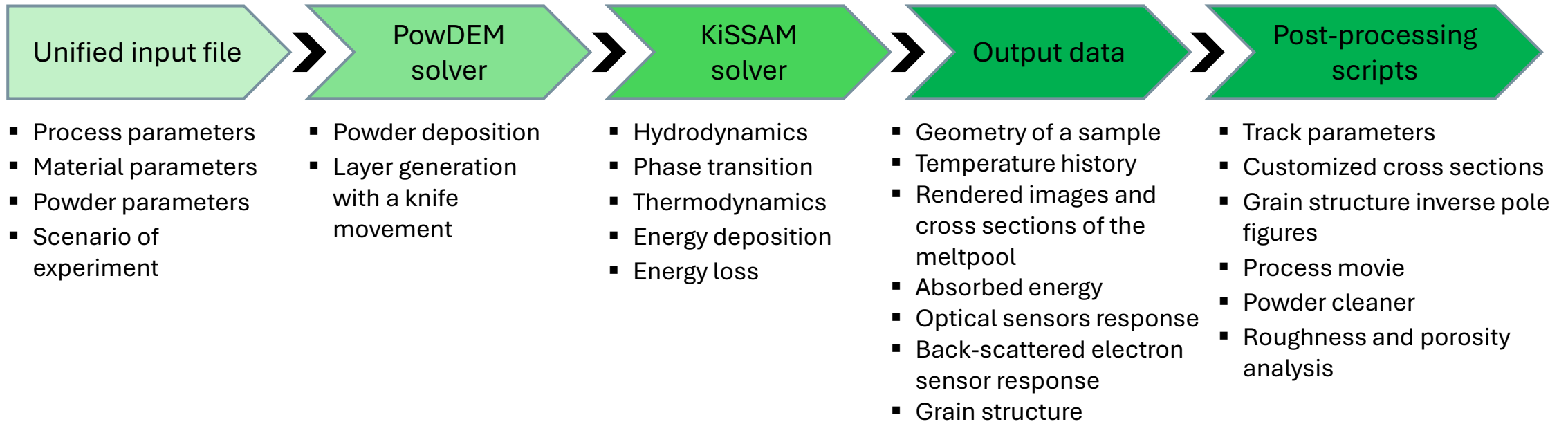
Sensors and detectors photodiode response simulation

Powder bed packing Discrete Element Method (DEM) solver with knife movement

Grain microstructure simulation at solidification same as CAFE model

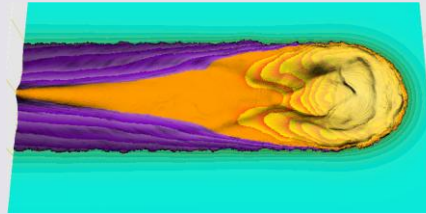


KiSSAM workflow

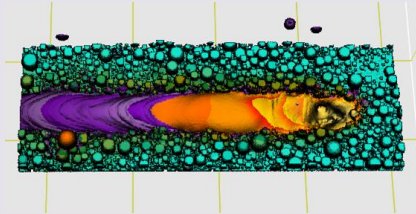


Simulation performance

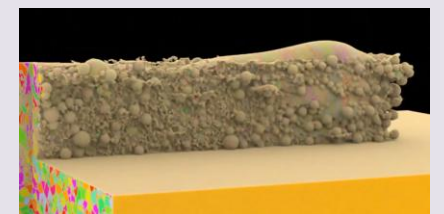
- KiSSAM is a high performance software implemented on CUDA C++ for NVIDIA GPUs.
- Typical performance is faster than **0.5 hr per 1 ms** of scanning time.
- Performance scales with increasing performance of continually modernized GPUs



Single tracks on a plate
~ 0.5-1 h



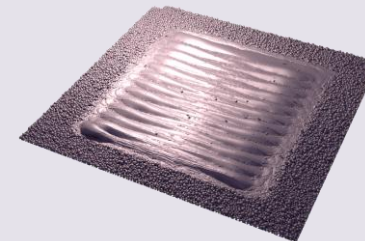
Single tracks on powder
~ 0.5-1 h



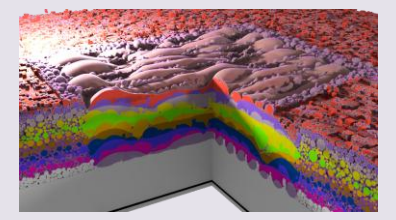
Thin walls
~ 1-3 days



Contours
~ 2-4 h



Single layers
~ 6-12 h



Bulk samples
~ 1-2 weeks

Simulation times are given for a single GeForce RTX 3090 24 GB GPGPU

Physics-based material parameters

✓ Library of verified materials

- Inconel 625
- Ti6Al4V
- Al alloy AA5182
- CoCr
- Stainless steel SS316L
- AlSi10Mg
- NiTi

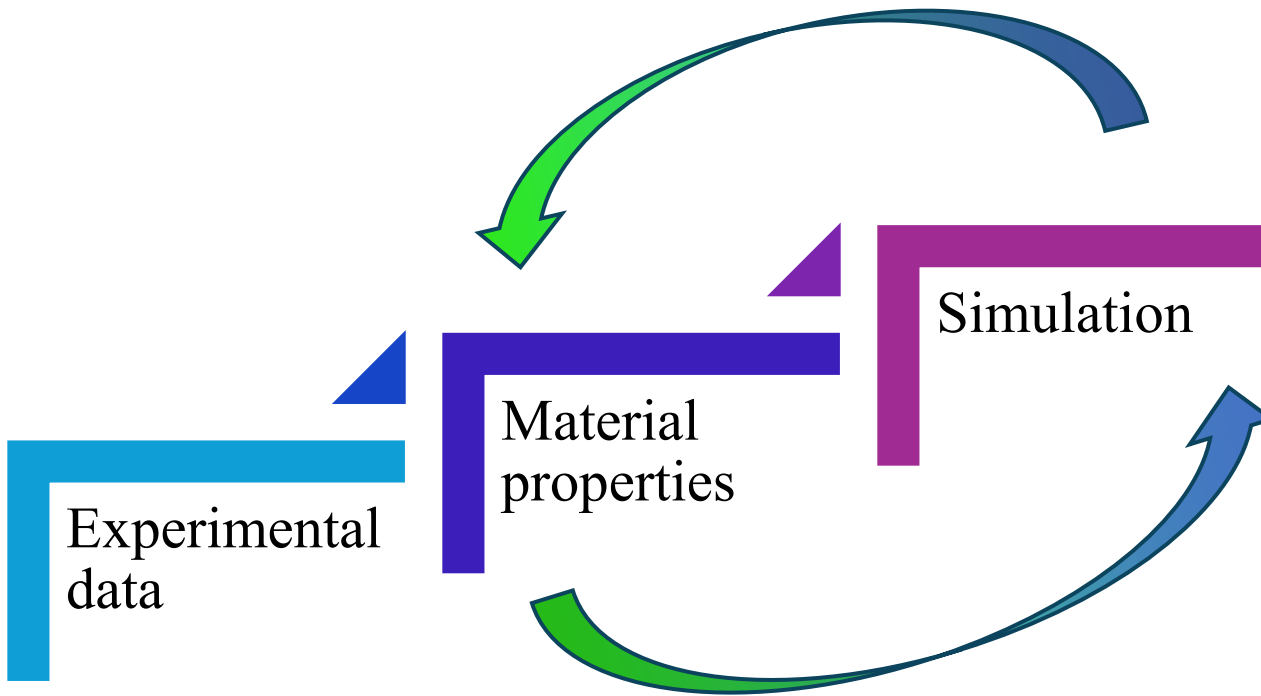
✓ Temperature dependent properties

- Thermal diffusivity
- Heat capacity
- Material absorbance
- Surface tension

Snapshot from input.json

```
101  ✓  "MaterialsLibrary": {
102  ✓      "Ti6Al4Vmy": {
103          "name"           : "Ti6Al4V",
104          "density"        : 3920.0,
105          "viscosity"      : 2.6e-6,
106          "tdiffusivitySolid" : [ [298 ,2.788e-6], [1873,9.024e-6] ],
107          "tdiffusivityLiquid" : [ [1923,1.040e-5], [2173,1.116e-5] ],
108          "transientConduction" : "Phase",
109          "surfTension"     : [ [1877,1.5], [2877,1.05] ],
110          "mushyPDAS"       : -1.0,
111          "Tsolidus"        : 1877.0,
112          "Tliquidus"       : 1923.0,
113          "HeatCapacityIntervalsT" : [ 0 , 1173 , 1373 , 1923 , 2173 ],
114          "HeatCapacityVolumeVals" : [ 2.84e6, 4.04e6, 3.03e6, 3.16e6, 3.16e6 ],
115          "LatentHeat"      : 1.143e9,
116          "RayAbsorptionSolid" : [ [300 , 0.3 ], [1000, 0.3] ],
117          "RayAbsorptionLiquid" : [ [1923, 0.3 ], [3000, 0.3] ],
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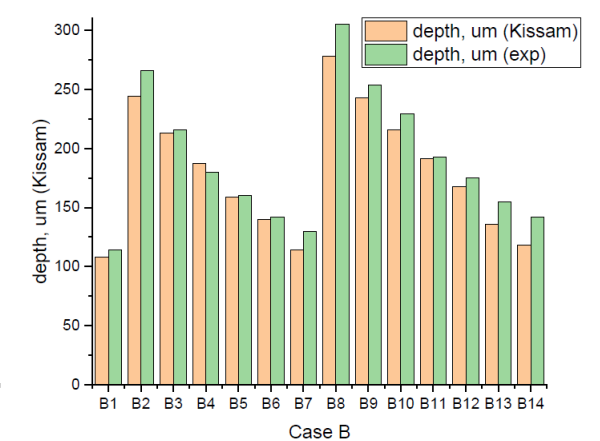
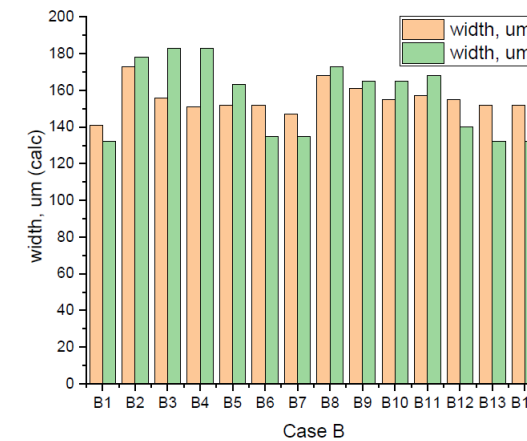
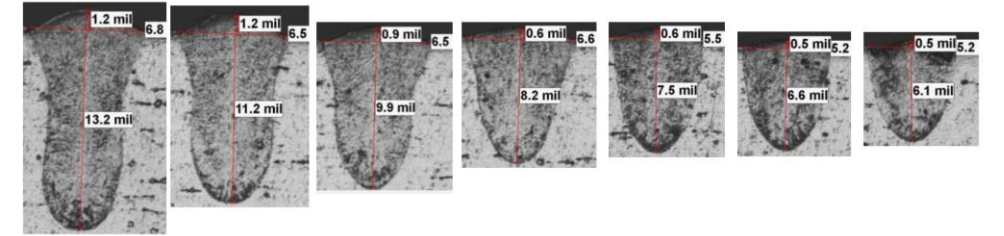
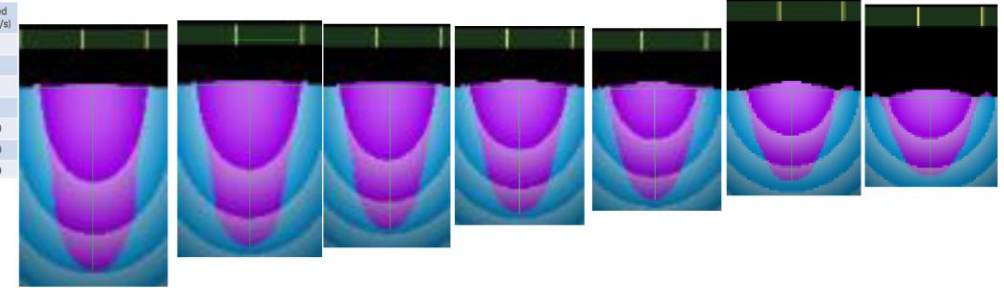
Material properties validation workflow



In collaboration with



Track #	Power (W)	Speed (mm/s)
B8	400	600
B9	400	700
B10	400	800
B11	400	900
B12	400	1000
B13	400	1100
B14	400	1200



Selected KiSSAM features and applications

- Process map generation
- Process optimization
- Benchmark for simplified models
- Full part high-fidelity mesoscale simulations
- Grain structure simulation
- Process monitoring
- Surface quality and porosity simulation
- Complex scanning strategies
- Multi-beam PBF simulation



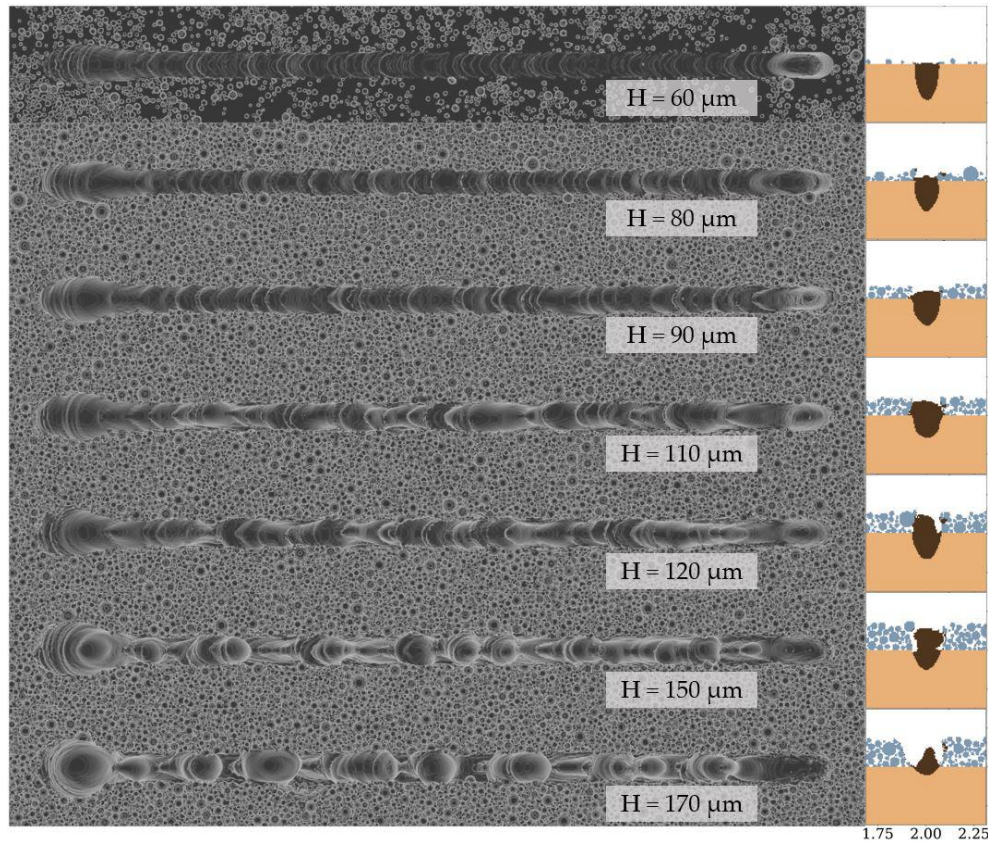
Process maps: Identifying scanning beam parameters for producing smooth tracks

Beam Width is 50.0 μm

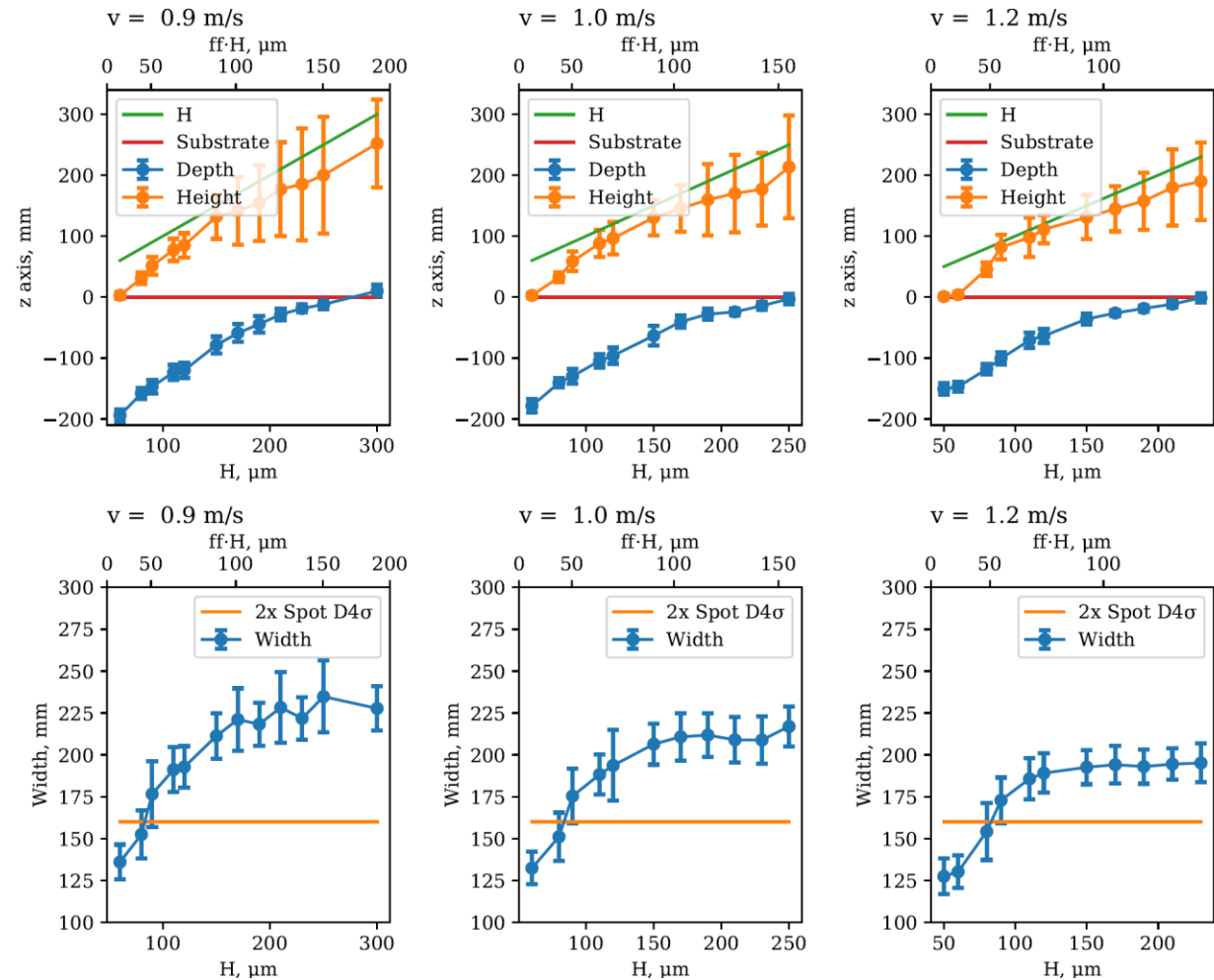
	Speed = 0.4 mm/s	Speed = 0.7 mm/s	Speed = 1.0 mm/s
Power = 400.0 W			
Power = 250.0 W			
Power = 300.0 W			
Power = 350.0 W			

D. Nakapkin et.al. Finding Optimal Parameter Ranges for Laser Powder Bed Fusion with Predictive Modeling at Mesoscale, Sim-AM 2019 (2019)

Process optimization: Influence of an increased layer thickness on the morphology of single tracks in AlSi10Mg Alloy



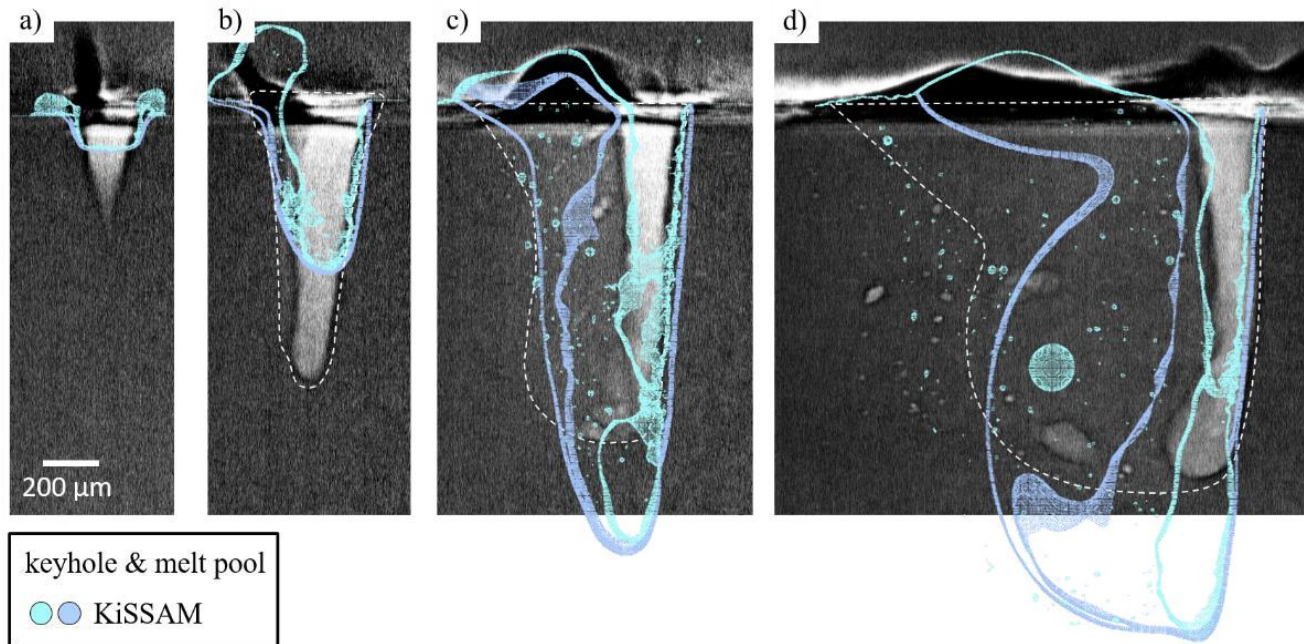
$P = 350W$, $v = 0.9 \text{ m/s}$



Upper limits to the powder layer thickness at 160-190 μm have been identified

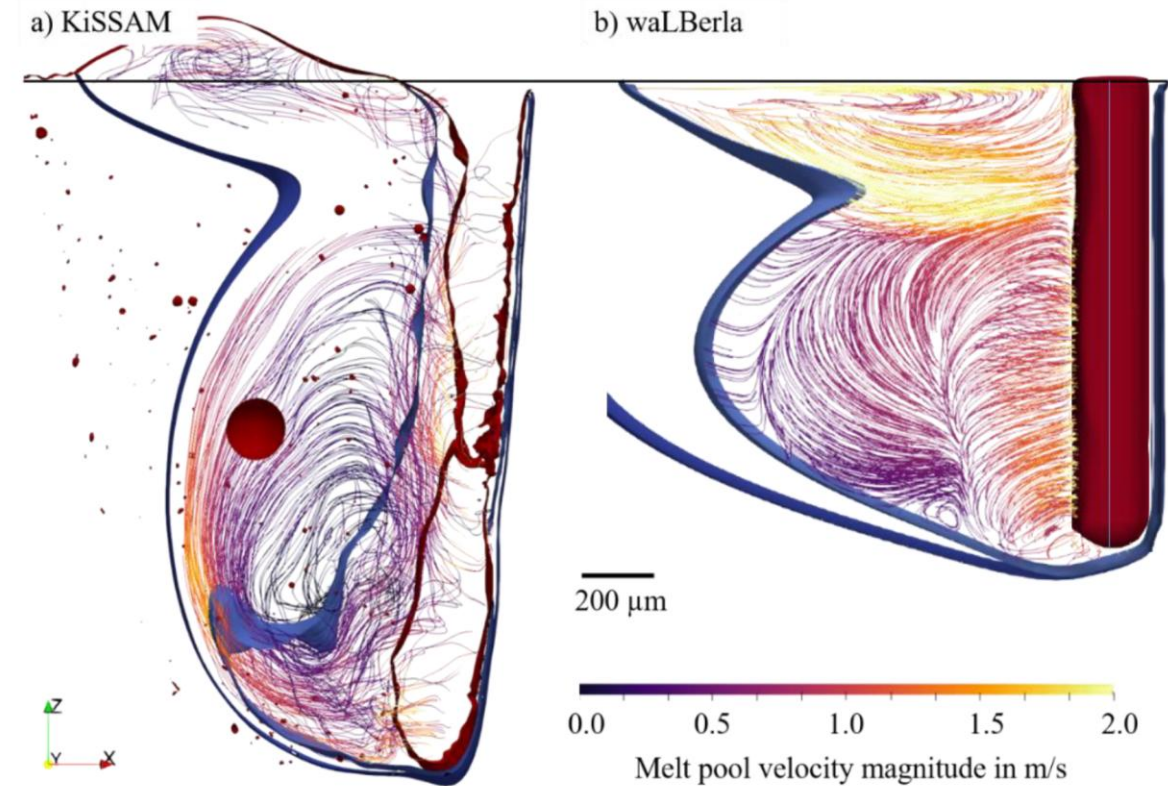
High-fidelity simulation as a benchmark for simplified models

KiSSAM simulation of a dynamic keyhole development overlaid over the X-ray synchrotron images of keyholing in stainless steel 1.4301.

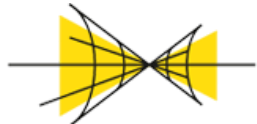


Melt pool characteristics and flow velocities obtained with KiSSAM are used to benchmark and tune the simplified model

Comparison of **dynamical keyhole** (KiSSAM) and a **fixed keyhole** simulations (waLBerla) for assessing the flow in the meltpool

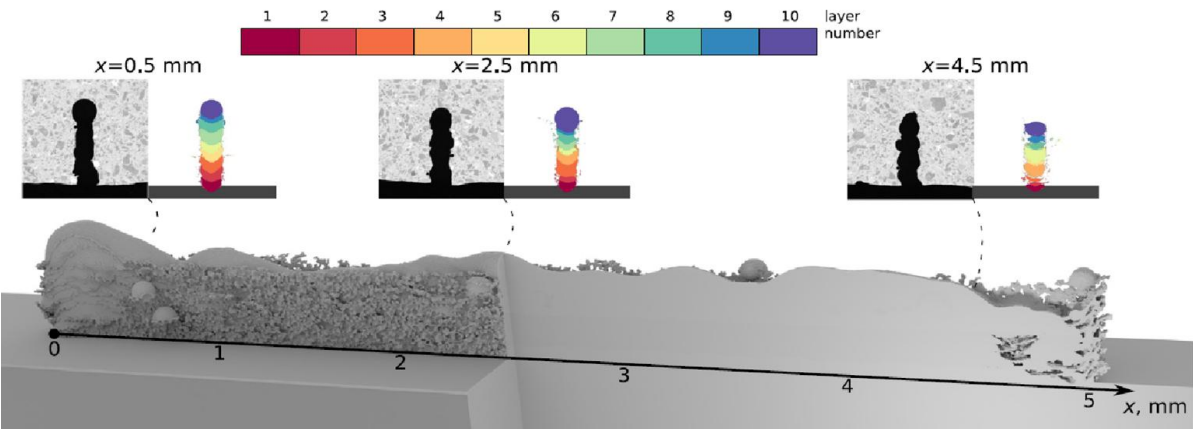
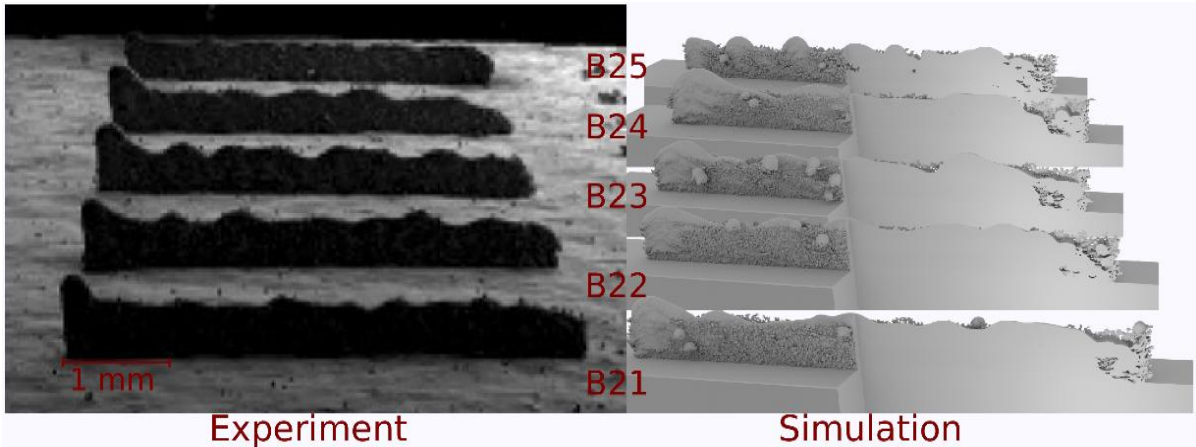


Simulating whole parts with mesoscale precision

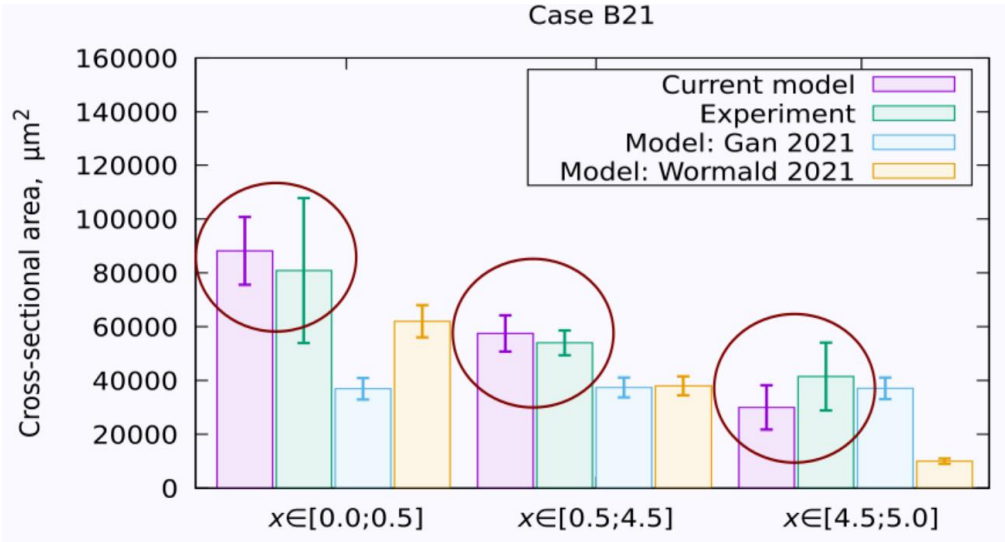
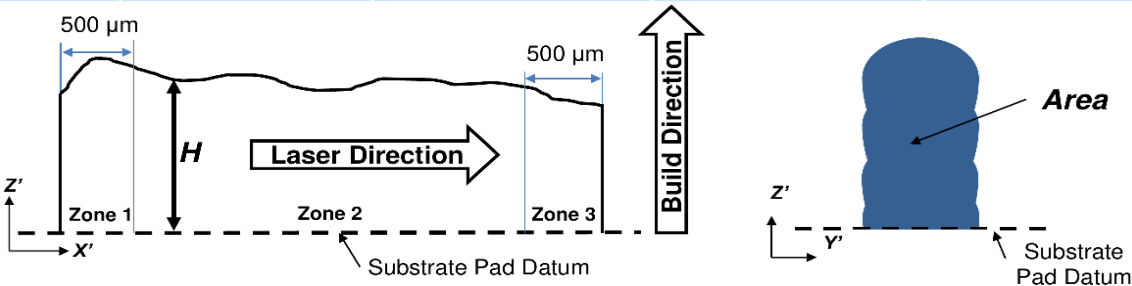


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The US Air Force Research Laboratory (AFRL) Additive Manufacturing (AM) Modeling Challenge Series
Schwalbach, E. J. et al. Integrating Materials and Manufacturing Innovation 10.3 (2021): 319-337



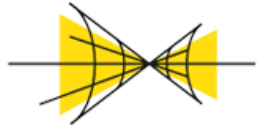
Source	Beam width, μm	Velocity, m/s	Power, W	Alloy
Laser	100	0.99 – 1.529	241 – 300	Inconel 625



Careful tuning of poorly known wetting properties allows accurate simulation of thin wall morphology

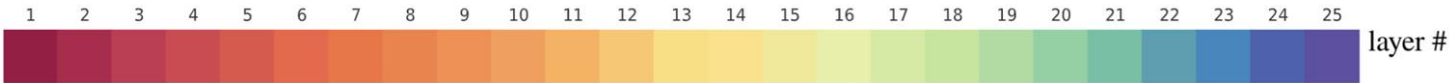
B.Korneev et al. A numerical study of powder wetting influence on the morphology of laser powder bed fusion manufactured thin walls Additive Manufacturing, V. 74, 103705 (2023)
I. Valuev. High-Fidelity simulations with KiSSAM. ICAM 2026

KiSSAM as a digital twin: Optimizing part morphology with spot melting scanning strategy

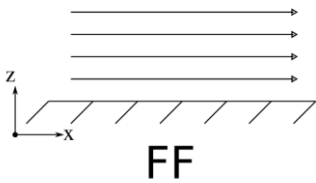


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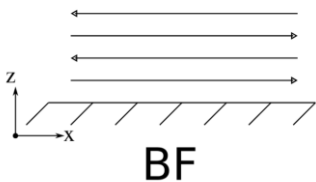
Final wall morphology (25 layers)



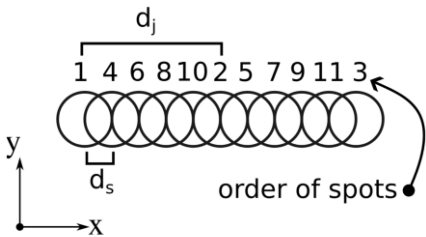
Single direction
(forward-
forward) scan



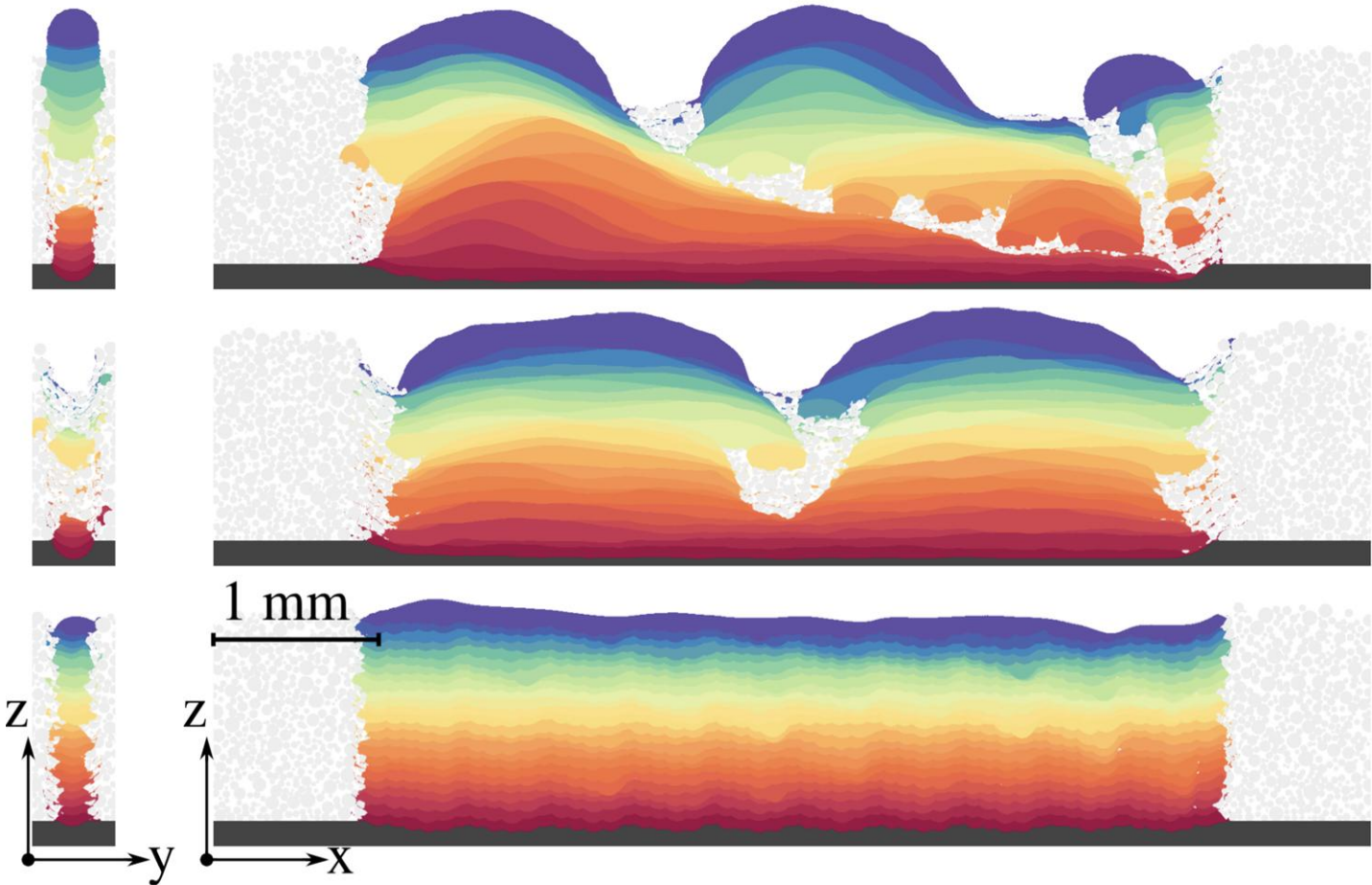
Alternating
directions (back
and forth) scan



Spot melting



Top: FF build, middle: BF build, bottom: SM build. Right: cross-section, left: longitudinal section through the middle of the wall (25 layers) is shown. Color represents layer number. Substrate is dark grey, powder is light grey.



KiSSAM as a digital twin: Optimizing part morphology with spot melting scanning strategy



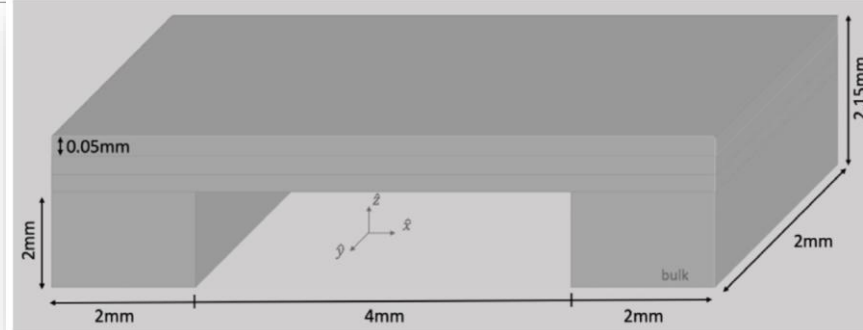
PBF



B. Korneev et.al. Spot melting improves the morphology of ultrathin wall builds: a numerical study. Progress in Additive Manufacturing, 10(12), 10477-10485 (2025).

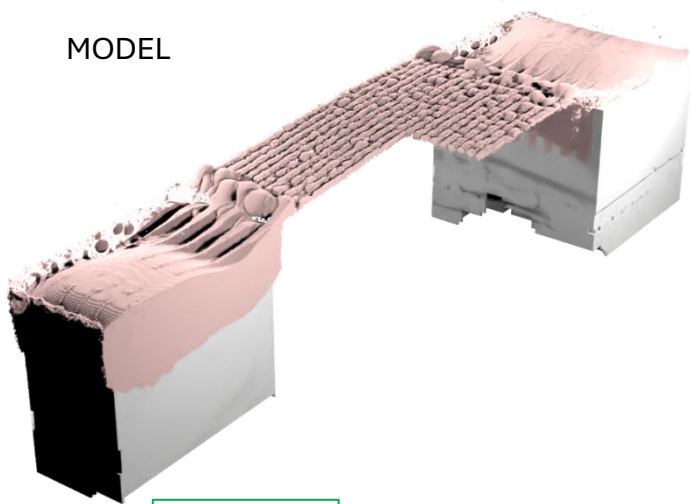
Optimization of printing parameters for the “bridge” overhang structure: laser power modulation

Case	Layer #	Power fraction, k	Overhang power [W]	Column/Nominal power [W]
A	1, 2, 3	0.10, 0.10, 0.10	38, 38, 38	382
B	1, 2, 3	0.175, 0.175, 0.175	67, 67, 67	382
C	1, 2, 3	0.25, 0.25, 0.25	96, 96, 96	382
D	1, 2, 3	0.65, 0.65, 0.65	248, 248, 248	382
E	1, 2, 3	1.00, 1.00, 1.00	382, 382, 382	382
F	1, 2, 3	0.25, 0.50, 0.75	96, 191, 287	382

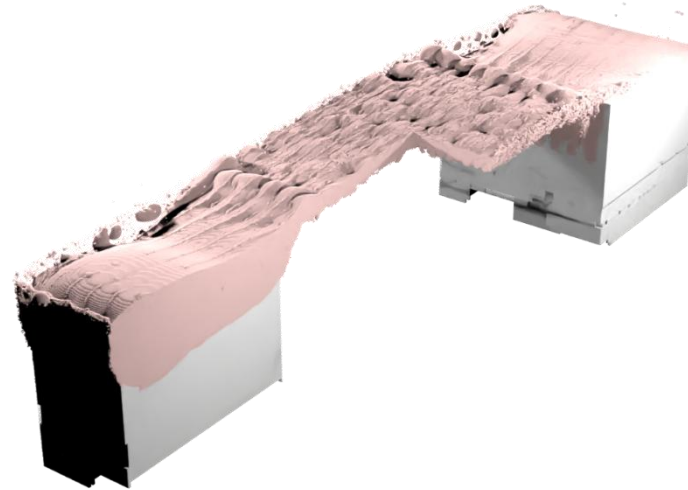


A. Ashby et. al. *Additive Manufacturing*, V. 53, May 2022, 102669

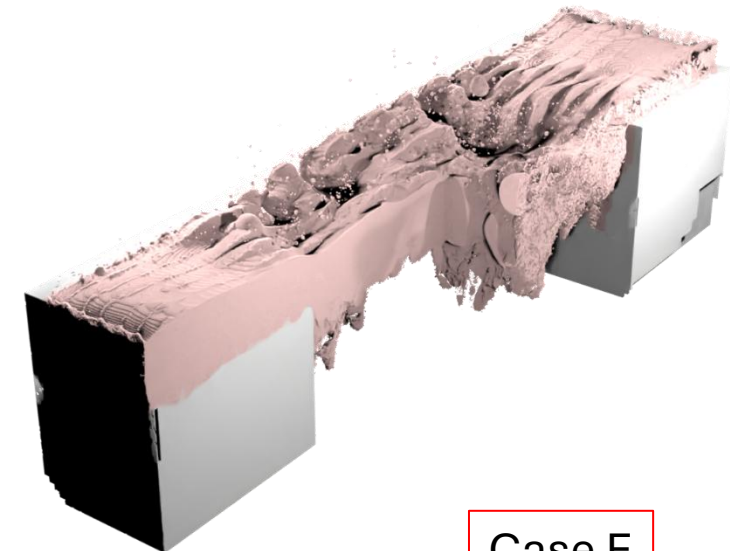
MODEL



Case A



Case F



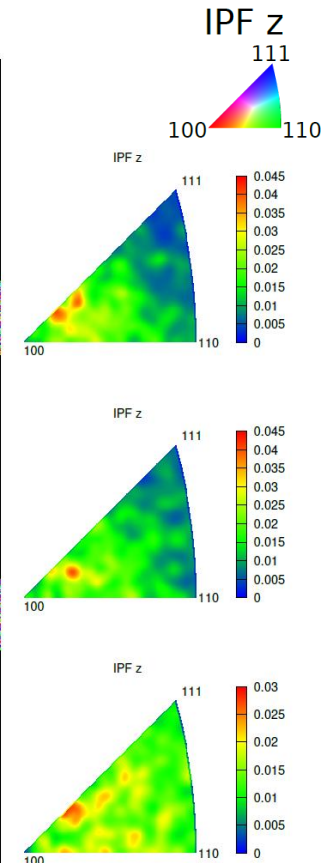
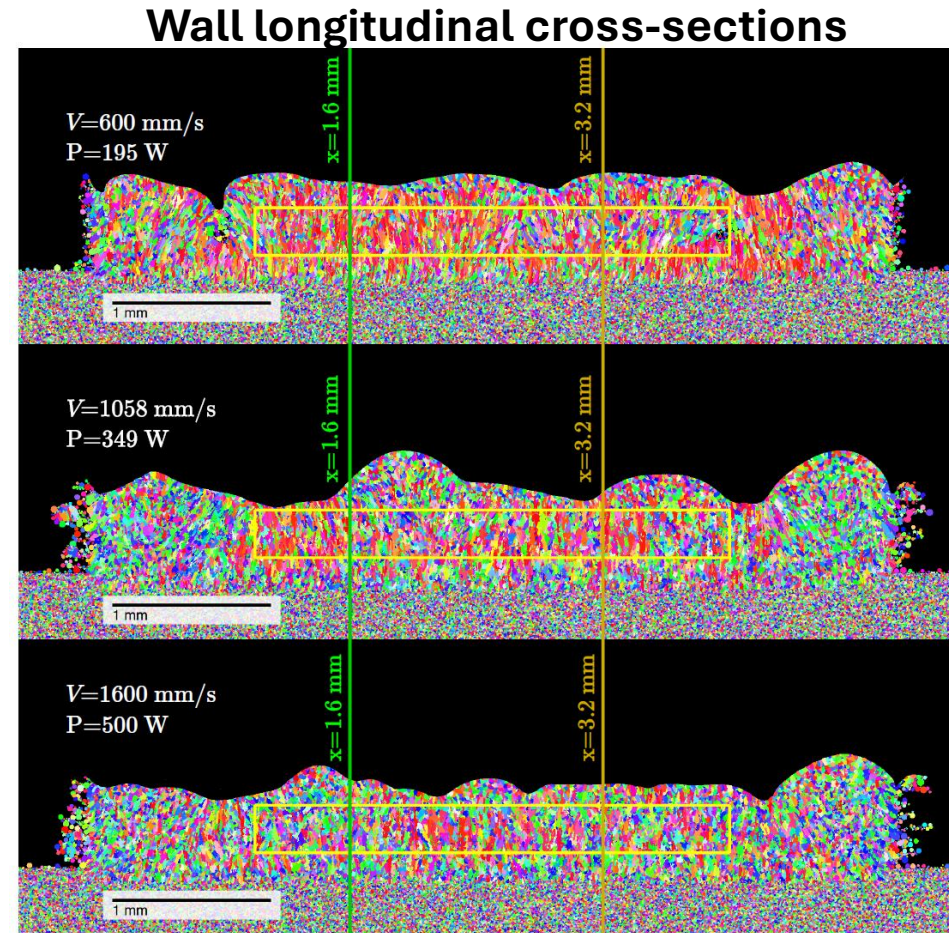
Case E

Microstructure properties: simulating impact of the printing regime on grain structure for thin walls (SS316L)



The amount of long grains with $\langle 100 \rangle$ crystallographic orientation decreases at higher scan velocities.

Melt pool becomes longer and fragments



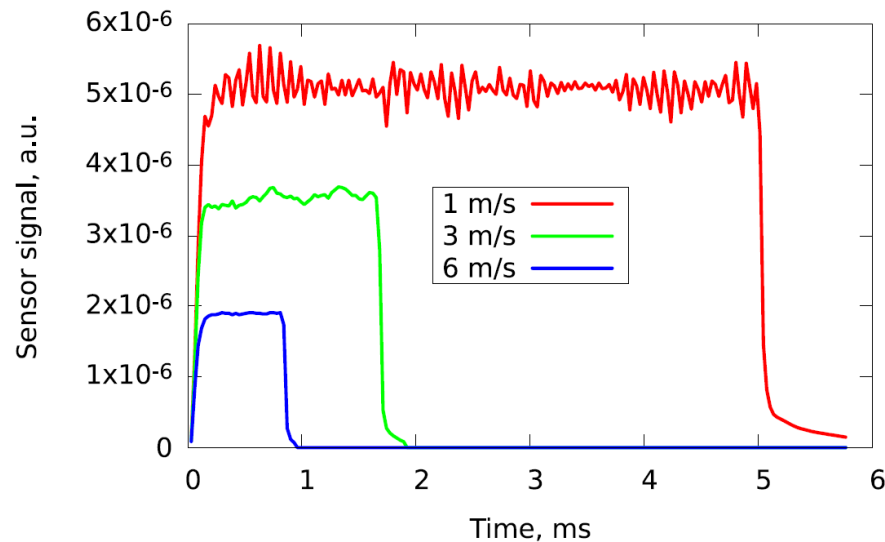
The amount of long $\langle 100 \rangle$ grains decreases

S. Belousov et.al. Variations in morphology and microstructure caused by different melt pool dynamics in laser powder bed fusion of ultrathin walls, in: SIM-AM2025. URL https://www.scipedia.com/public/Belousov_et_al_2026a

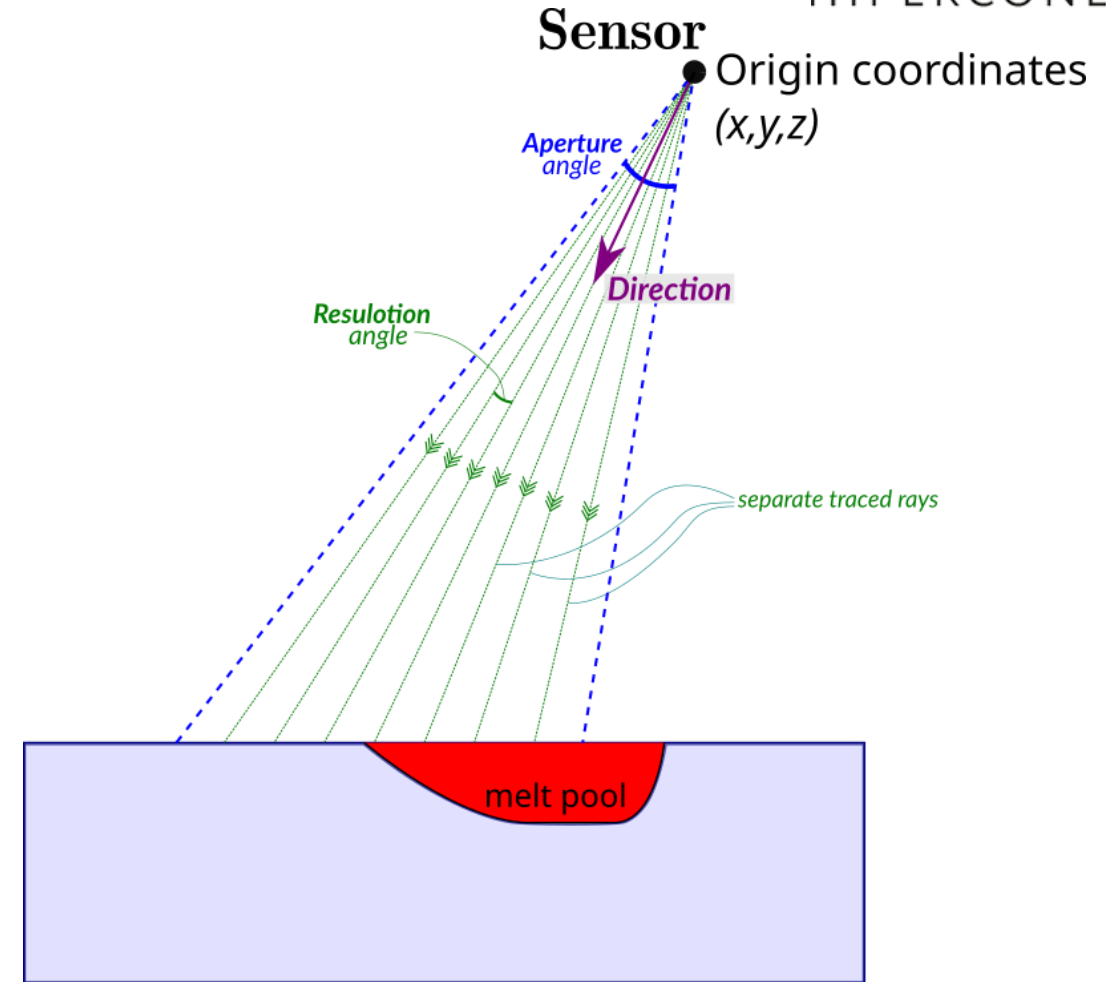
Simulating process monitoring during PBF



- Local temperature probes
- Photodiode sensors
- Back-scattered electron sensors



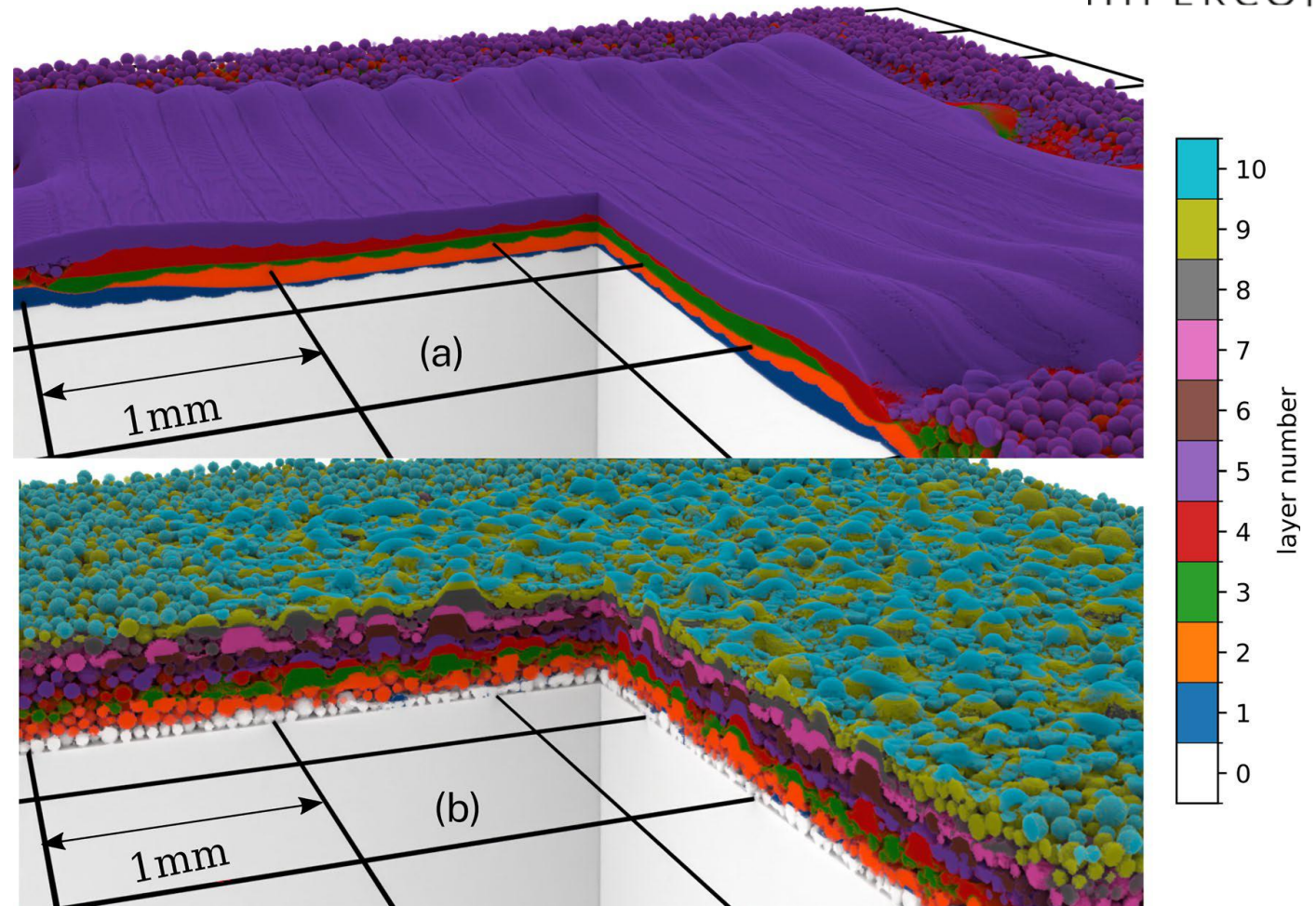
Photodiode sensor response examples for EB-PBF
for different scan velocities



Photodiode sensor scheme

Simulating surface quality and porosity

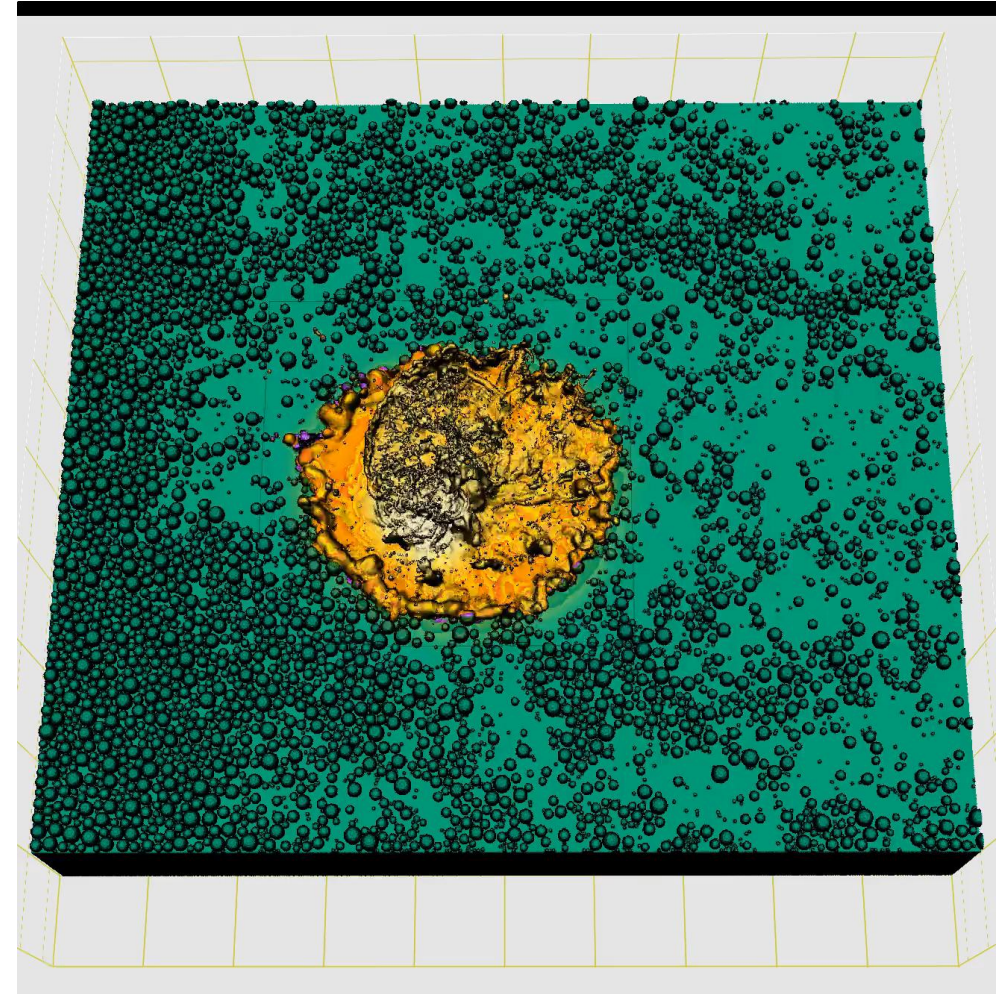
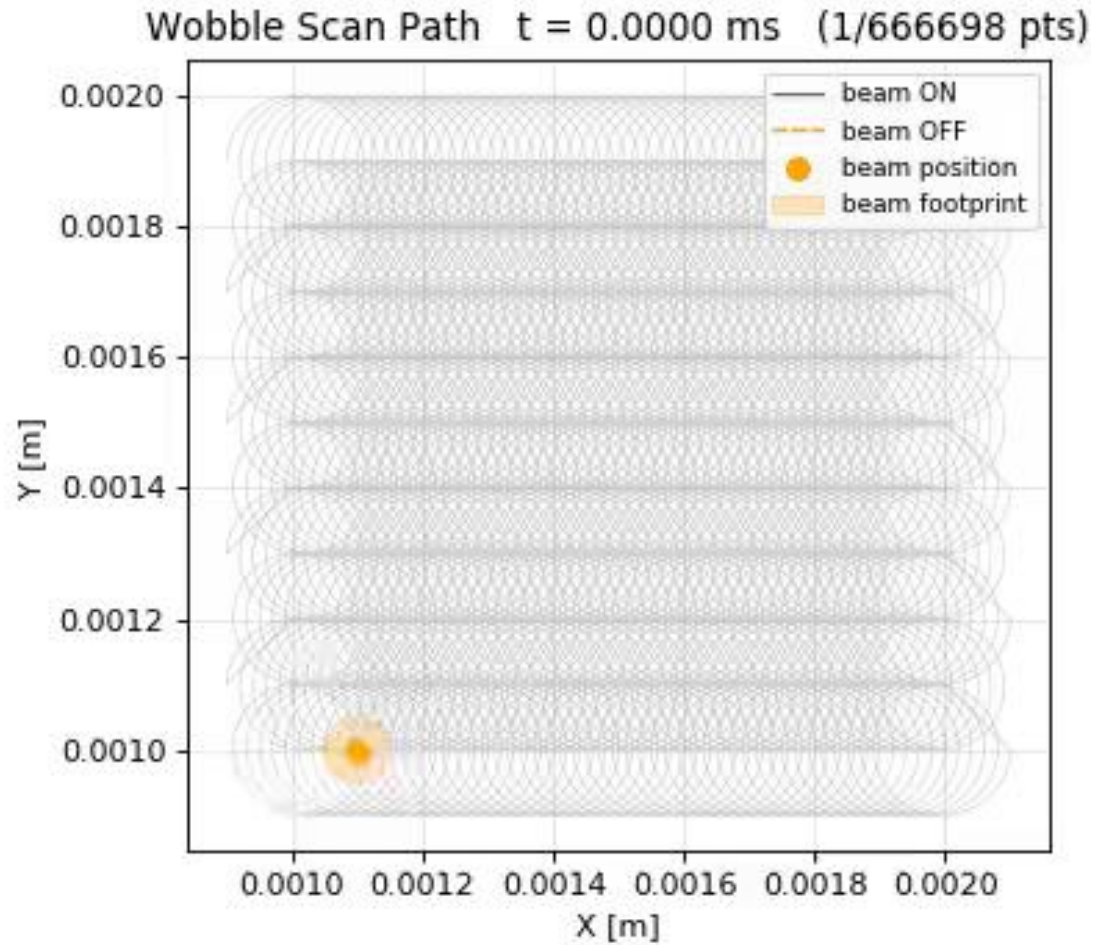
- Electron beam size: 880 μm
- Velocity: 4.27 m/s
- Scan: zigzag
- Hatch spacing: 0.26 mm
- Time delay: 6.17 ms



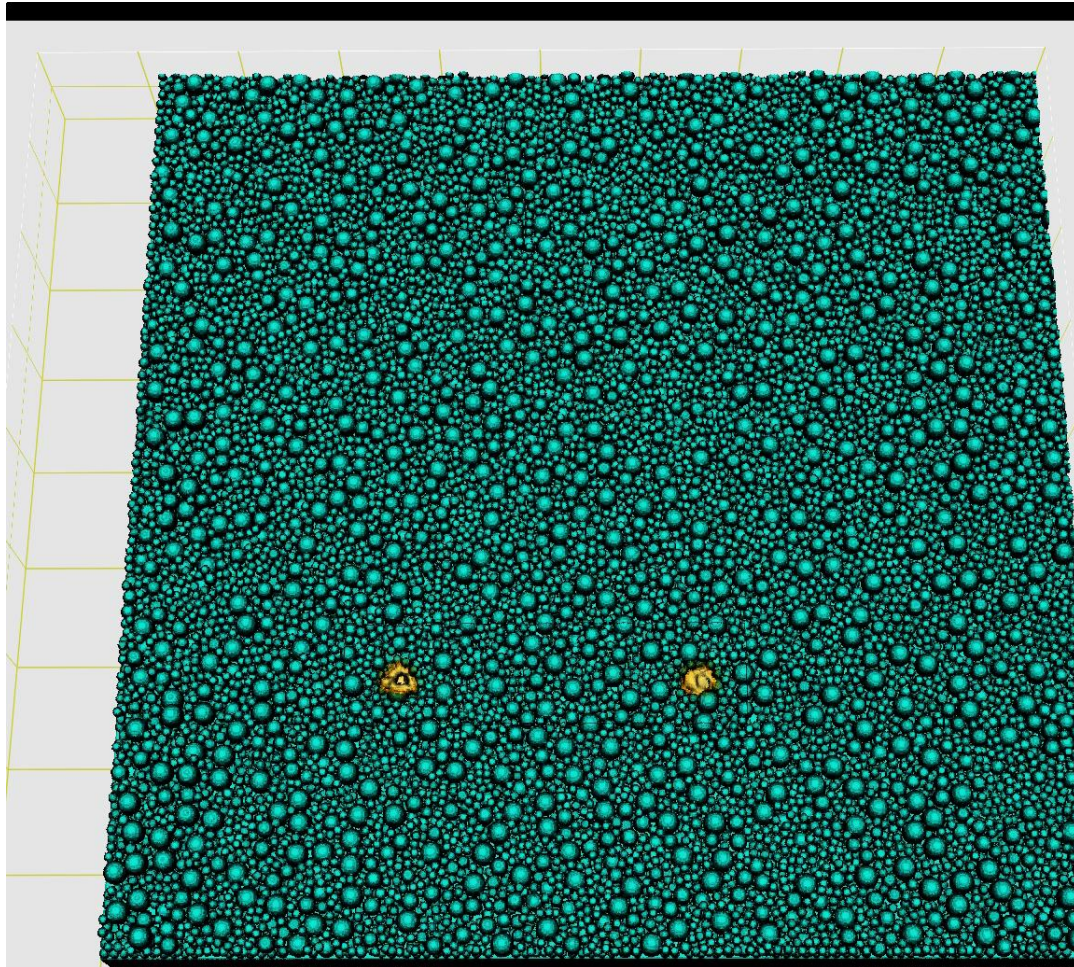
- Electron beam size: 880 μm
- Velocity: 4.27 m/s
- Scan: zigzag
- Hatch spacing: 0.20 mm
- Time delay: 9.4 ms

Increased delay between successive tracks leads to lower integral heat input and increased porosity

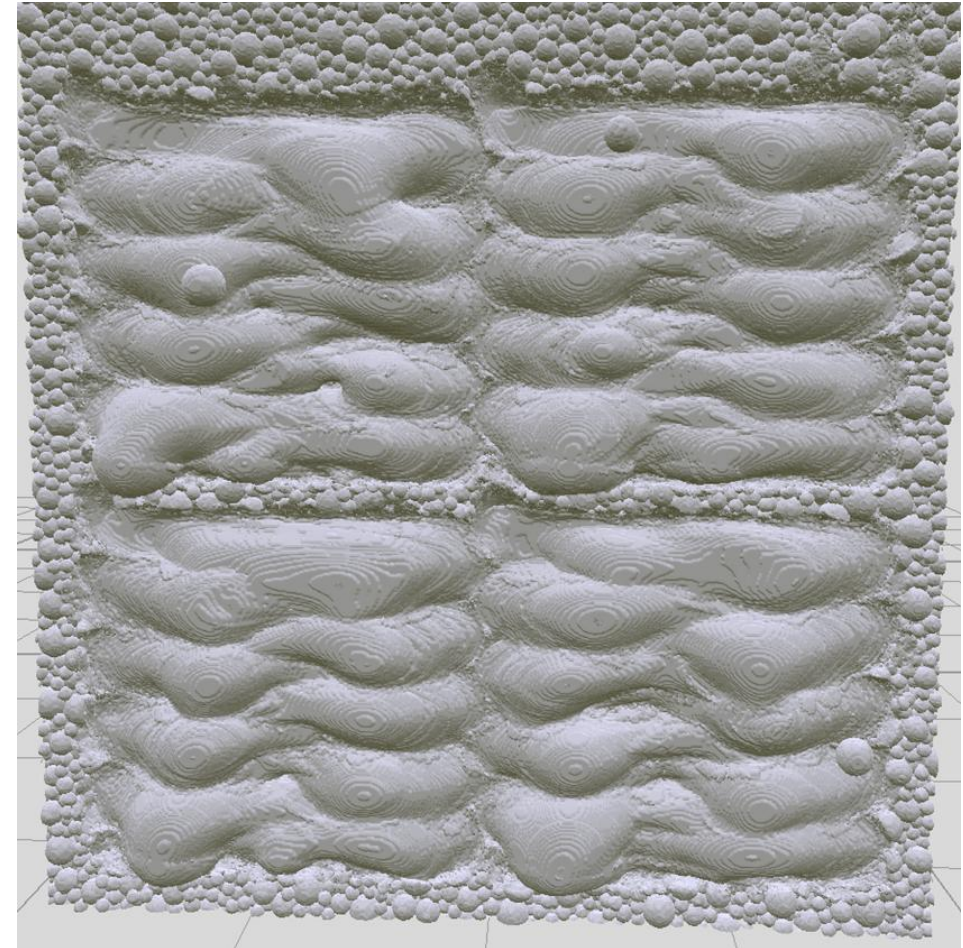
Complex scanning strategies: a wobbling scan



Multi-beam modeling



- Independent beam paths
- Any time gap between beams
- Any number of beams

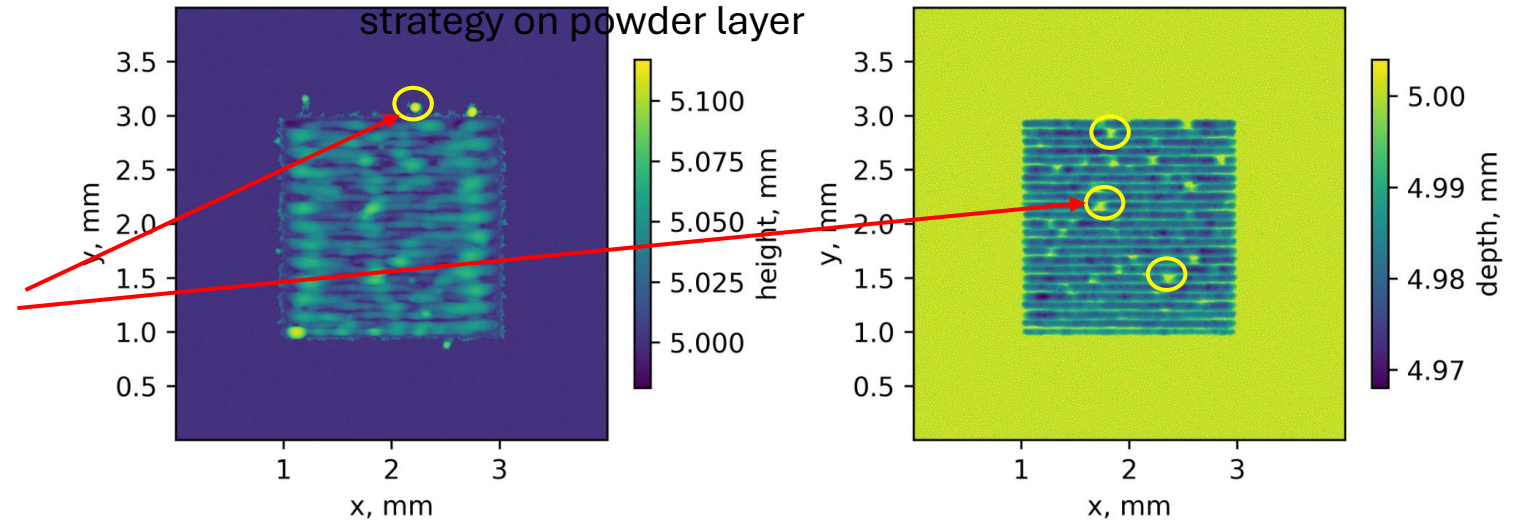


Multi-beam modeling: decreasing roughness with a post-heating defocused beam

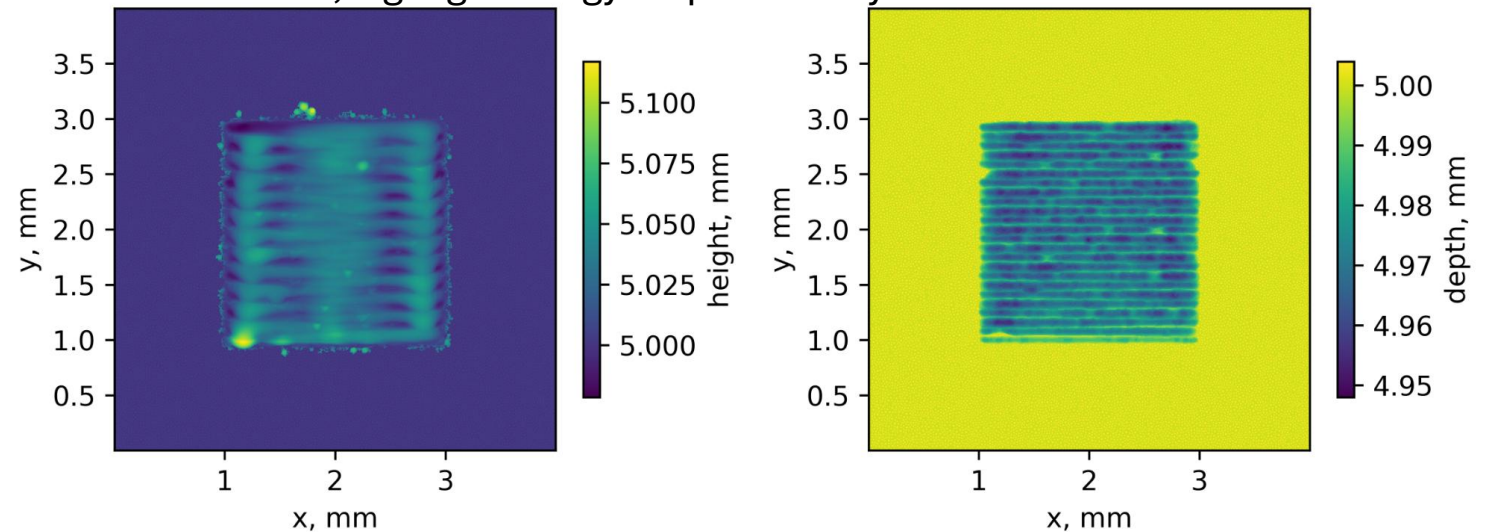


- Without post-heating, lack-of-fusion regions are observed (note the light green spots).
- Post-heating improves the uniformity of melt penetration with depth (almost no spots).

No post-heating: single beam, zig-zig



Postheating: two beams moving one after another, second beam is defocused, zig-zig strategy on powder layer.



Selected publications

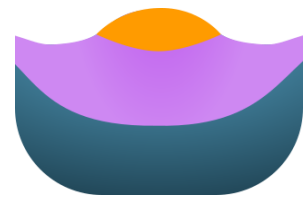


1. S. Belousov et.al. Variations in morphology and microstructure caused by different melt pool dynamics in laser powder bed fusion of ultrathin walls, in: SIM-AM2025. URL https://www.scipedia.com/public/Belousov_et_al_2026a.
2. J. Plewinski et.al., Impact of Modeling Assumptions on Simulated Melt Pool Dynamics Compared to High-Speed X-ray Observations, in: Mathematical Modeling of Weld Phenomena, vol. 14, p. 195 (2026).
3. B. Korneev et.al.. Spot melting improves the morphology of ultrathin wall builds: a numerical study. Progress in Additive Manufacturing, 10(12), 10477-10485 (2025).
4. S. Chernyshikhin et.al. Surface tension measurements of NiTi alloy for the melt pool simulation during Laser Powder Bed Fusion. Materials Letters, 139696 (2025).
5. A. Zakirov et.al.. KiSSAM: Efficient Simulation of Melt Pool Dynamics during PBF using GPUs. Progress in Additive Manufacturing 9 (5), 1491-1508 (2024).
6. M. Bogdanova et.al. Mesoscale Simulation of Laser Powder Bed Fusion with an Increased Layer Thickness for AlSi10Mg Alloy. Journal of Manufacturing and Materials Processing, 8(1), 7 (2024).
7. B. Korneev et.al. A numerical study of powder wetting influence on the morphology of laser powder bed fusion manufactured thin walls. Additive Manufacturing, 74, 103705 (2023).
8. A. Zakirov et.al. Predictive modeling of laser and electron beam powder bed fusion additive manufacturing of metals at the mesoscale. Additive Manufacturing, 35, 101236. (2020).
9. D. Nakapkin et al. Finding Optimal Parameter Ranges for Laser Powder Bed Fusion with Predictive Modeling at Mesoscale, Sim-AM 2019 (2019)

KiSSAM licensing and collaboration options



- Web-interface at <https://kissam.cloud> (cloud simulation capability)
- Trial license (including cloud)
- Commercial and academic licenses available
- EOM module
- Joint research projects with industrial partners



Thank you for your attention!



- Visit <https://kissam.cloud> to know more about KiSSAM and get your free trial

Join the growing
community of
KiSSAM users and
collaborators!



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MÜNCHEN



and more...

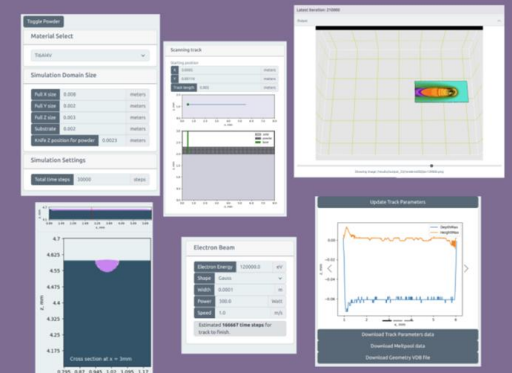
Web Interface for KiSSAM Cloud Computing

User friendly graphical simulation setup, post-processing, and diagnostics are available in the web interface.

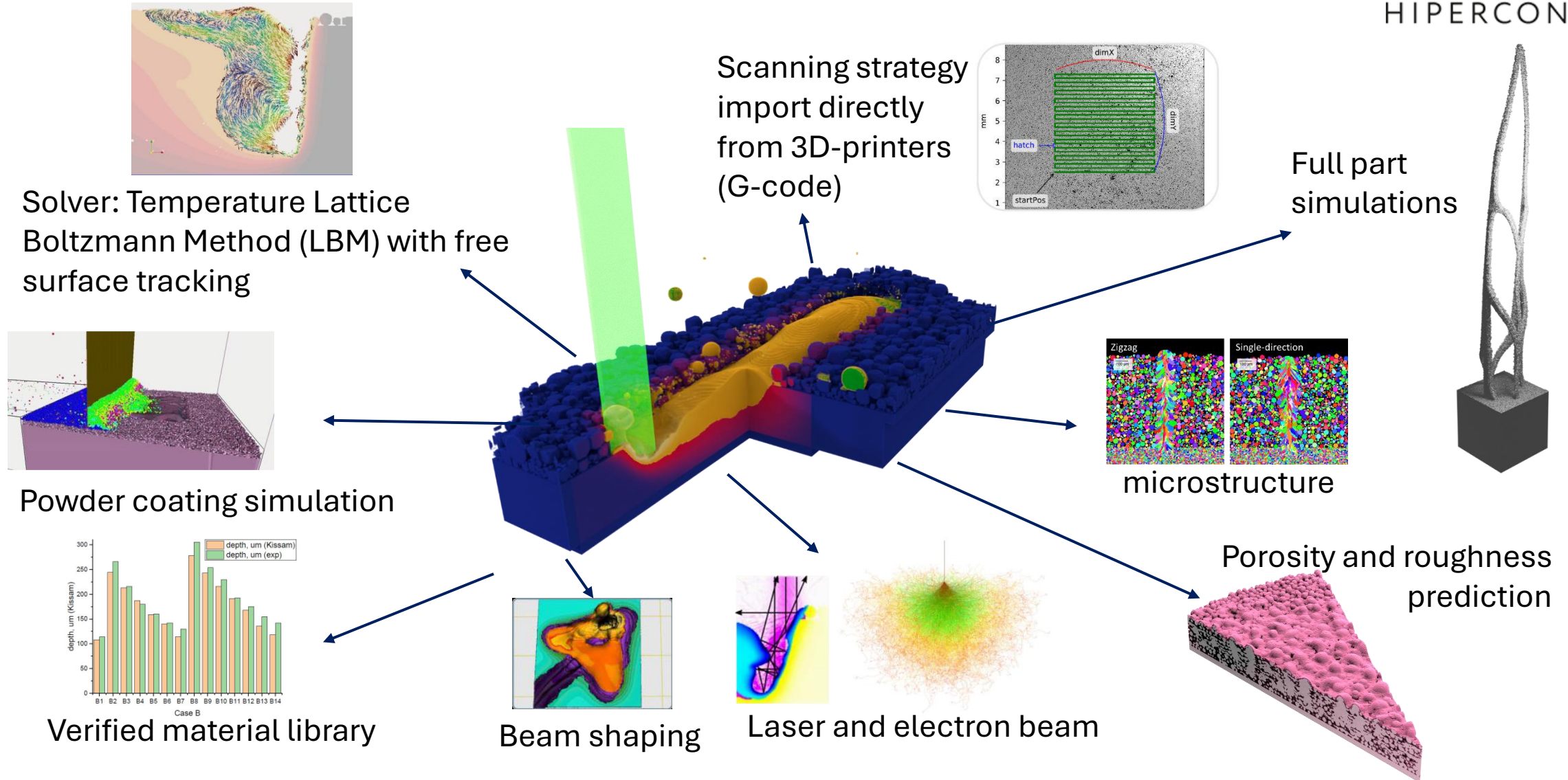
Contact info@hipercone.com for a trial version.

Or fill in the [Form](#).

Login



KiSSAM: A high-fidelity simulation at the mesoscale



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

Previously with KiSSAM...

- Process map generation

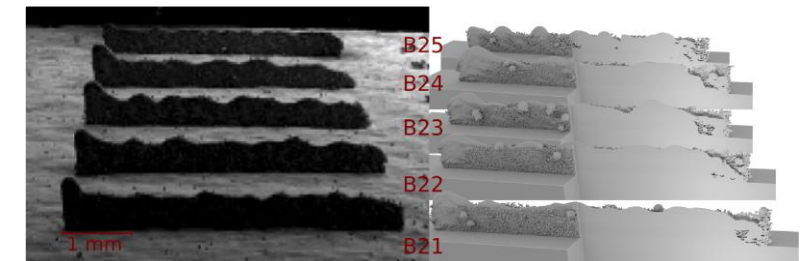
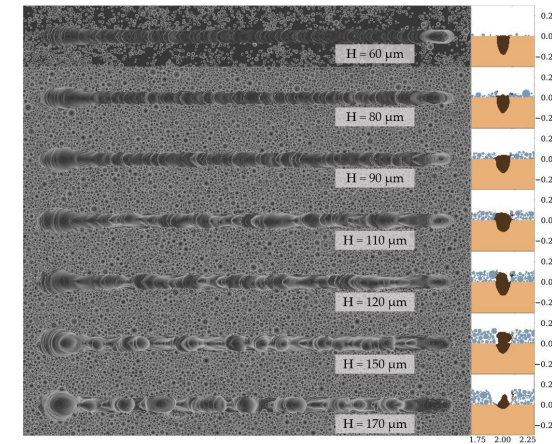
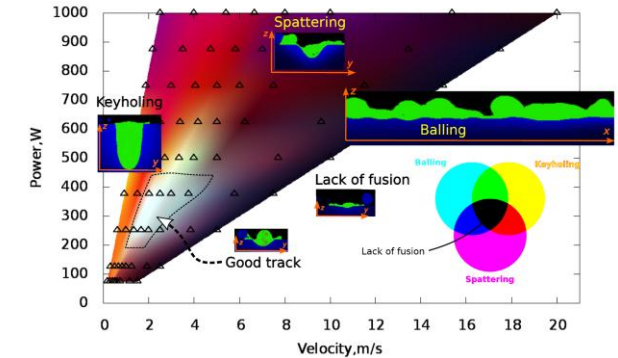
D. Nakapkin et.al., Sim-AM 2019: II International Conference on Simulation for Additive Manufacturing (pp. 297-308). CIMNE (2019).

- 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).



Bulk porosity prediction

GOAL¹

Determine porosity of bulk sample with different scanning strategies

SOLUTION

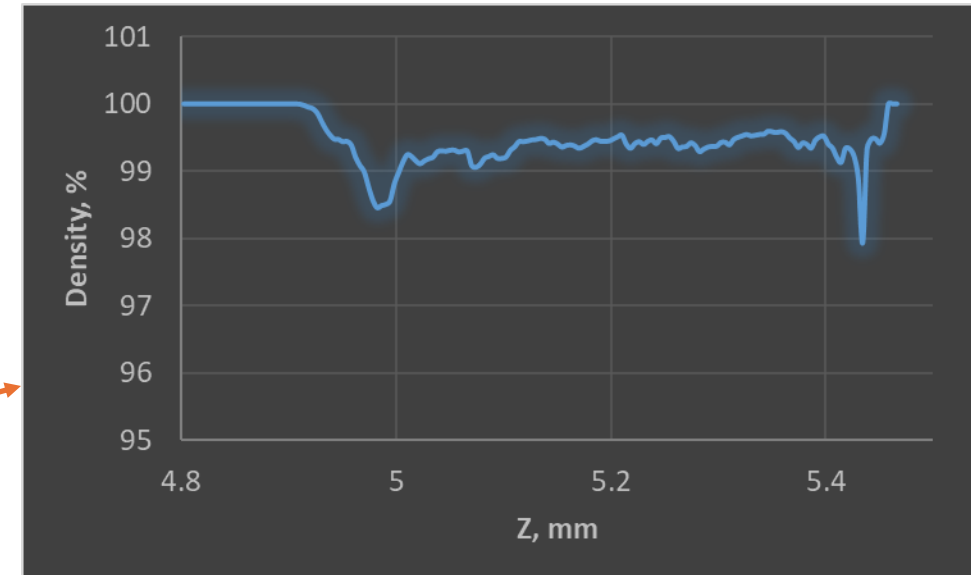
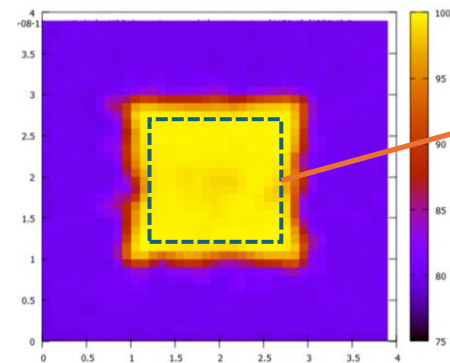
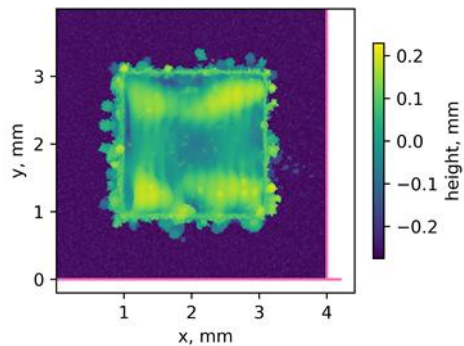
Multilayer modeling with rotated pattern at each layer.
Utilization of the time gap between successive tracks to avoid melt pool overlap

ANALYSIS

Quality of remelted material, porosity and microporosity

OUTCOME

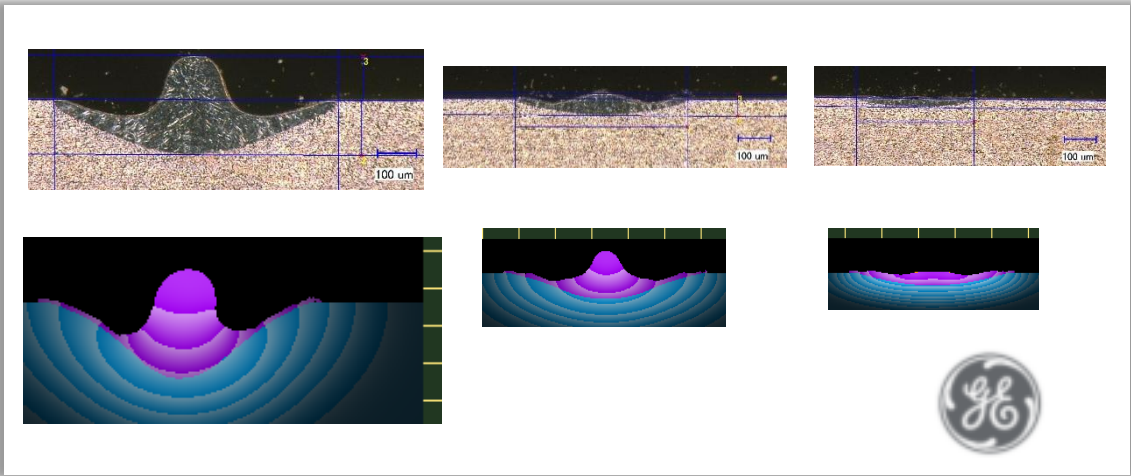
Optimal strategy to decrease porosity



Basic Model Validation on cross-sections

ELECTRON BEAM PBF

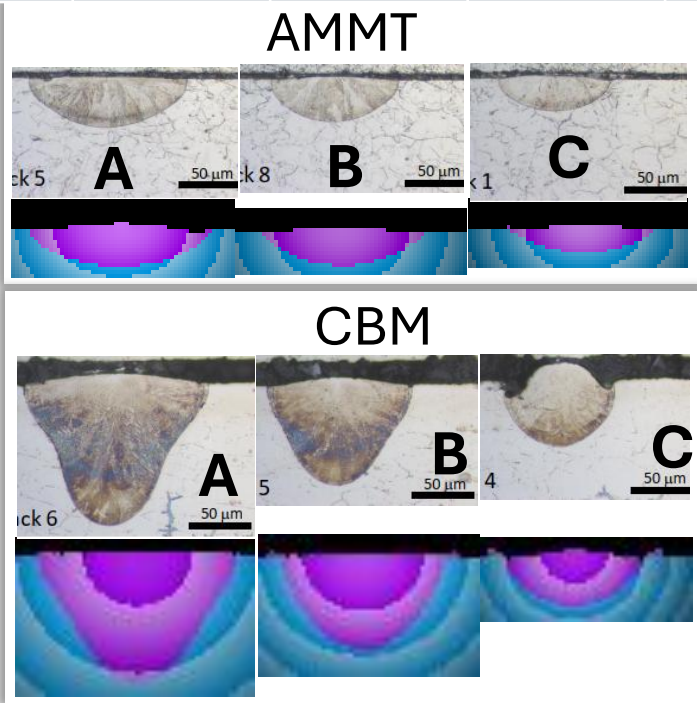
Source	Beam size, um	Velocity, m/s	Current, mA / Voltage, KV	Material
E-beam	500	1, 3, 6	15 mA 60 kV	Ti-6Al-4V



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

LASER PBF

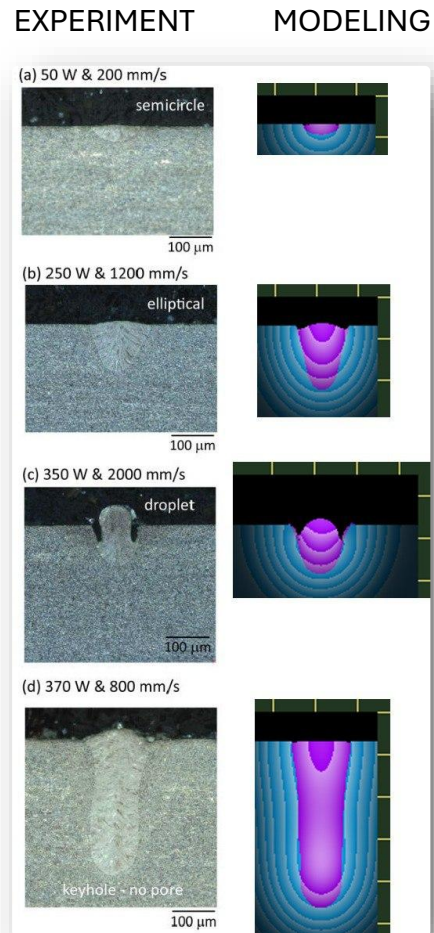
Source	Beam size, um	Velocity, m/s	Power, W	Material
Laser	100, 170	0.4 – 1.2	137.9 - 195	Inconel 625



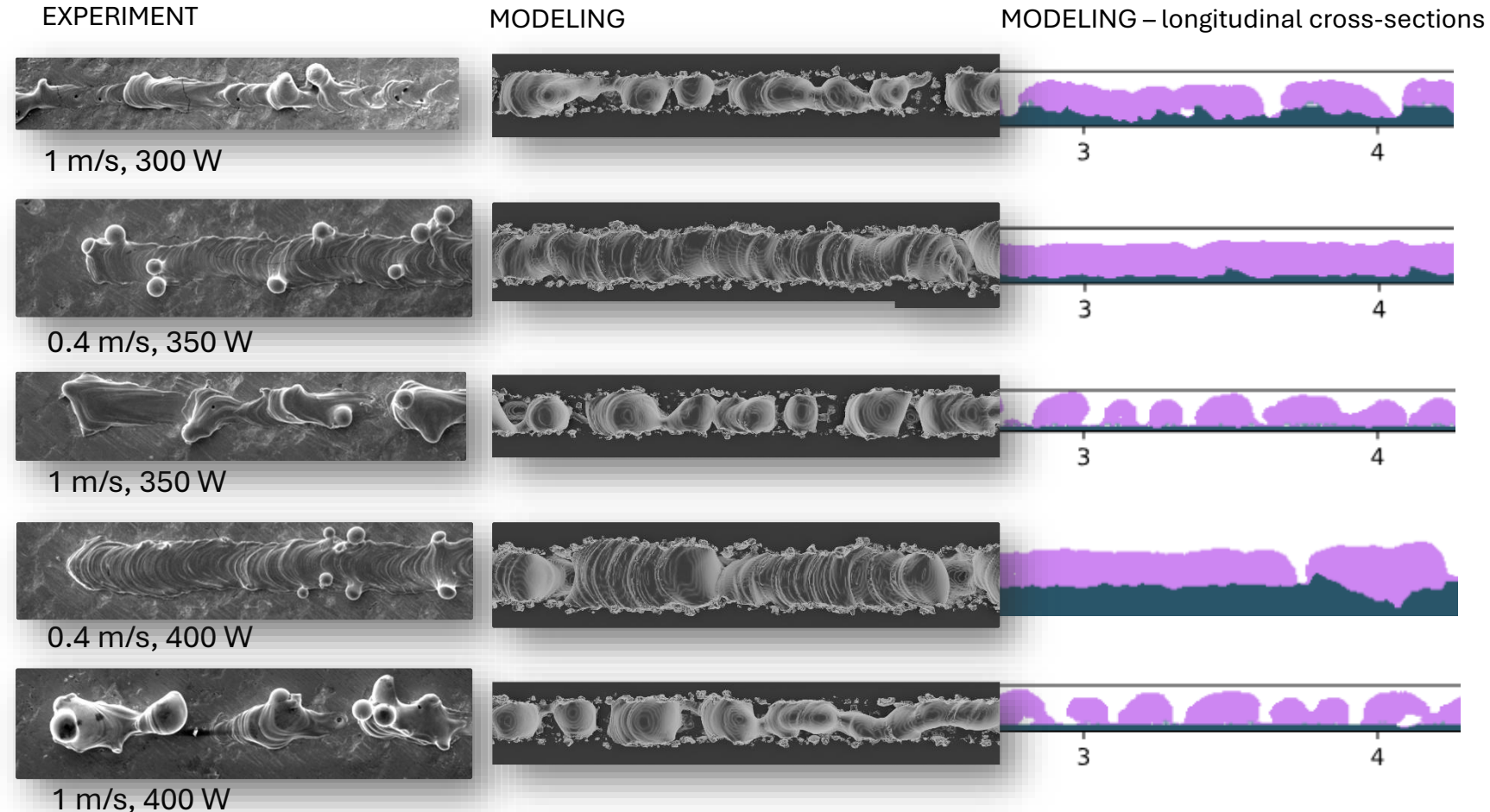
B. Lane et al. *Integrating Materials and Manufacturing Innovation* volume 9, 16–30 (2020)

Advanced Validation on different experimental data

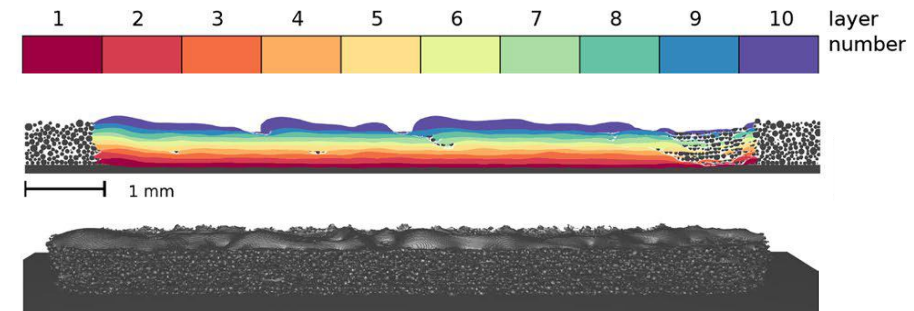
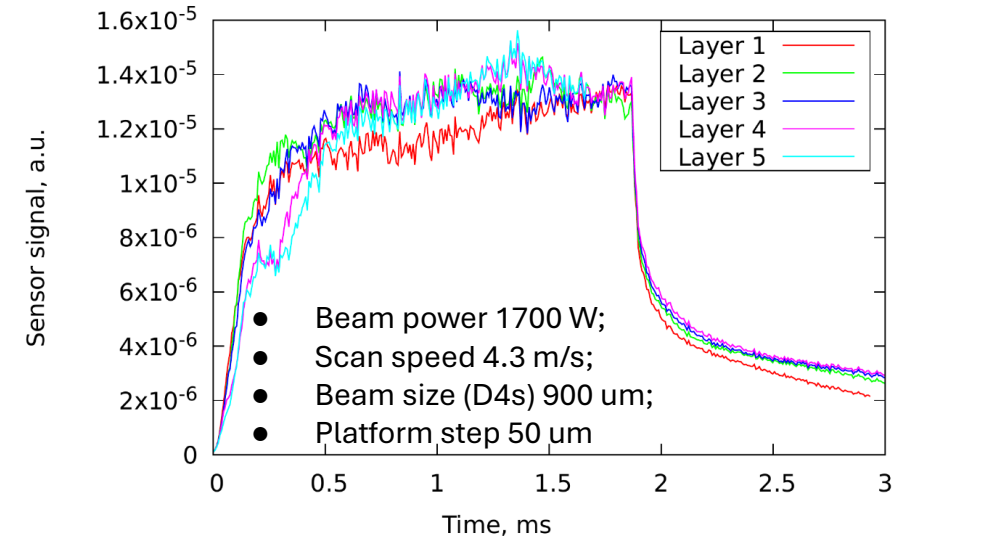
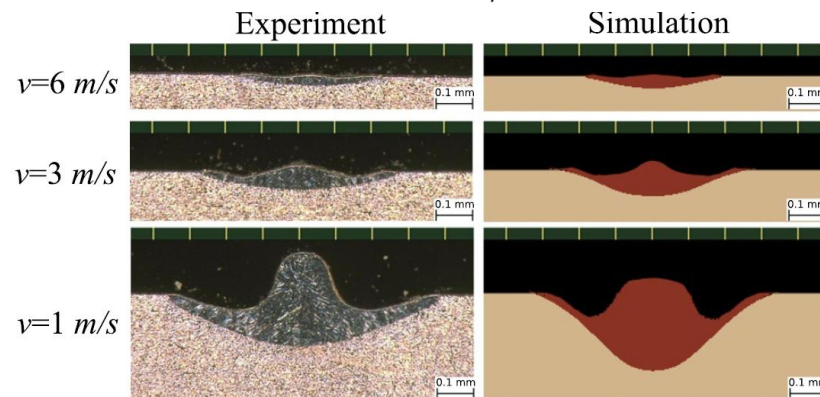
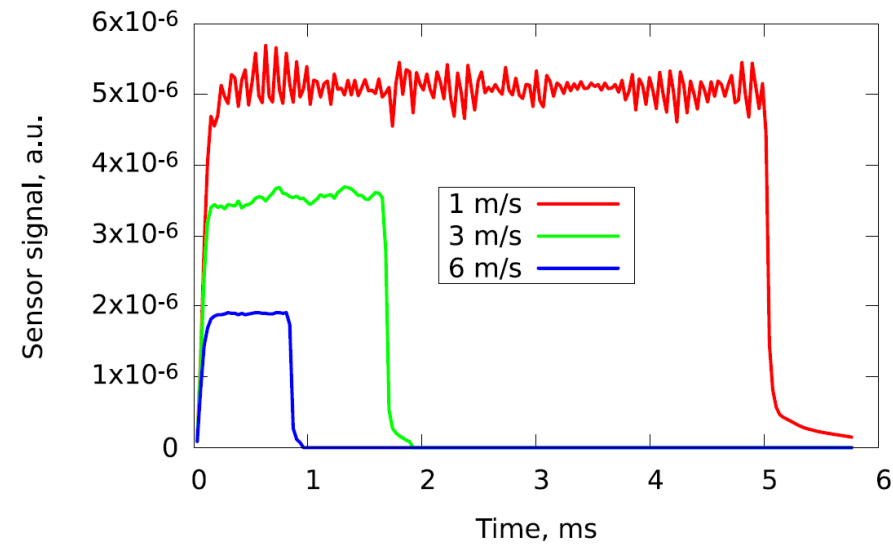
Validation with cross-sections



Validation with SEM data



Process Monitoring: Photodiode sensor response during thin wall build with EB-PBF



- Sensor signal gradually grows as the build progresses, indicating heat build up in the thin wall.

See our paper: A. Zakirov et. Al. KiSSAM: efficient simulation of melt pool dynamics during PBF using GPUs, Progress in Additive Manufacturing. 18 p. (2024)



- ## Why don't we go for... **simulation?**