

Professorship of Laser-based Additive Manufacturing

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Jonas Grünewald, M.Sc.

Energy & Turbomachinery Network, 27.03.2025

Our Vision

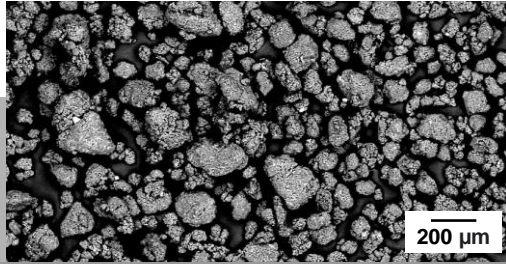
We transfer groundbreaking research in additive manufacturing to industrial applications and accelerate the industry transition into green manufacturing



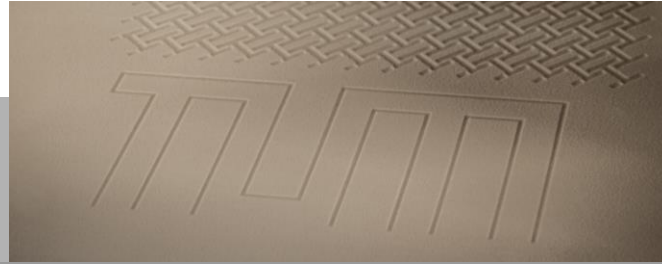
Our Mission

We are creating a toolbox towards first-time-right production and new applications fields in laser-based Additive Manufacturing

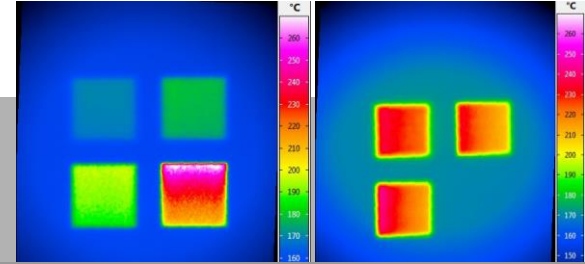
Our Focus



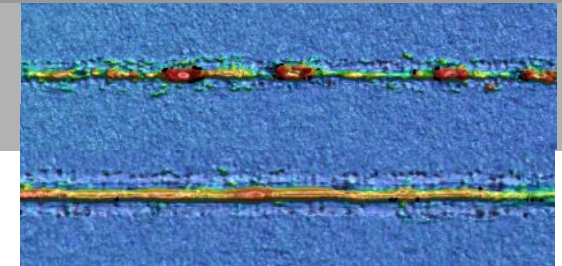
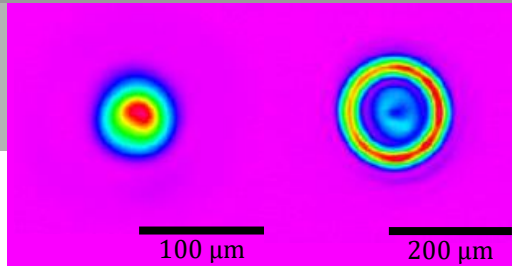
Laser- and powder-based processes



Plastics and metals



Material development/
process optimization



AM@LBAM



Innovative process strategies in PBF-LB/M

- Beam shaping and Scanner-based strategies
- Pulsed exposure



Quality assurance in PBF-LB/P

- Process monitoring in PBF-LB/P
- Prediction of part properties using ML



Applications of AM

- AM for high power e-drives
- Production of cooling channels with defined surfaces



Laser material interaction

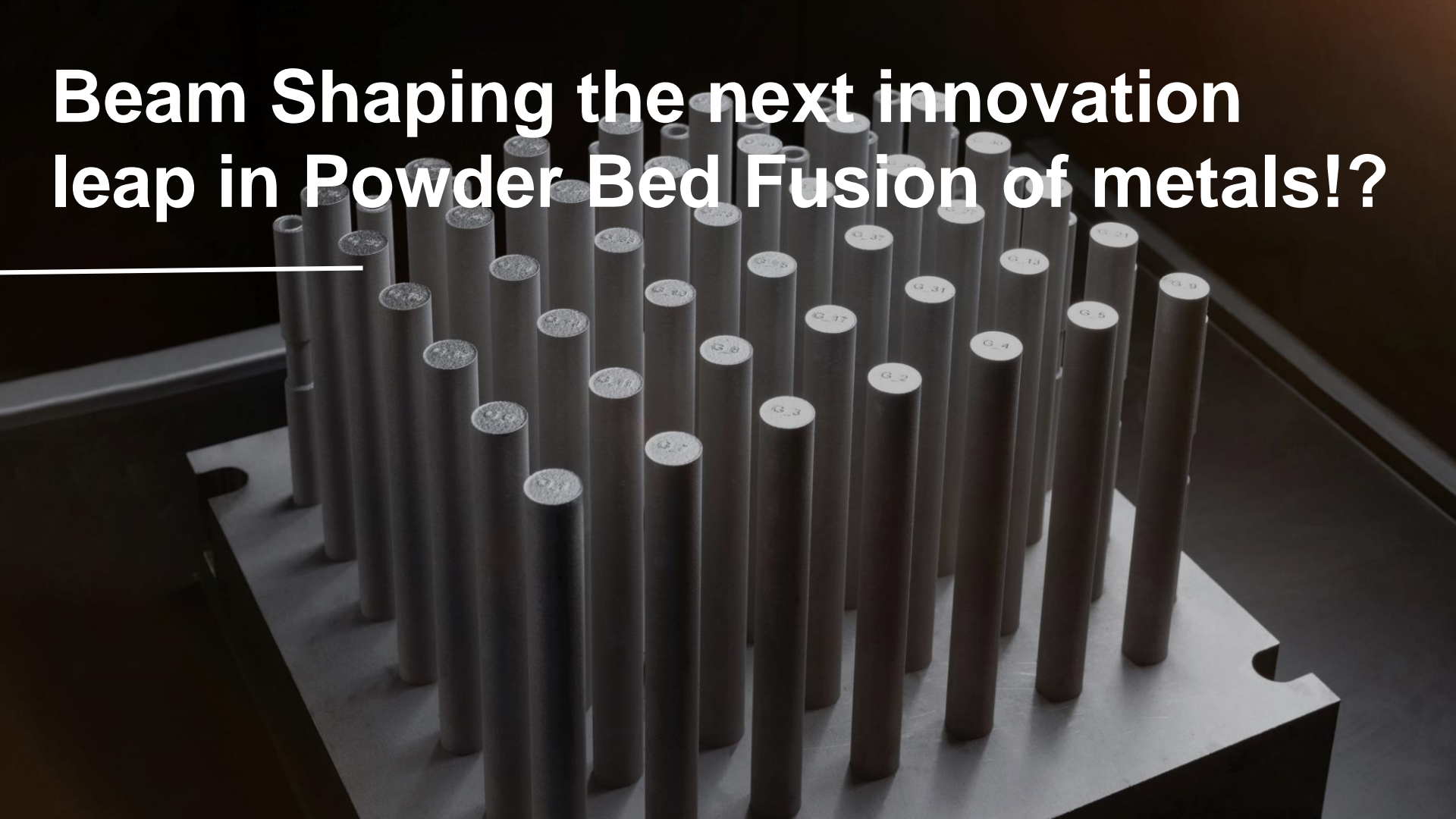
- Linking absorption to process behavior
- Monitoring techniques like multi-spectral imaging
- Data fusion and digital twin



Binder Jetting

- Process Monitoring
- Sustainability by recycling of powder from other AM processes

Beam Shaping the next innovation leap in Powder Bed Fusion of metals!?



Agenda

- i. Introduction and Motivation
- ii. State of the Art
- iii. Beam Shaping @ TUM
- iv. Conclusion and Outlook

Time elapsed: 0.000125 sec

316L, 100 W, 5 m/s



Introduction and Motivation

Highly dynamic and chaotic powder bed fusion process with spatter, denudation, and keyholing.

➔ **Insufficient reproducibility and productivity** with state-of-the-art Gaussian beam in PBF-LB/M.

Introduction and Motivation

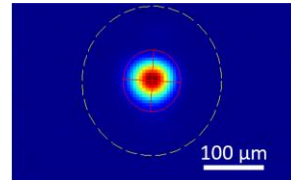
One size fits it all

Pocket tools

[victorinox.com]



Compromises regarding
functionality, usability,
and **efficiency**



[EOS]

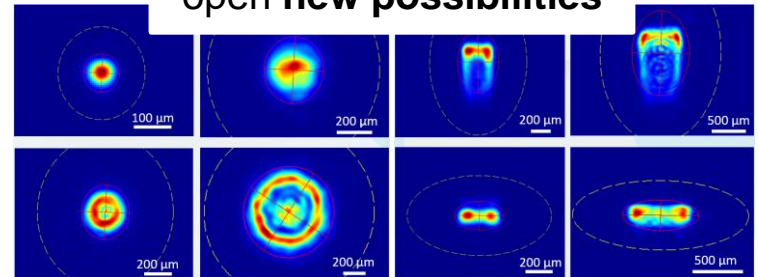
Multitool –

Set of tools in the same footprint

[victorinox.com]



Beam shaping multitool
open **new possibilities**



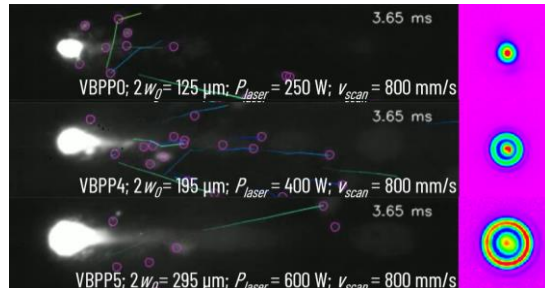
[EOS]

Laser-based
Powder Bed Fusion
of Metals

Research highlights @ LBAM

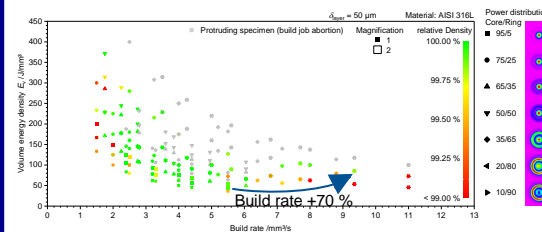
Enhanced process robustness

- Larger process window [Grünwald et al. 2021]
- Higher process robustness [Grünwald et al. 2025 (submitted)]
- Reduced spatter formation [Grünwald et al. 2023]



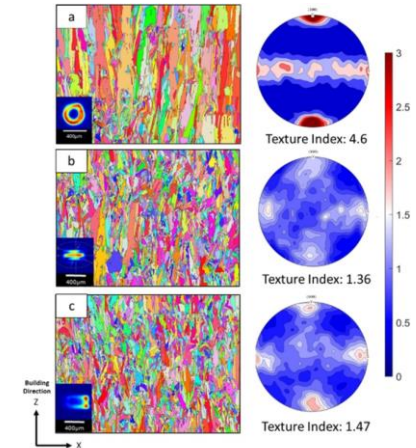
Process acceleration

- Productivity improvement [Grünwald et al. 2021]
- Increased build rate [Grünwald et al. 2024, Wudy et al. 2025 (accepted)]



Tailoring of microstructure

- Dependence of beam profile [Mirzabeigi et al. 2024]



Alternative beam profiles offer enormous potential for tailoring energy input in laser-based powder bed fusion of metals

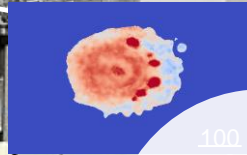
ETN project idea

Beam
Shaping

Multispectral
imaging

Microstructure
control

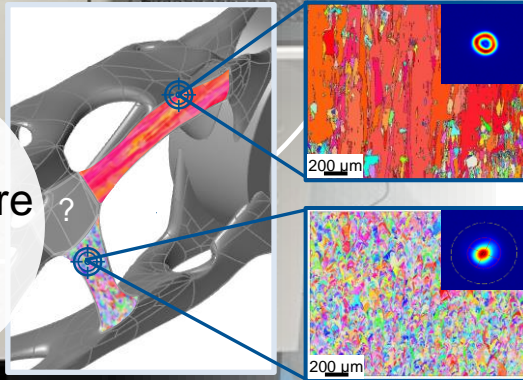
- **Innovative process strategies:** Combining new beam shapes with monitoring systems to enable:
 - Processing of new hard-to-weld materials
 - Acceleration of the process (by a factor of min. 3) and reducing the costs per part
 - Tailoring of the microstructure and properties



100

200 μ m

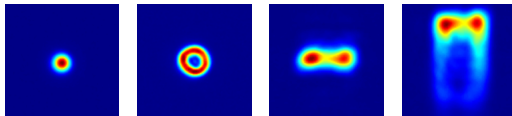
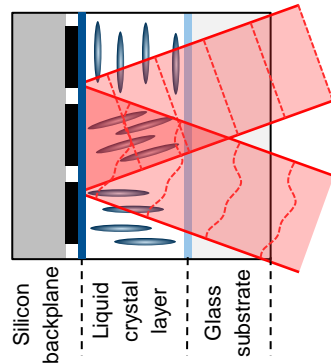
200 μ m



Laser Beam Shaping @ TUM

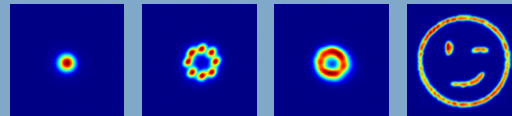
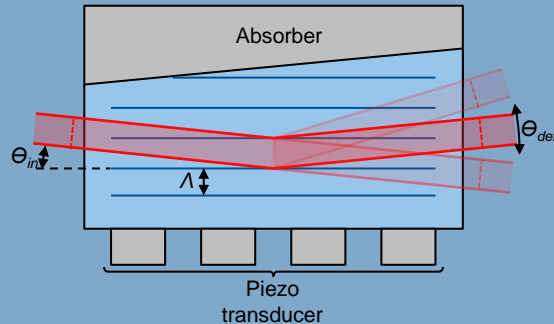
Spatial light modulator (SLM)

Change in wavefront due to local change in refractive index by tilting liquid crystals



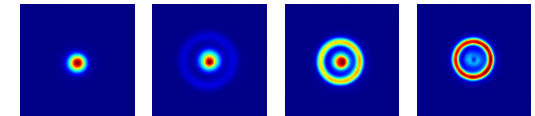
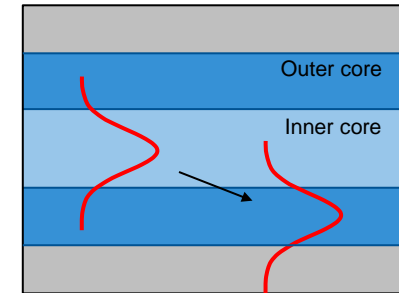
Acousto-optic deflector (AOD)

Ultra-fast deflection of the laser radiation by frequency change of acoustic sound waves

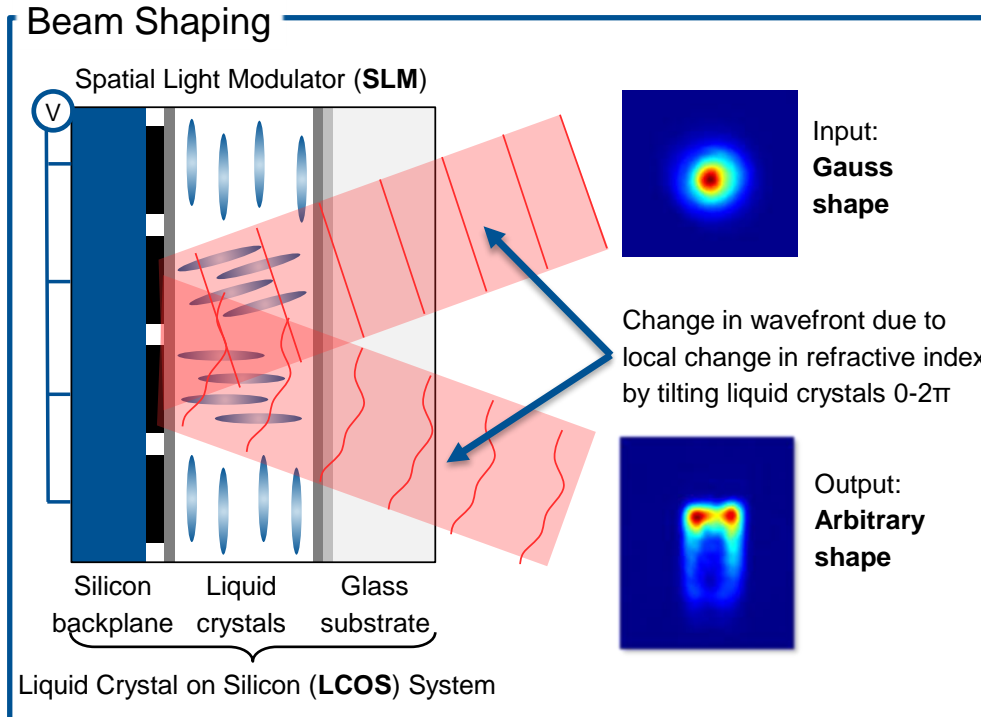


Multi-core fiber

Change in relative intensity distribution via redistribution across fiber cross-section

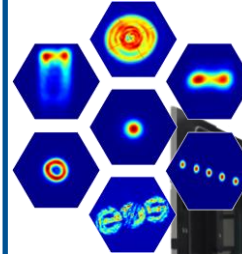


Spatial light modulators – Principle

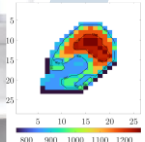
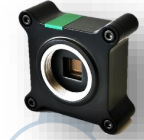


InShaPe System

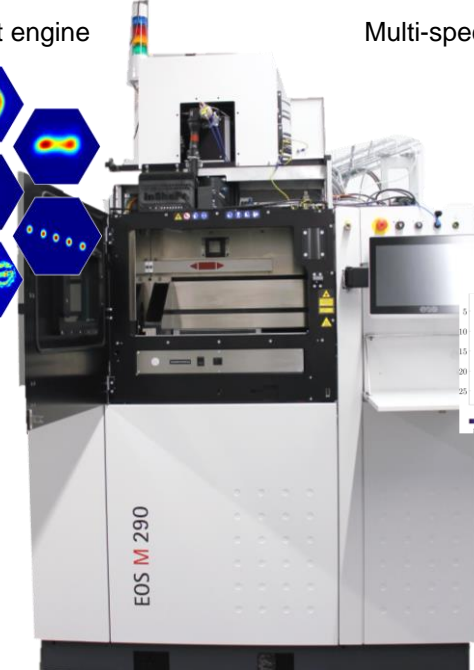
Novel light engine



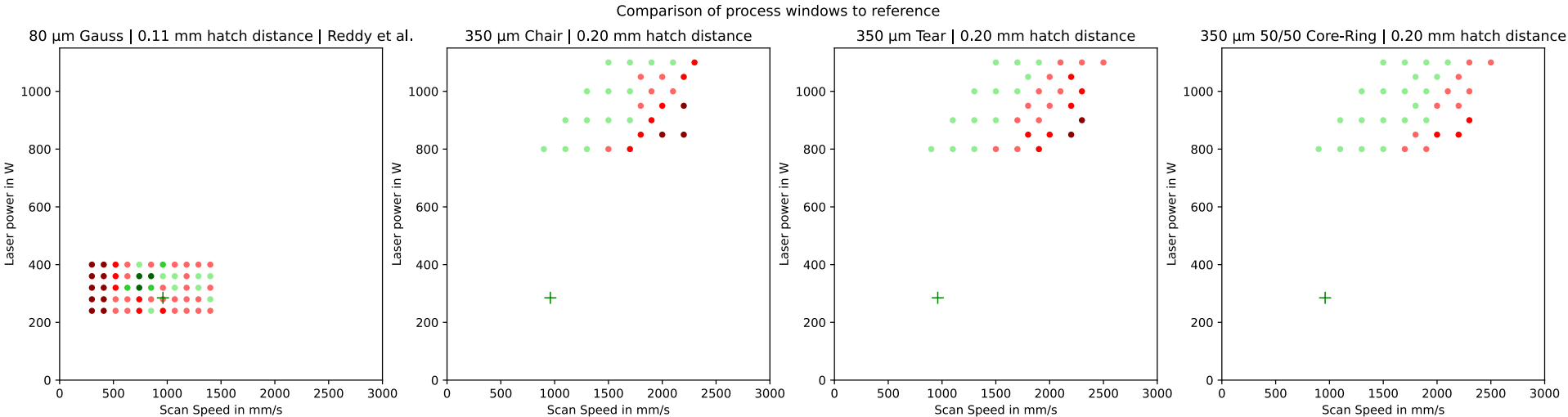
Multi-spectral imaging



Cooperation
Prof. Kizel,
Technion



Beam shaping with SLM – Experiments

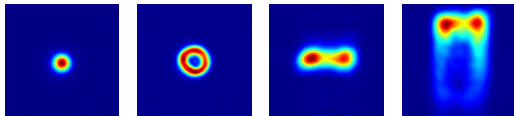
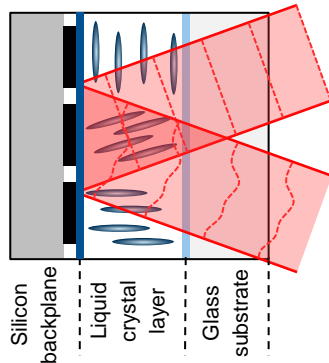


➔ Significant increase in productivity up to a factor of 3 with computer-simulated beam shapes compared to the Gaussian reference

Laser Beam Shaping @ TUM

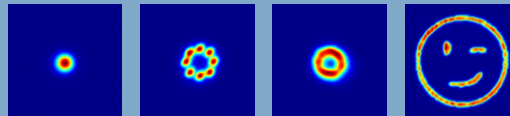
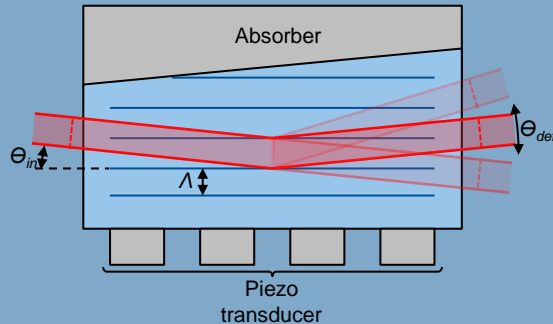
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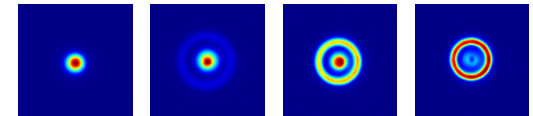
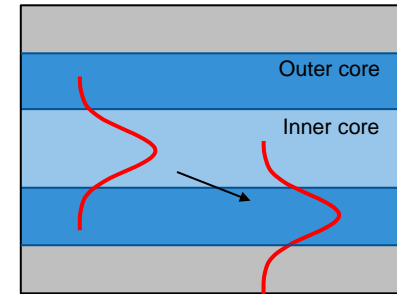
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Multi-core fiber

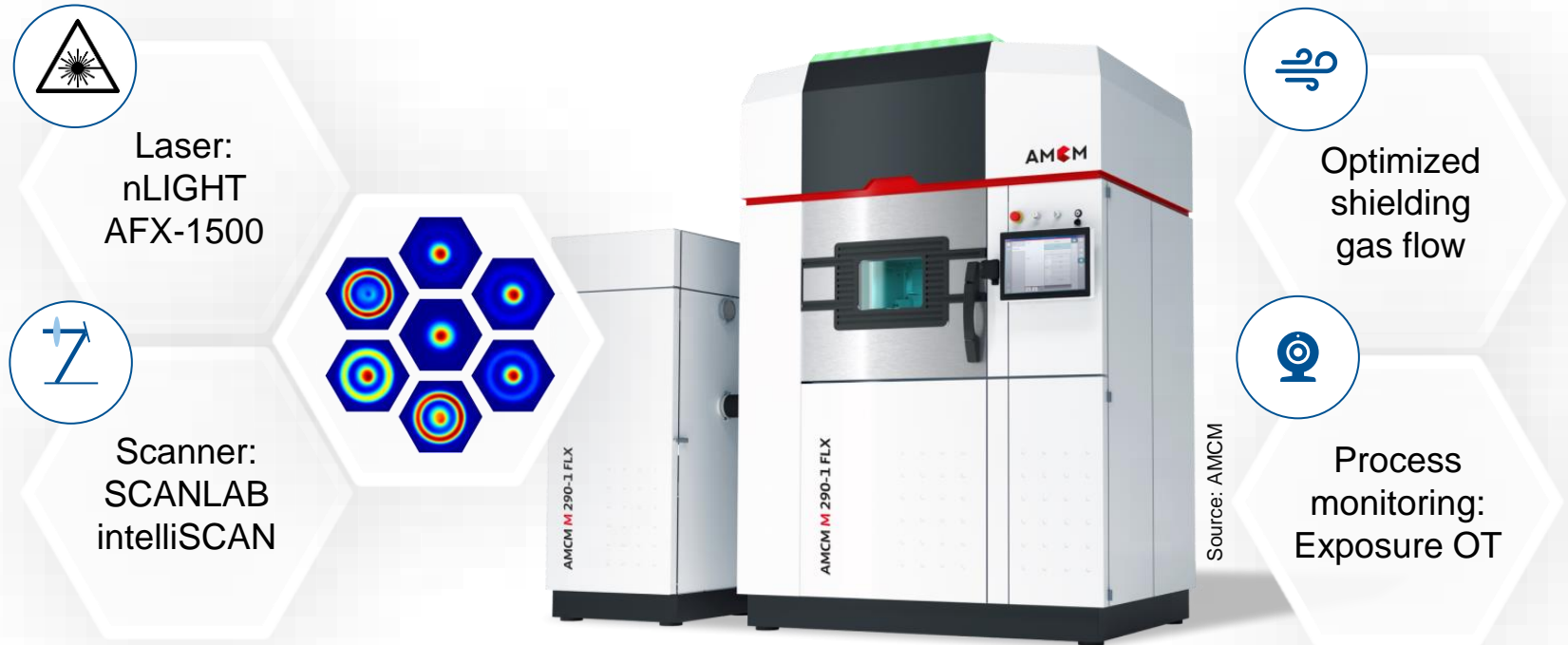
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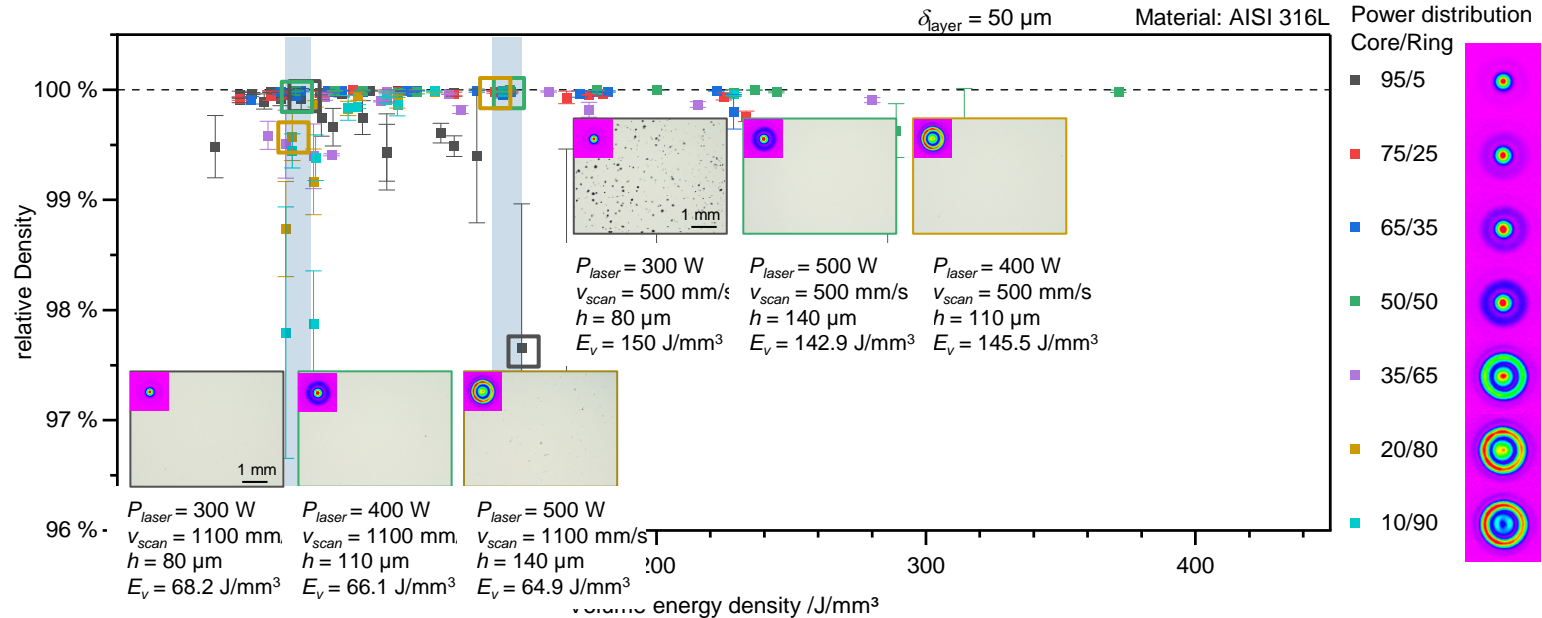
Experimental setup with extended exposure and monitoring options



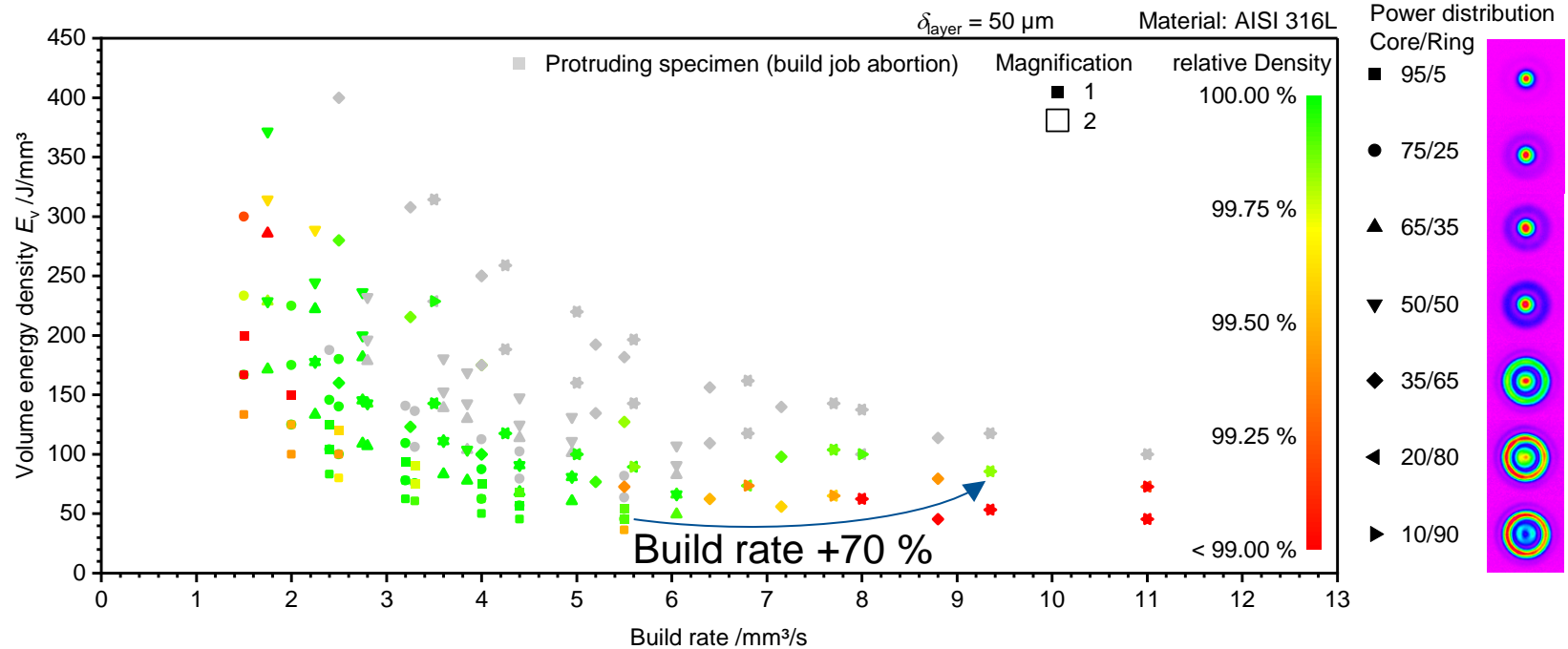
Industrial setup with higher TRL coming in June



Multi-core fiber – Process window



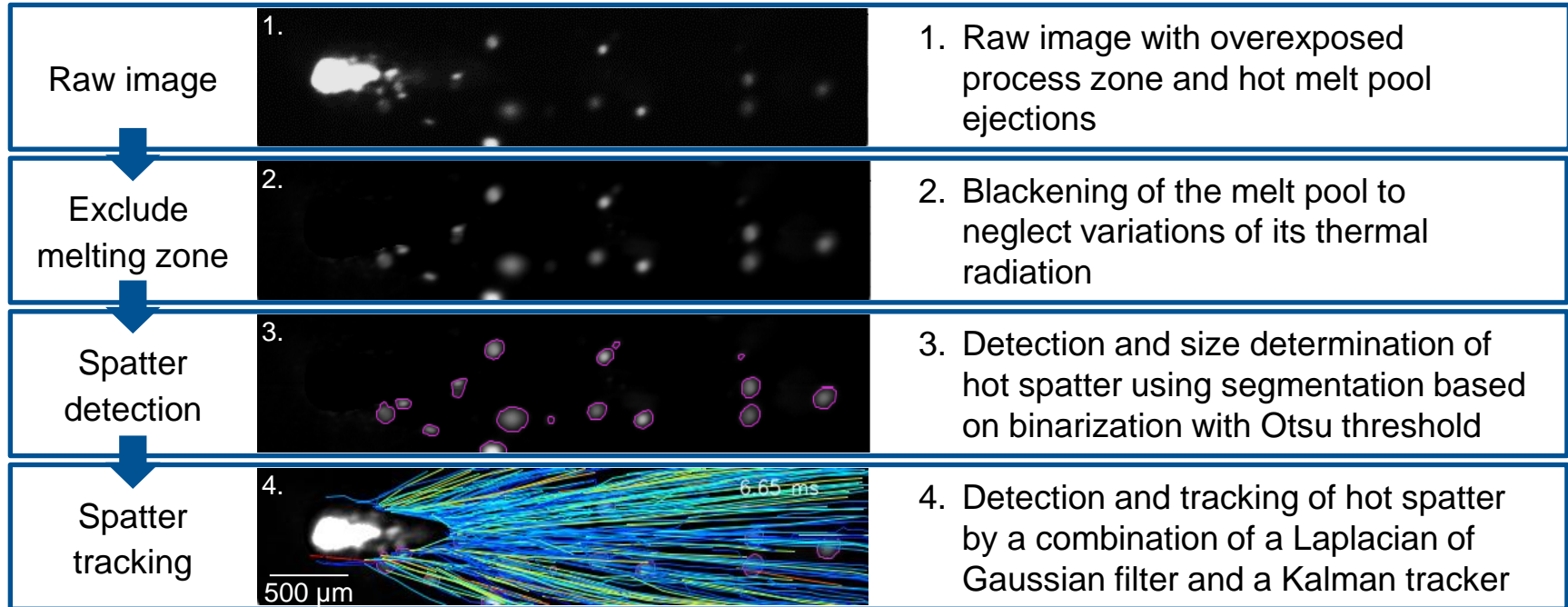
Multi-core fiber – Production speed



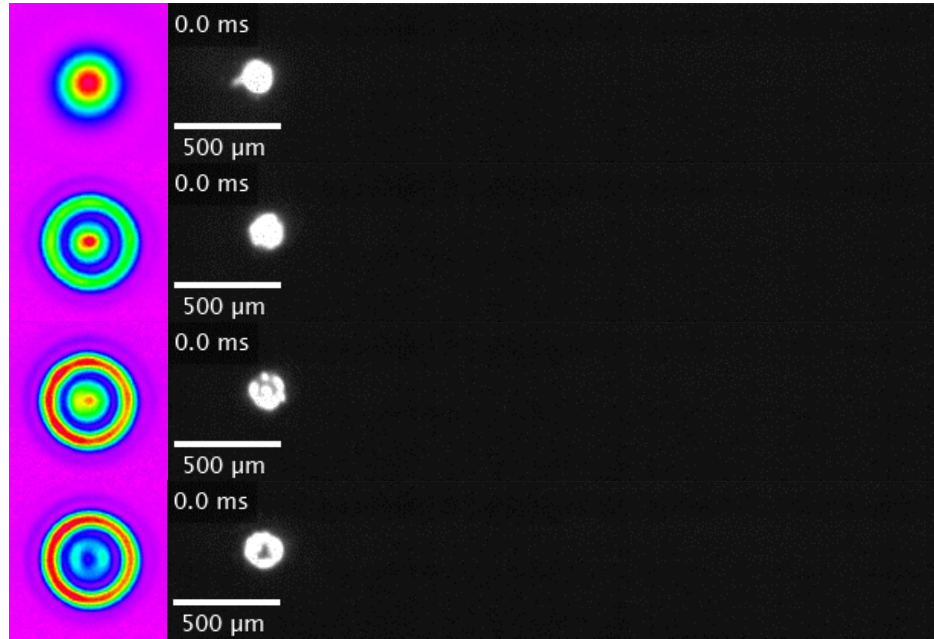
Experimental setup with extended exposure and monitoring options



Multi-core fiber – Process stability and spatter detection



Multi-core fiber – Process stability and spatter detection



95/5 $M = 2$ $2w_0 = 176.2 \mu\text{m}$

$P_{\text{laser}} = 300 \text{ W}$

$v_{\text{scan}} = 800 \text{ mm/s}$

40/60 $M = 1$ $2w_0 = 189.8 \mu\text{m}$

$P_{\text{laser}} = 300 \text{ W}$

$v_{\text{scan}} = 800 \text{ mm/s}$

20/80 $M = 1$ $2w_0 = 197.5 \mu\text{m}$

$P_{\text{laser}} = 300 \text{ W}$

$v_{\text{scan}} = 800 \text{ mm/s}$

10/90 $M = 1$ $2w_0 = 205.4 \mu\text{m}$

$P_{\text{laser}} = 300 \text{ W}$

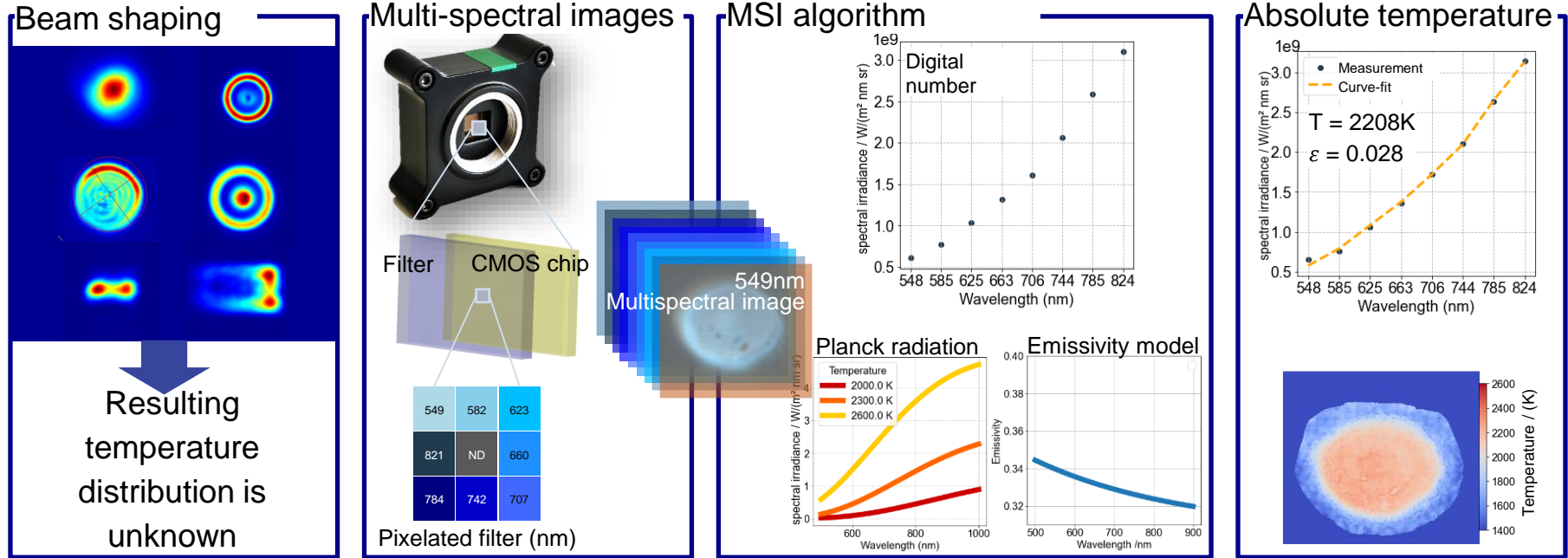
$v_{\text{scan}} = 800 \text{ mm/s}$

Grünewald, J., Reimann, J., & Wudy, K. (2023). Influence of ring-shaped beam profiles on spatter characteristics in laser-based powder bed fusion of metals. *Journal of Laser Applications*, 35(4).

Experimental setup with extended exposure and monitoring options

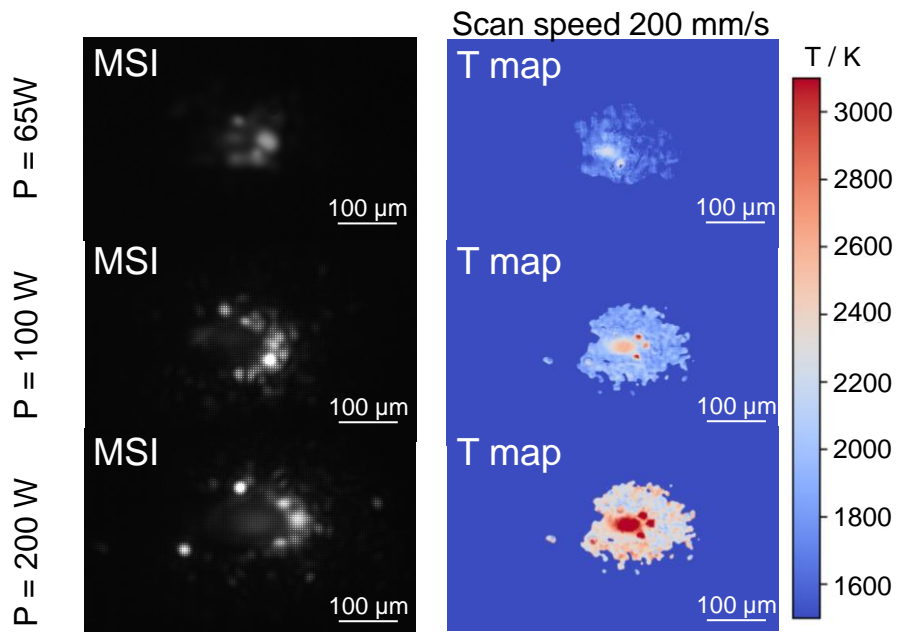


Multispectral Imaging – State of the art

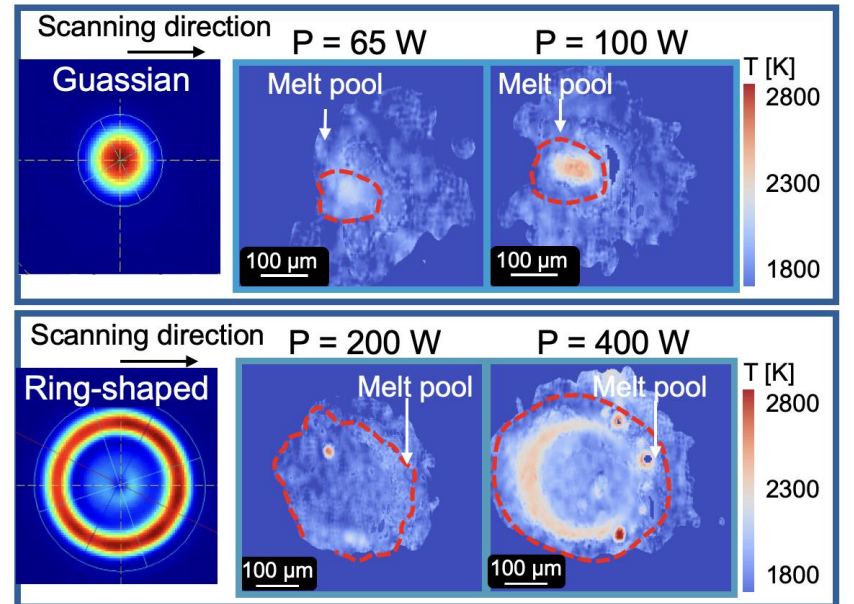


Temperature Map under different beam shape

Influence of Laser Power



Influence of different beam shapes

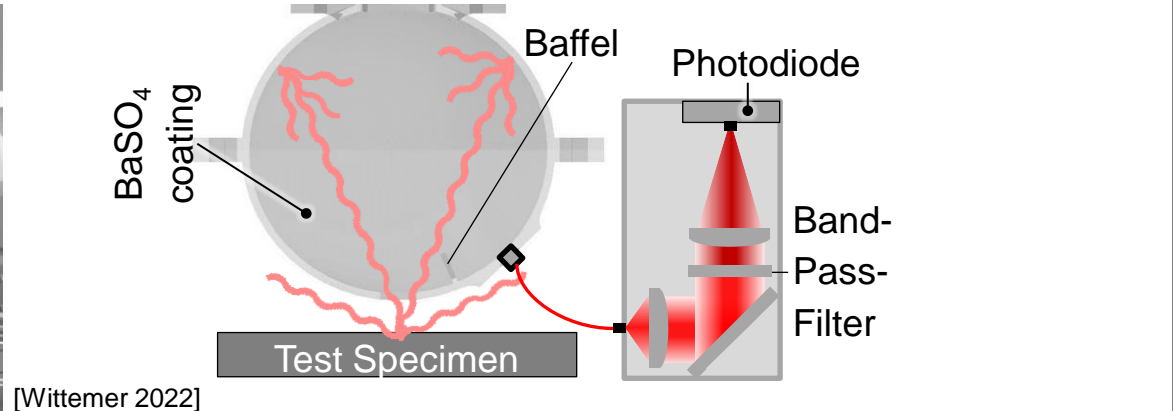
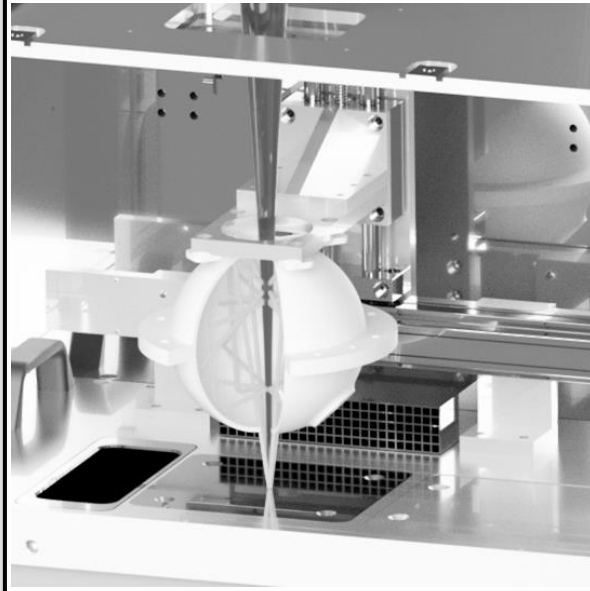


Experimental setup with extended exposure and monitoring options



Methodology – Integrating sphere measurement

Sphere-based setup

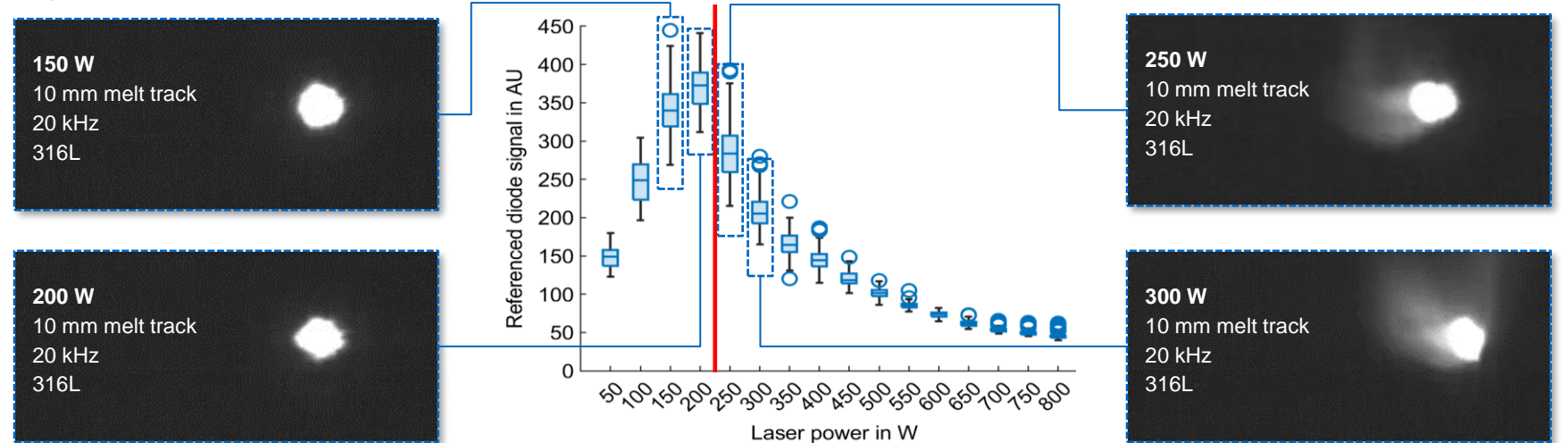


- Small measuring area (1 cm^2)
- Limited gas flow speed due to sphere interference
- + Low complexity and hardware cost
- + Low data processing effort

Reflection monitoring & sensor fusion

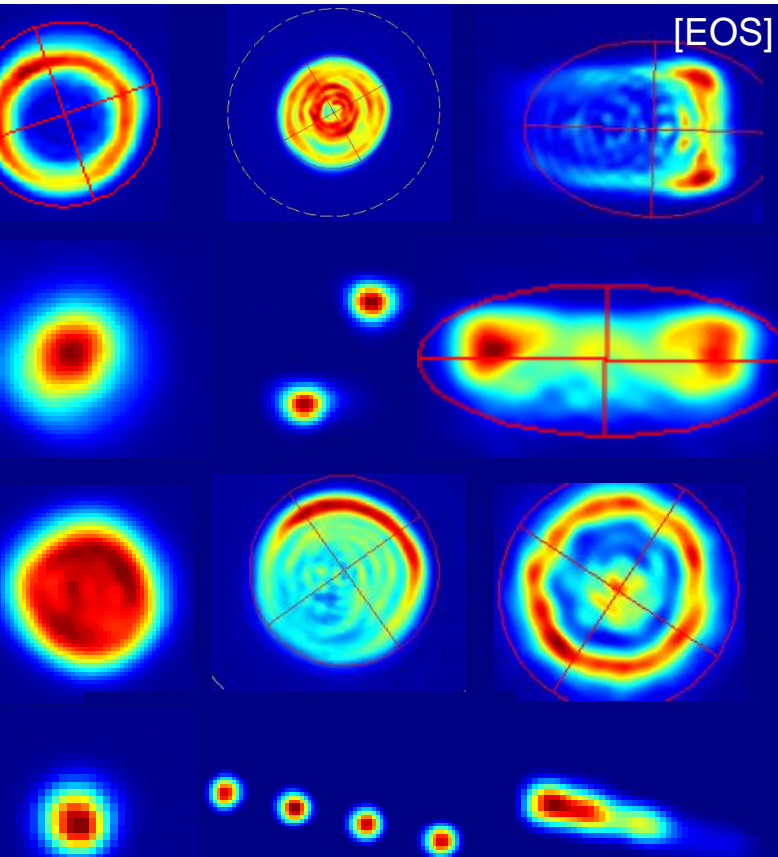
[Wittermer 2023]

Signal characteristic over laser power increase



Increased absorption due to geometry change of the melt pool and absorption in the plume

▶ The start of the sphere-based signal decrease coincides with the onset of vapor formation



Conclusion

LBAM is able to investigate the influence of new beam shapes on the process and process results

- From low TRL with infinite design space and extended monitoring capabilities
- To high TRL with industrial conditions

Alternative beam shapes enable

- improved process stability
- tailoring of microstructure

Outlook

Within the proposed ETN project the **beam shaping and monitoring capabilities are combined** to enable the **fast and reliable processability of two nickel-based alloys** with **desired microstructural properties**.

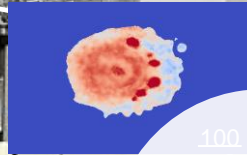
ETN project idea

Beam
Shaping

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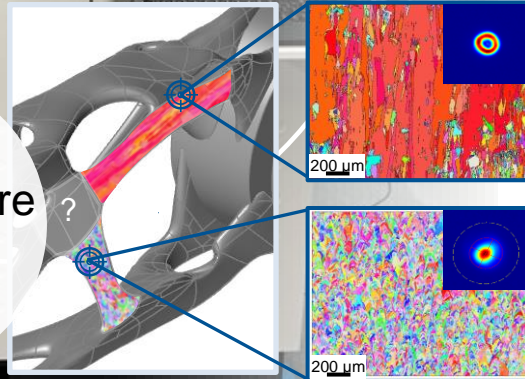
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200 μ m

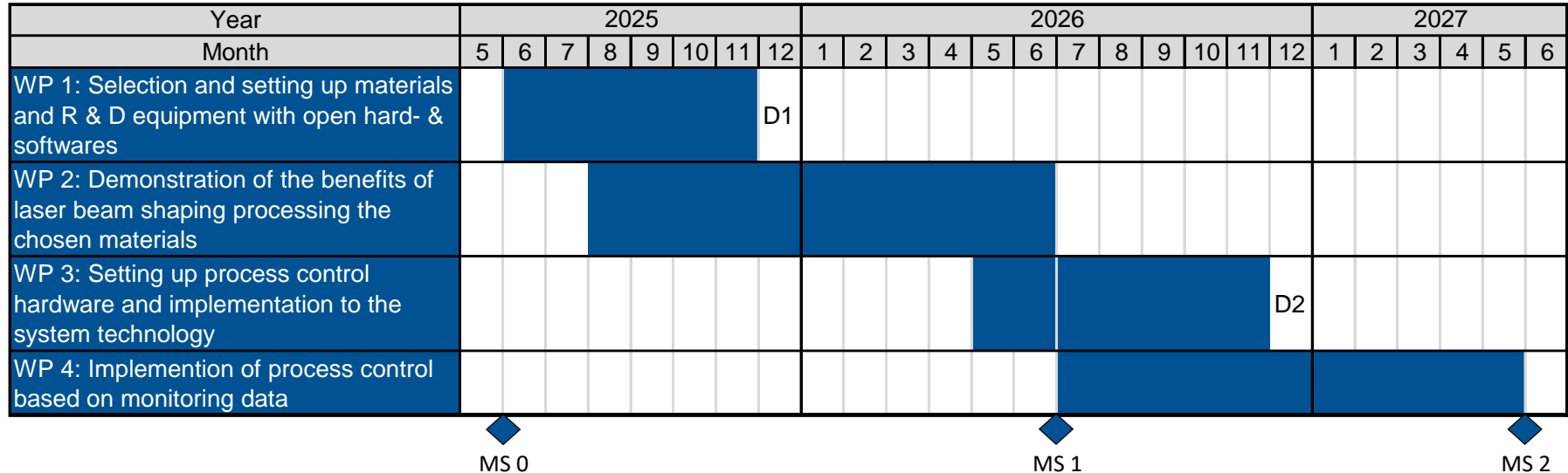
200 μ m



ETN Project Proposal

- Demonstration of microcrack-free PBF-LB/M of turbine for two defined high gamma prime alloys (e.g. IN939, AE13421) using state-of-the-art process strategies
- Implementation of beam shaping technology to improve the AM process productivity combined with the manufacturing of defect-free parts
- Implementation of monitoring systems to evaluate process behavior (thermal imaging, absorption measurements, and diode-based optical process emission measurements)
- Controlling the melting and solidification behavior for defect-free manufacturing based on the monitoring data of the demanding high gamma prime alloys
- Transfer to industrial equipment

ETN Project Proposal



Deliverable 1 – Report on recommendations on laser beam shaping equipment and process setup.

Deliverable 2 – Report on recommendations on melt pool monitoring/controlling.

Milestone 0 - Start of the project, **Milestone 1** - Laser beam shaping equipment and process setup capabilities demonstrated,

Milestone 2 - Demonstrate melt pool monitoring/controlling.

Thanks to the team!



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