Jikai Wang, Volker Rominger and Daniel Flamm

Machine-learning driven laser beam characterization

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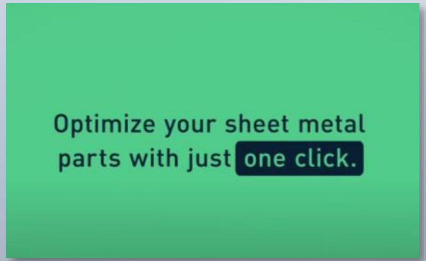
AI at TRUMPF

Machine Tools

Laser Technology



Optimate

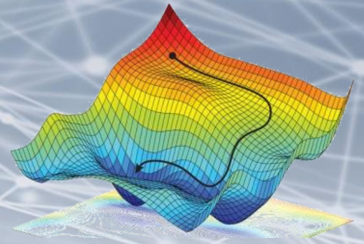
AI Filter & EasyModel AI for VisionLine Detect

TruLaser Center

Online Coherence Tomography

Sorting Guide

Hybrid Model



TRUMPF Laser Application Center (LAC)

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75% of the resources are used for customer requests
25% of the resources are used for research and development

High variety in laser applications

- Cutting
- Welding
- Marking
- Micro processing
- …

5000 application requests with
1000 visits and
500 standard demos per year

Over 200 kW output laser power in total

about **140** employees in
8 different locations worldwide

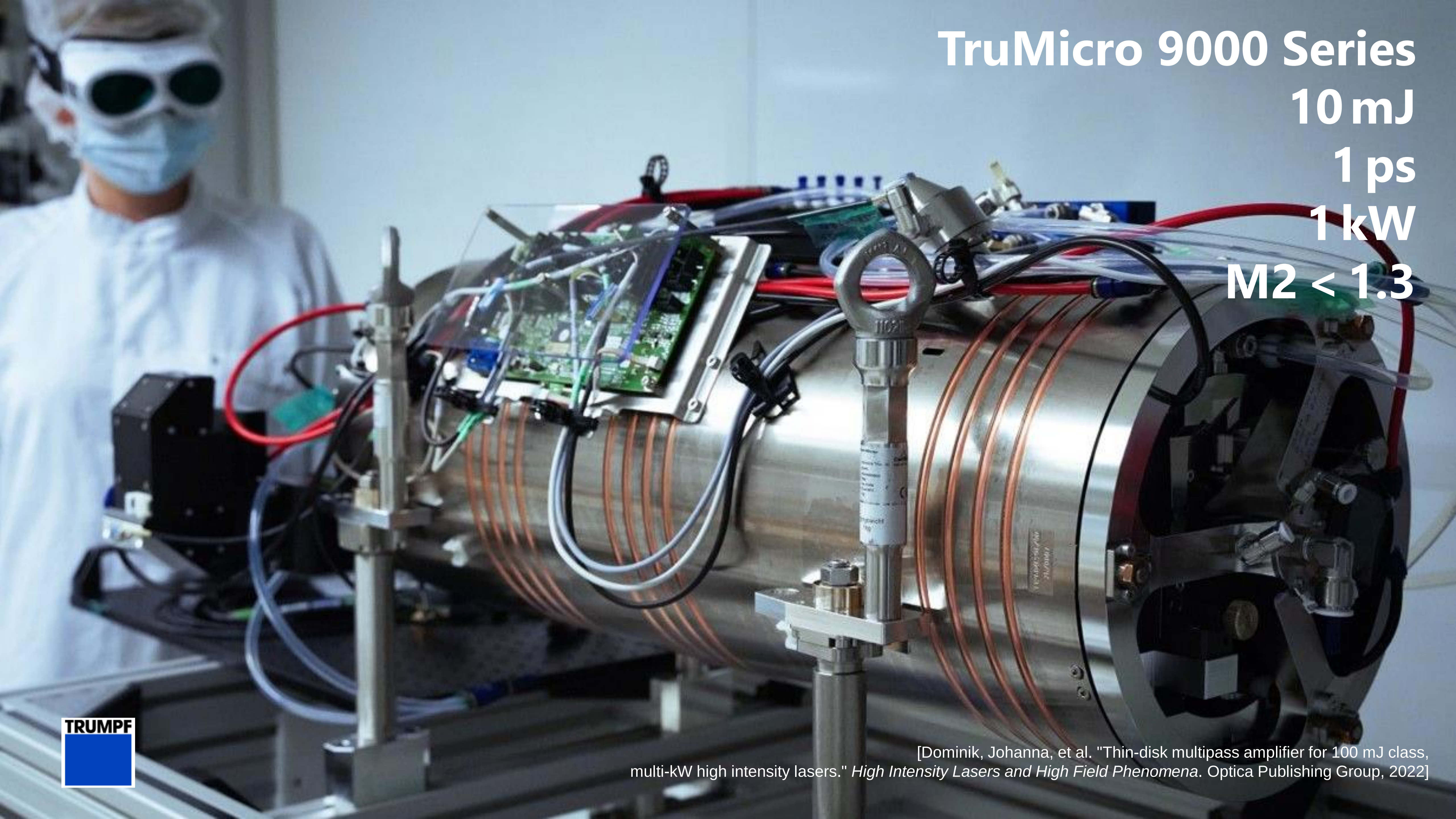
TruMicro 9000 Series

10 mJ

1 ps

1 kW

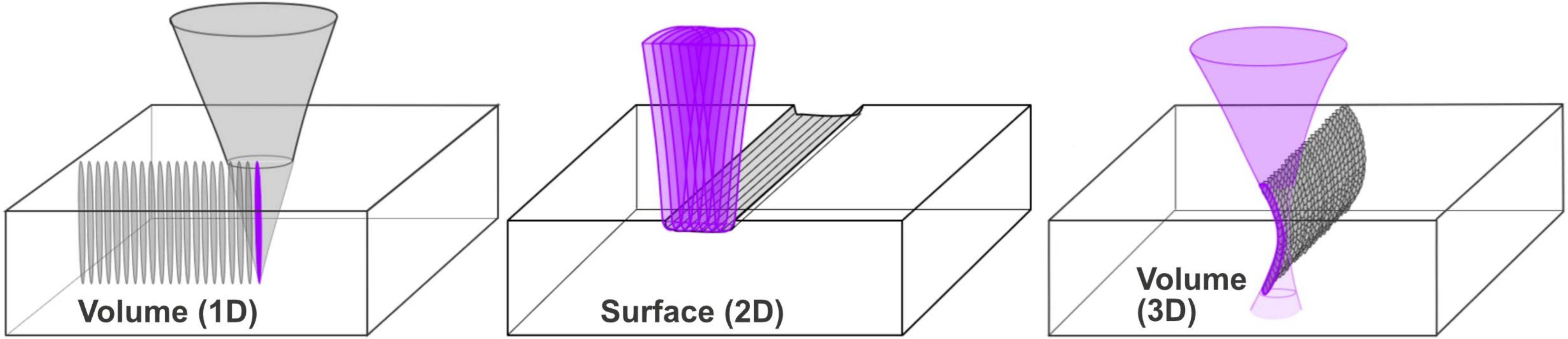
M2 < 1.3



[Dominik, Johanna, et al. "Thin-disk multipass amplifier for 100 mJ class, multi-kW high intensity lasers." *High Intensity Lasers and High Field Phenomena*. Optica Publishing Group, 2022]

Simultaneous Processing of Large Working Volumes or Areas

Structured light concepts for parallel processing



[Flamm, D., *et al.*, Opt. Engineering 60, 2, 025105, (2021)]

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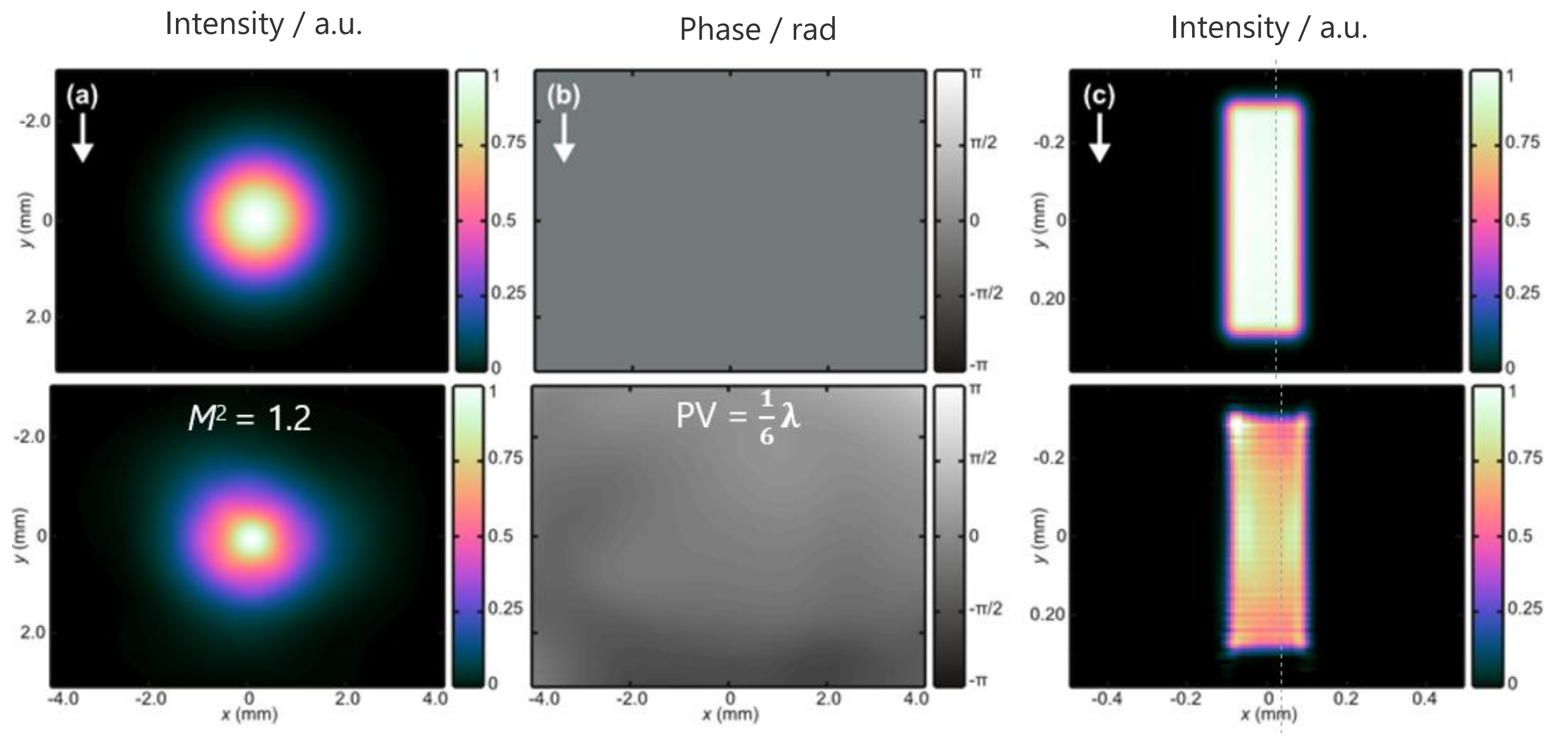
Flat-top generation with field mapper

Best beam quality required for certain applications

Ideal case

Real case: TruMicro 9000



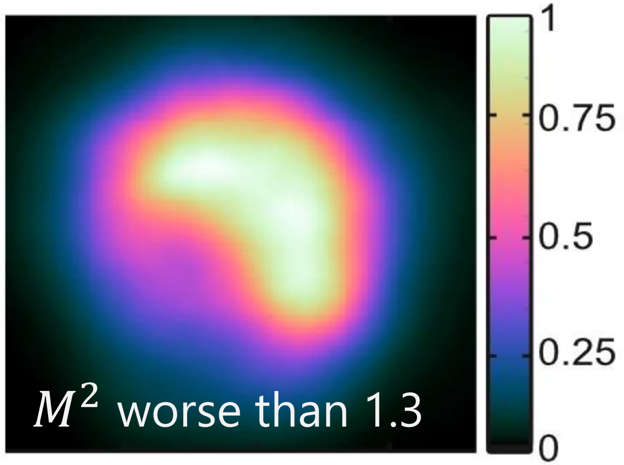
[Mathews, D, et al., *Laser-based Micro-and Nanoprocessing XVIII. Vol. 12873. SPIE*, 2024.]

Stabilization and improvement of beam quality

Main goal: Beast beam quality from AO and ML

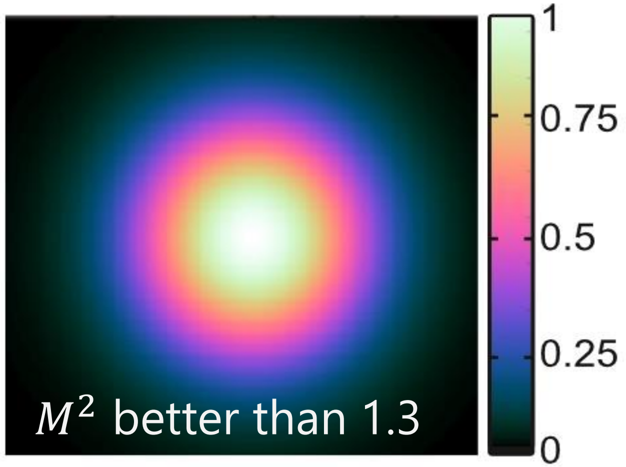
What we face:

High-power/ high-energy Laser → Beam Transportation →



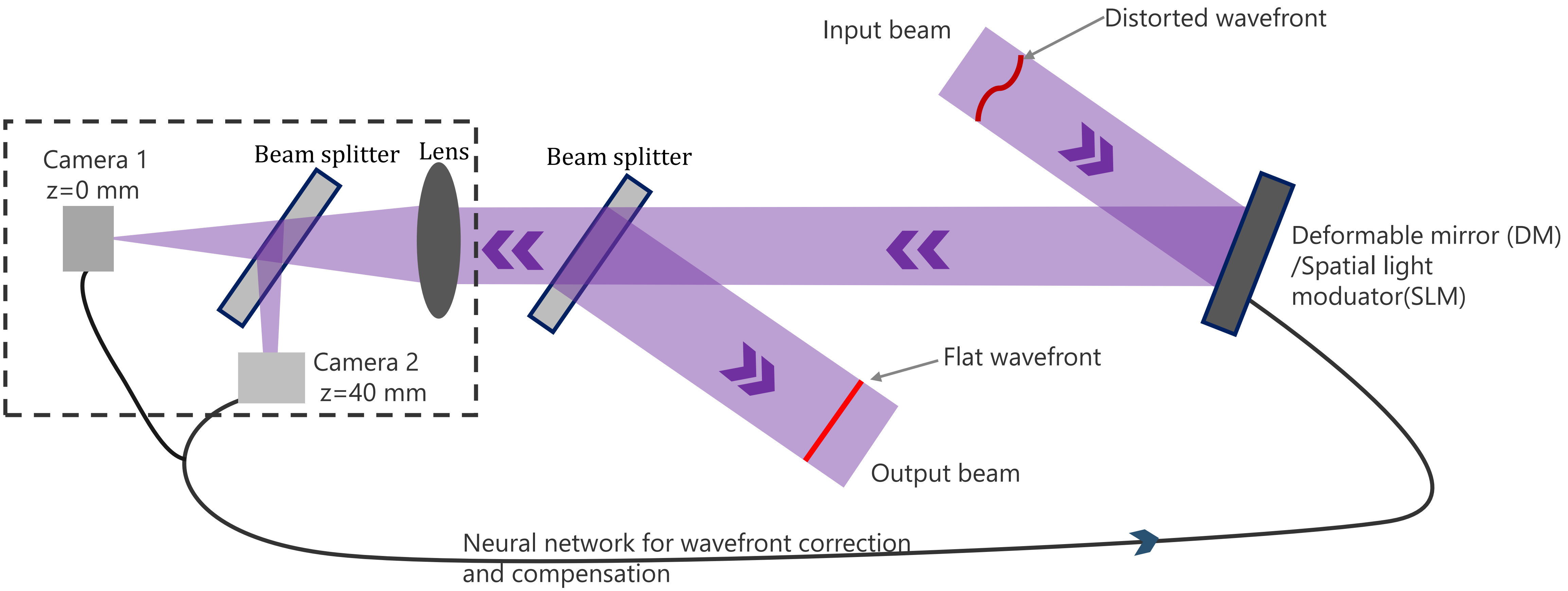
What we need:

High-power/ high-energy Laser → Beam Transportation → **Adaptive optics with machine learning** →



Deep learning driven adaptive optics

Requiring cameras-only instead of wavefront sensors

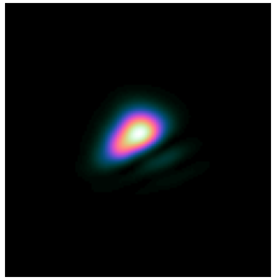


[Wang, J., et al., Laser+ Photonics for Advanced Manufacturing. Vol. 13005. SPIE, 2024.]

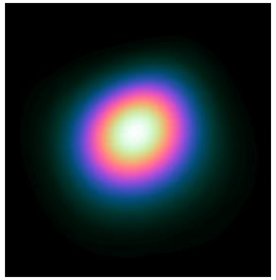
Deep learning: Convolutional U-Net

Optical field at hand with prediction time of ~100 ms

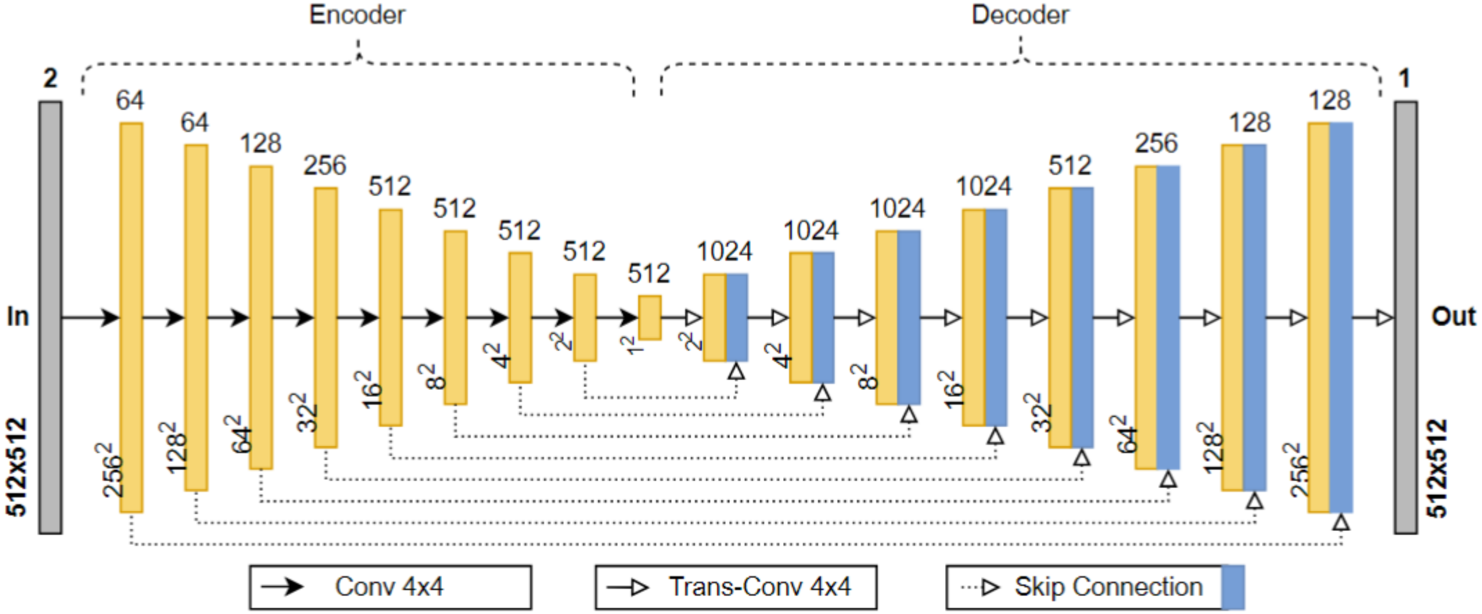
Camera 1



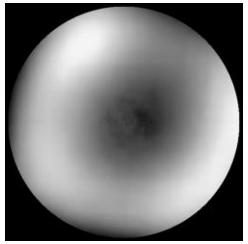
Camera 2

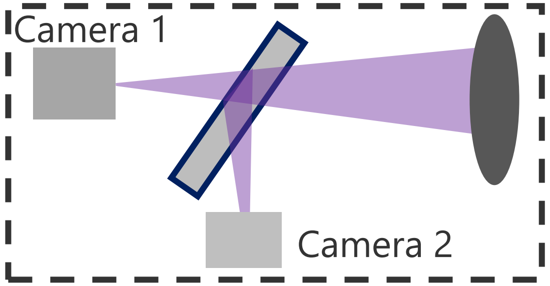


Convolutional U-Net



Predicted wavefront





Isola, P., Zhu, J. Y., Zhou, T., & Efros, A. A. (2017 In *Proceedings of the IEEE conference on computer vision and pattern recognition* (pp. 1125-1134)

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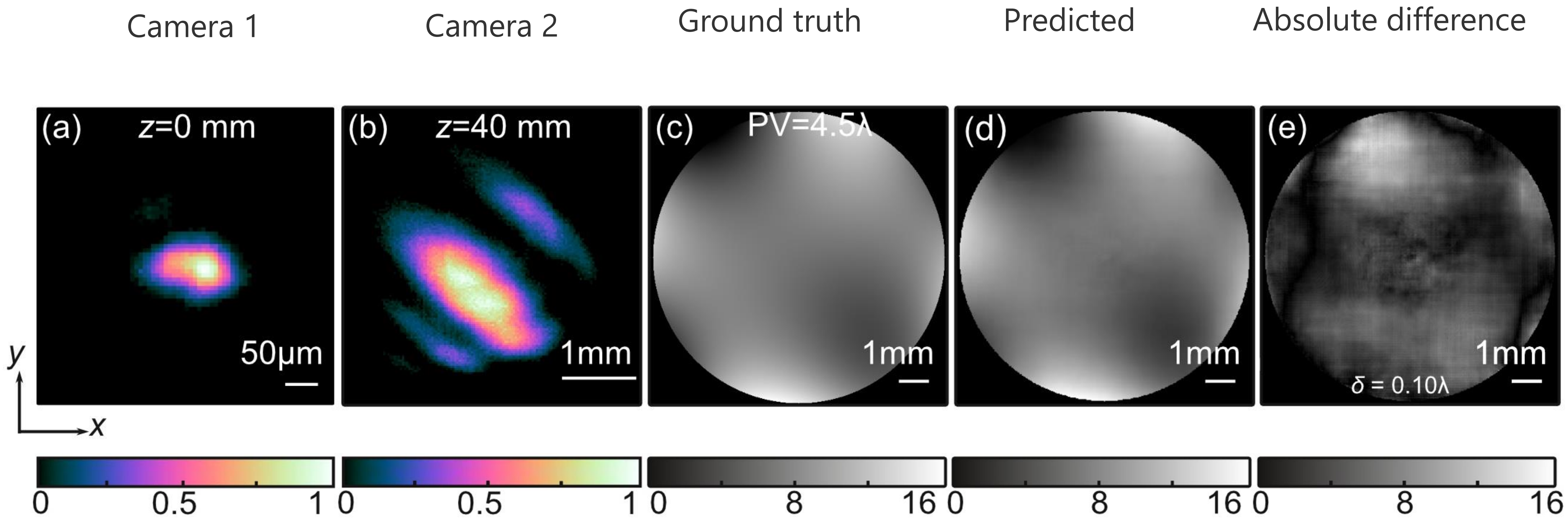
Example of phase prediction

Prediction accuracy comparable with that of interferometers



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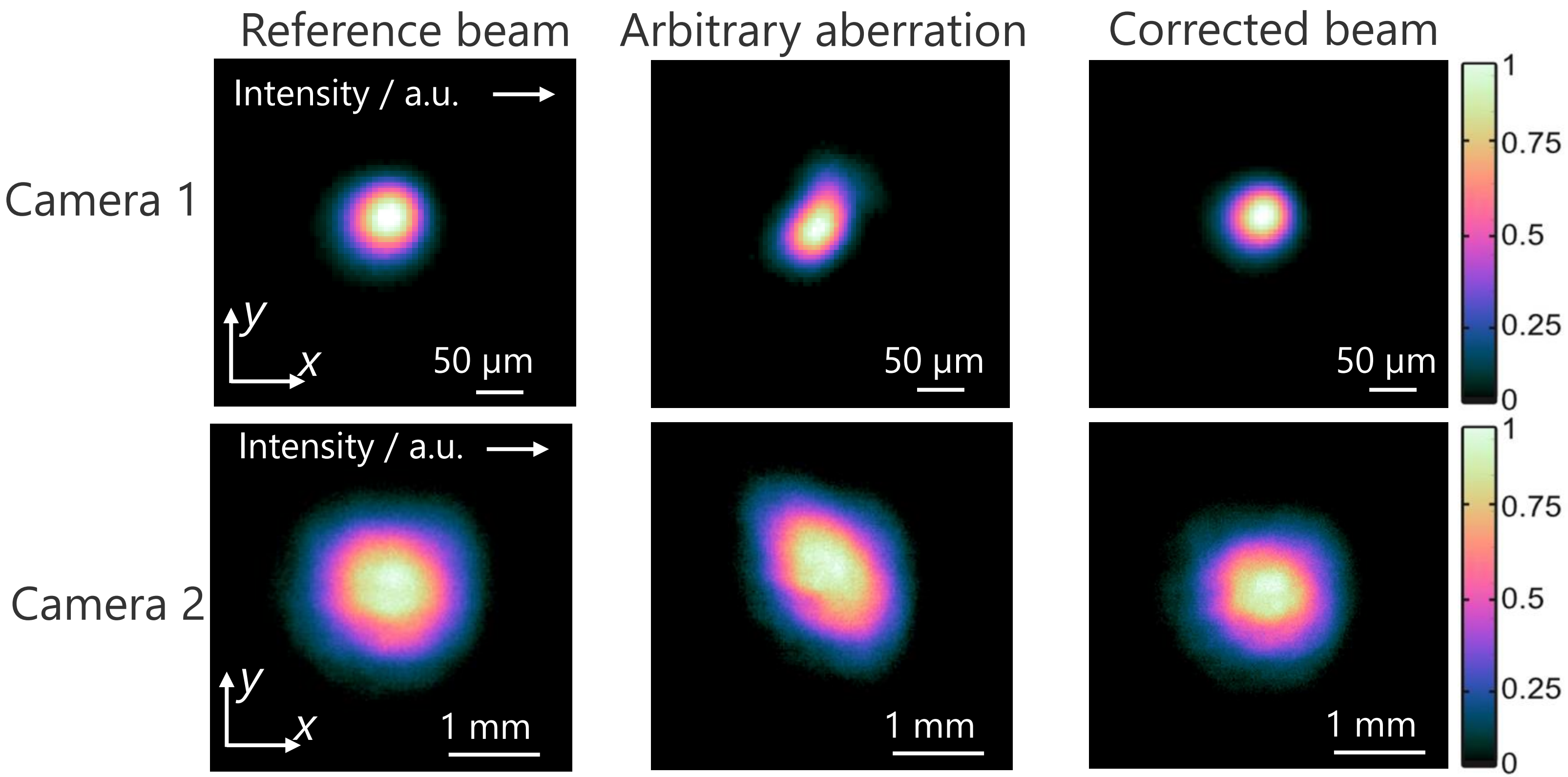
Correction result based on deep-learning

Real-time wavefront correction (~150ms)



Reference beam: Original beam without external aberration

Arbitrary aberration: Beam distorted with an arbitrary aberration

Corrected beam: Aberration compensated with <u>cameras and deep learning algorithm</u>

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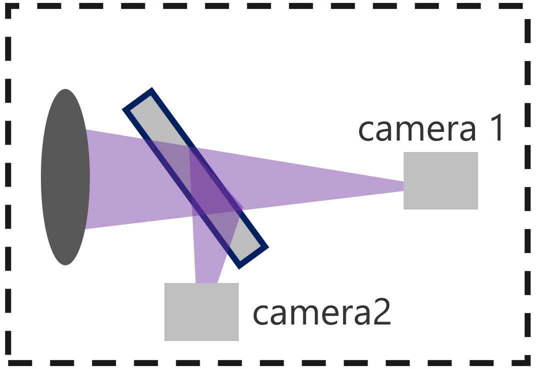
Summary

Low-cost device enabling real-time laser beam wavefront correction

Low-cost Device



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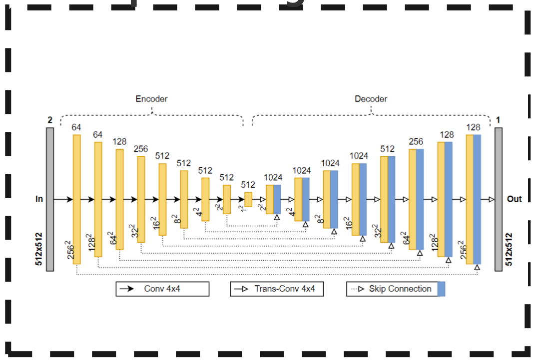
Deep learning network



1 Optical field access from two cameras and U-Net (intensity-only measurement)

2 Real-time prediction of the phase (~ 100ms)

3 Phase prediction accuracy comparable with interferometers ($\sim\frac{1}{17}\lambda$ @RMSE)

4 Successful implementation of closed-loop for beam quality enhancement

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Thank You.

Contact Person

Jikai Wang

Advanced Optical Systems - LAC

Jikai.wang@trumpf.com