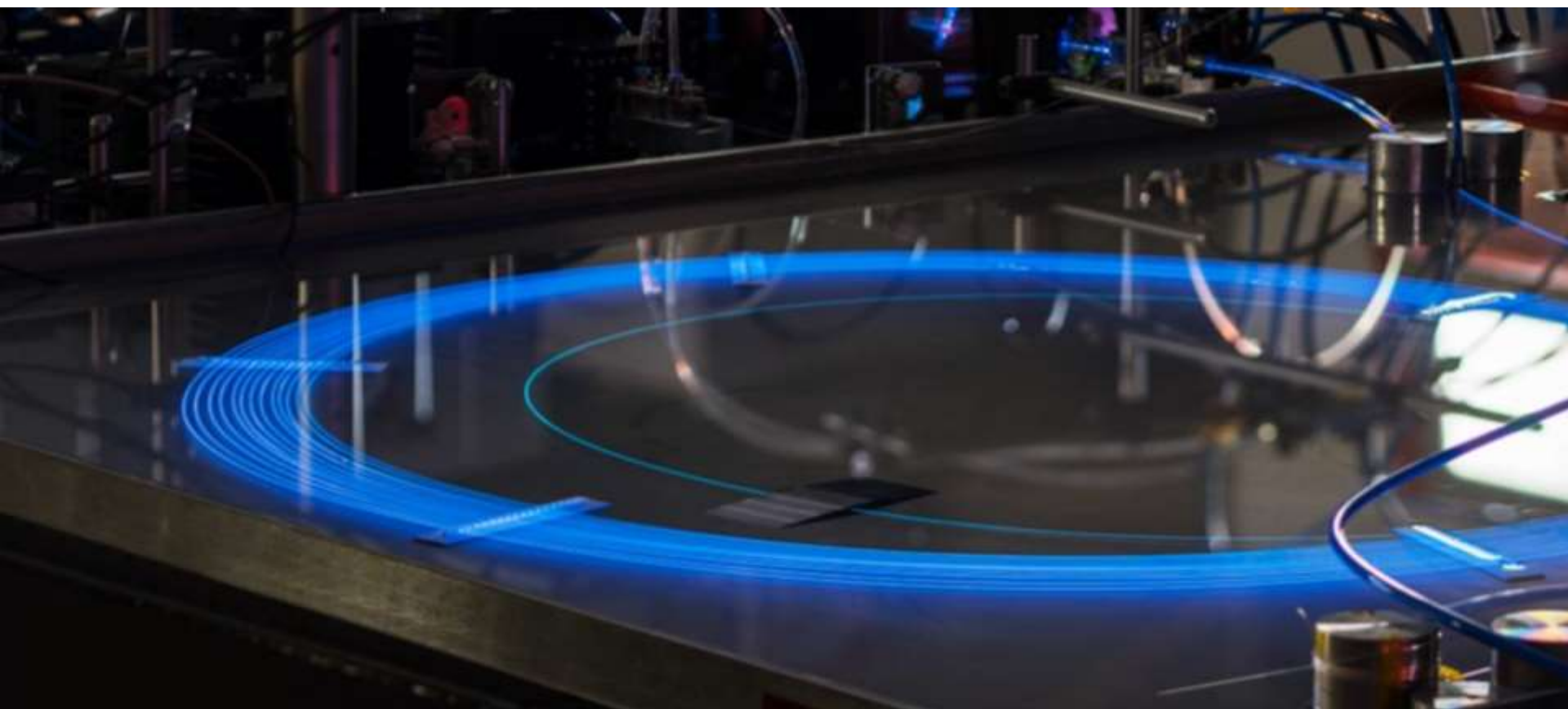


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# HIGH-PERFORMANCE SINGLE-MODE YB-DOPED FIBERS AND AMPLIFIER POWER SCALING TO MULTI KW AVERAGE POWER



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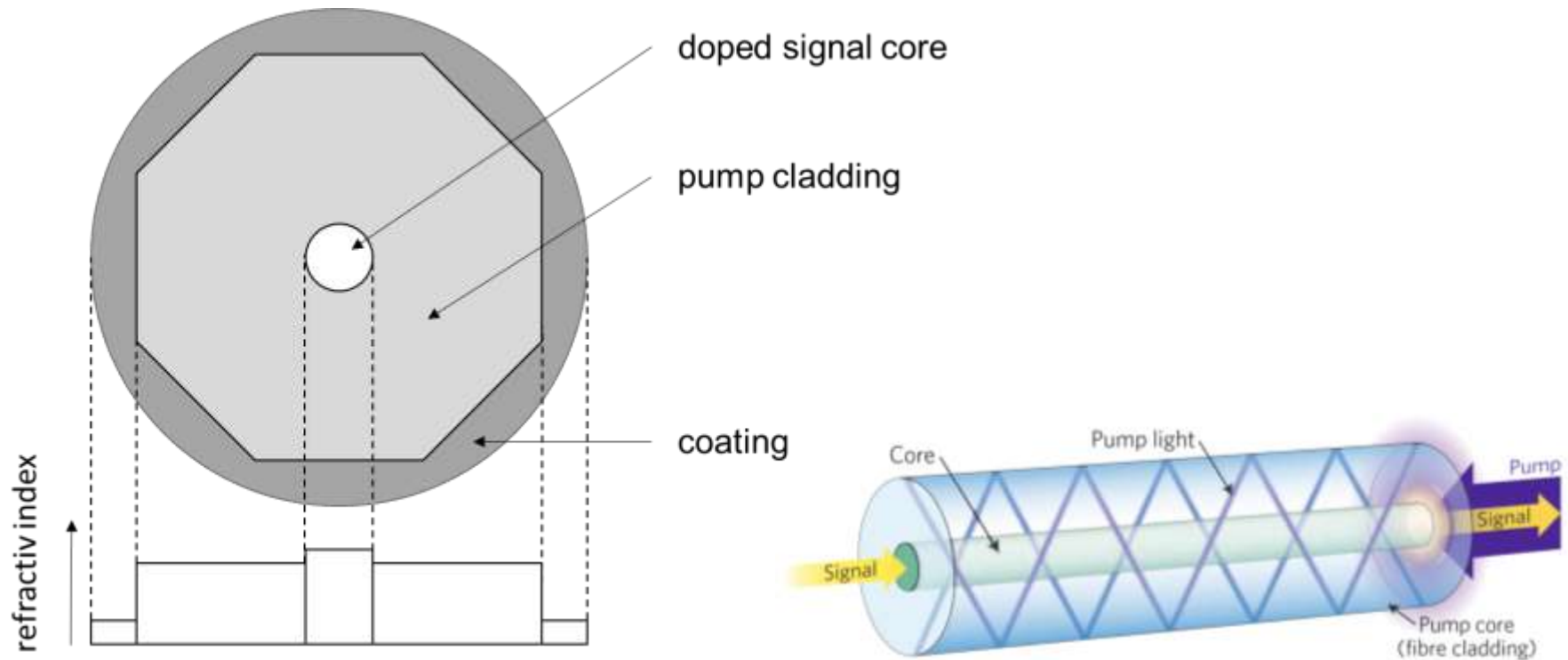
# AGENDA

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- Introduction
- TMI Threshold investigation
  - Commercial fiber
  - Custom fiber development
- Discussion and Summary

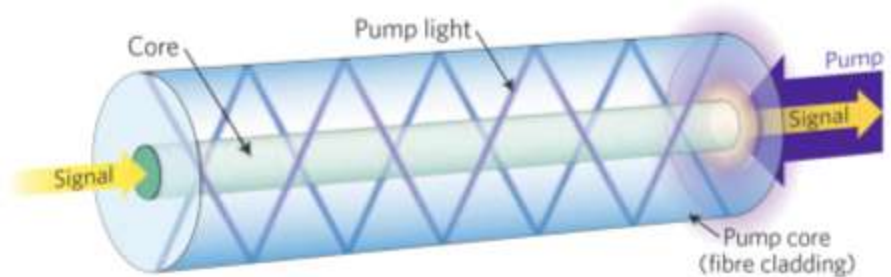
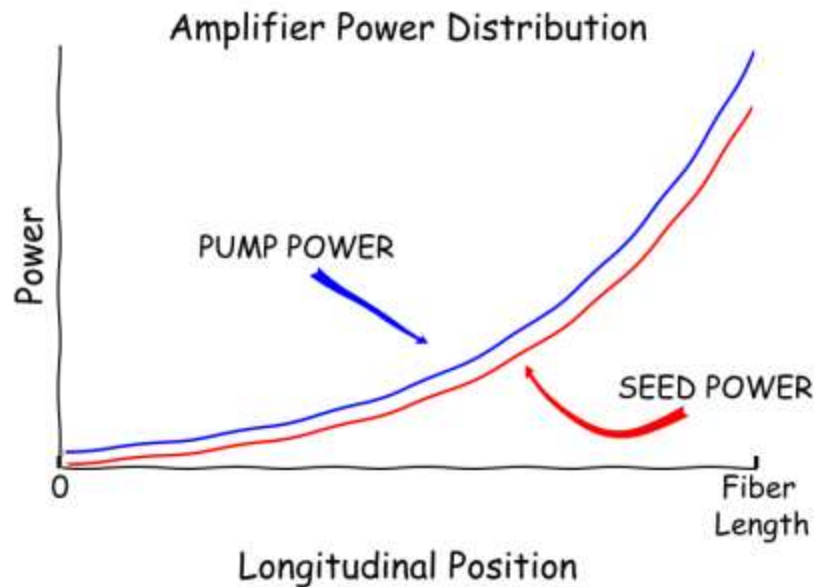
# Introduction

## ■ Brightness enhancement in double clad fibers



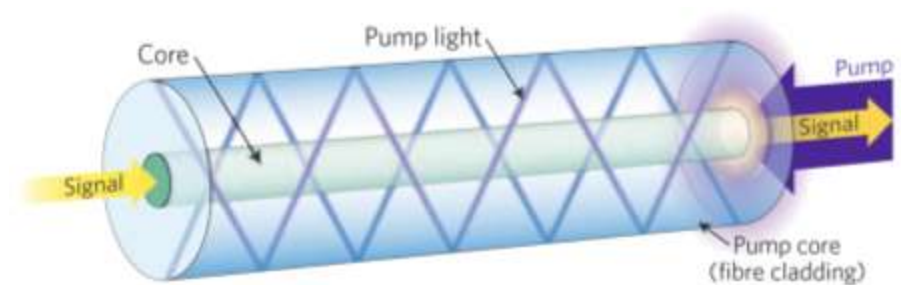
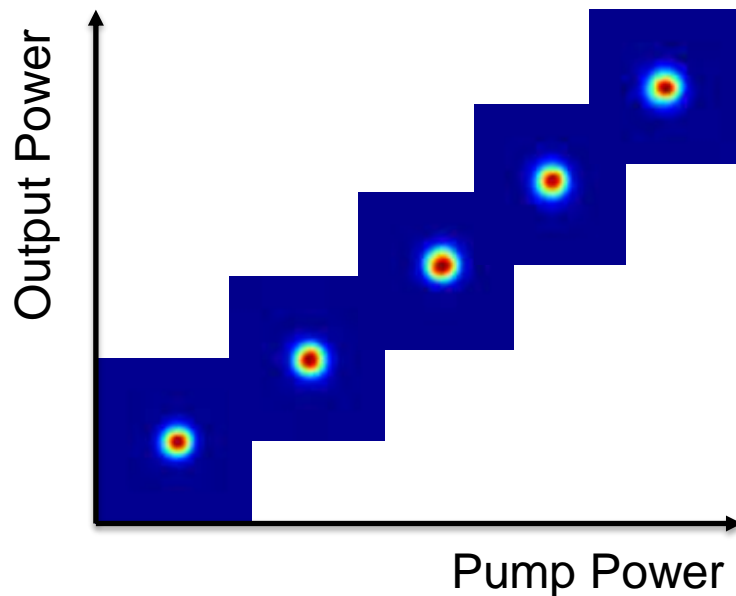
# Introduction

- Brightness enhancement in double clad fibers
- High single-pass gain ( $>30\text{dB}$ )



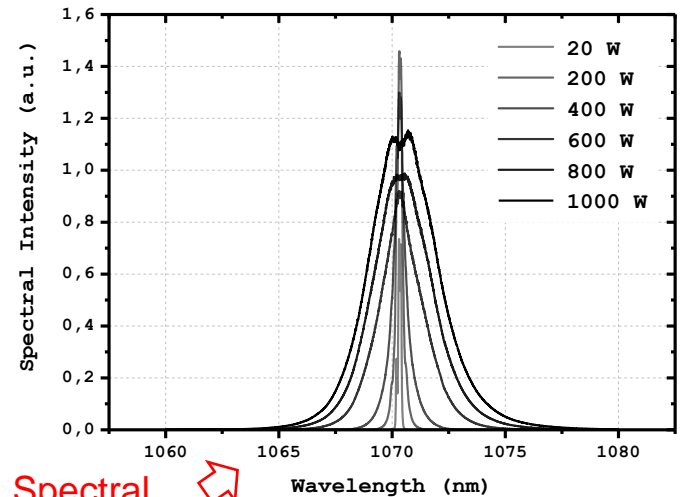
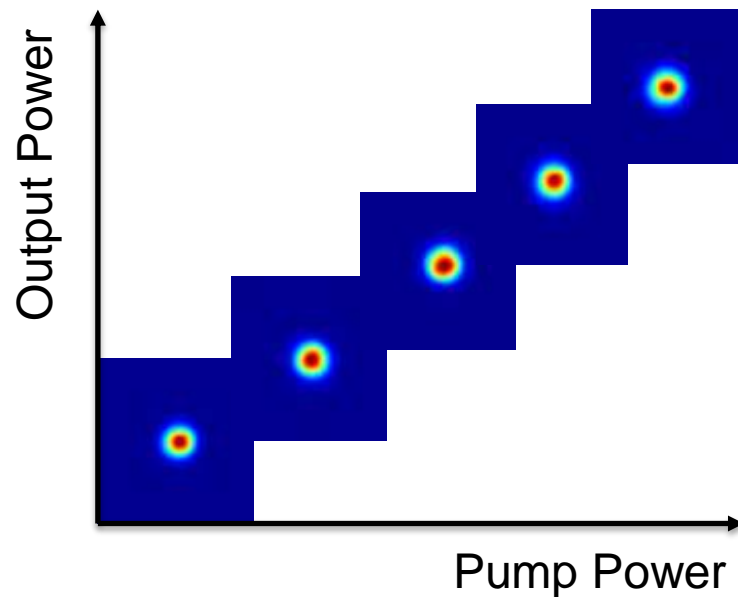
# Introduction

- Brightness enhancement in double clad fibers
- High single-pass gain ( $>30\text{dB}$ )
- Diffraction-limited output independent of output power

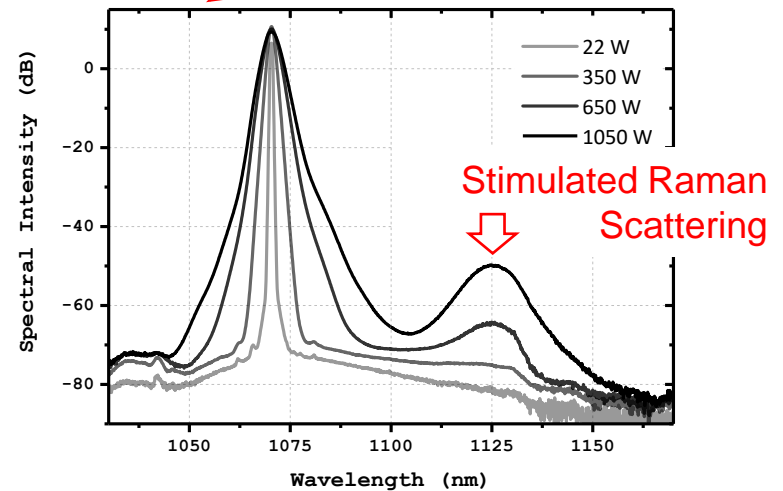


# Introduction

## ■ Nonlinear Effects

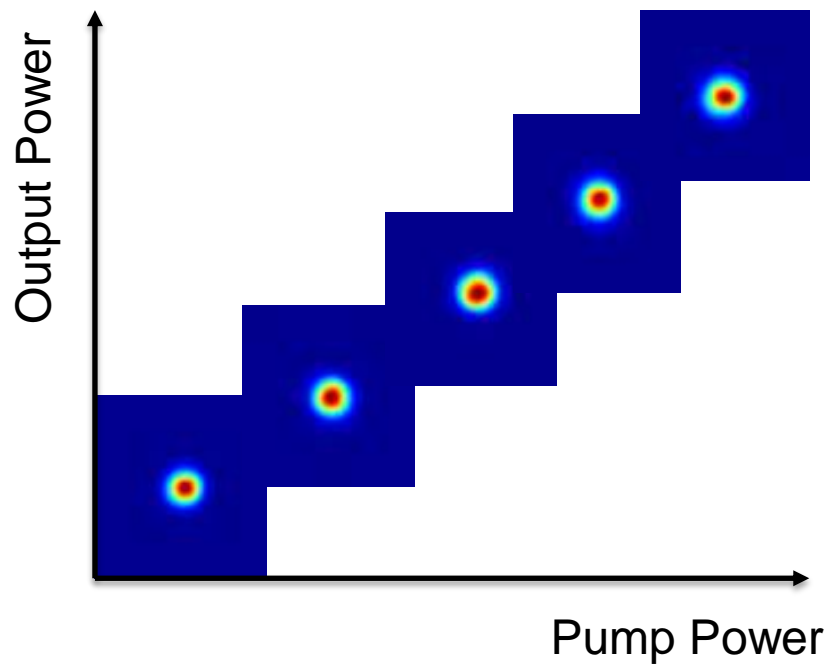


Spectral  
broadening



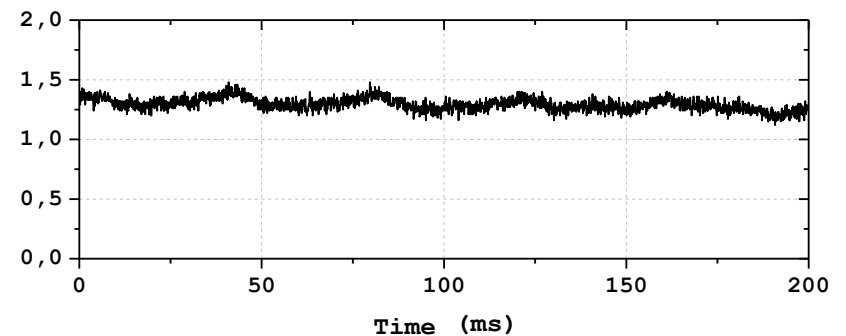
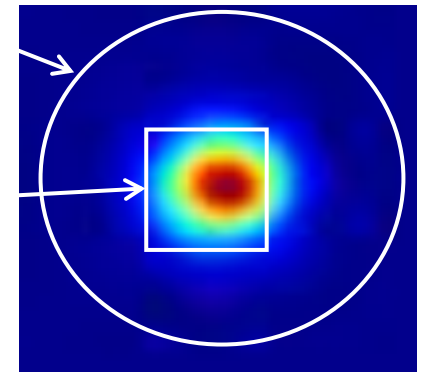
# Introduction

## ■ Transverse Mode Instabilities (TMI)



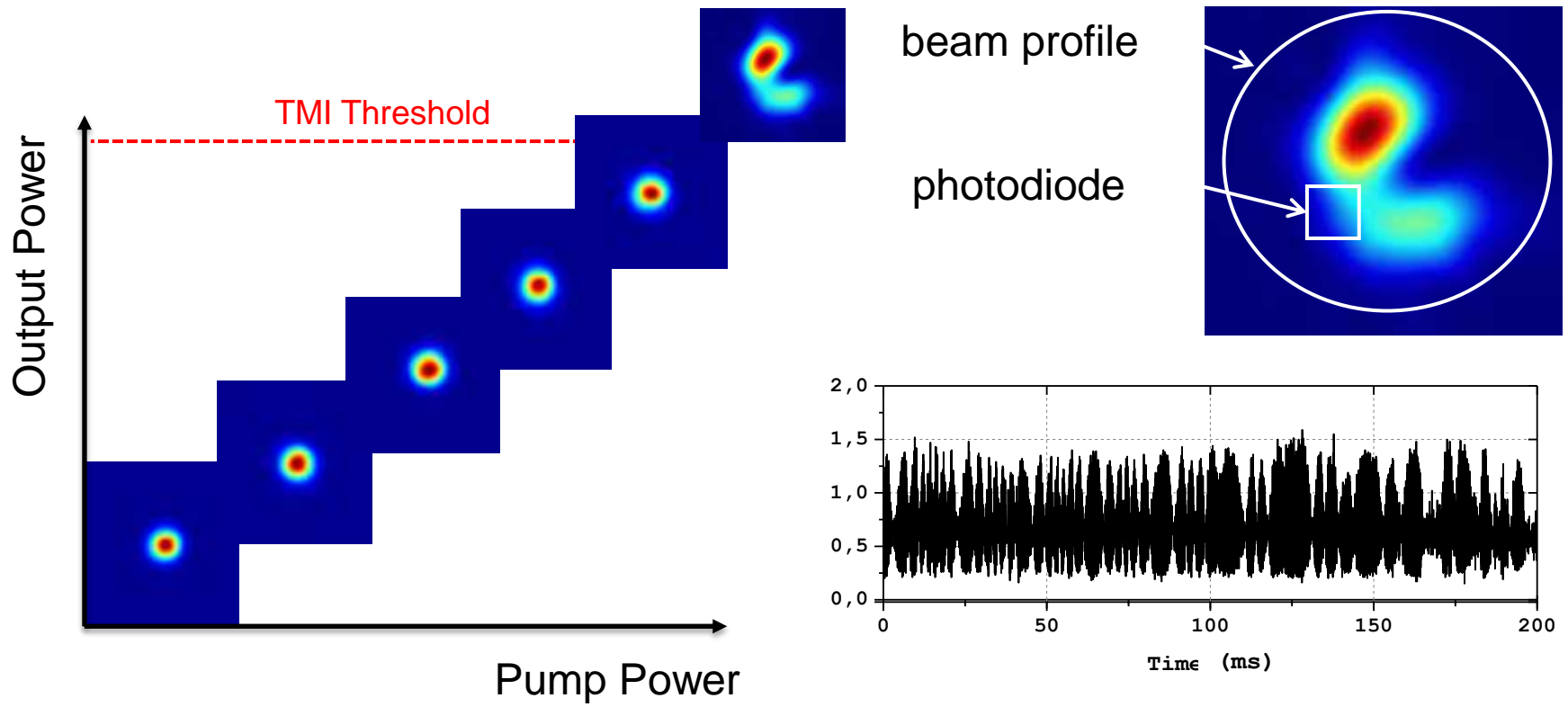
beam profile

photodiode



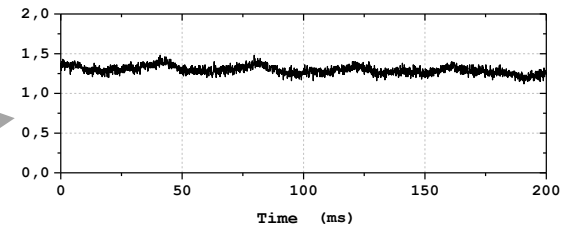
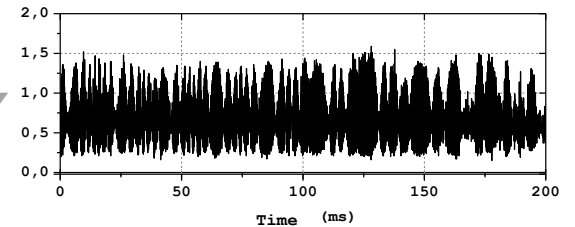
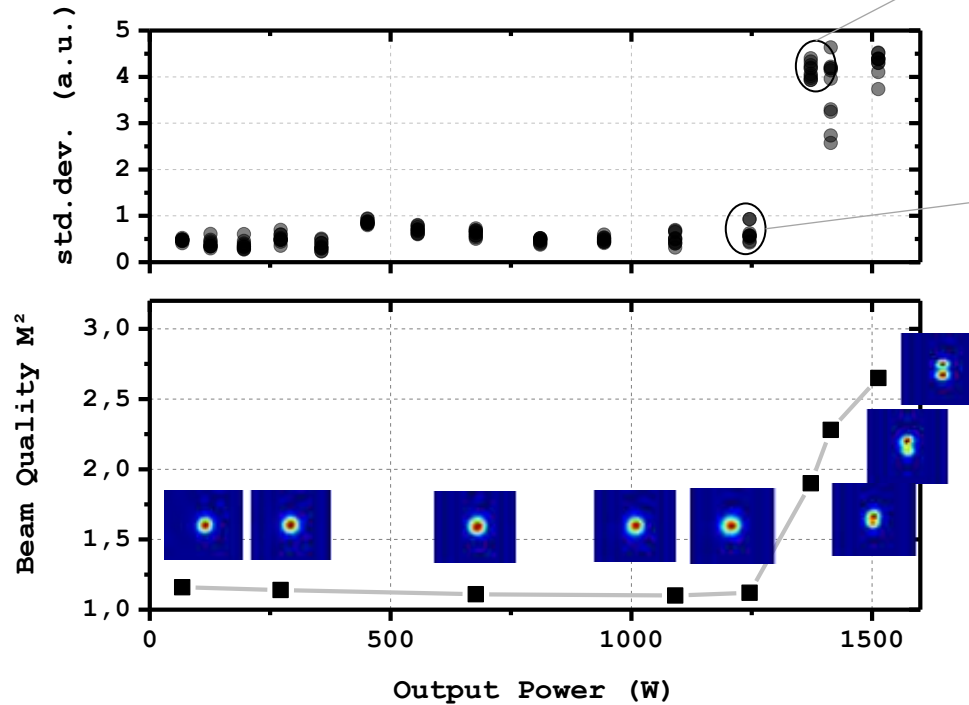
# Introduction

## ■ Transverse Mode Instabilities (TMI)



# Introduction

## ■ Transverse Mode Instabilities (TMI)



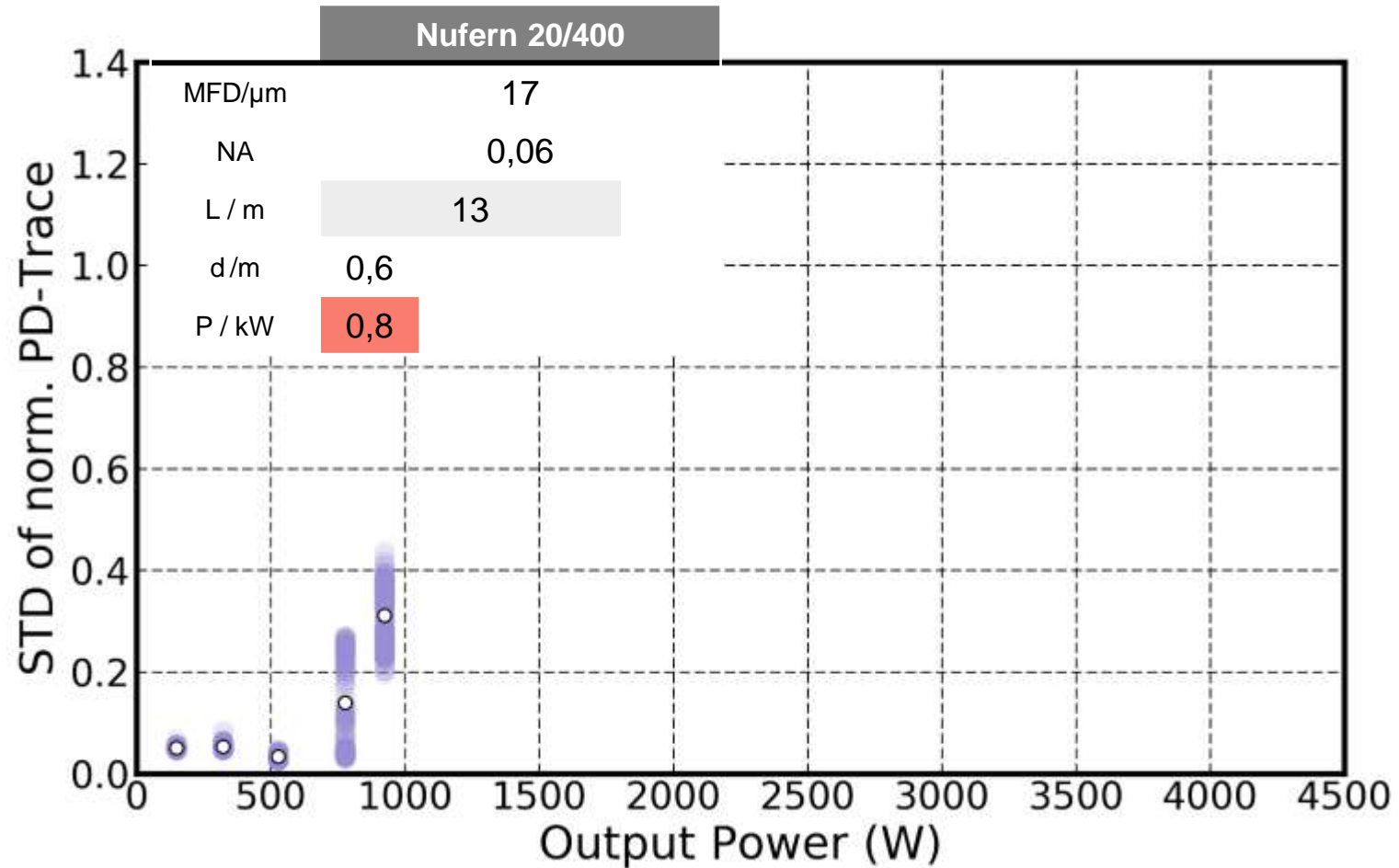
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# AGENDA

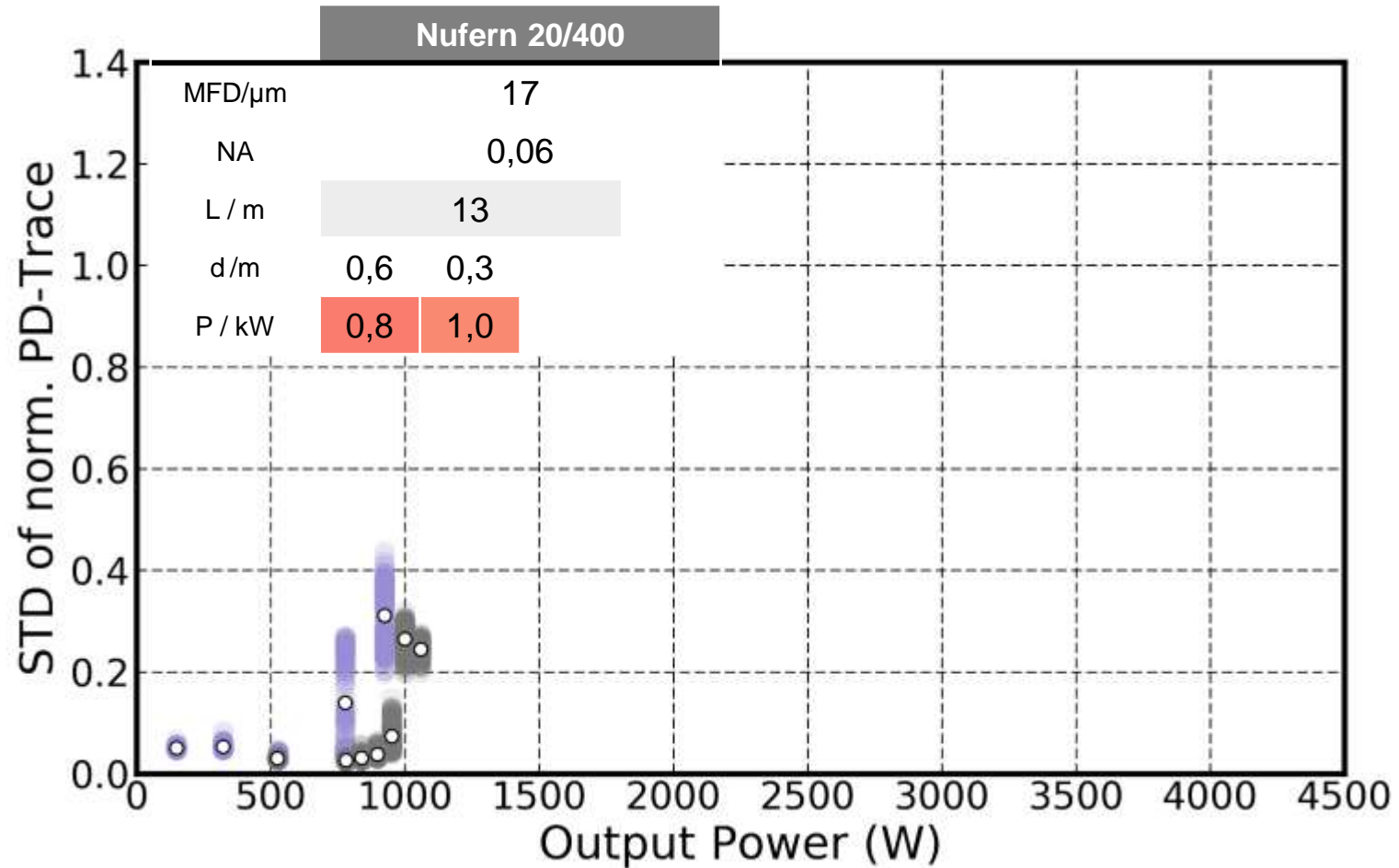
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- Introduction
- TMI Threshold investigation
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  - Custom fiber development
- Discussion and Summary

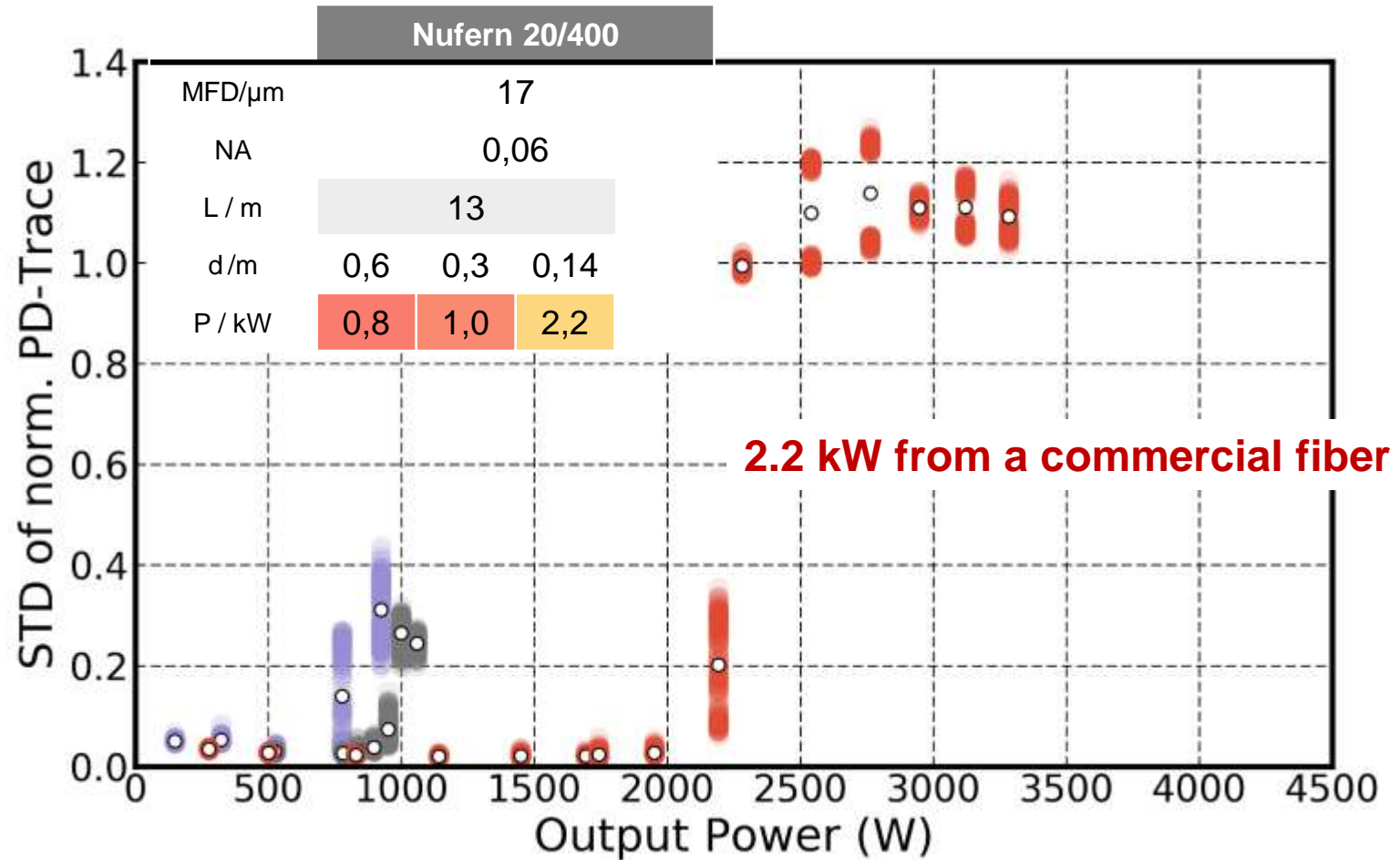
# TMI Investigations



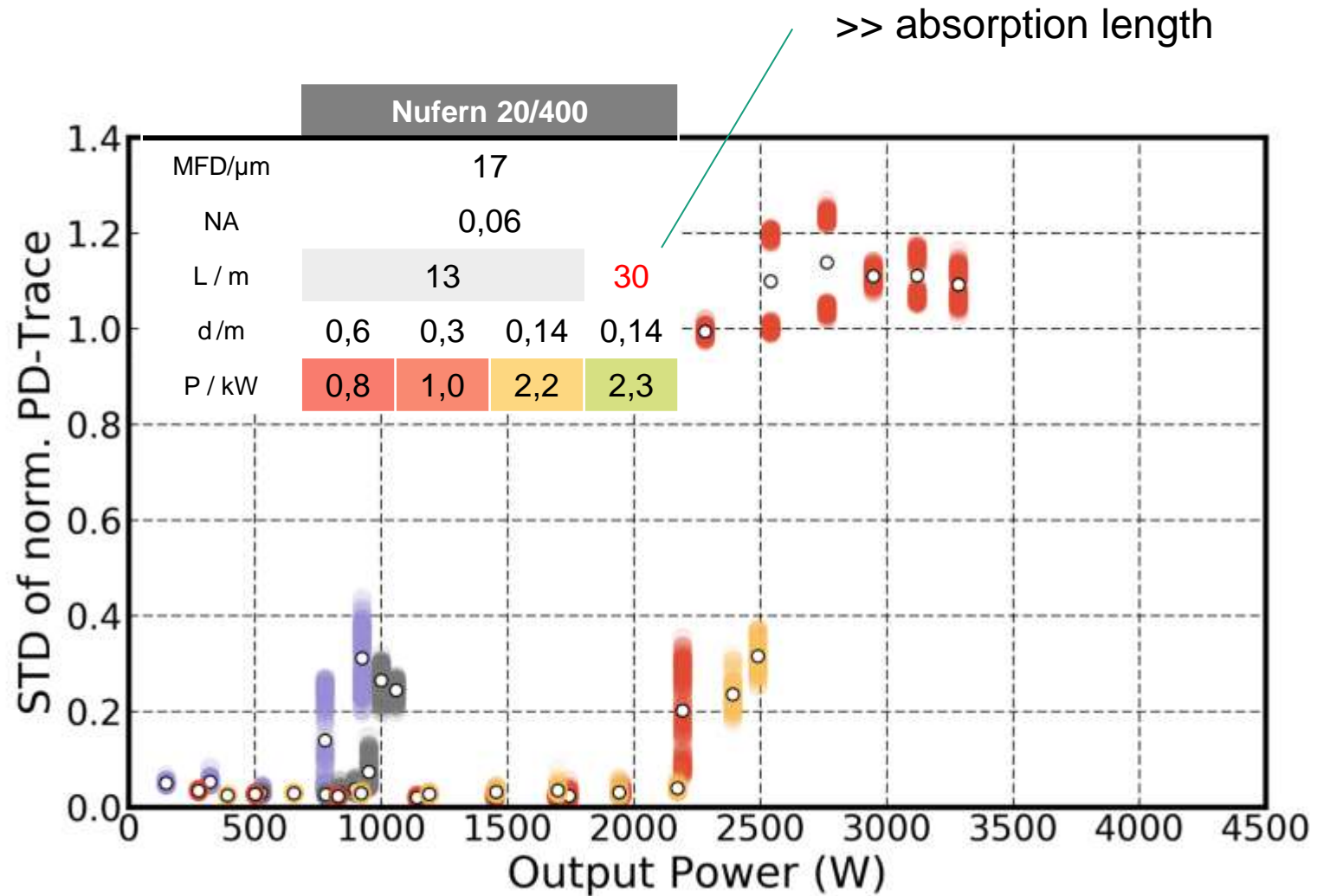
# TMI Investigations



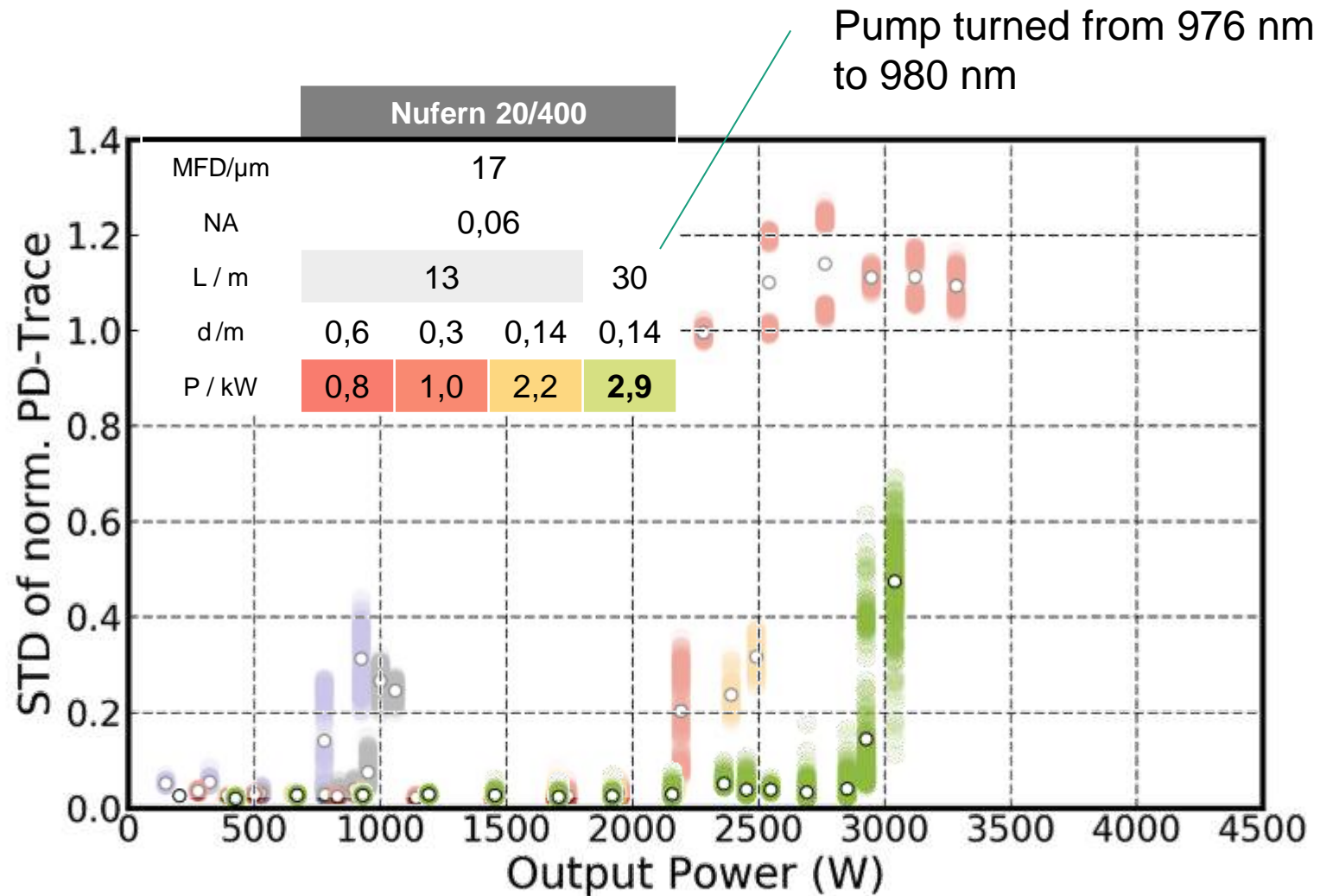
# TMI Investigations



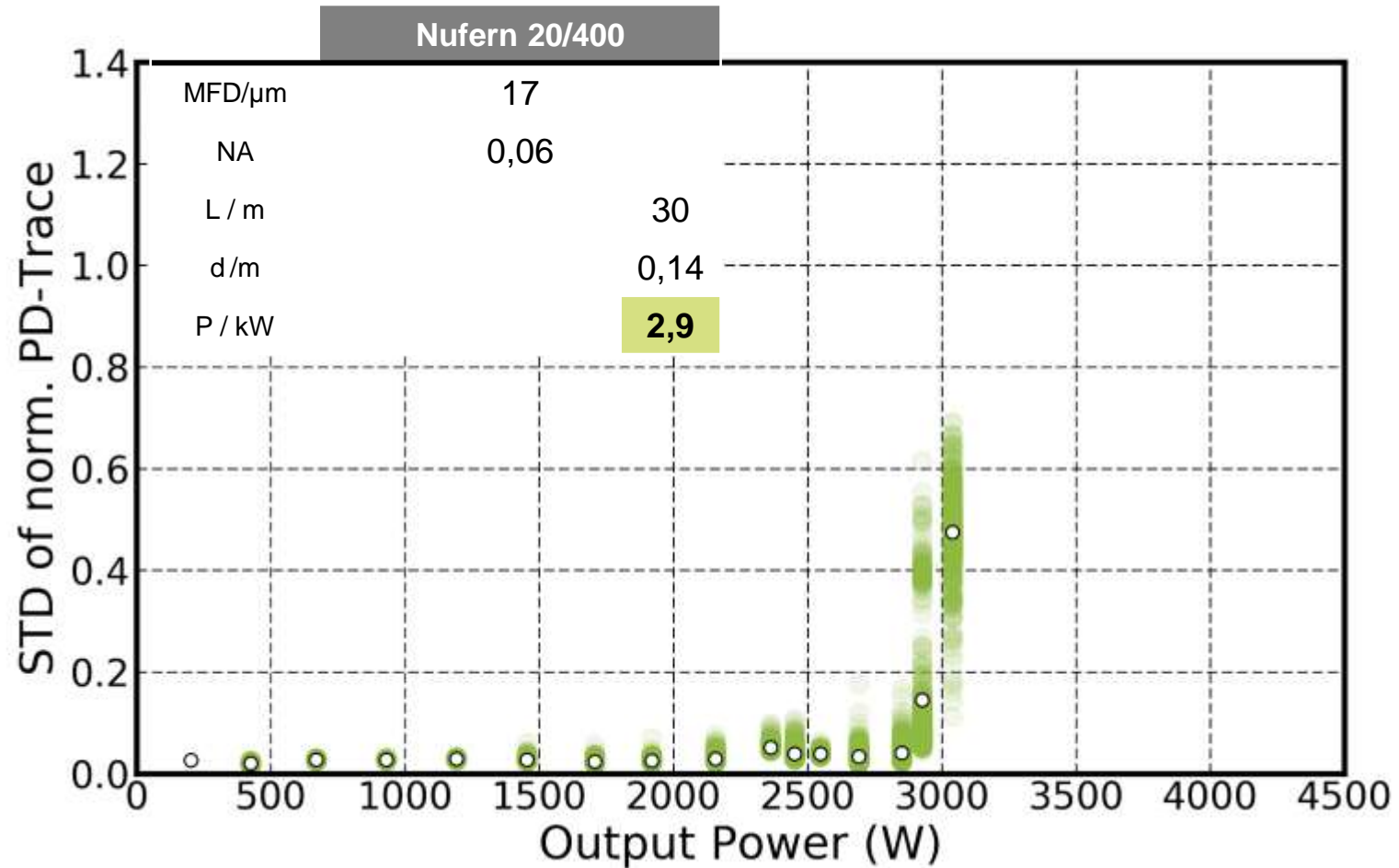
# TMI Investigations



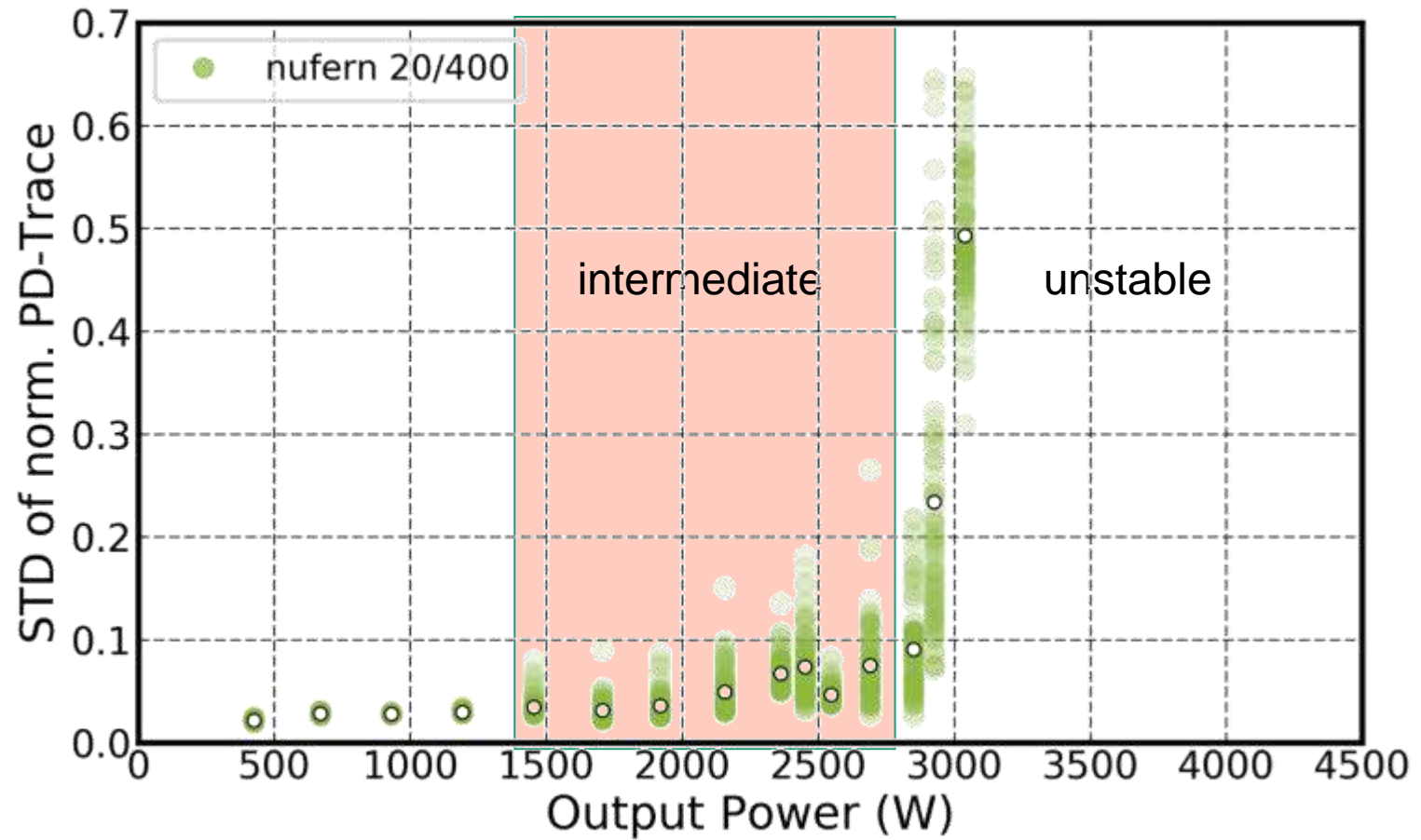
# TMI Investigations



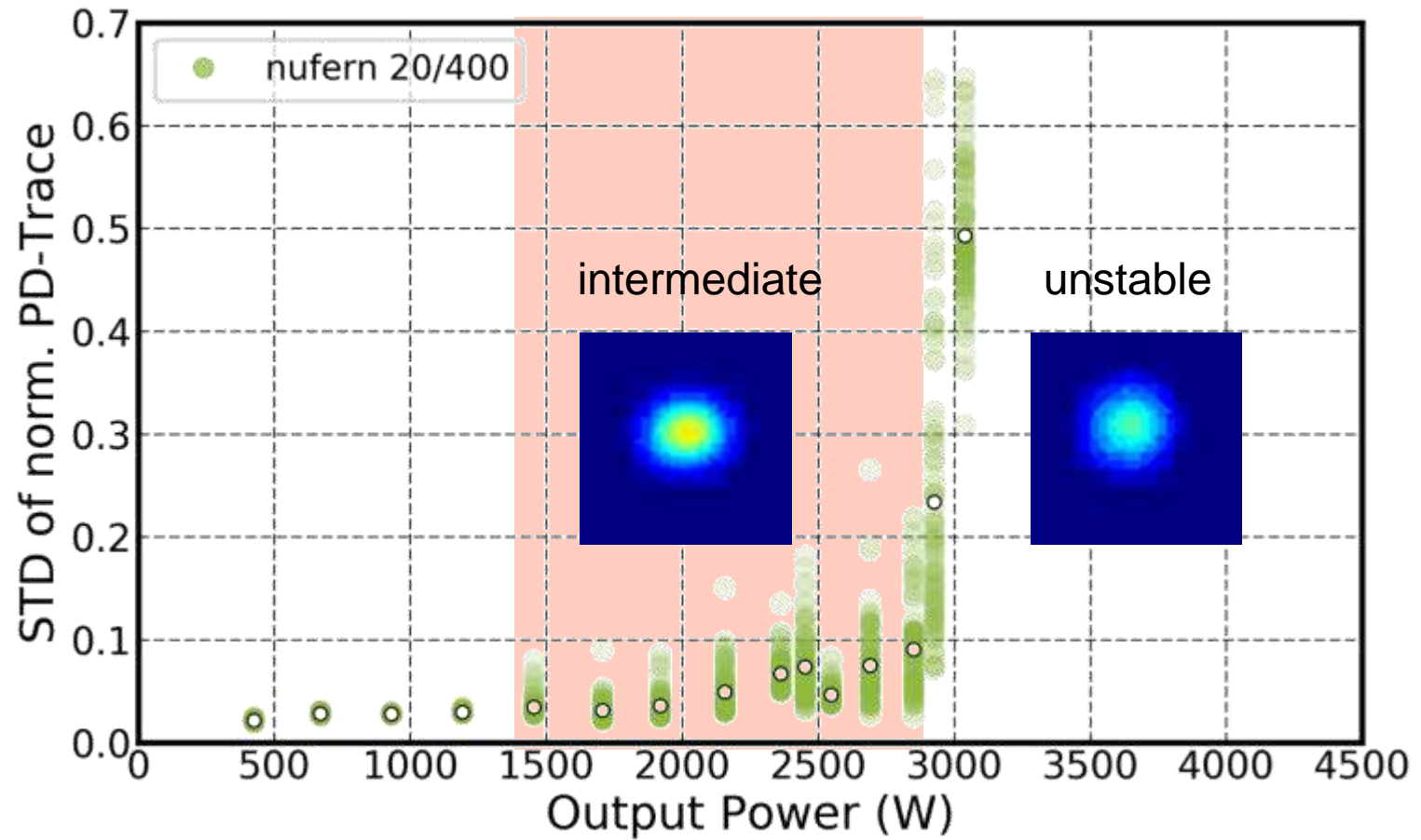
# TMI Investigations



# TMI Investigations



# TMI Investigations



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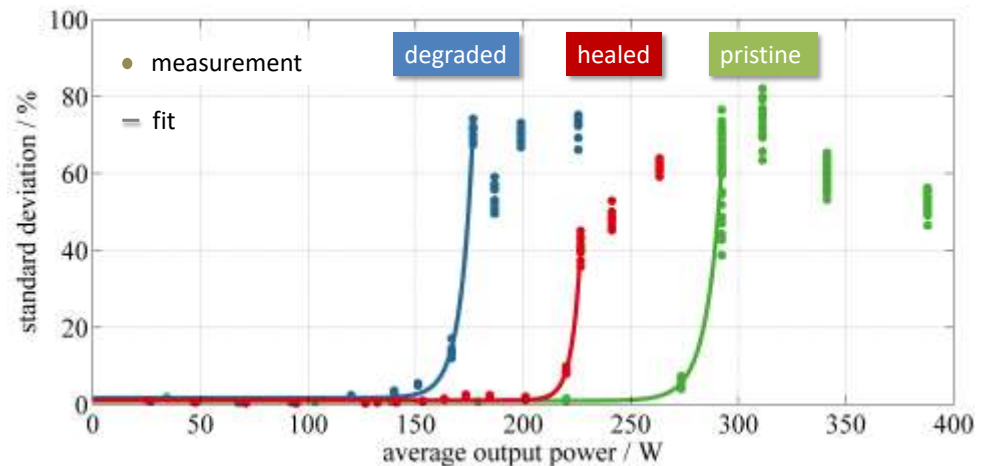
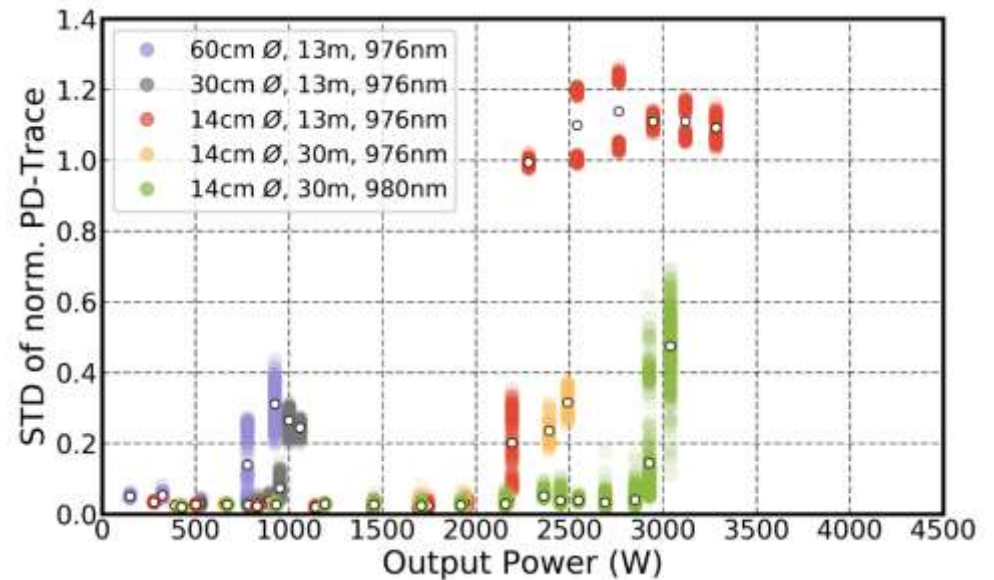
# AGENDA

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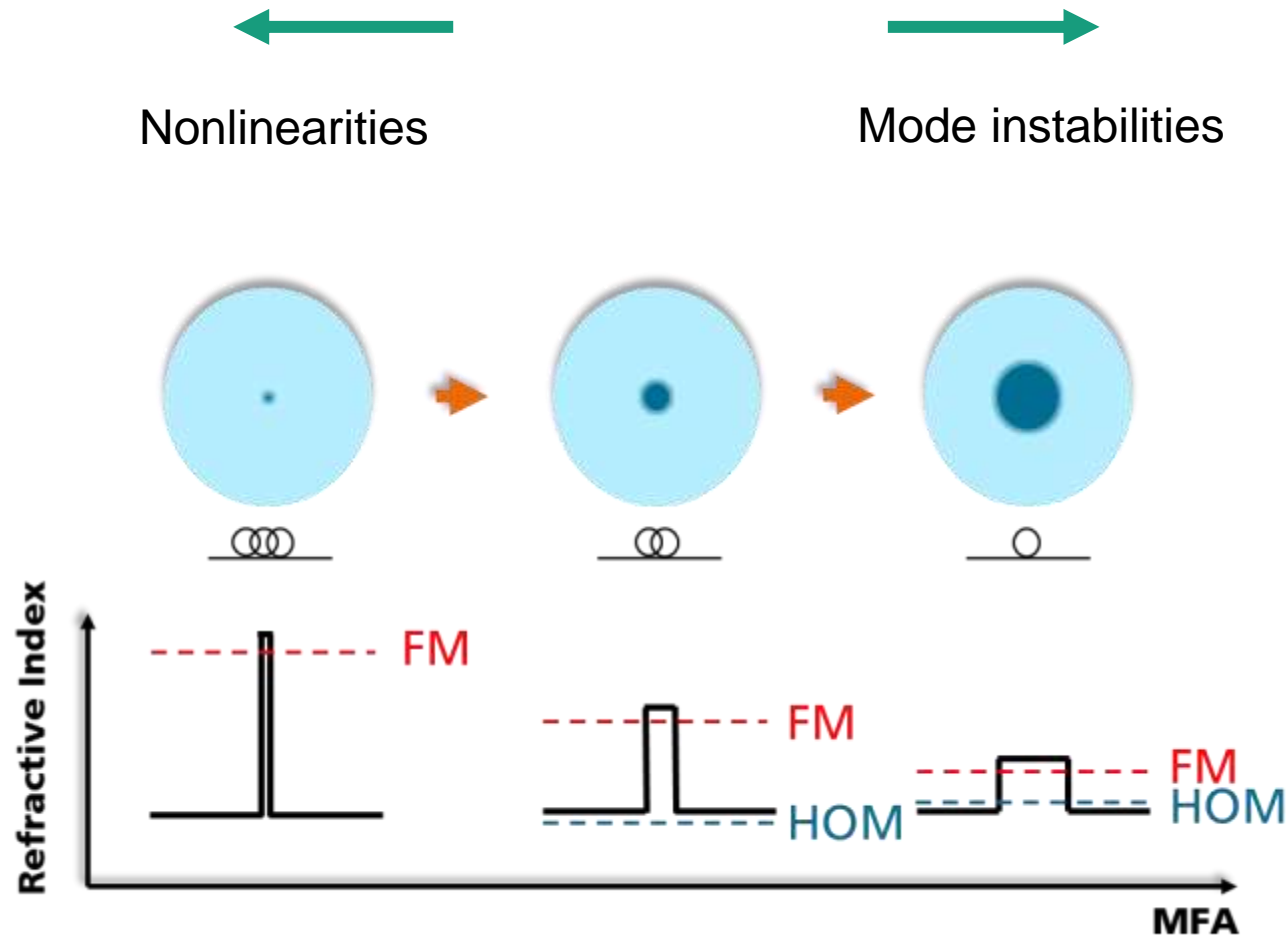
- Introduction
- TMI Threshold investigation
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- Discussion and Summary

# TMI Investigations

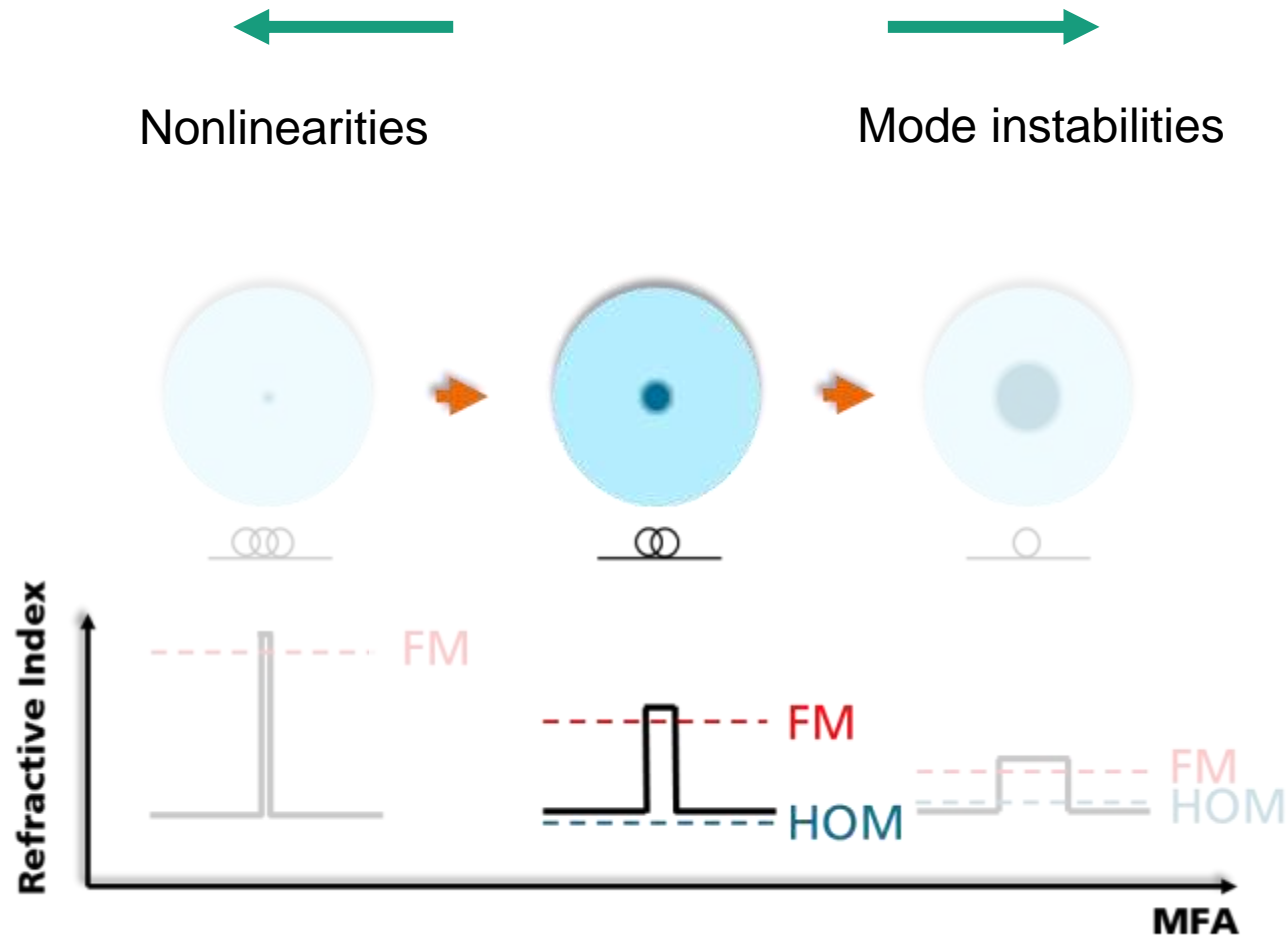
- TMI is sensitive to:
  - Bending
  - Mode excitation
  - Pump configuration
  - Photodarkening



# Fiber Design and Technology



# Fiber Design and Technology

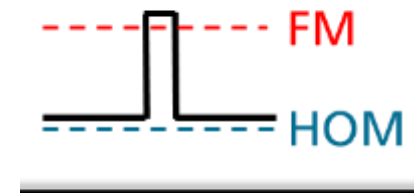


# Fiber Design and Technology

- Enabled by low Yb doping
  - Reduced photodarkening & longer fibers
  - Increase absorption length → Lower heat load

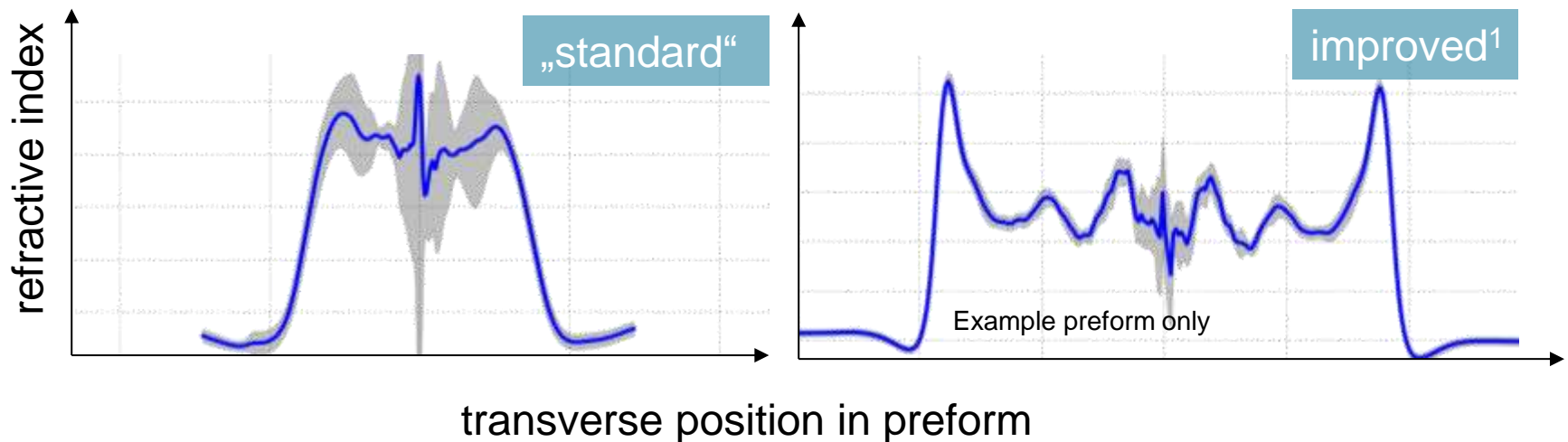


**Overcome Limitations**

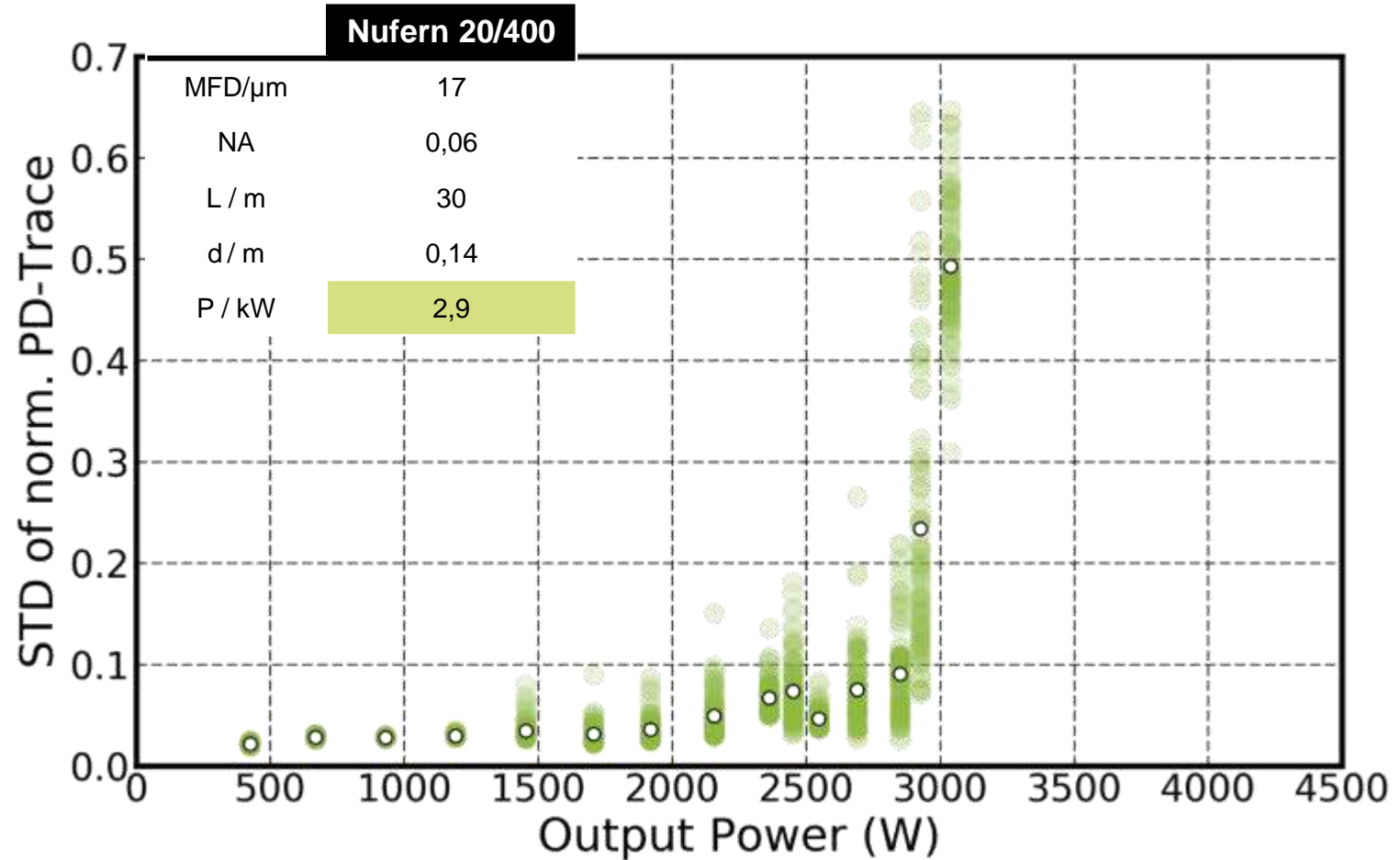


# Fiber Technology Development

- Improvements in manufacturing
  - Longitudinal homogeneity
  - More material > 5km from one preform
  - Tailoring of index profile

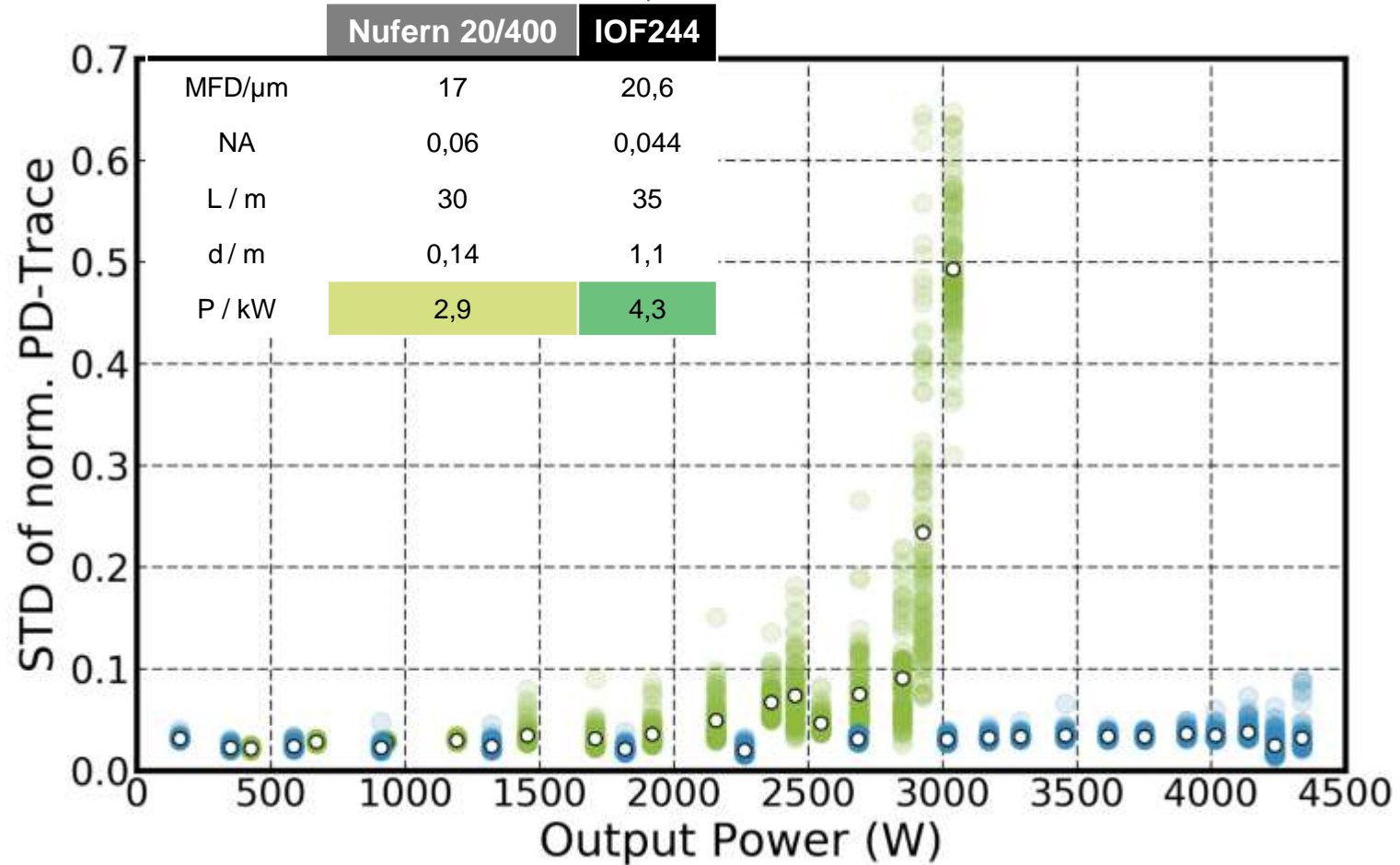
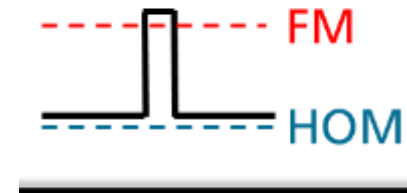


# TMI Investigations



# TMI Investigations

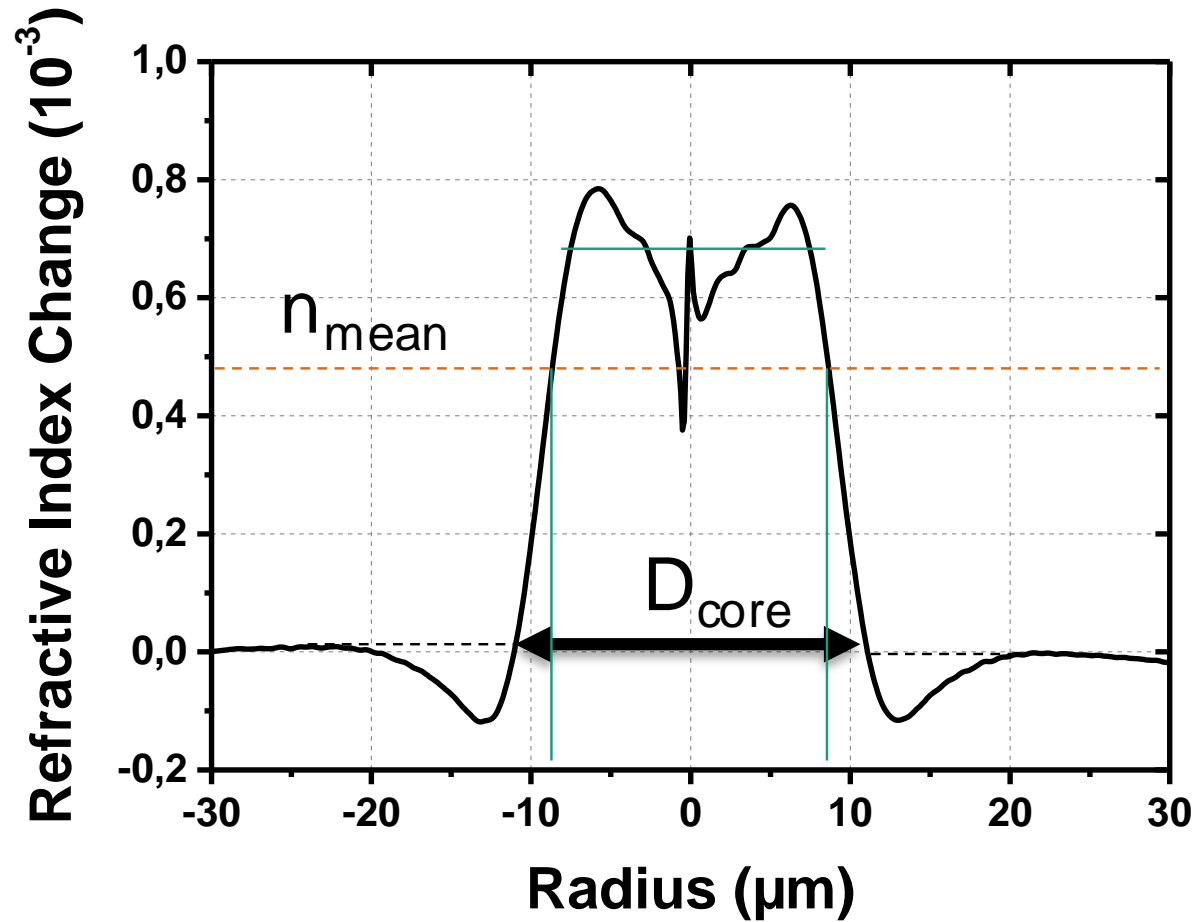
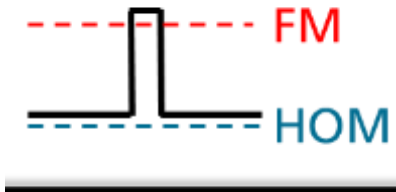
„standard“



# Fiber properties

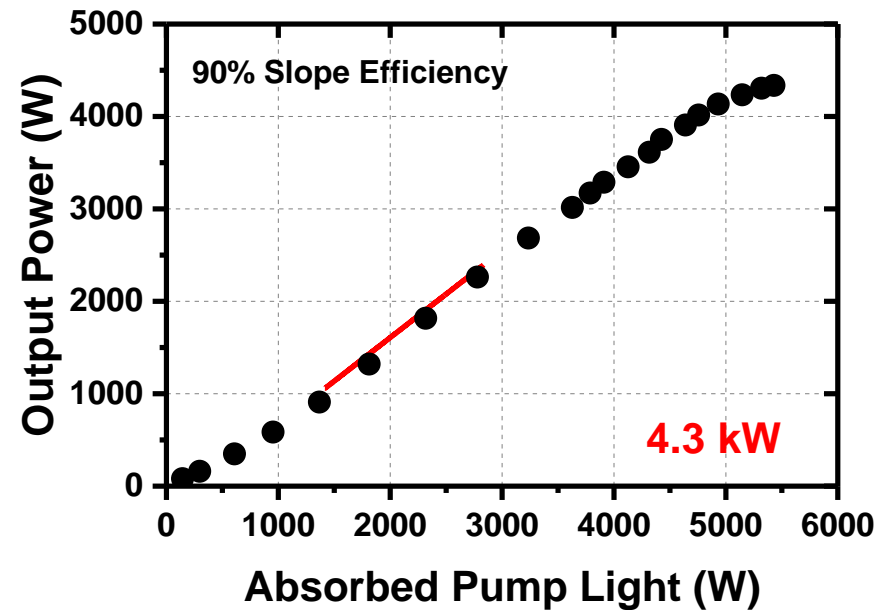
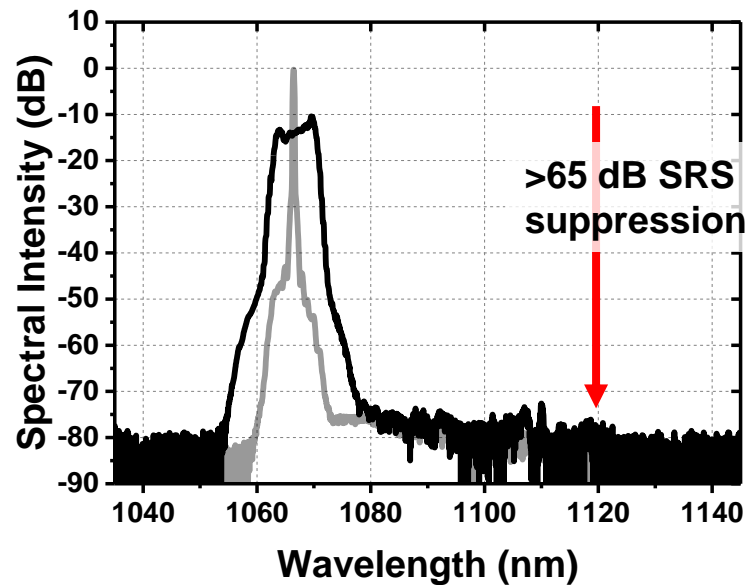
IOF244

MFD/ $\mu\text{m}$	20,6
NA	0,044
L / m	35
d / m	1,1
P / kW	4,3

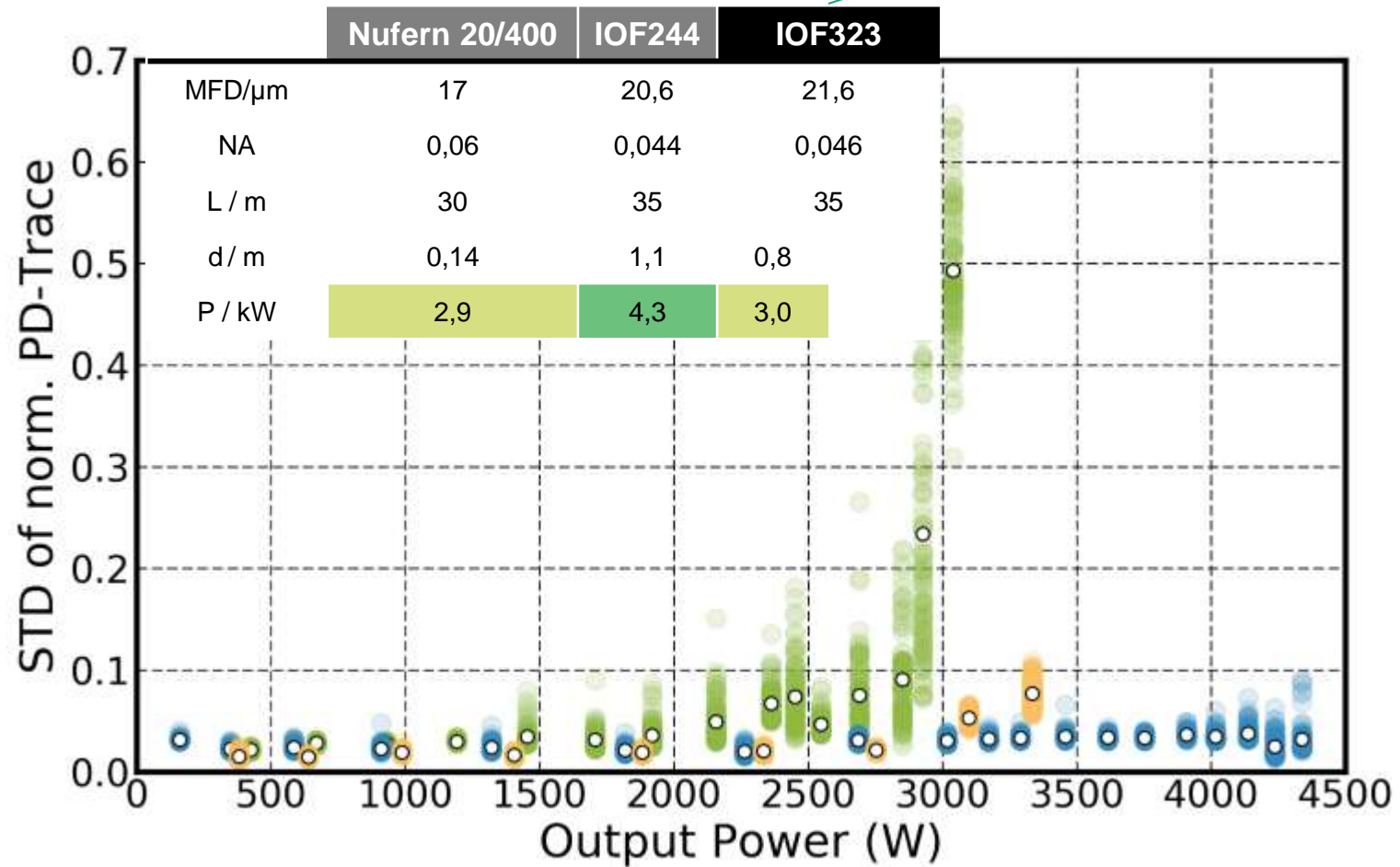


# Scaling Experiments

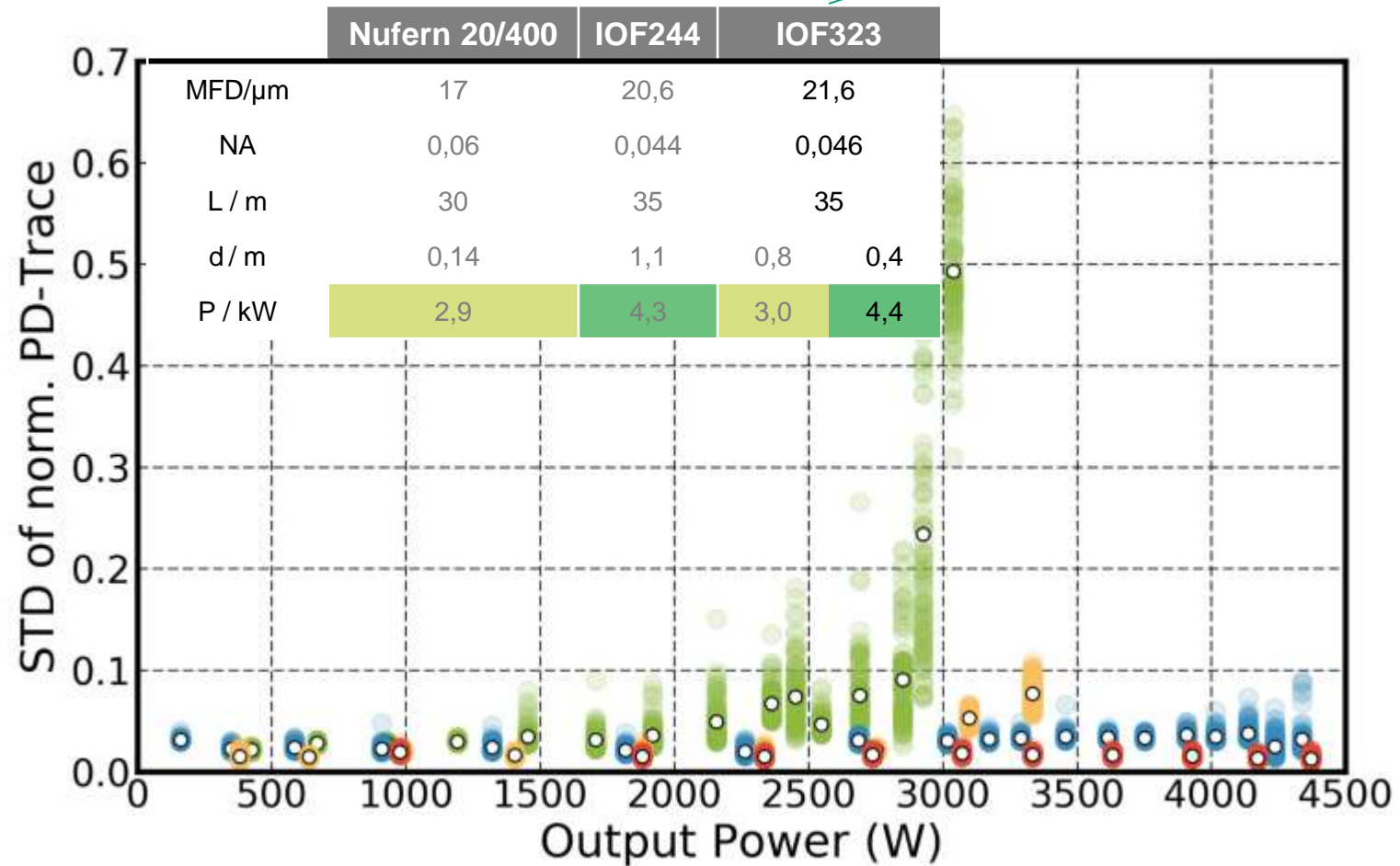
- Seeded by two wavelength
  - Broadening to 7 nm
  - Pump limited



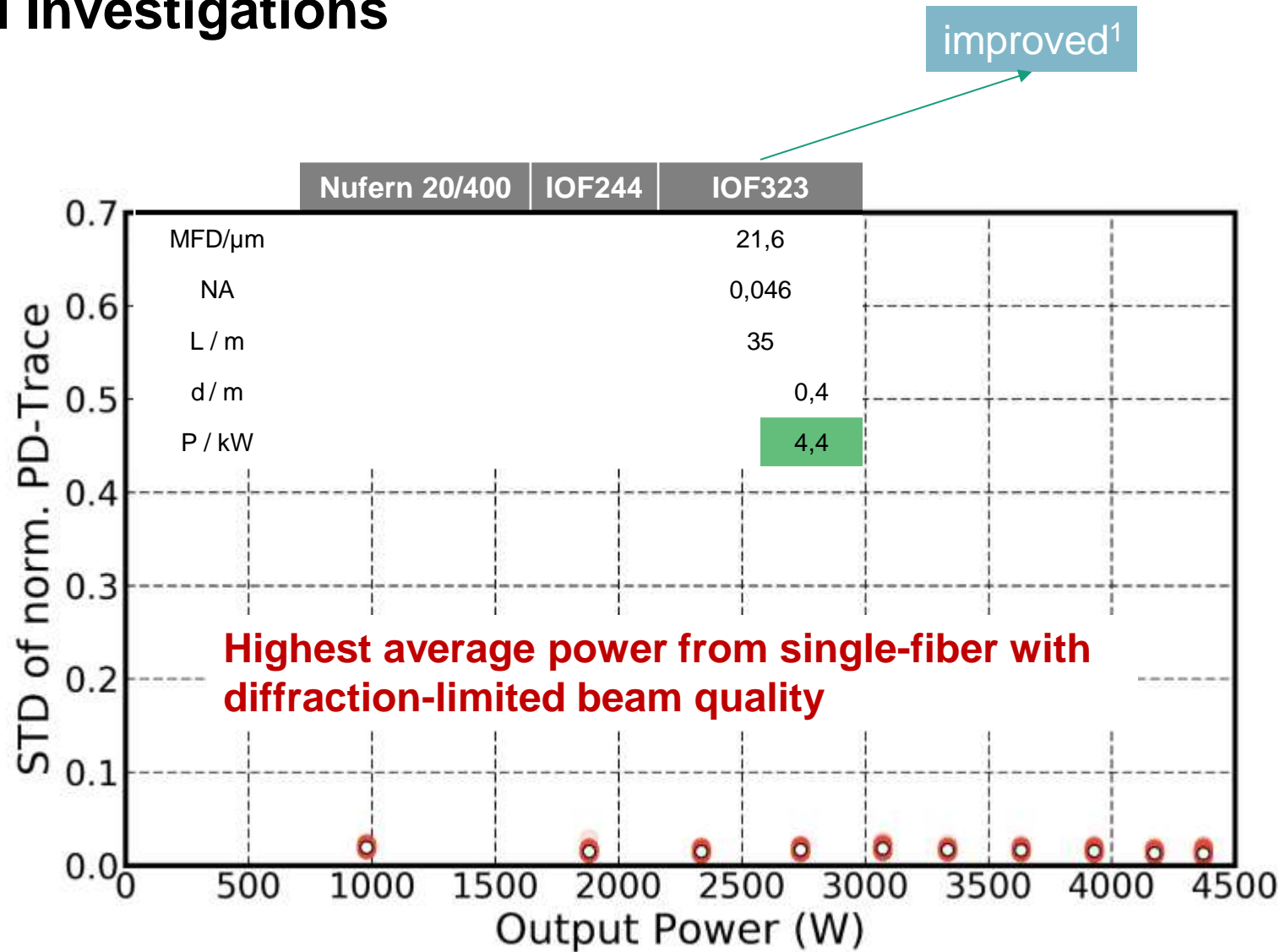
# TMI Investigations



# TMI Investigations



# TMI Investigations



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# AGENDA

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- Introduction
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# Summary

- TMI Investigations with commercial fibers → nearly 3kW stable output power
- Improvement of our own fibers→

	Nufern 20/400				IOF282		IOF267	IOF244	IOF323	
MFD/ $\mu\text{m}$	17				23,1		22,7	20,6	21,6	
NA <sub>mean core</sub>	0,06				0,042		0,041	0,044	0,046	
length / m	13			30	30		35	35	35	
d <sub>bending</sub> /m	0,6	0,3	0,14	0,14	1,0	0.5	1,1	1,1	0,8	0,4
P <sub>Max</sub> / kW	0,8	1,0	2,2	2,9	0,5	1,5	2,8	4,3	3,0	4,4

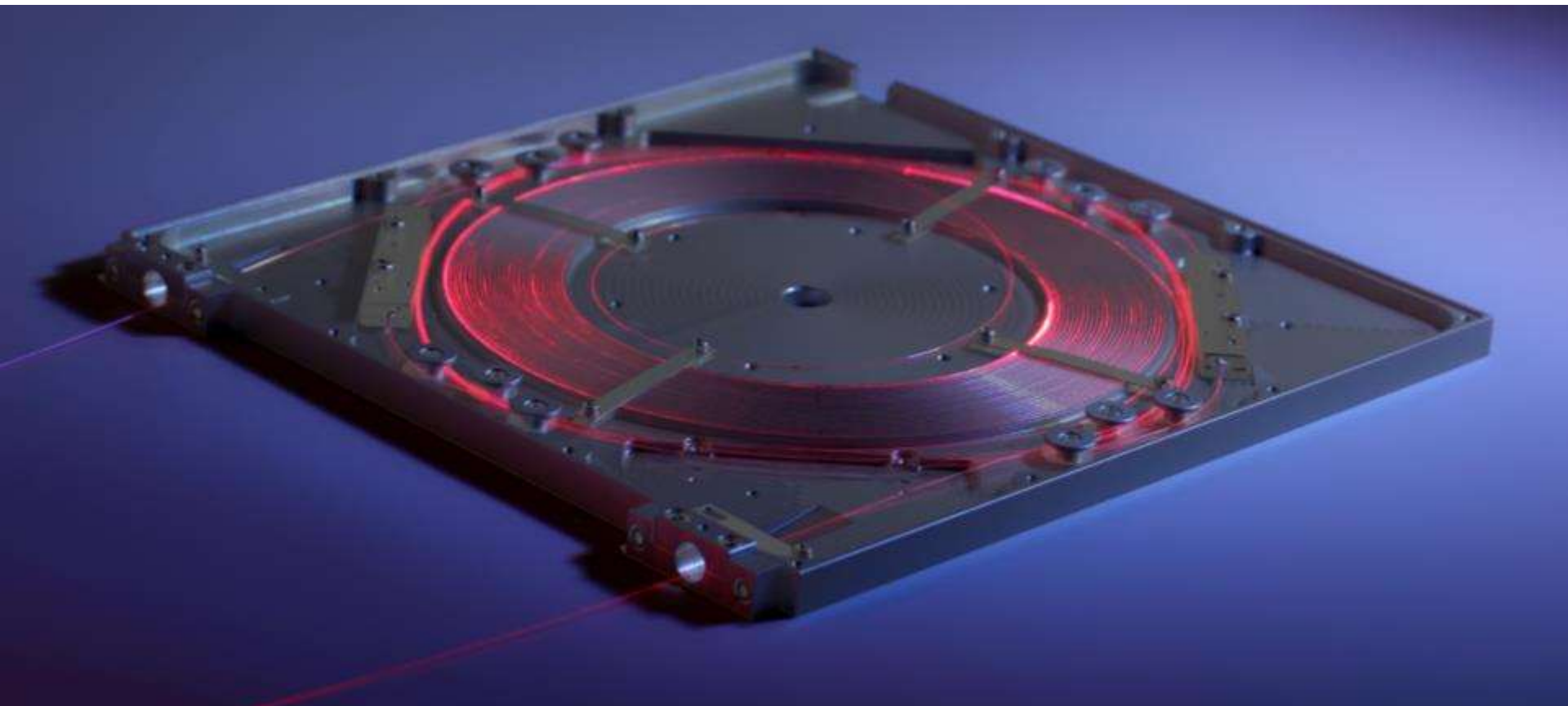
GEFÖRDERT VOM



Thank you.



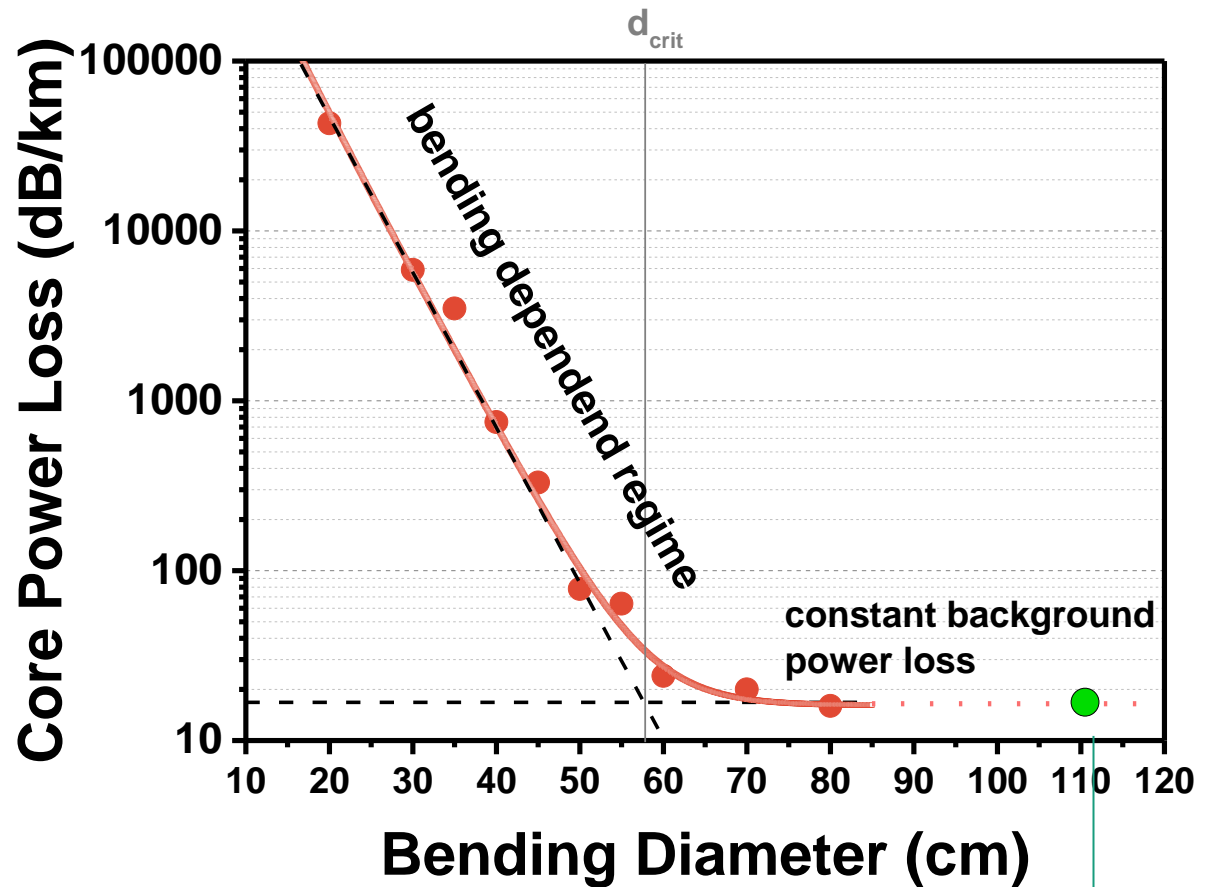
Bundesministerium  
für Bildung  
und Forschung



# Fiber properties

IOF244

MFD/ $\mu\text{m}$	20,6
NA	0,044
L / m	35
d / m	1,1
P / kW	4,3



Operation point

Worst case scenario