

# Industrial Fiber Beam Delivery for Ultrafast Lasers

System Technology and Industrial Application

Bastian Kruschke

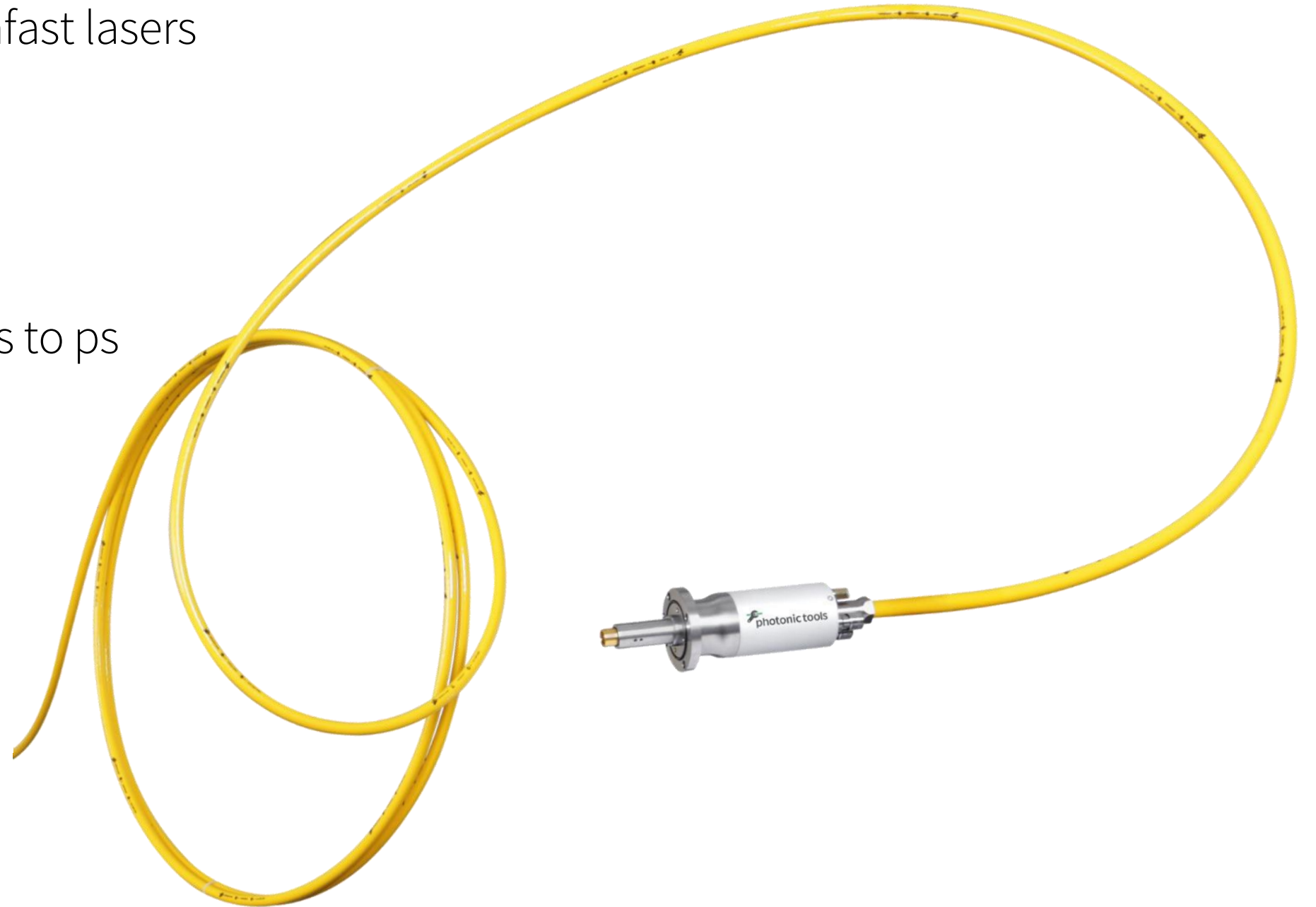
15.11.2017 | Swissphotonics Workshop | Specialty Optical Fibers



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# Motivation

- Photonic Tools' fiber beam delivery for ultrafast lasers is now employed in several installations
- Spotlight on performance
  - Compatible to 1  $\mu\text{m}$  laser sources from fs to ps
  - Fiber length up to 10 m
  - Transmission > 85%
  - Peak power > 1GW,
  - Polarization extinction ratio > 30:1



# Photonic Tools



- Photonic Tools´ task – and mission – is to provide the ultrafast laser industry with the industrial photonic tools enabling a productive industrial laser application!
- Located in Berlin-Adlershof, Europe´s largest technology park
- Started end of 2013 by the management team who also founded HIGHYAG Lasertechnologie in 1995

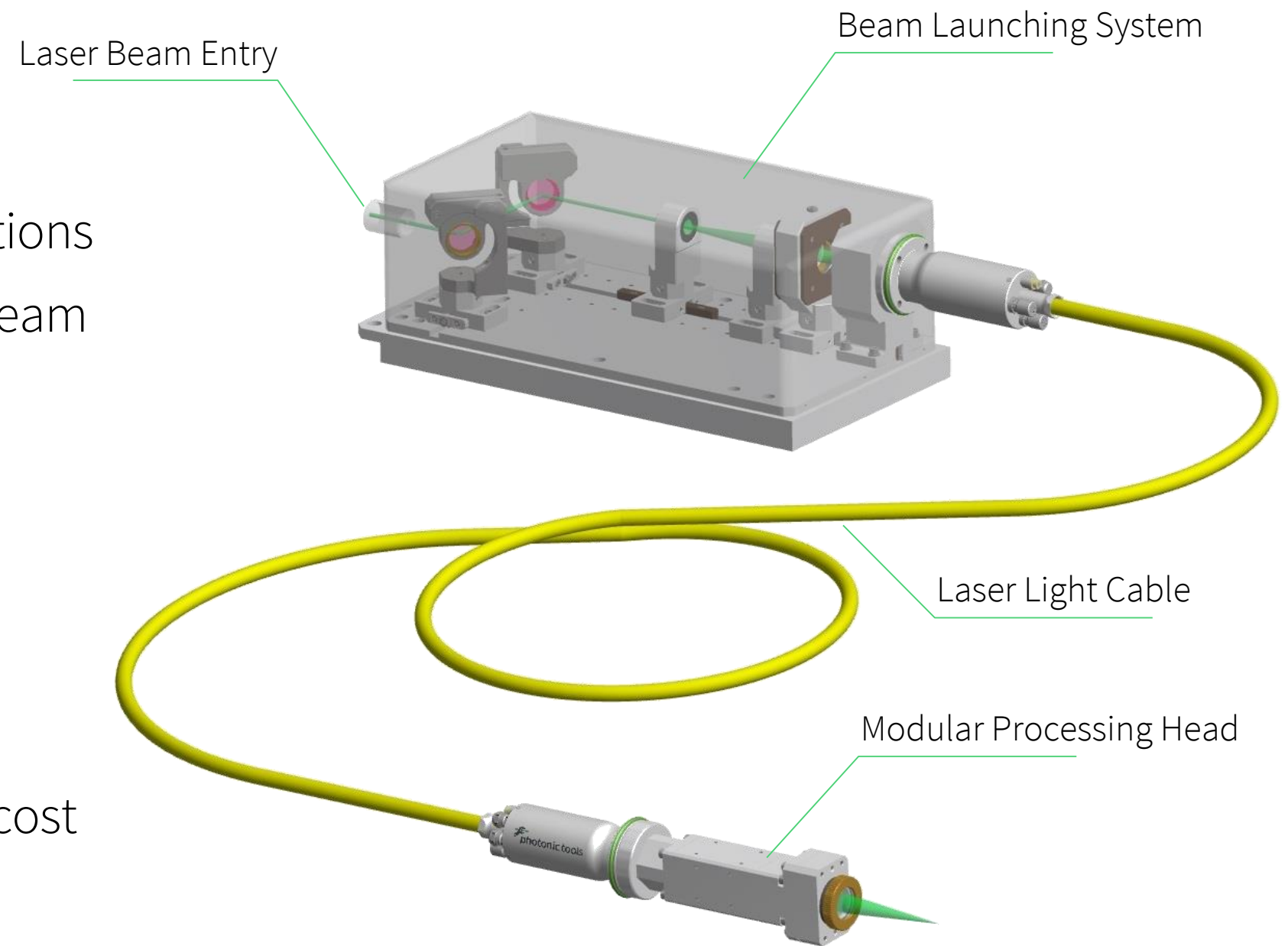
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# Agenda

- Motivation
- Industrial Fibre Beam Delivery System for Ultrafast Lasers
- Integration and System Technology
- Conclusion and Outlook

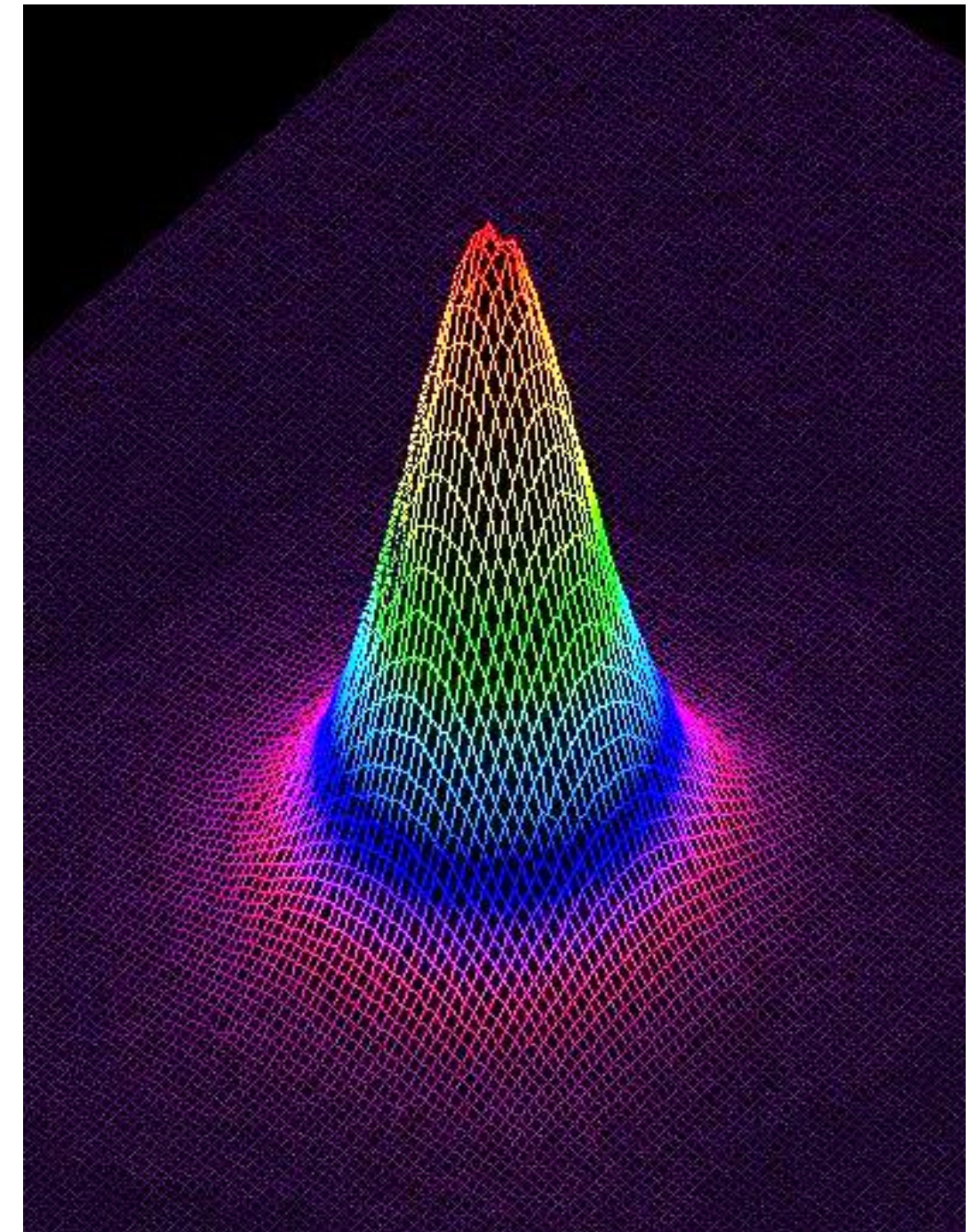
# Ultrafast Fiber Beam Delivery System

- Easy system integration
  - Separation of laser and application
  - Flexible routing and use in dynamic applications
  - Fiber tip as „tool center point“ for the laser beam
- Better service and cost-effectiveness
  - Limited to no need for realignment
  - Easy setup and exchange of components
  - Savings on installation, running and service cost



# Fiber Beam Delivery Performance

- High transmission and preserved pulses
  - Transmission typically 85- 90% for beam delivery system
  - Pulse duration preserved (+/- 10%)
  - Good polarization maintainance (PER > 30:1)
- Excellent beam quality
  - Typical  $M^2 = 1.2 - 1.4$
  - Very symmetrical Gaussian beam profile

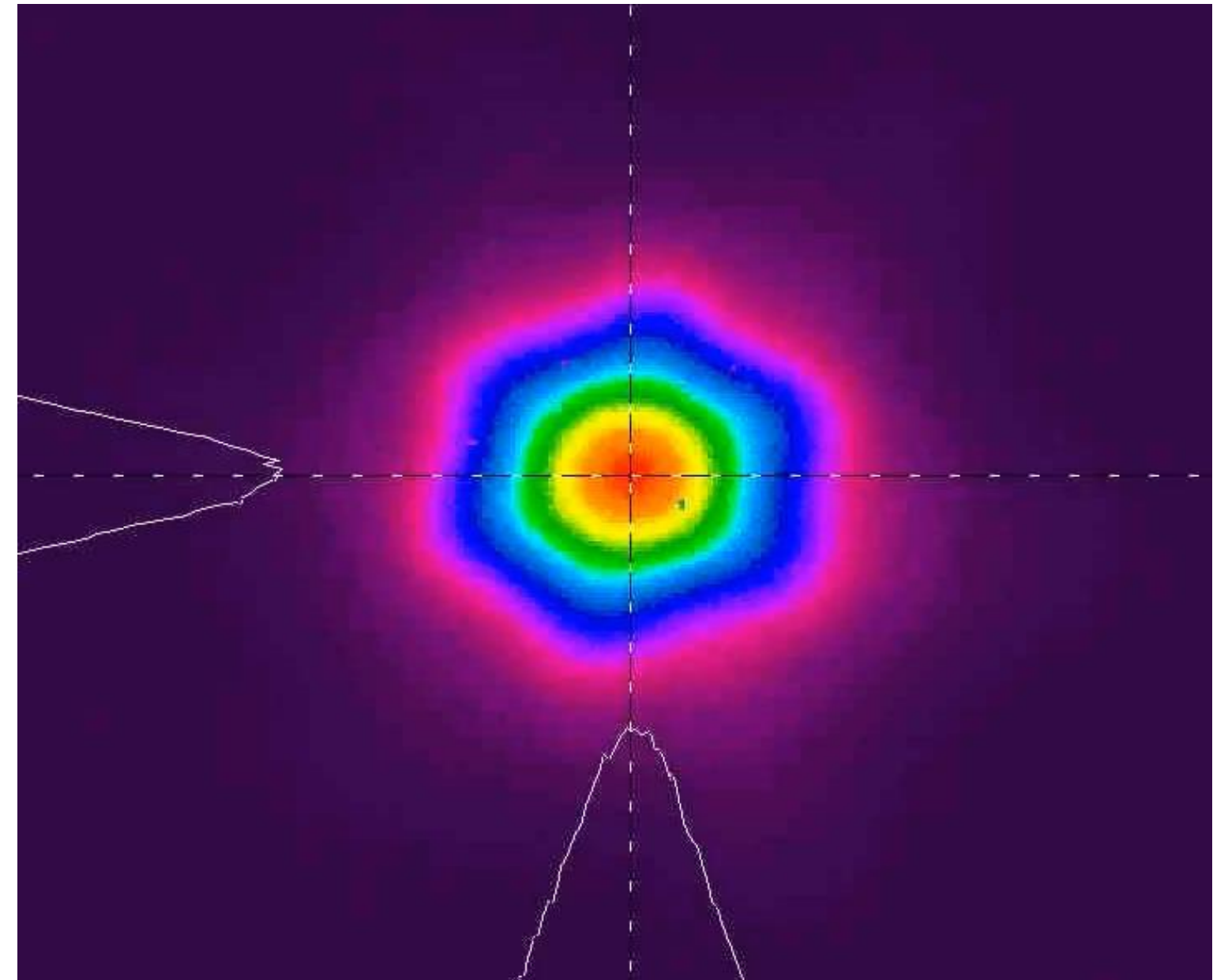


# Fiber Beam Delivery Performance

- Marginal change in modal content
  - Very small movement of center of gravity ~ 1% of spot
  - Impact on intensity profile mostly in “outer fringes” of the beam profile
- Transmitted power stays constant (~1%)

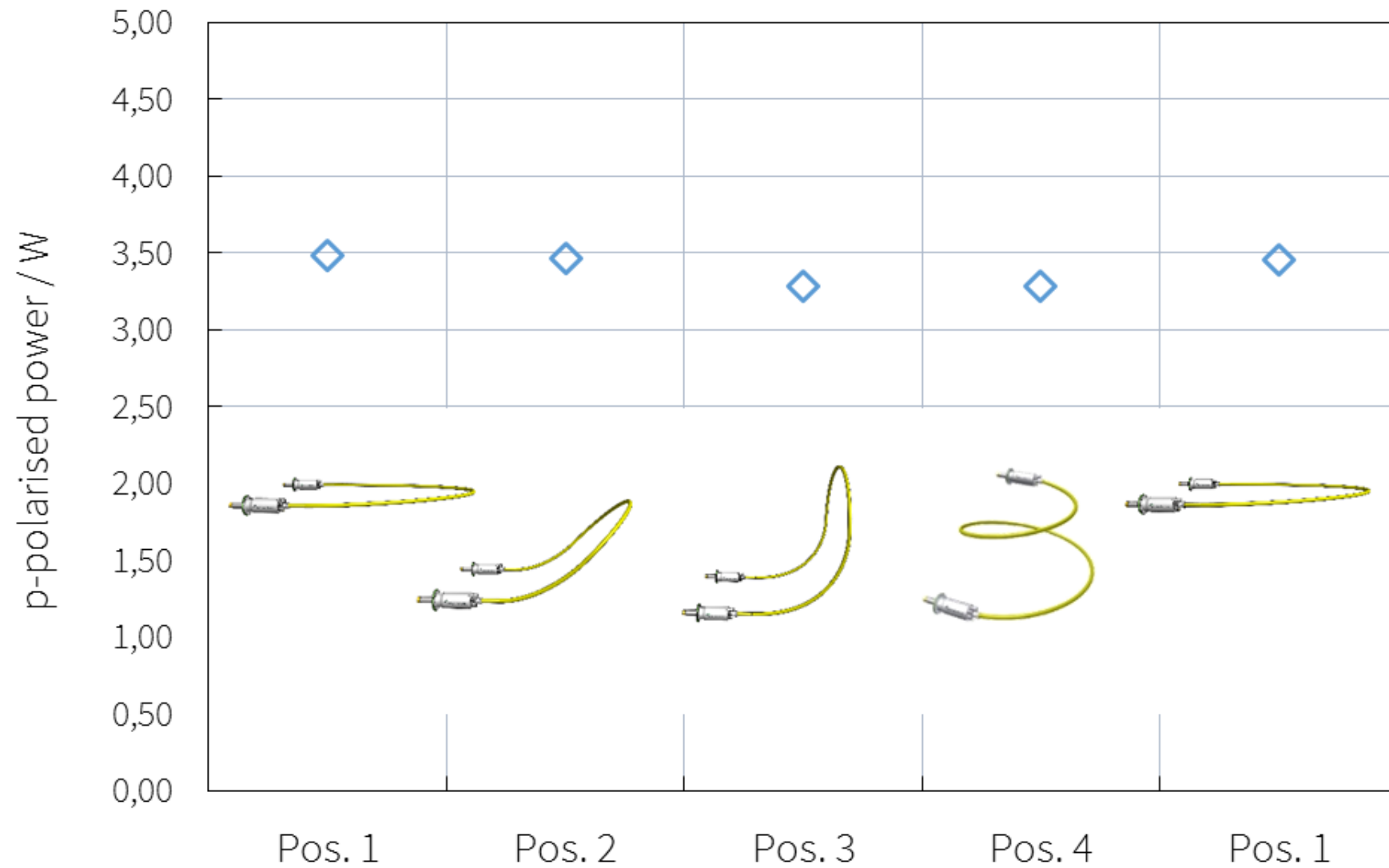


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Near-field time lapse during cable movement

# Fiber Beam Delivery Performance

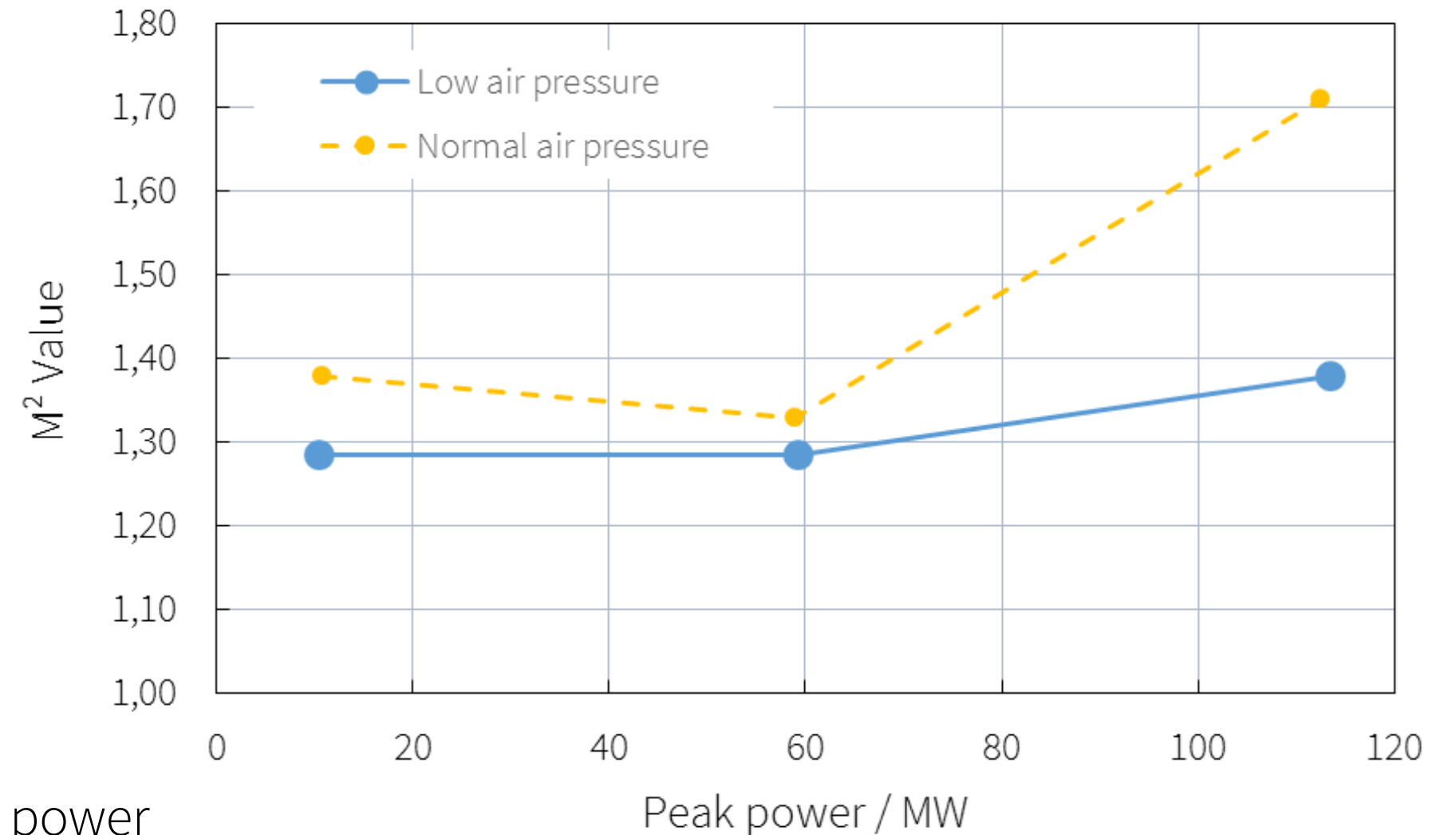


- Polarization maintained in applications with static laser light cable
- Polarization stabilization implemented for dynamic application (PER > 30:1)
- Laser light cable is insensitive to bending operation

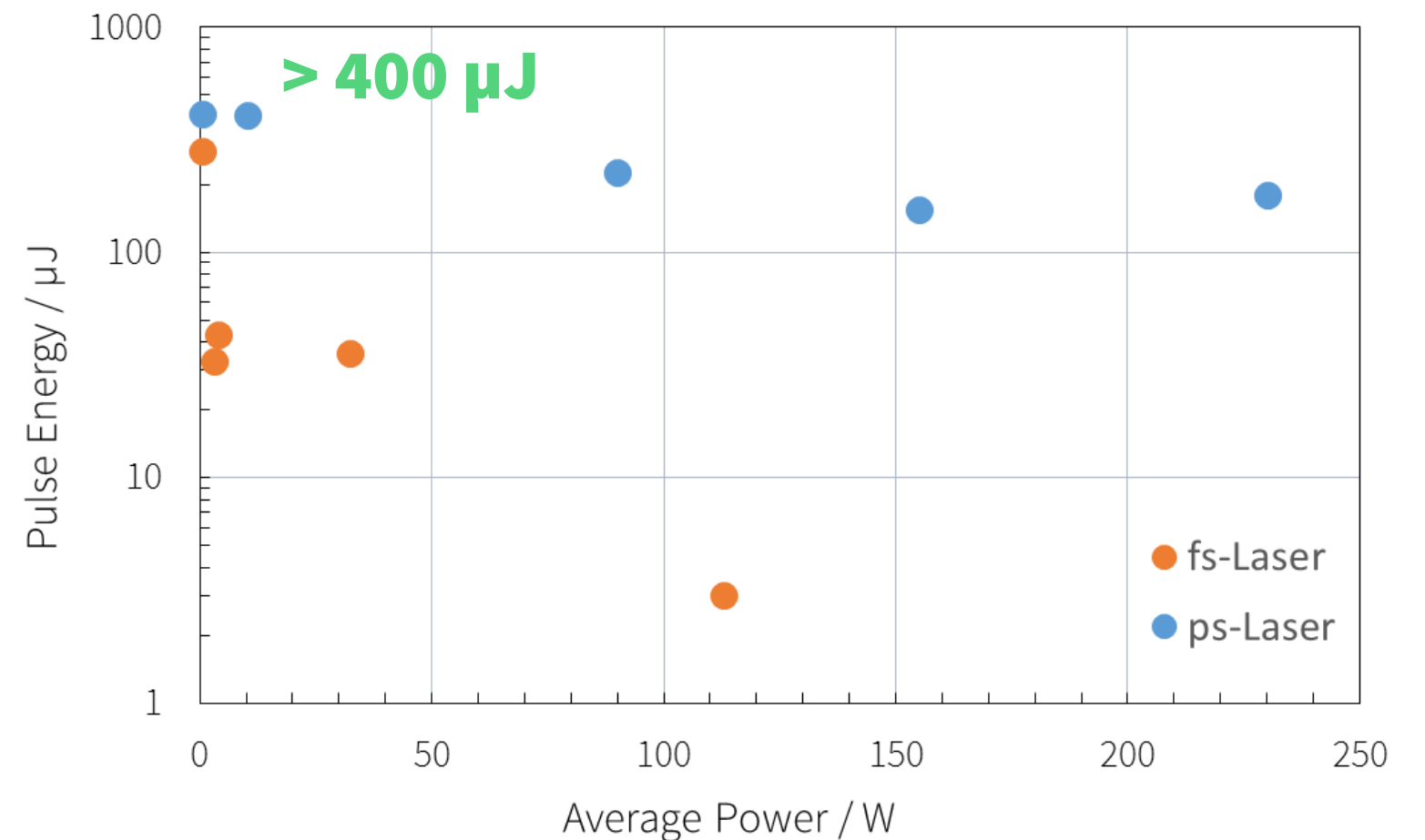
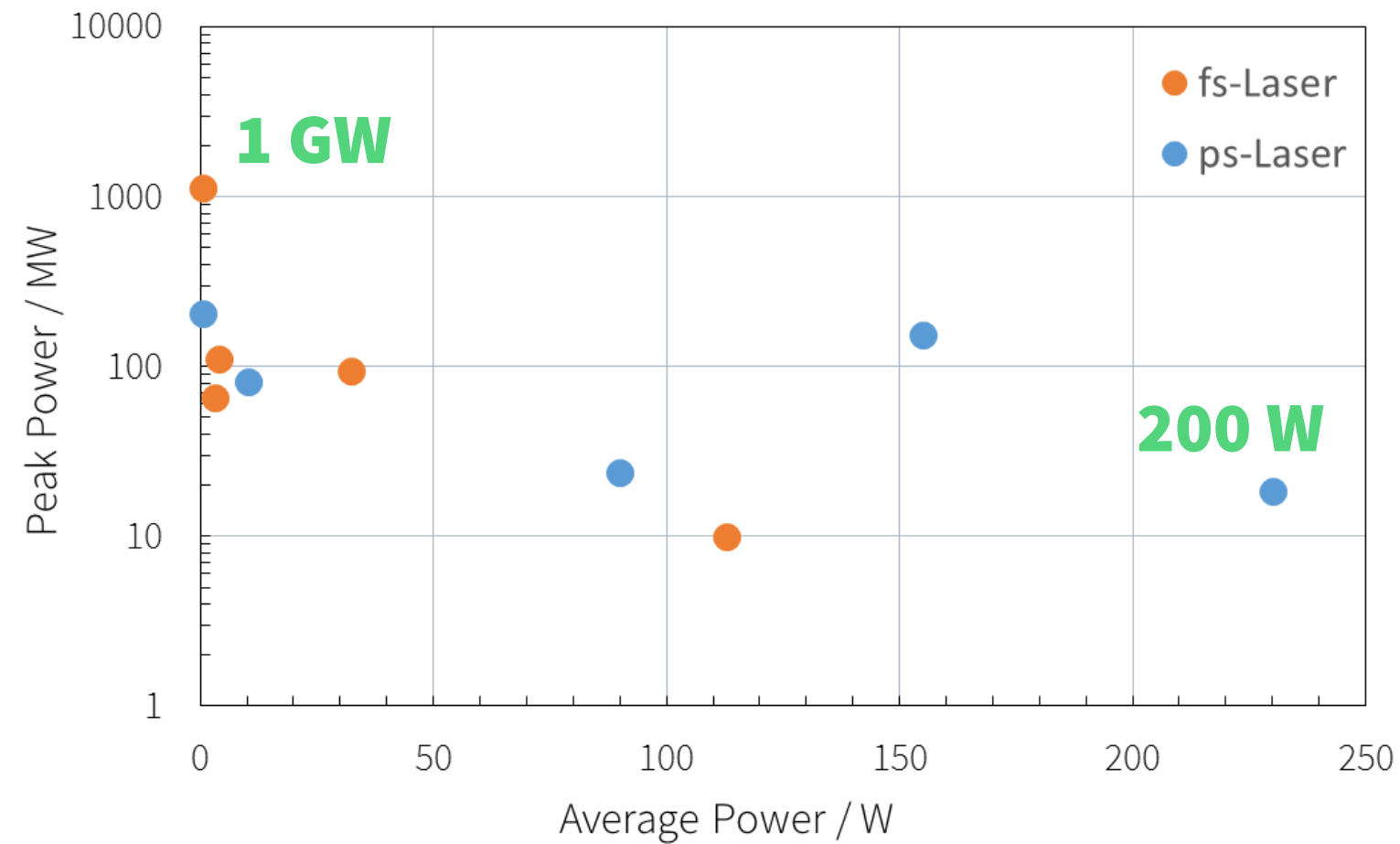


# Fiber Beam Delivery Performance

- Nonlinear effects in air
  - Higher order modes potentially excited
  - Spectral broadening
  - Increased pulse duration
  - Beam quality degradation
- Solution
  - Control of gas pressure inside fiber
  - Laser light cable features gas connector
  - Nonlinearity controlled for > 100 MW peak power



# Overview of Application Results

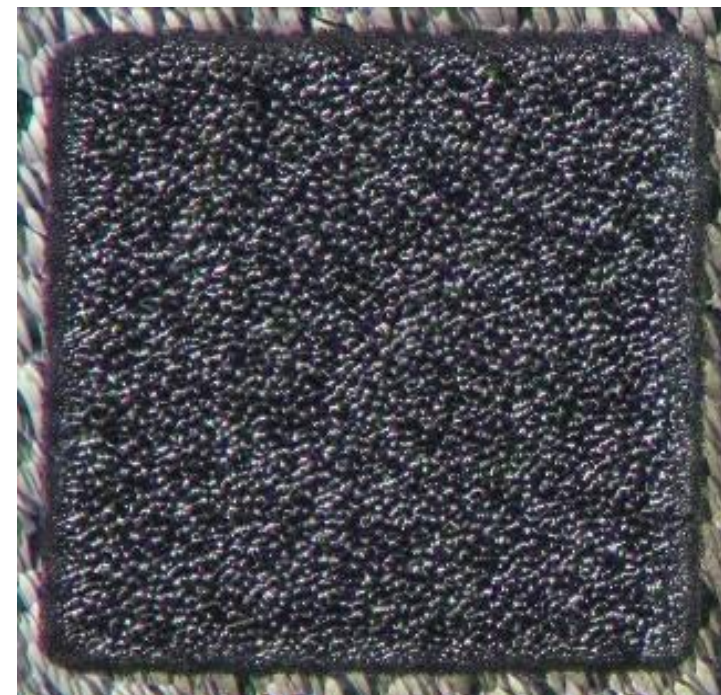
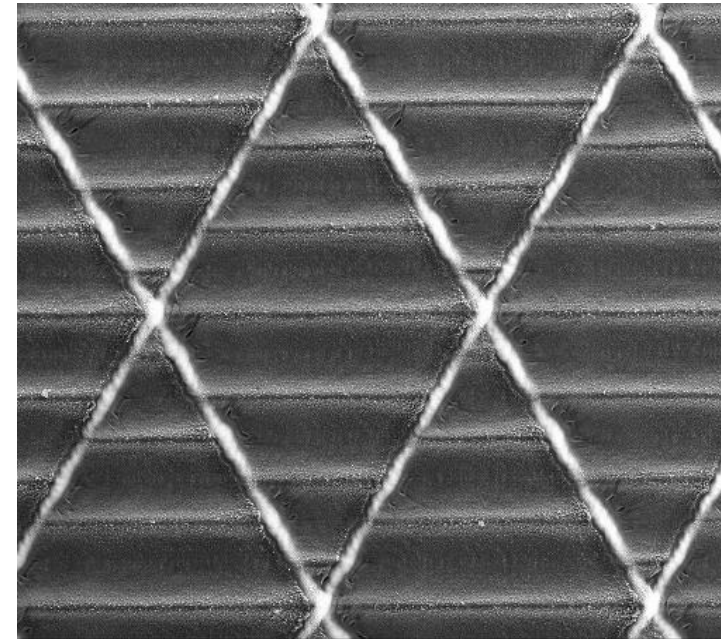


● Broad range of laser parameters can be addressed

# Application of Fiber Beam Delivery

- Shark skin structure
  - Fiber beam delivery with collimation unit directly attached to scanning system
  - Identical results to free-space beam delivery
  
- Silicon surface patterning
  - Fiber beam delivery to scanning system
  - Gas pressure used to increase spectrum
  - Improved ablation results (factor of 2)

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Parameter	Value	Unit
Power	1	W
Pulse energy	5	$\mu\text{J}$
Pulse duration	10	ps
Scan speed	4.4	m/s

Parameter	Value	Unit
Power	12.5	W
Pulse energy	12.5	$\mu\text{J}$
Pulse duration	750	fs
Scan speed	4	mm/s

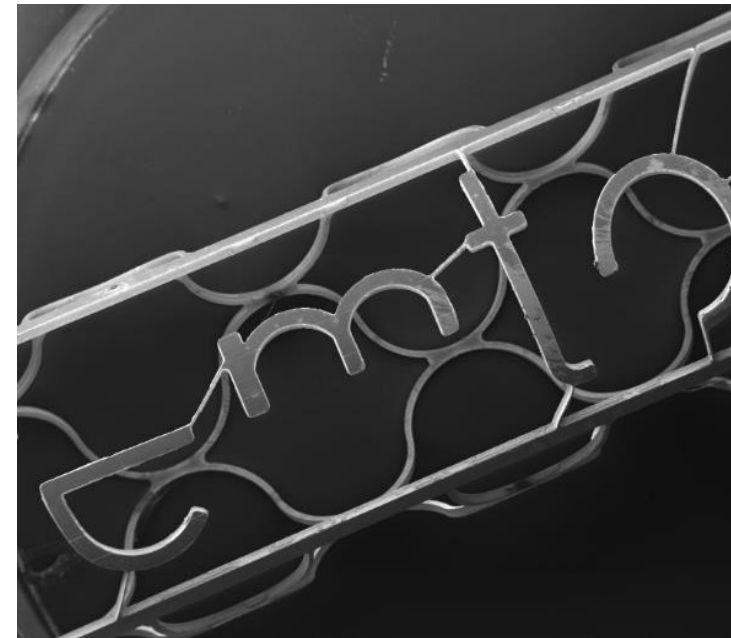
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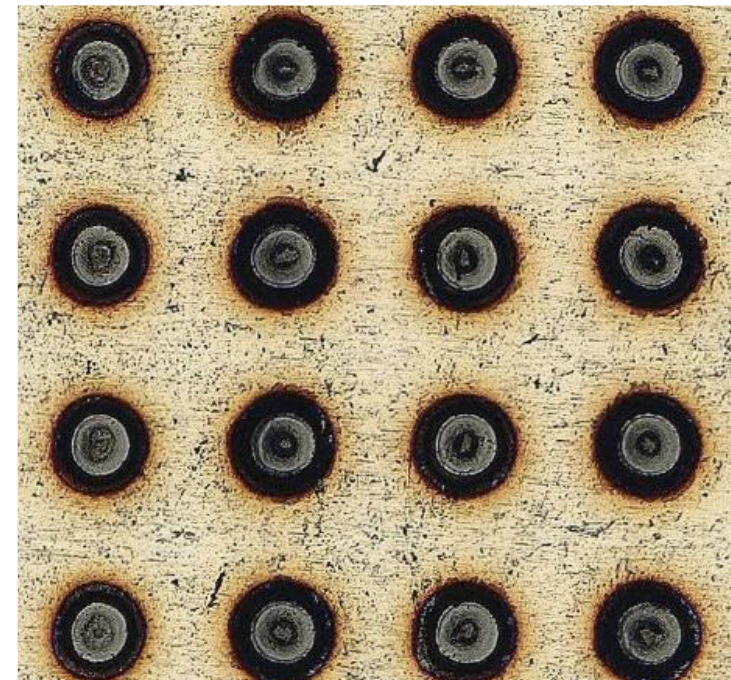
# Application of Fiber Beam Delivery

- Nitinol stent cutting with fs-laser
  - Fiber beam delivery to focusing system
  - Cutting shows better homogeneity
  - Daily alignment obsolete
  
- Spot Patterning
  - Fiber beam delivery to scanning system
  - Highly dynamic and strong fiber bending
  - Better spot roundness as laser with free space beam delivery

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Parameter	Value	Unit
Power	4	W
Pulse energy	4	μJ
Pulse duration	350	fs
Scan speed	-	m/s



Parameter	Value	Unit
Power	20	W
Pulse energy	3	μJ
Pulse duration	20	ps
Scan speed	-	m/s

In cooperation with femtos and Fraunhofer ILT

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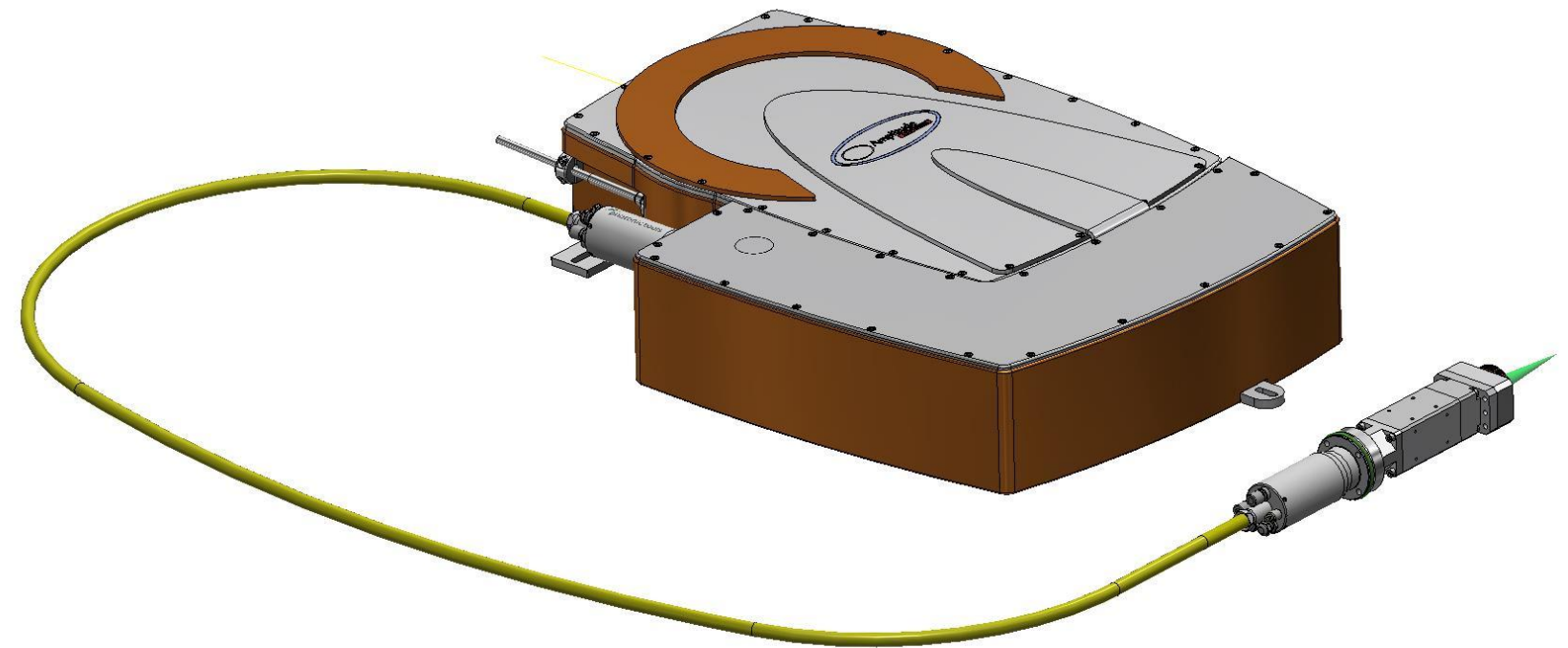
# System Integration of Laser and Beam Launching

- Status quo fiber beam delivery
  - Modular system structure
  - Very flexible application to a broad range of laser sources
  - Laser and Beam Launching Unit mounted on common base (e.g. optical table)
- Desire for laser-integrated fiber coupling
  - Smaller footprint
  - Only one system to mount on a machine
  - Simplified assembly (no beam alignment)

# System Integration of Laser and Beam Launching

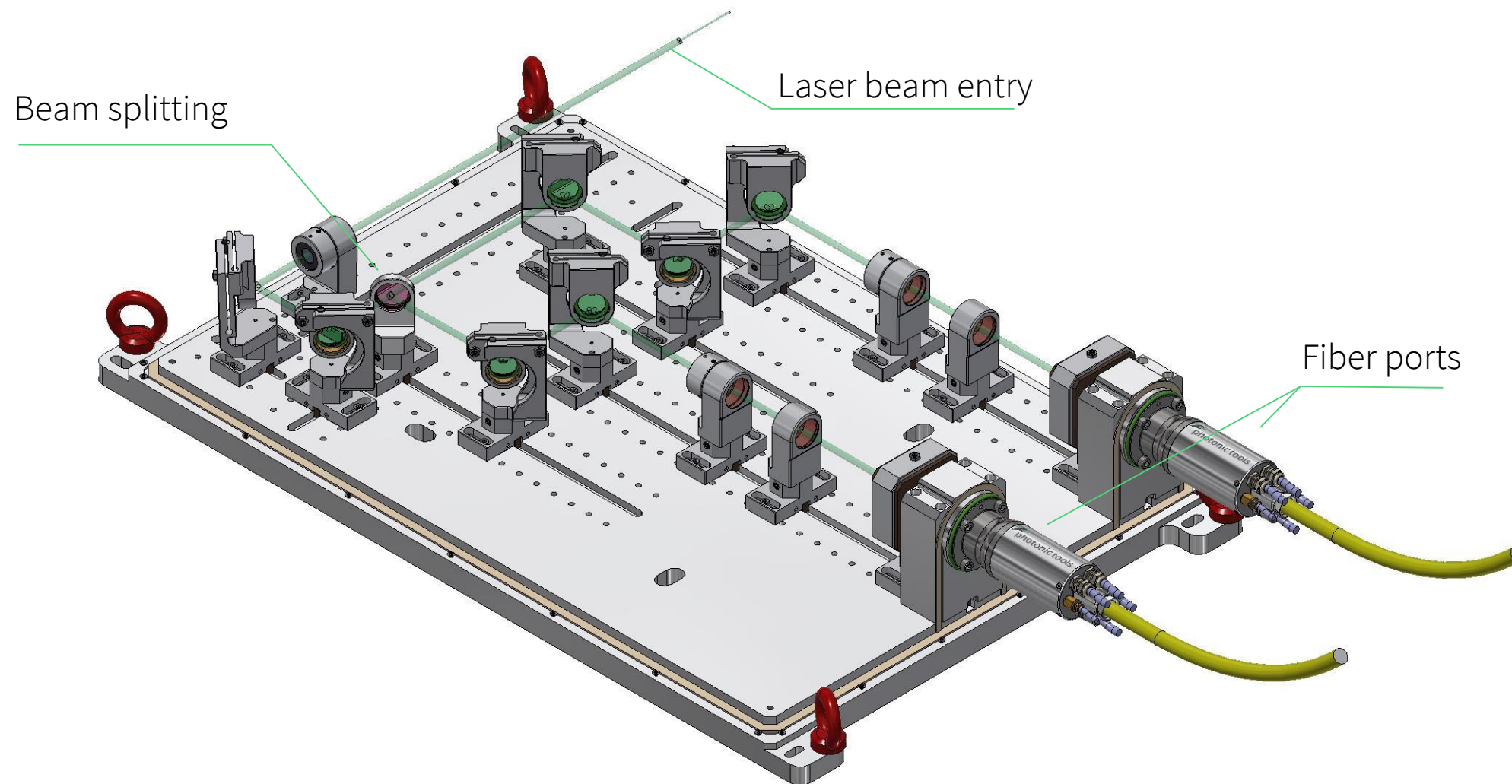
- Next level of ultrafast fiber beam delivery
  - Closely integrated fiber coupling
  - Plug and play fiber exchange
  - Easy to use and install
- Technological advantages
  - Based on modular BLS technology
  - Laser beam and optical components enclosed
  - Compatible to PT laser light cables
  - Pre-aligned fiber coupling

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Amplitude femtosecond fiber delivery module

# Parallel Processing with Beam Sharing Unit



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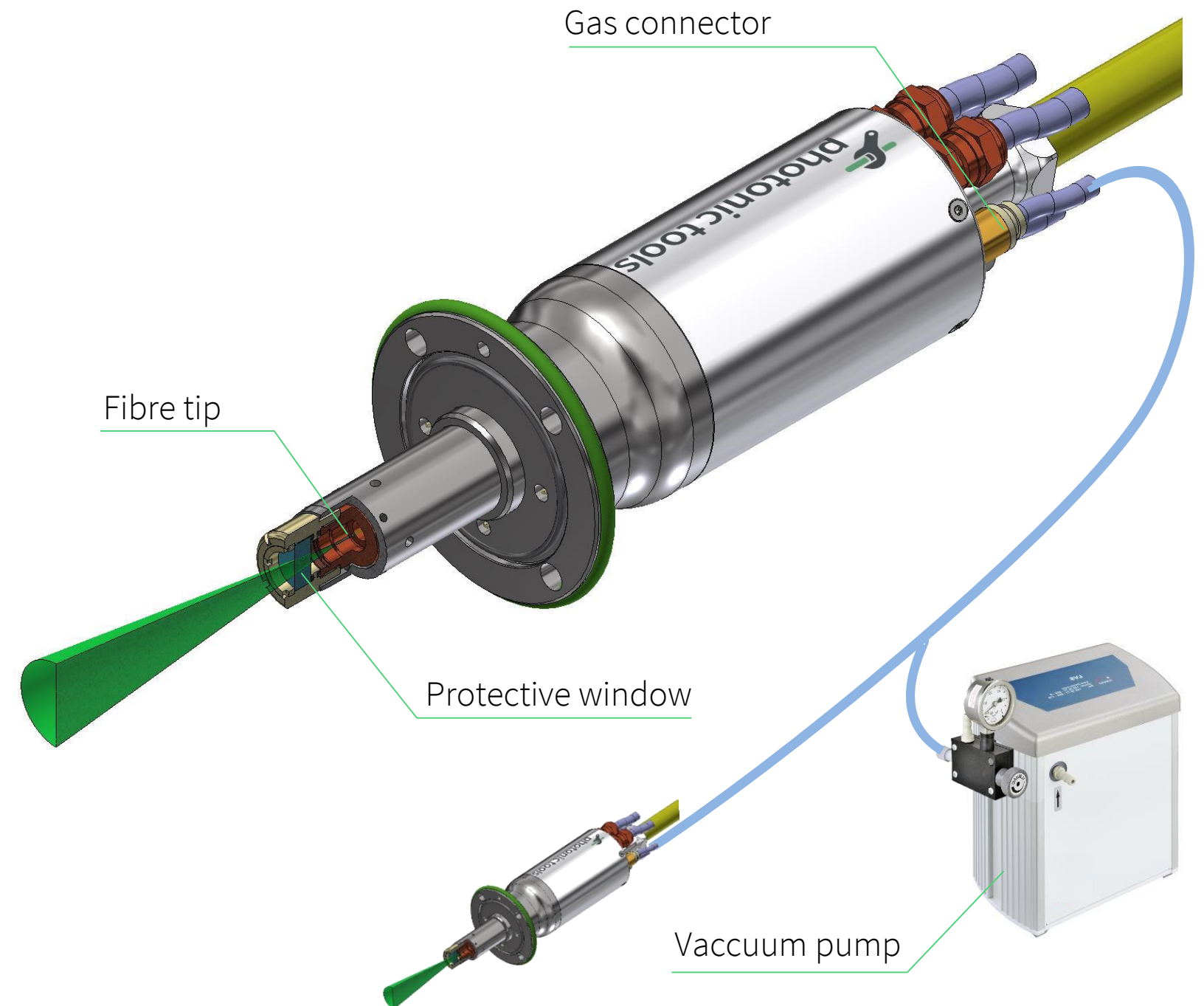
- Energy sharing
- Based on the modular BLS
- Precise control of energy ratio between fiber ports
- Ratio tunable 40:60 – 60:40
- Optional modules
  - Shutter
  - Attenuator
  - Additional fiber ports
- Cost effective solution compared to multiple lasers



# Gas Control System

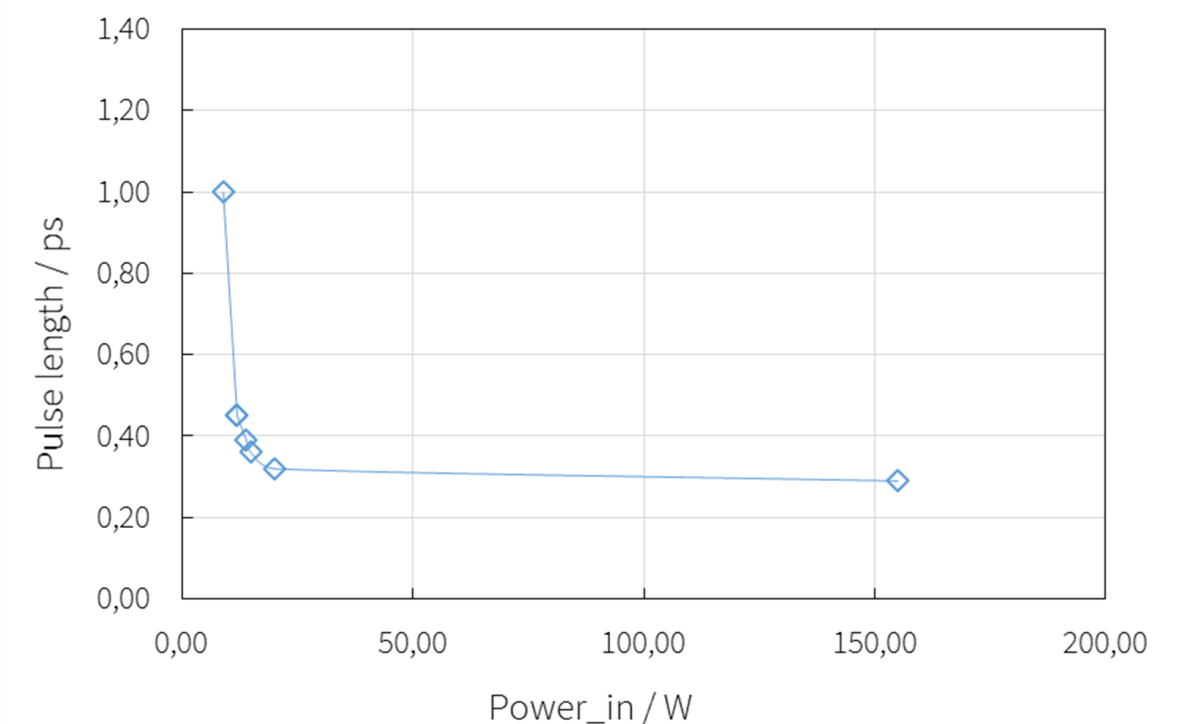
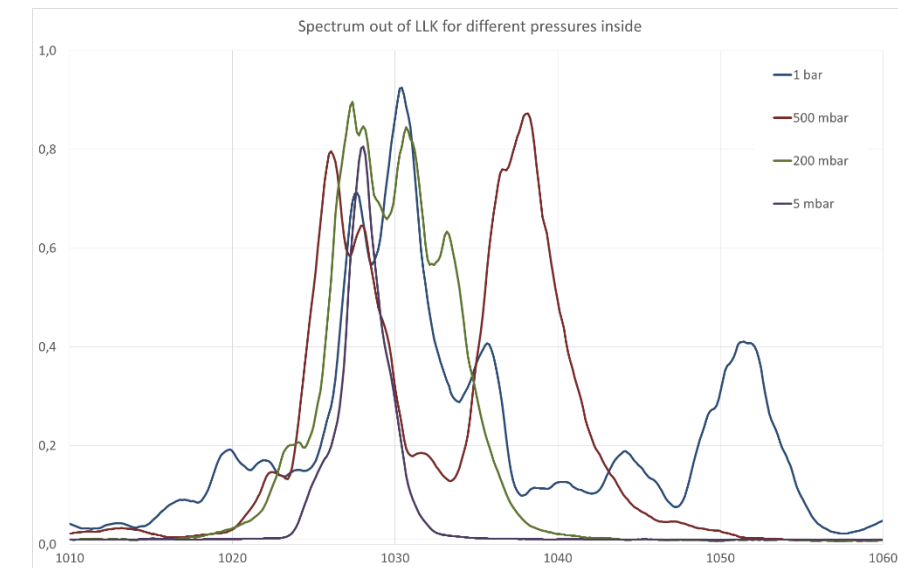
- Laser light cable with gas connector
  - Fiber inside sealed volume
  - Gas connection on either end of LLK
  - Pressure from 5 mbar to 2 bar possible
- Application
  - Vacuum pump for low nonlinearity
  - Pressure control for bandwidth control
  - SPM induced chirp for pulse compression

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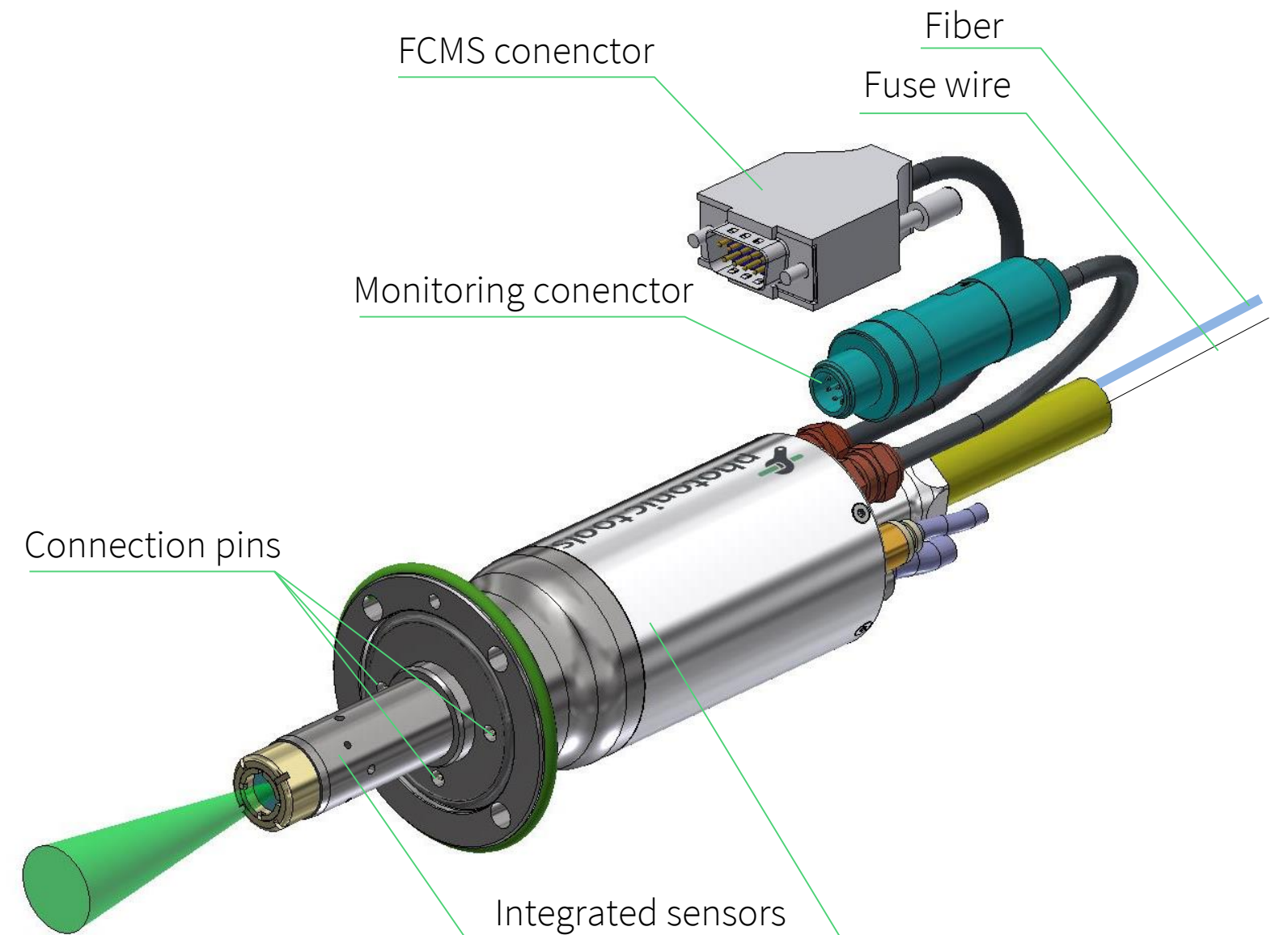
# Gas Control System

- Changing spectral bandwidth
  - Low pressure (~20 mbar) for undisturbed laser pulses
  - Induced self phase modulation (SPM) at high pressure
  - Changing bandwidth is a matter of a few seconds
  - Influence on material absorption and thin film interference
- Changing pulse duration
  - Requires gas control and dispersive compressor
  - Use SPM induced chirp at high pressure
  - Pulse duration can be decreased by ~ factor of 10
  - Enables process combinations with ps and fs



# Safety and Monitoring

- Fiber Continuity Monitoring System
  - Fiber plug detection
  - Fiber breakage detection
  - Thermal control
- Additional Monitoring
  - Possibility to observe beam coupling conditions
  - Monitoring of stray light and temperature inside laser light cable connector

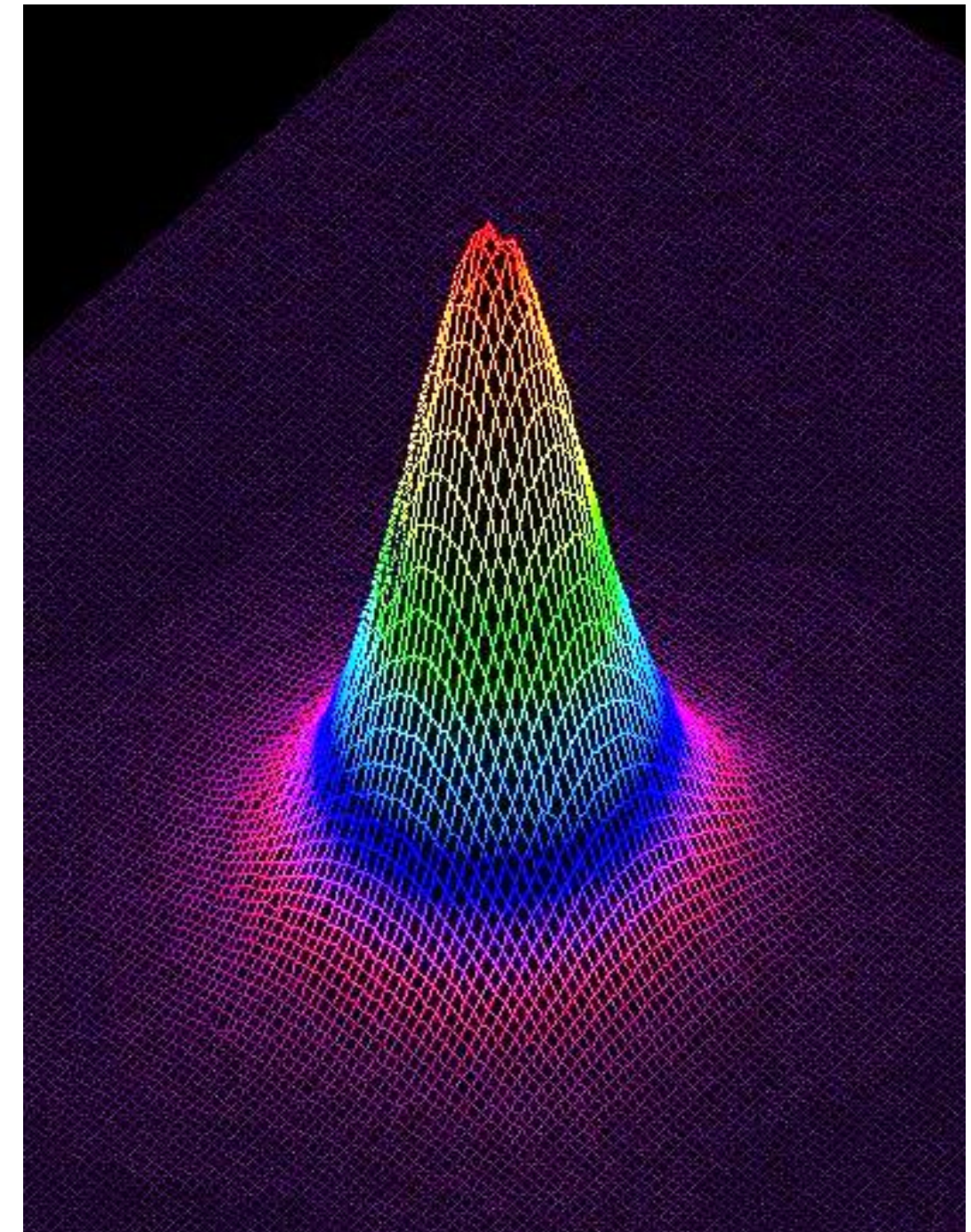


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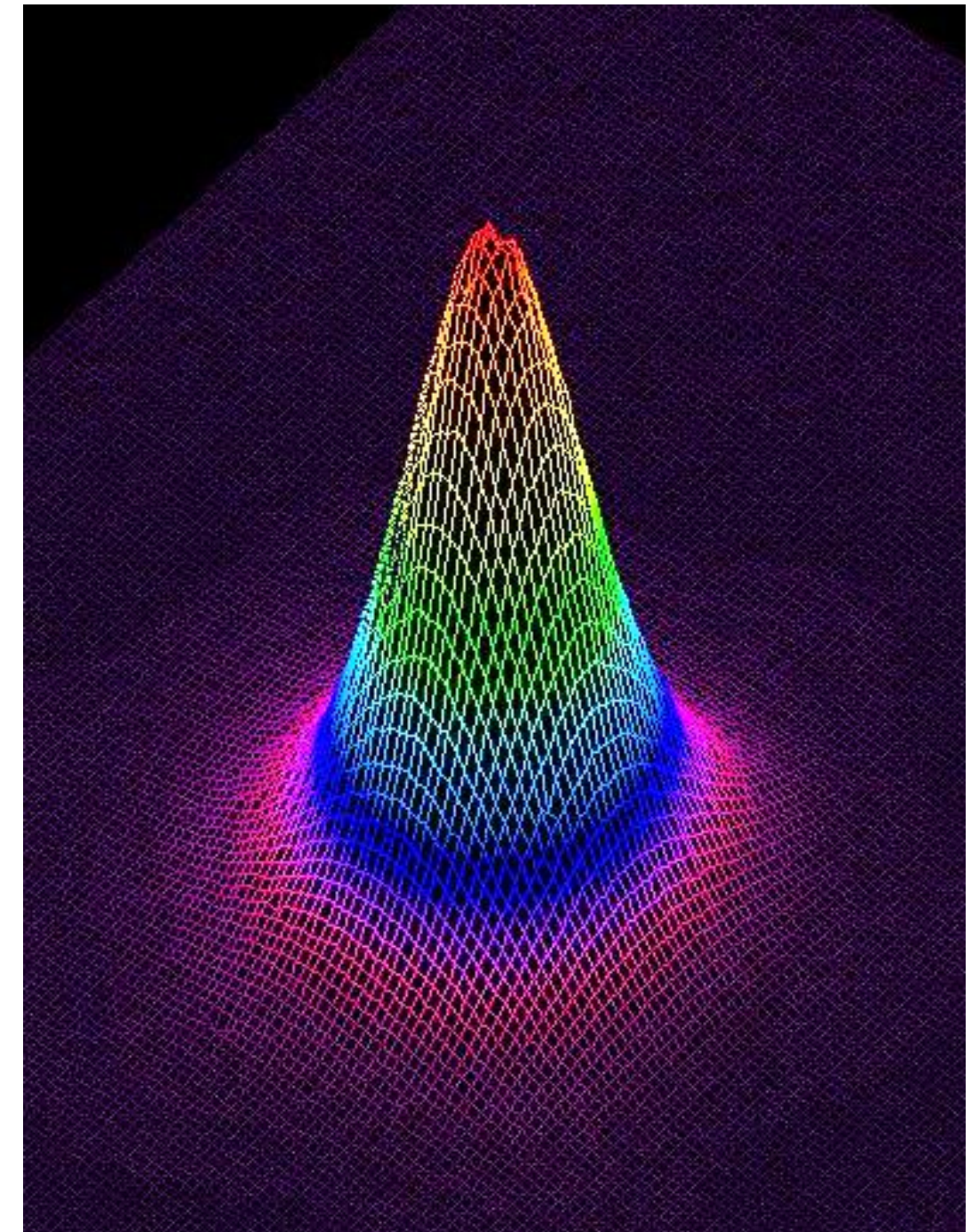
# Conclusion

- Ultrafast fiber beam delivery is now available to a broad range of applications and laser sources
- Several installations with ultrafast laser systems on the market
- Productivity and ease of use can be enhanced with
  - Modules for beam sharing
  - Extended safety functionality
  - Laser systems with integrated fiber ports
  - Modular collimation modules and processing heads



# Conclusion

- Applications successfully demonstrate the system performance
- For typical beam delivery applications we could demonstrate
  - Single mode beam quality
  - Stable operation at high power
  - Defined polarization even in dynamic applications



# Thank You !

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