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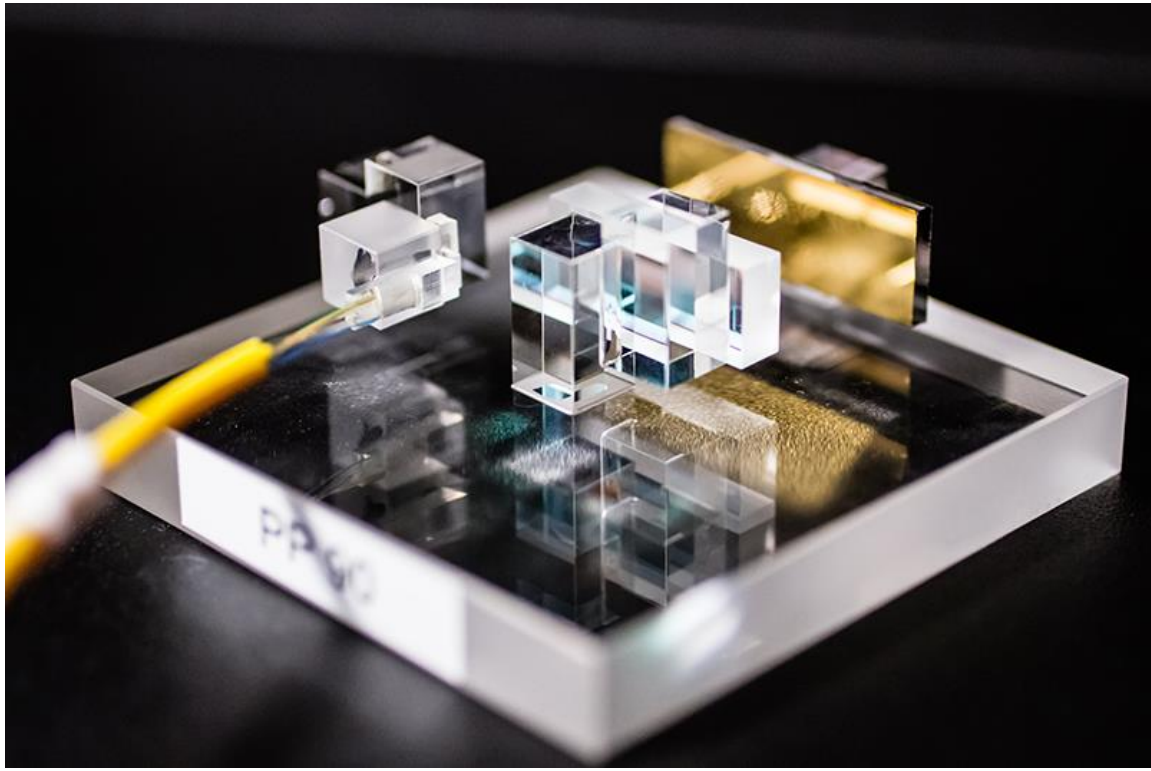
EPIC
EUROPEAN PHOTONICS INDUSTRY CONSORTIUM

Tackling Micromachining Challenges With Beam Shaping Using Multi-Plane Light Conversion Technology



EPIC LWoP

Munich, June 28th, 2023

Ivan GUSACHENKO – Lead Engineer for Laser Micromachining

LASER World of PHOTONICS

We develop, manufacture, and sell beam shaping solutions

cailabs

Headquarters:
Rennes, France

Cailabs, a deep-tech company

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Unique technology (MPLC)
and **expertise** in beam shaping

22
patent families

70%
export

70+ employees
(**30** PhDs)

43 M€
raised

20+ sales partners
worldwide

References:

SAFRAN

DLR

PRECITEC

Rexel

NEC

Amplitude

DGA

LZH
LASER ZENTRUM HANNOVER e.V.

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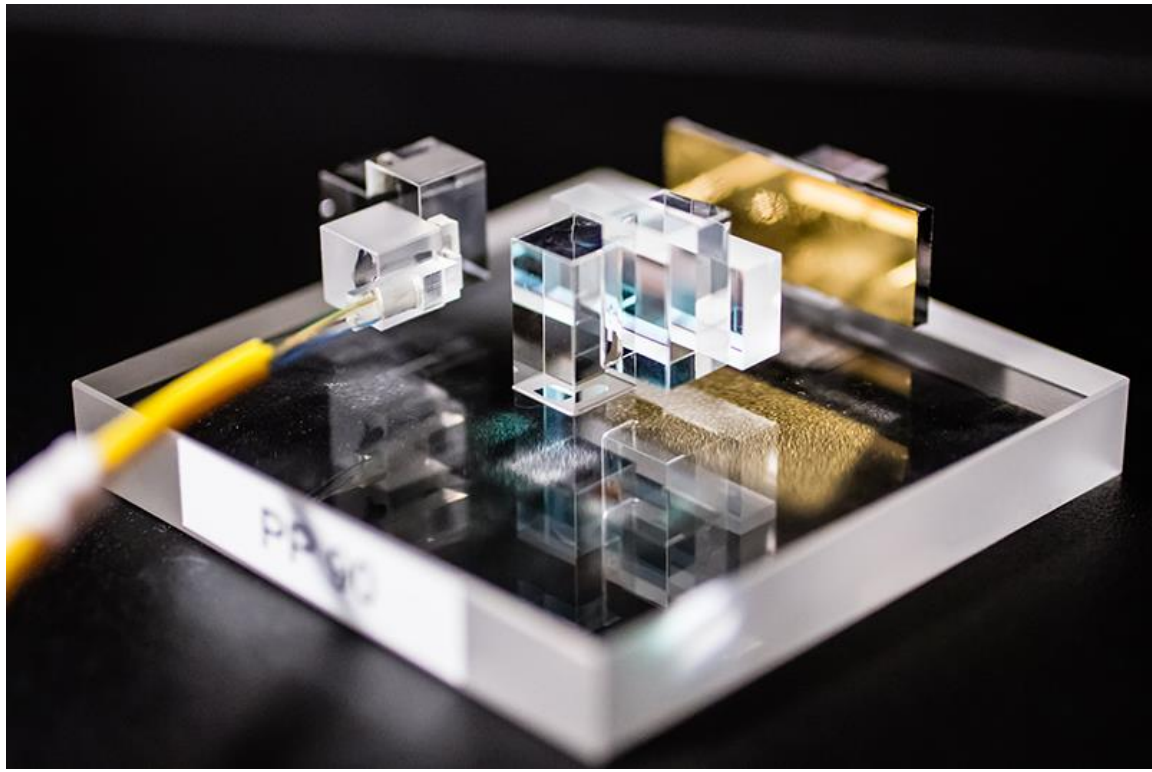
Agenda

- Beam-Shaping of Ultra-Short Pulse lasers
- Tackling micromachining challenges with beam-shaping
- Conclusion



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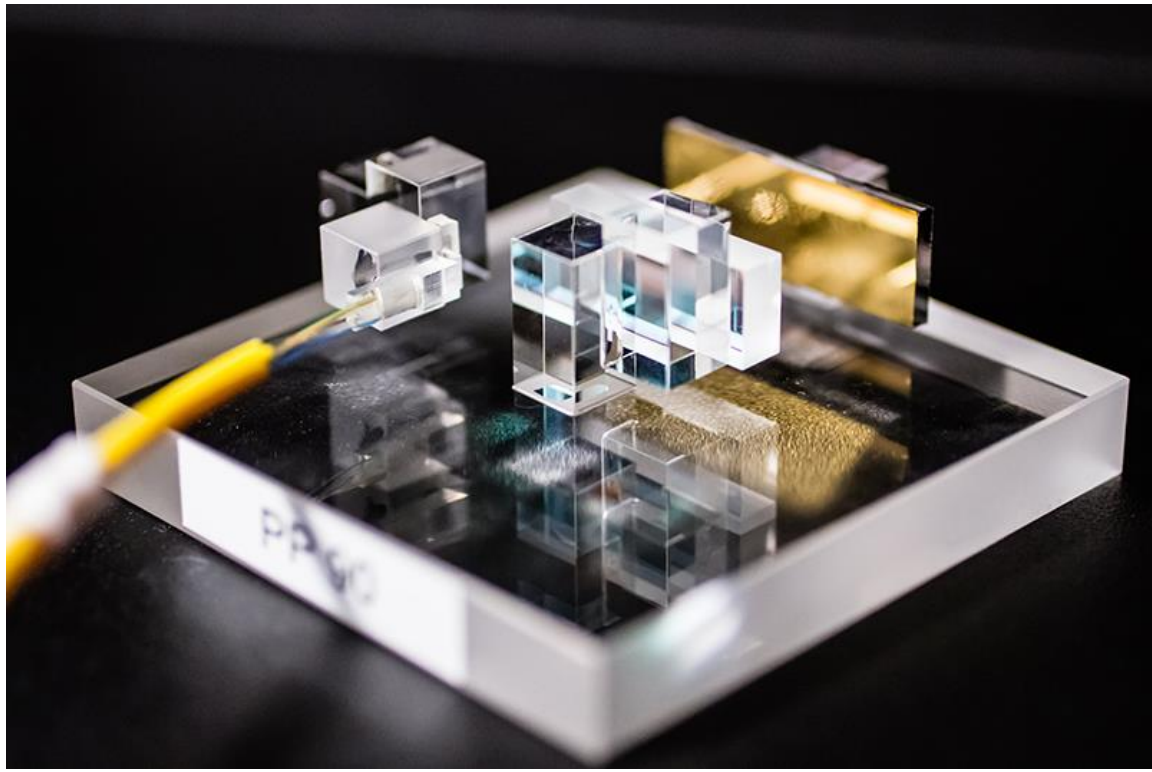
- **Beam-Shaping of Ultra-Short Pulse lasers**
  - **Review of beam-shaping technologies**
  - Performance criteria for shaped beams
  - Performance comparison
- Tackling micromachining challenges with beam-shaping
- Conclusion



Beam shaping of USP lasers – Technologies review
Multiple laws of optics can be used to generate a shaped beam

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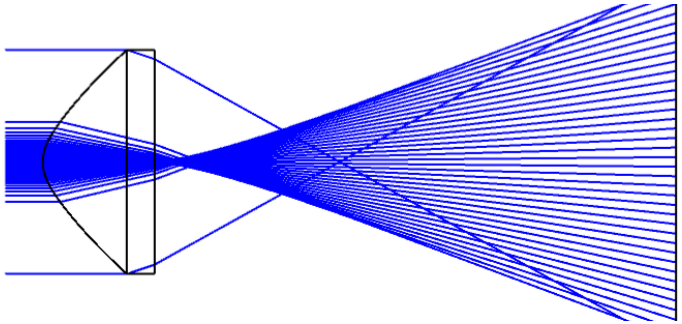
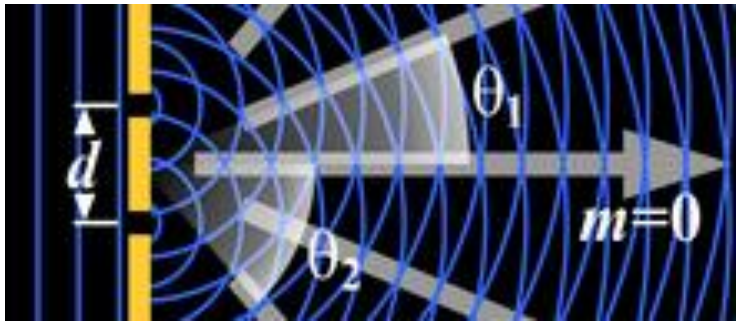
There are multiple ways to generate a top-hat :



Ray tracing

Classical beam-shapers such as aspheric

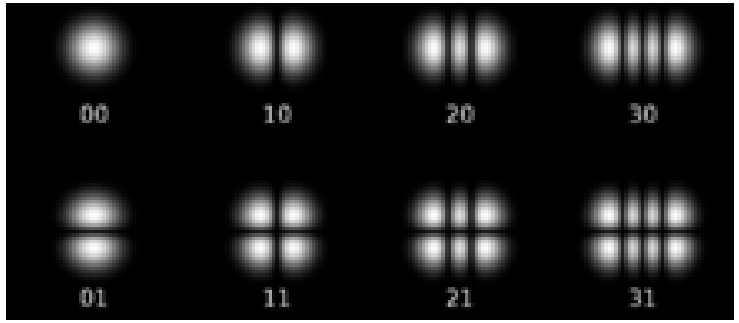
Light is tuned using **Fresnel laws**



Diffraction

Diffractive Optical Elements (DOEs)

Light is tuned using **physical optics laws**



Mode propagation

Multi-Plane Light Conversion (MPLC)

Light is tuned using unitary **mode transformation**

Image credit to Wikipedia and Shape optics

Beam shaping of USP lasers – Technologies review
Multi-Plane Light Conversion, based on modes propagation laws

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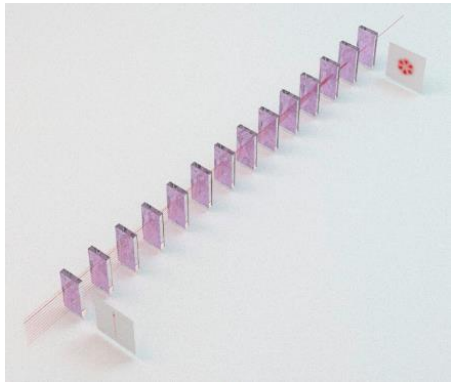
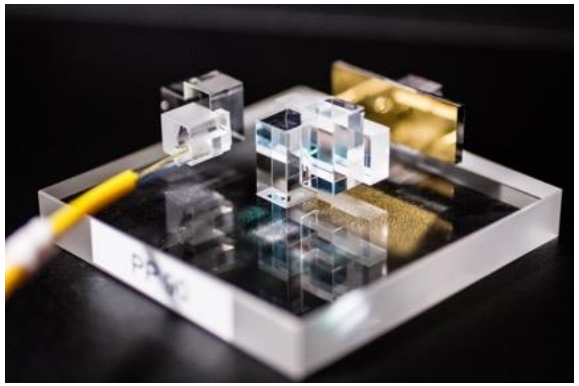
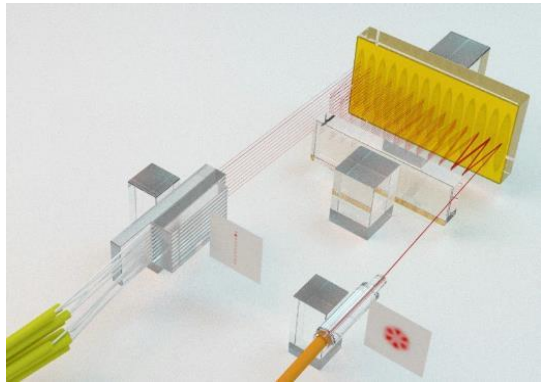
Multi-Plane Light Conversion (MPLC)

- **Free-form beam shaping** through succession of spatial phase profiles and propagation
- **Passive** beam shaping with **no intrinsic loss**
- **Reflective implementation**, can handle high power / energy
- **Single or multiple, fibered or free-space, input and output**

➔ **A good solution for high power or high energy shaping and combining!**







Labroille, G. et al., Optics Express, 22(13), 15599-15607.

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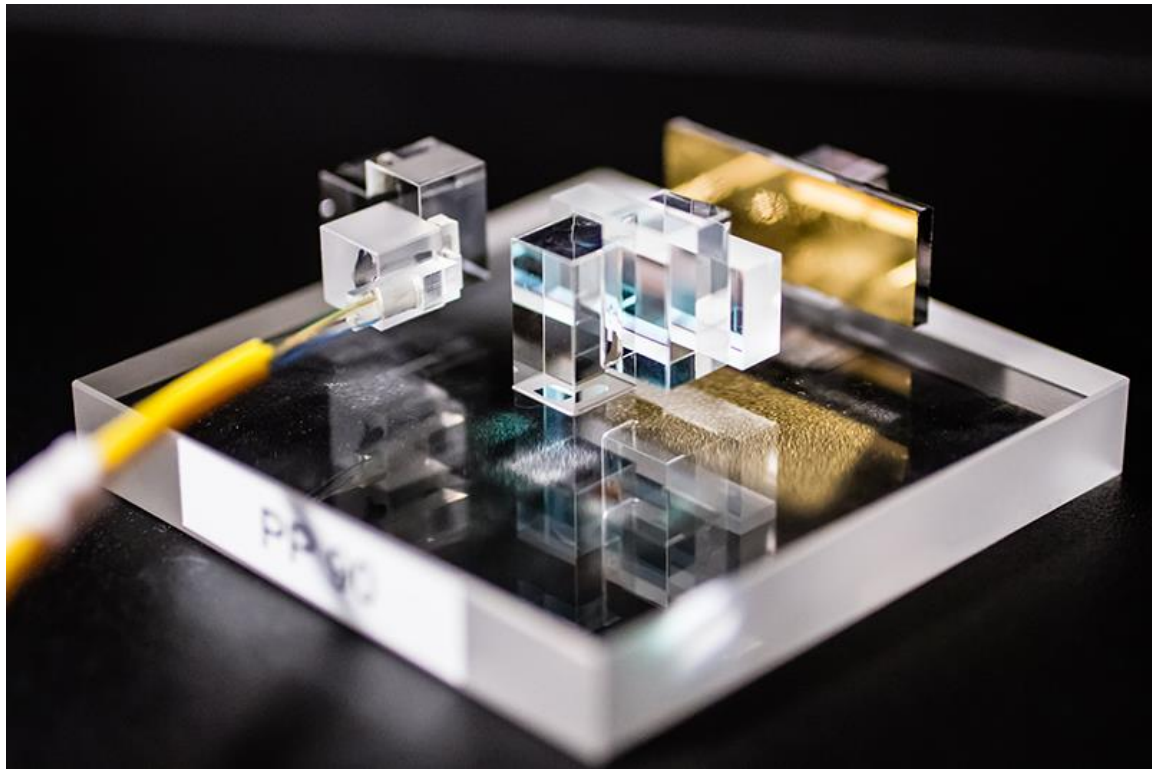

Beam shaping of USP laser – Beam-shaping performance criteria
<u>Criterion 1 :</u> Shape efficiency (home-made !)

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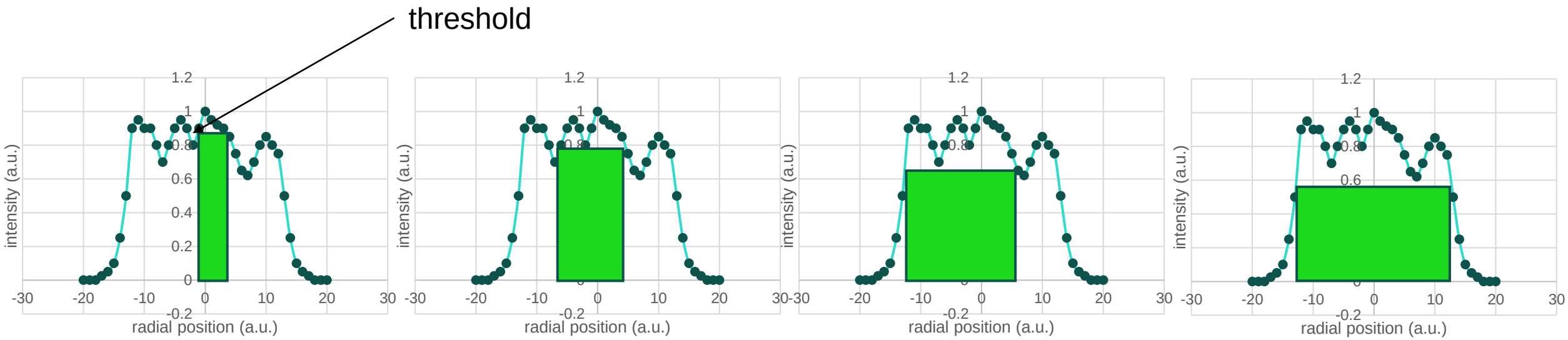
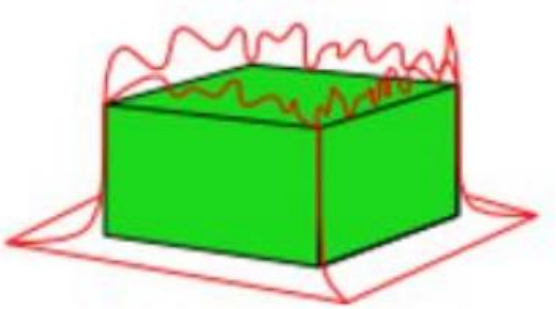
Shape Efficiency is the maximum ratio between **the energy contained in an ideal 3D** shape (cuboid, cylinder ...) inscribed in the beam shape **and the total energy** of the beam shape.





Beam shaping of USP laser – Beam-shaping performance criteria
Criterion 2 : Depth Of Field (home-made again)

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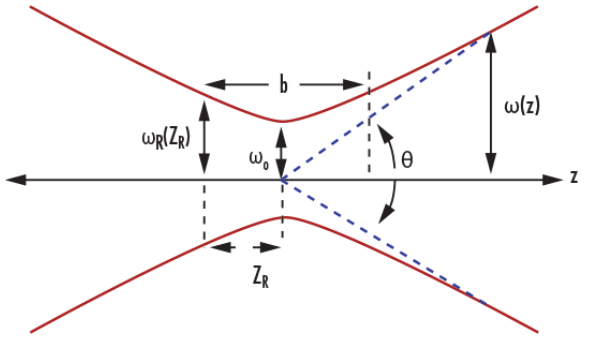
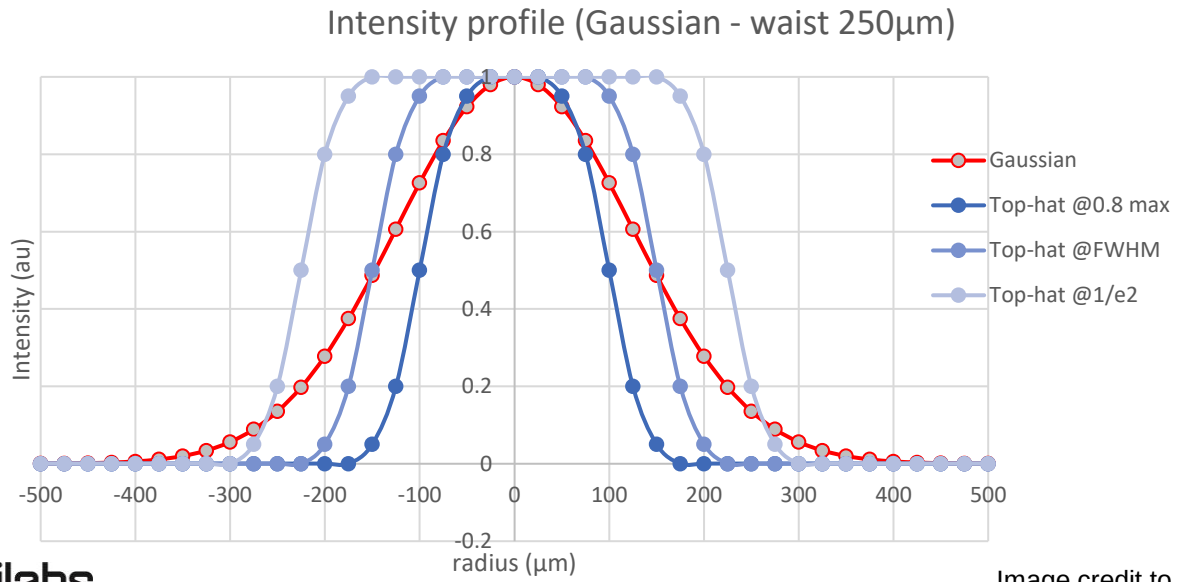
For a Gaussian it is generally admitted that it is **the Rayleigh range :** $z_R = \frac{\pi\omega_0^2}{\lambda}$



Depth of field depends on: the beam **dimension, sharpness and** the **technology** used.

The comparison with a Gaussian is not simple as the **definition of the beam dimension** impacts the depth of field.



- We will talk in **% of Z_R,** and define the beam **dimension at 1/e²**
- We will look at the **visual profiles**
- We will calculate the **shape efficiency**

Image credit to Edmund Optics

Beam shaping of USP laser – Beam-shaping performance criteria
Criterion 3 : Robustness to misalignment

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Comparing the behavior of shapers to instabilities must be done **at equivalent diameter and divergence.**

Typical instabilities considered : **10 to 20% of w_0 shift, 10 to 20% of divergence tilt**

Criteria to compare the capability to handle instabilities:

- Visual aspect
- Shape efficiency

MPLC offers a passive beam stabilization function : misalignment is converted into a small transmission loss

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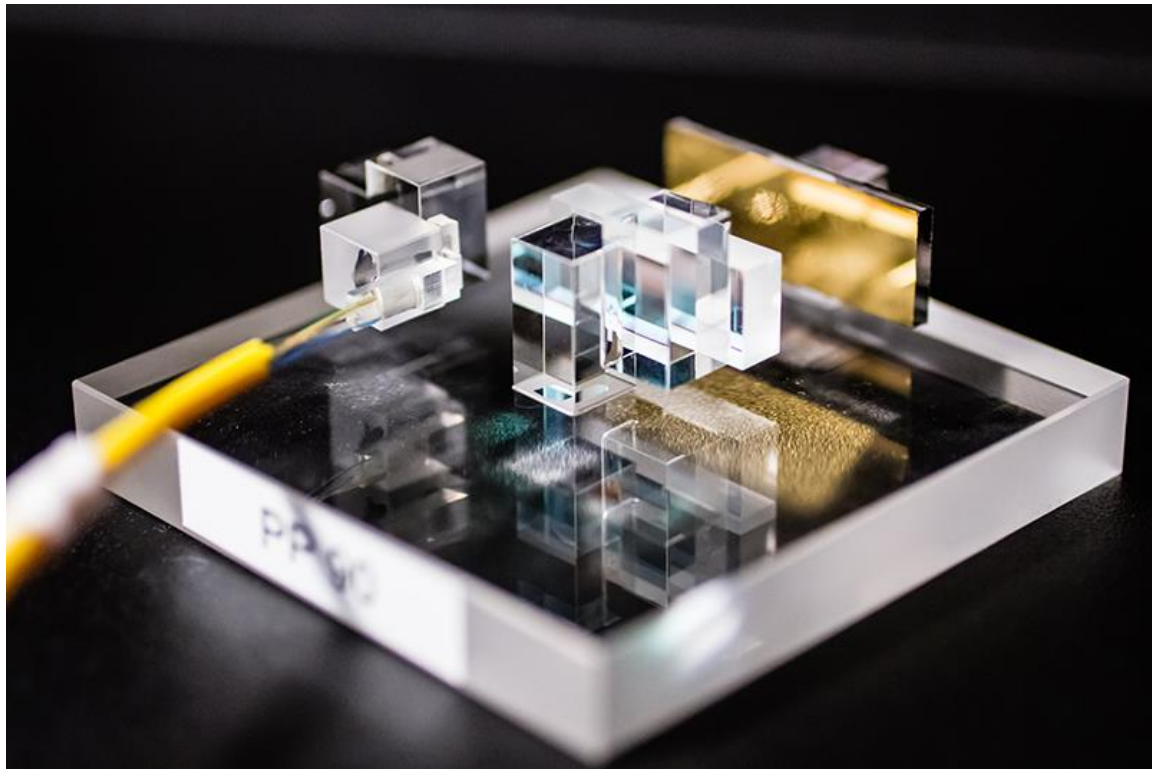

Beam shaping/splitting modules compatible with industrial constraints (laser, F-theta, scanner…)

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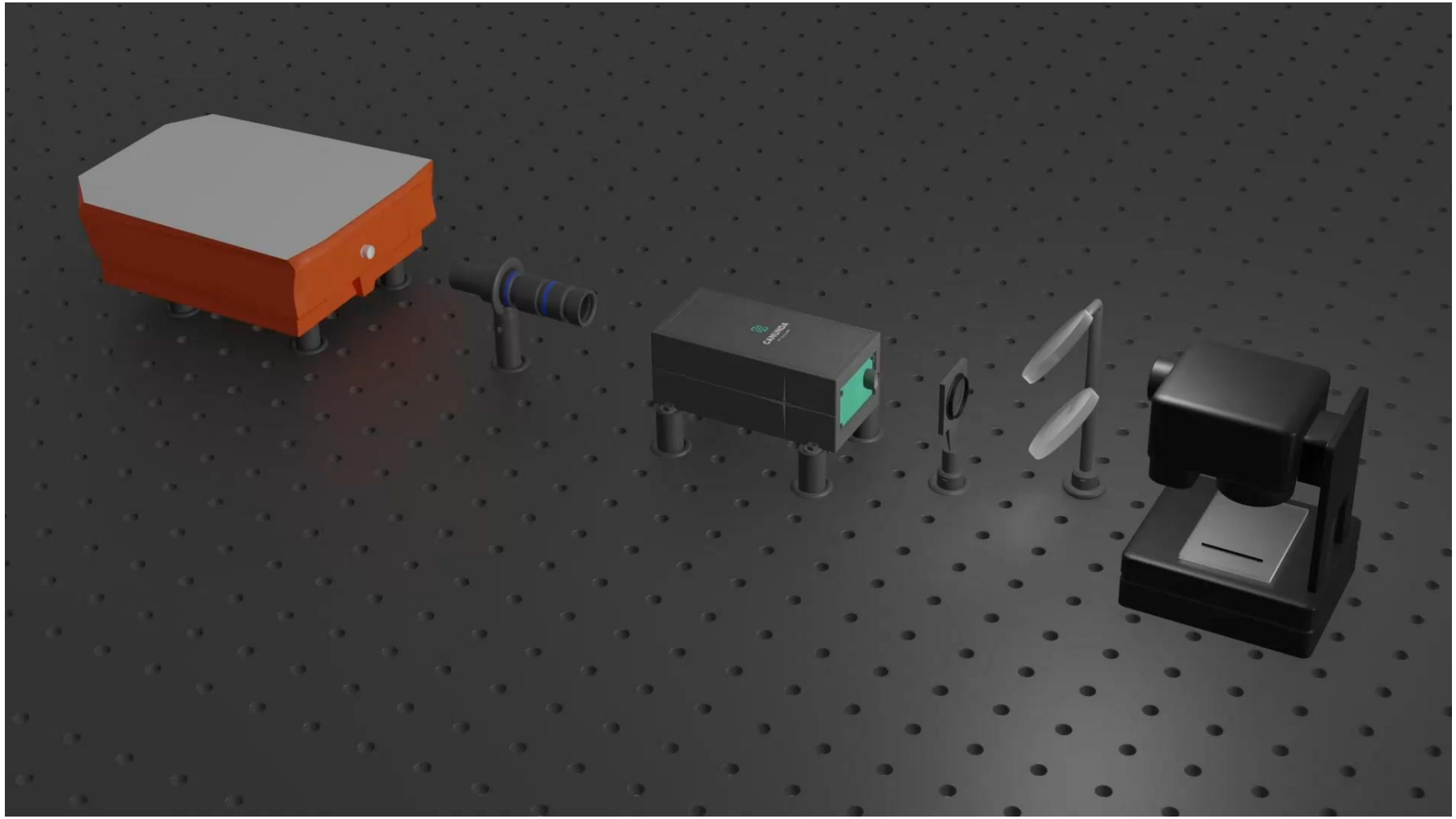


Depth Of Field : MPLC vs DOE

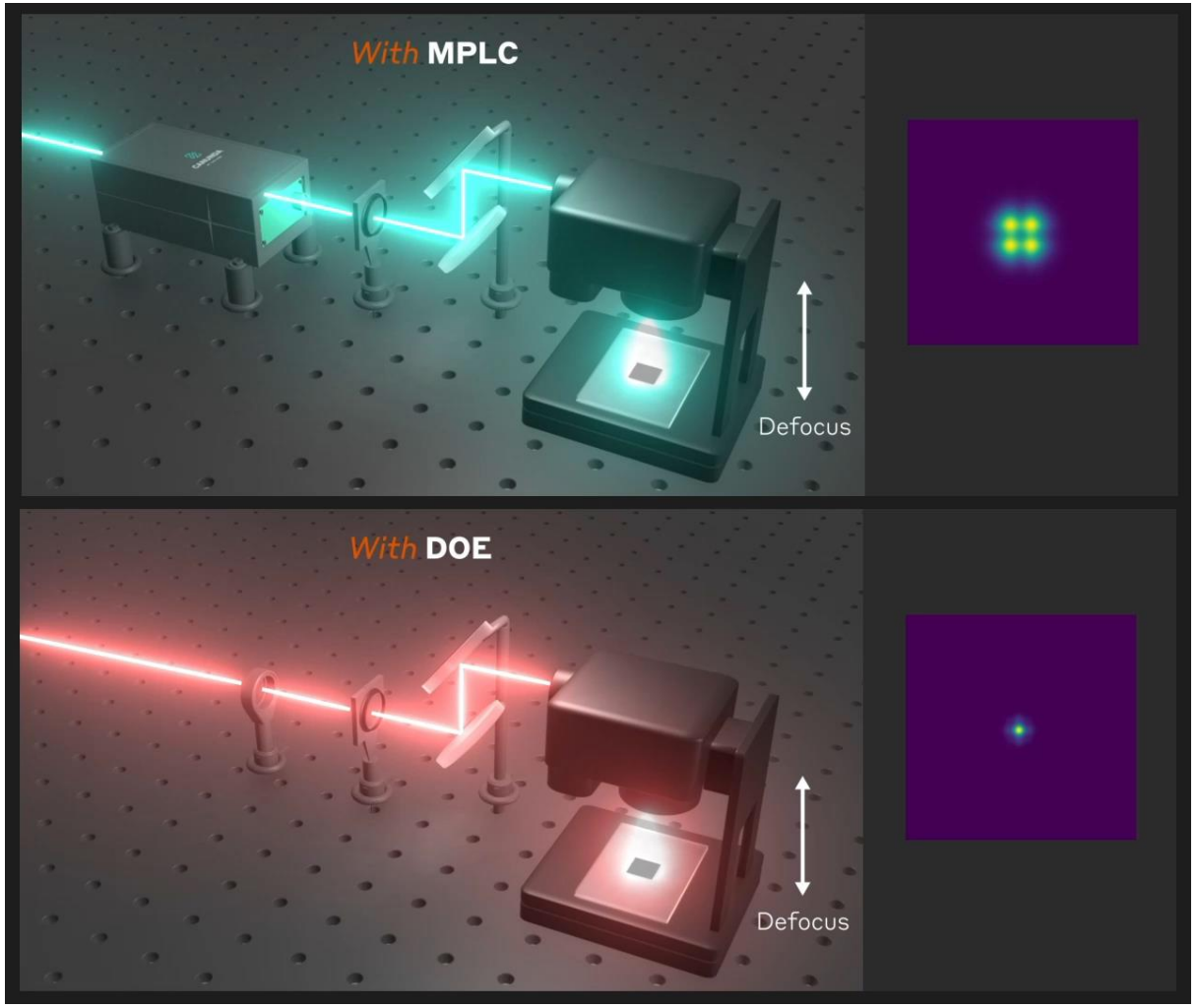
MPLC shape has minimal divergence for a given sharpness and size

80µm width square top-hat in the processing plane shaped beam

Note : 10 mm scanner aperture taken into account

Performance at the best focus :

	MPLC	DOE
Size (FWHM, µm)	78	69
Efficiency (%)	60%	42%
Uniformity (-)	0.06	0.32



Beam shaping of USP laser – Performance comparison
Depth Of Field : MPLC vs DOE

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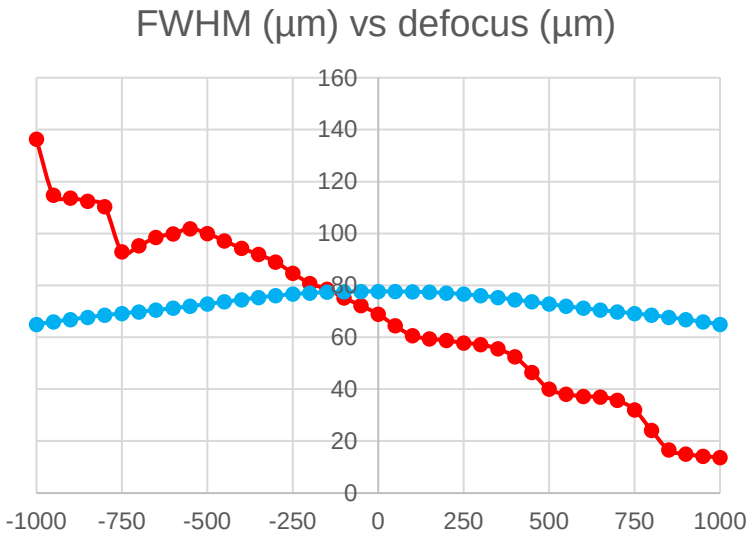

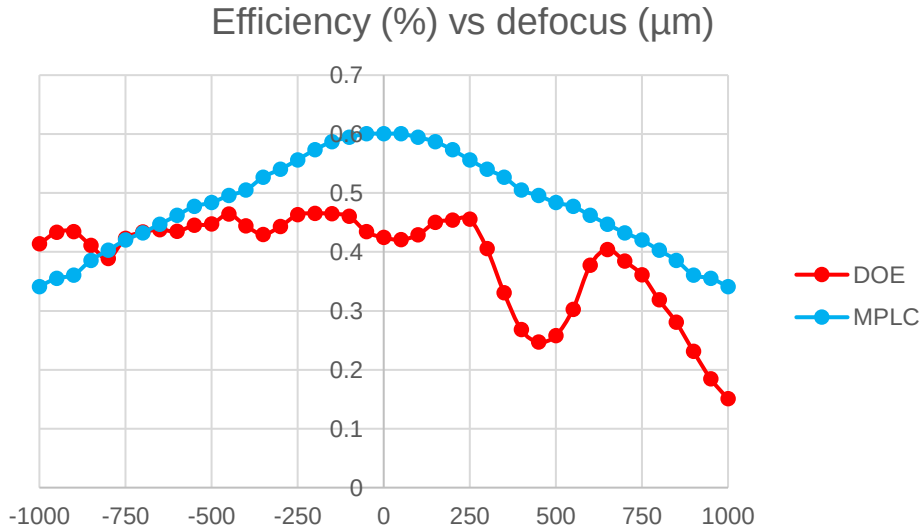

- The efficiency criteria is more relevant than the uniformity
- **MPLC's shape efficiency is higher, and its variations are more regular**
- **DOE top-hat size will vary lot** over the Depth of Focus

Input shift: MPLC vs DOE

MPLC shape stays stable at the cost of small transmission loss

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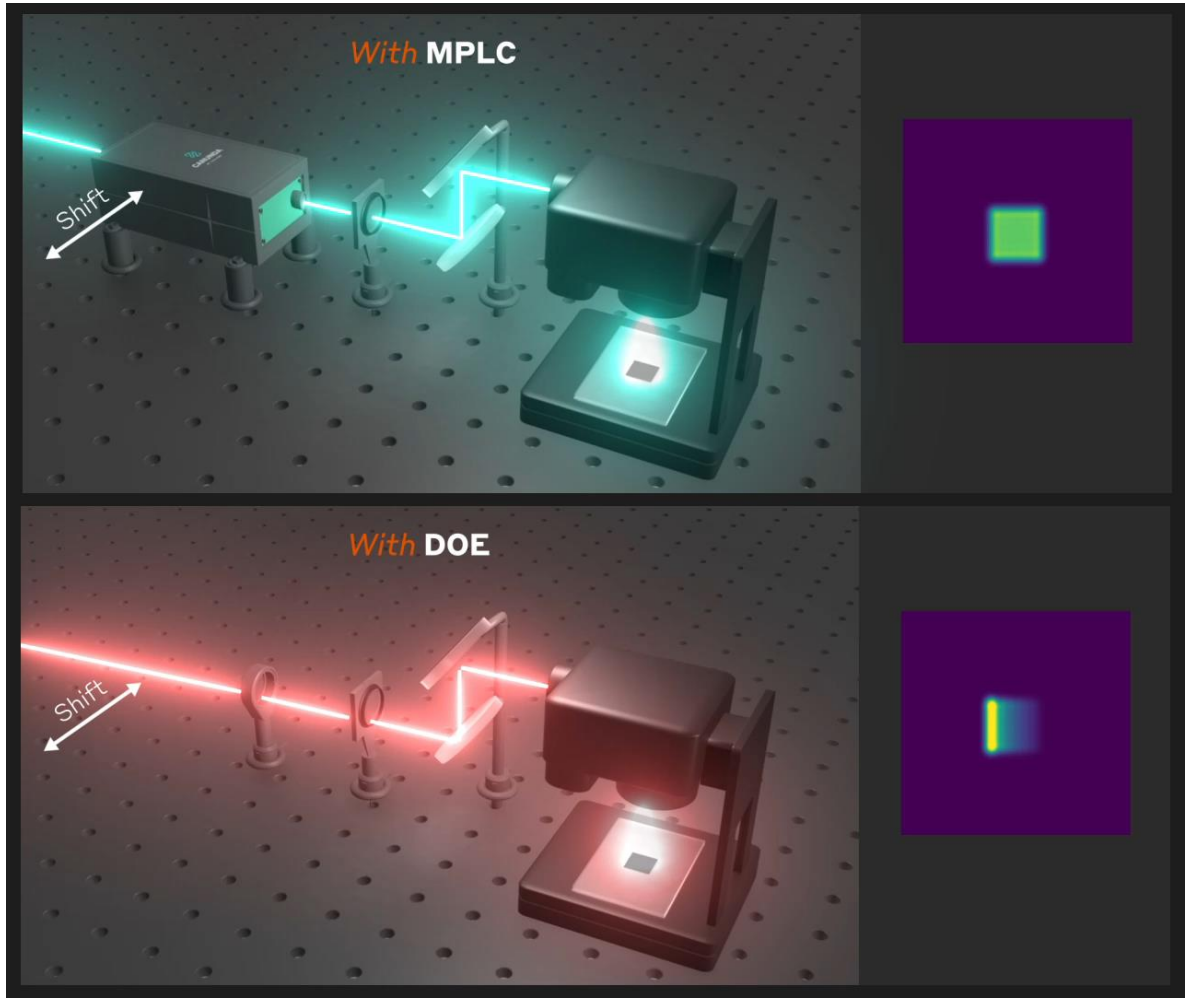
80 µm shapes in the processing plane

Note : no scanner aperture taken into account

MPLC : no deformation, loss of transmission

DOE : deformation, no loss of transmission



Beam shaping of USP laser – Beam-shaping performance criteria
Bonus : Robustness to misalignment for MPLC technology

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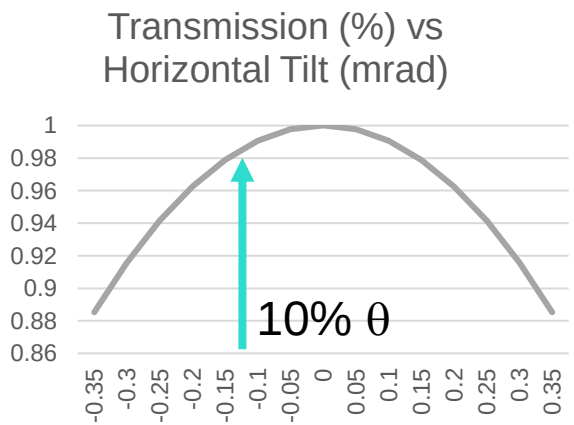
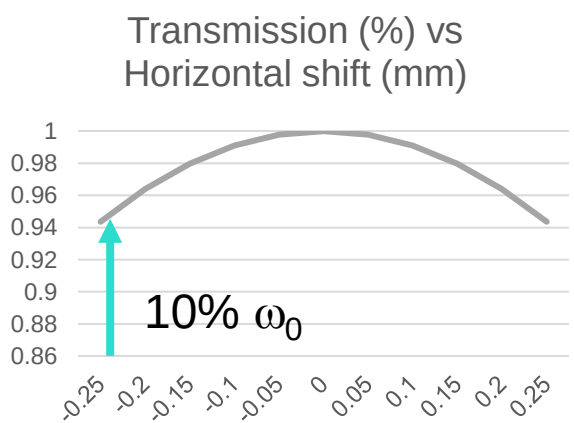
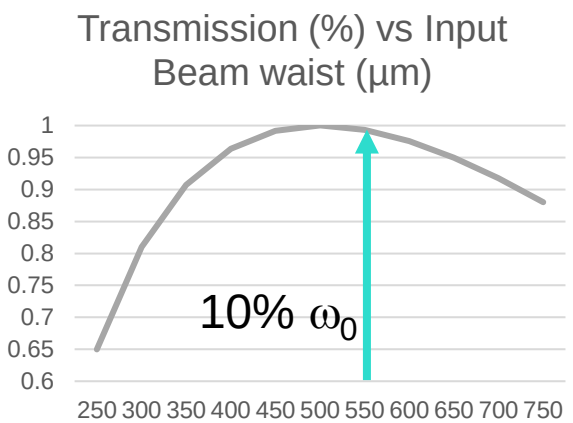
MPLC theoretical performance vs misalignment

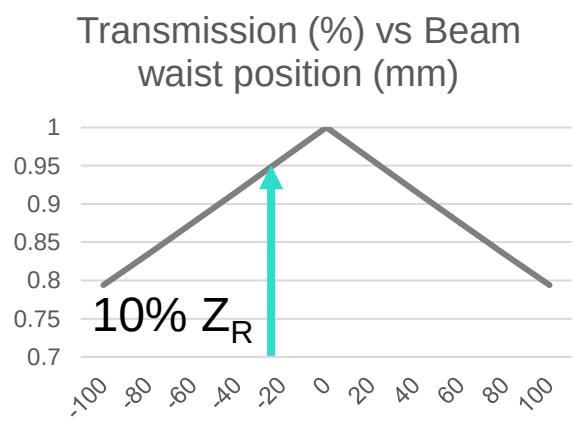
For an output beam of 500µm, w_0 = 250µm, θ=1,31mrad, Z_R = 190mm

Impact on transmission always < 5%









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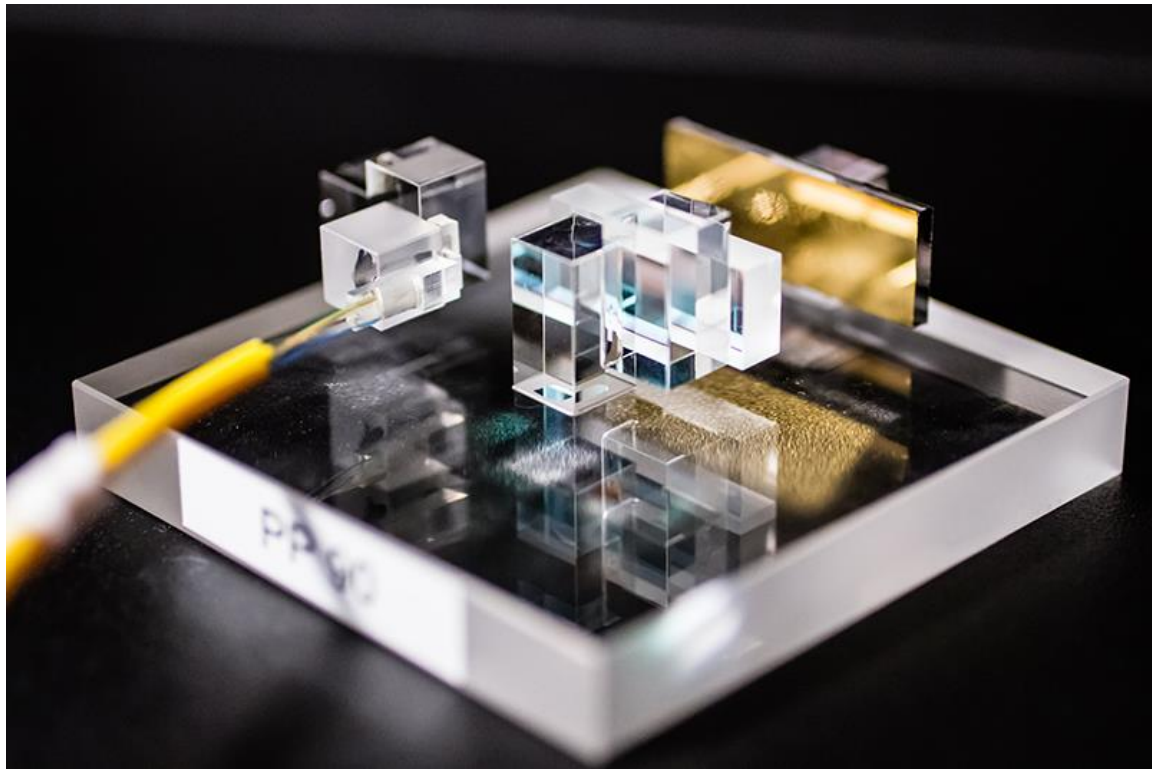
- Beam-Shaping of Ultra-Short Pulse lasers
- **Tackling micromachining challenges with beam-shaping**
  - Process speed
  - Manufacturing precision
  - Fiber delivery
- Conclusion



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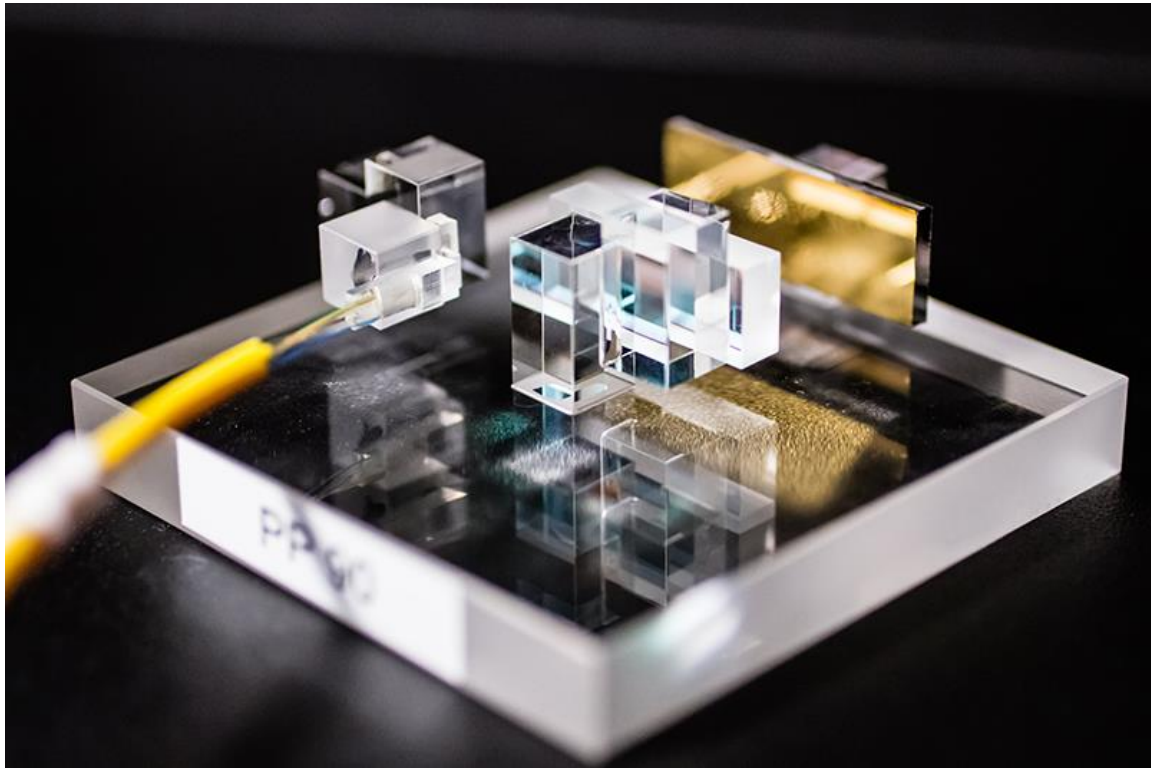

Tackling µ-machining challenges with beam shaping – Process speed

Preserved quality and process speed **x2.5** thanks to 5 splitted beams

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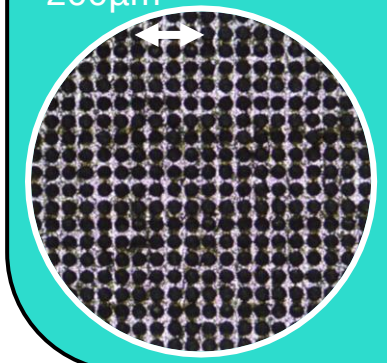
Surface texturing (tribological properties improvement) **…**

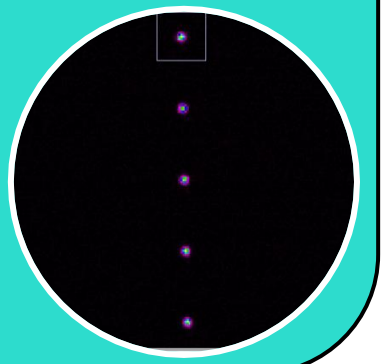
- Stainless steel
- 1030nm
- 4mm x 4mm
- Pitch of splitting pattern: 200µm
- Pitch of the scanning : 50µm



… with 5 splitted beams

in the processing plane :

- 5 splitted Ø40µm spots
- Homogeneity <2,5%
- Ellipticity <5%



Process speed **x2.5**

M. Ziat et al., Tribological Properties Improvement of Stainless Steel and Nickel Samples at Large Scale thanks to Beam Splitting with a Femtosecond Laser, ICALEO (2023)

MANUTECH

Tackling µ-machining challenges with beam shaping – Process speed
LIPPS generation with a **x20** process speed thanks to a line top-hat

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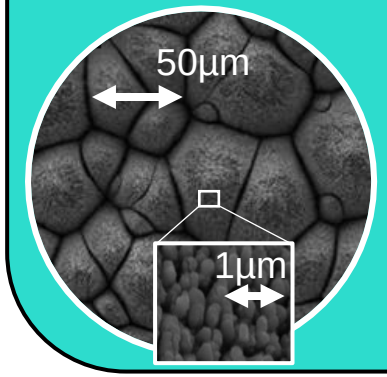
Surface texturing (Laser Induced Periodic Surface Structure for darkening effect generation) **…**

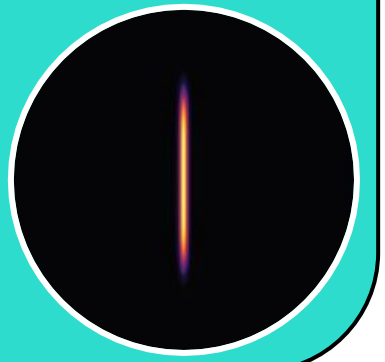
- Stainless steel 316L
- 1030nm
- <5% reflectivity



… with a line top-hat

in the processing plane :

- 600µm length
- 30µm width



Process speed **x20**

ALPhA NOV
Optics & Lasers Technology Center

C. Jacquard et al., Laser Induced Periodic Surface Structures generation by femtosecond laser and Multi-Plane Light Conversion beam shaping, SPIE Photonics West (2020)

Tackling µ-machining challenges with beam shaping – Process speed

Process speed **x10** thanks to a sharp square top-hat

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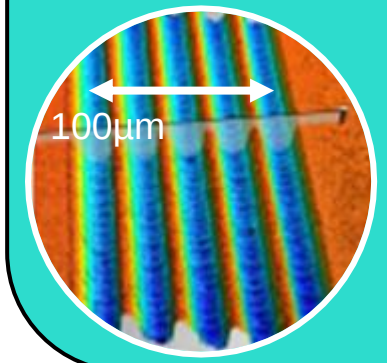
Surface texturing (aerodynamic performance improvement) **…**

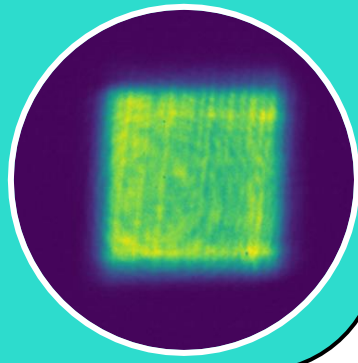


- Aluminium AU4G
- 1030nm
- 1 lateral pass (vs 13 for Gaussian)
- 21 longitudinal pass (vs 37 for Gaussian)
- 0.9 J/cm² (vs 0.6 for Gaussian) @2MHz

… with a square top-hat

in the processing plane :

- 15µm width
- Uniformity : 0.1
- Sharpness : t/L = 0.1



Process speed **x10**

E. Mottay et al., High Power Shaped Femtosecond Beams for Riblets Manufacturing, SPIE Photonics West (2023)

Amplitude

Tackling µ-machining challenges with beam shaping – Process speed

Glass drilling process speed **x5** thanks to a reflective Bessel beam

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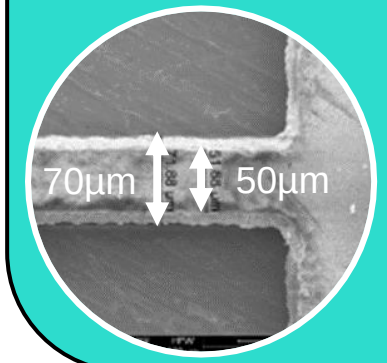
Glass drilling…

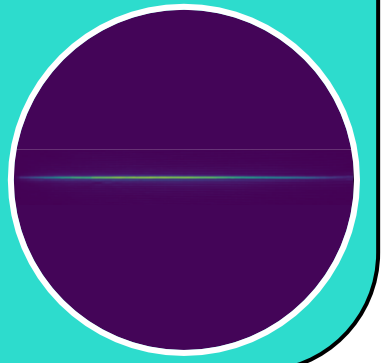


- UTG Schott D263 glass
- 1030nm
- 50µm thickness
- <10µm transition zone
- 50mm x 50mm without translation stage
- 1 scan drilling

… with a Bessel beam

in the processing plane :

- 20µm FWHM
- 45mm length
- 1/2250 aspect ratio



Process speed **x5**

A. Billaud et al., High Quality Bessel Beam Generation through Reflective Axicon for Glass Microprocessing, ICALEO (2019)

LZH LASER ZENTRUM HANNOVER e.V.

Tackling µ-machining challenges with beam shaping – Process speed
Laser cleaning with x4 Depth of Field and **+30%** efficiency thanks to MPLC

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Surface treatment (laser cleaning) …

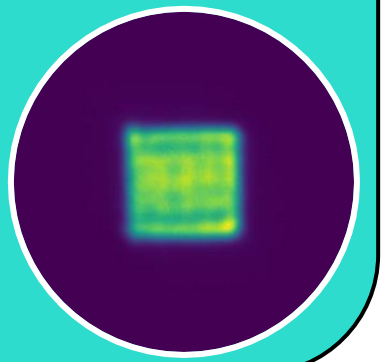
- Confidential material
- 1030nm
- 12,5mm scanner aperture
- 1m EFL focusing lens

Confidential application

… with a square top-hat

in the processing plane :

- 1mm x 1mm
- 59% efficiency (vs 45% DOE)
- ± 20mm Depth of Field (Efficiency max -5%) (vs ± 5mm DOE)



Depth of Field **x4**

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  - **Manufacturing precision**
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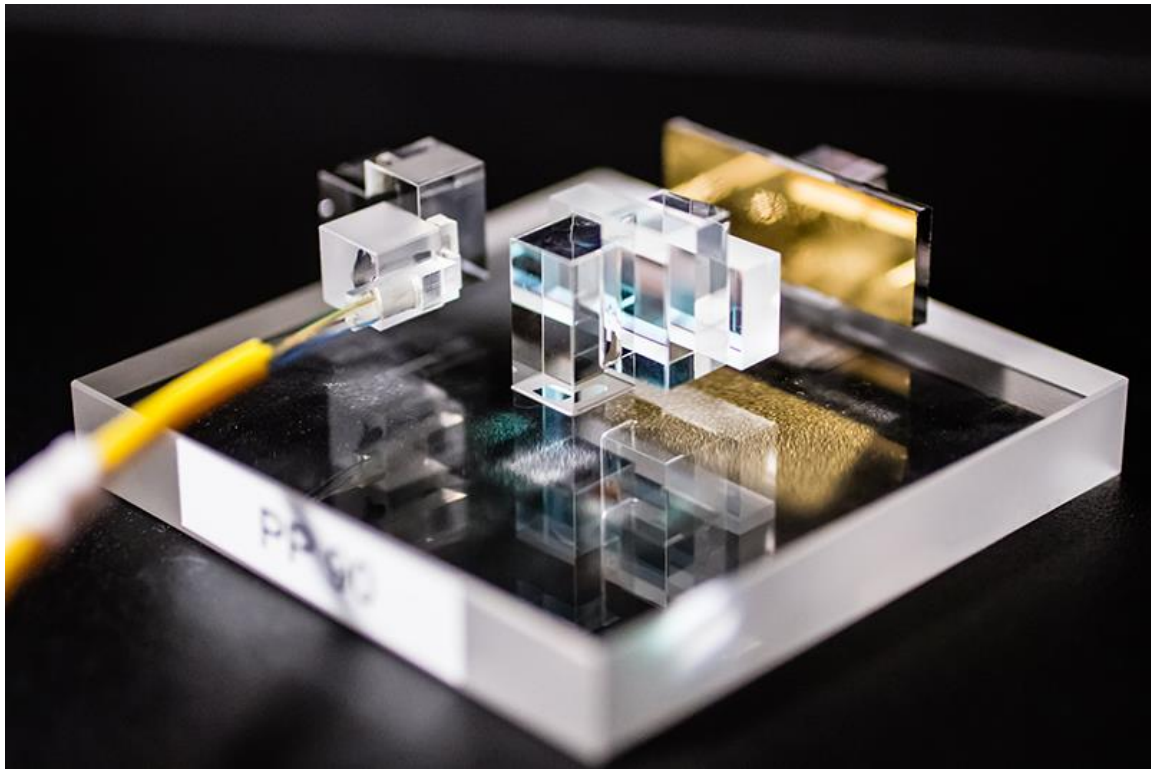

Tackling µ-machining challenges with beam shaping – Manufacturing Precision
DLIP with a ***/5*** homogeneity thanks to 4 splitted square top-hat

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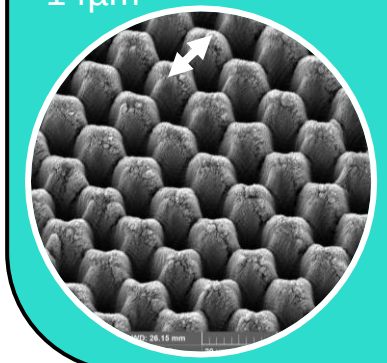
New

Surface texturing (DLIP generation) …

- Stainless steel
- 1030nm
- Roll-to-roll process

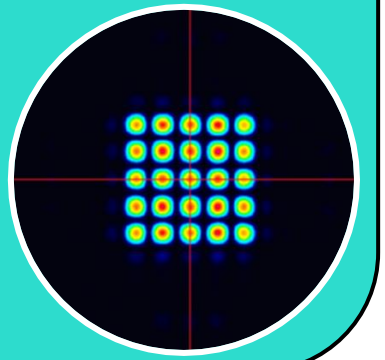
14µm



… with interferences based on 4 splitted square top-hat

in the processing plane :

- 14µm pitch



Homogeneity
/5

To be published

ALPhA NOV
Optics & Lasers Technology Center

Tackling µ-machining challenges with beam shaping – Manufacturing Precision

Fresnel lenses mold drilling precision improvement **x4** thanks to a triangle top-hat

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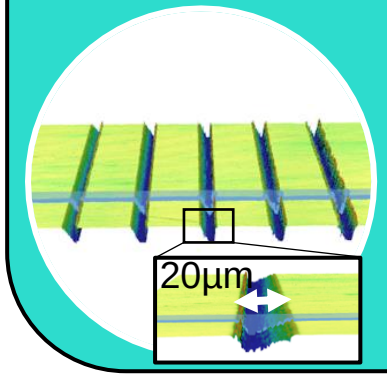
Triangular shape metallic groove drilling…

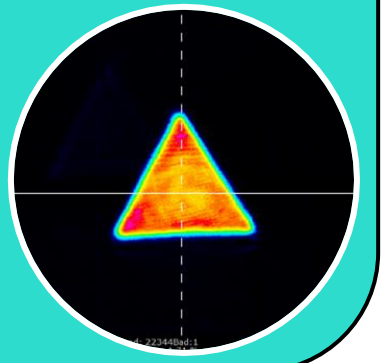
- Stainless steel
- 1030nm
- 5µJ per pulse
- 20mm/sec scanning



… with a triangular top-hat

in the processing plane :

- 10µm width
- Sharpness : t/L = 0.2
- Depth of Field : 9µm



Maximum positinoning precision **x4**

I. Gusachenko et al., Polymer injected lenses mould manufacturing improvement thanks to femto-second processing with a tailored MPLC-based beam shaper, LPM (2022)

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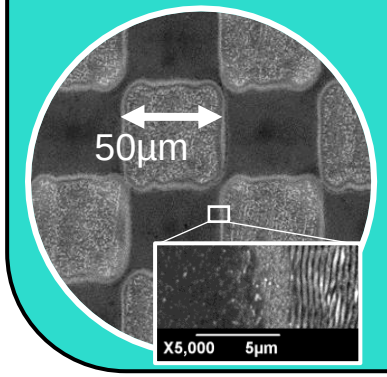
Tackling µ-machining challenges with beam shaping – Manufacturing Precision

LIPSS Transition length ***/5*** thanks to a sharp square top-hat

CANUNDA BY CAILABS

Surface texturing (LIPSS generation for hydrophobic texture properties) **…**

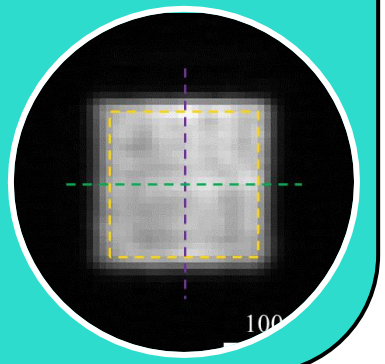
- Stainless steel
- 515nm
- 1KHz
- 0.16 J/cm²
- LIPSS pitch /2 vs IR



… with a square top-hat in green

in the processing plane :

- 50µm width
- Uniformity : 0.08
- Sharpness : t/L = 0.1



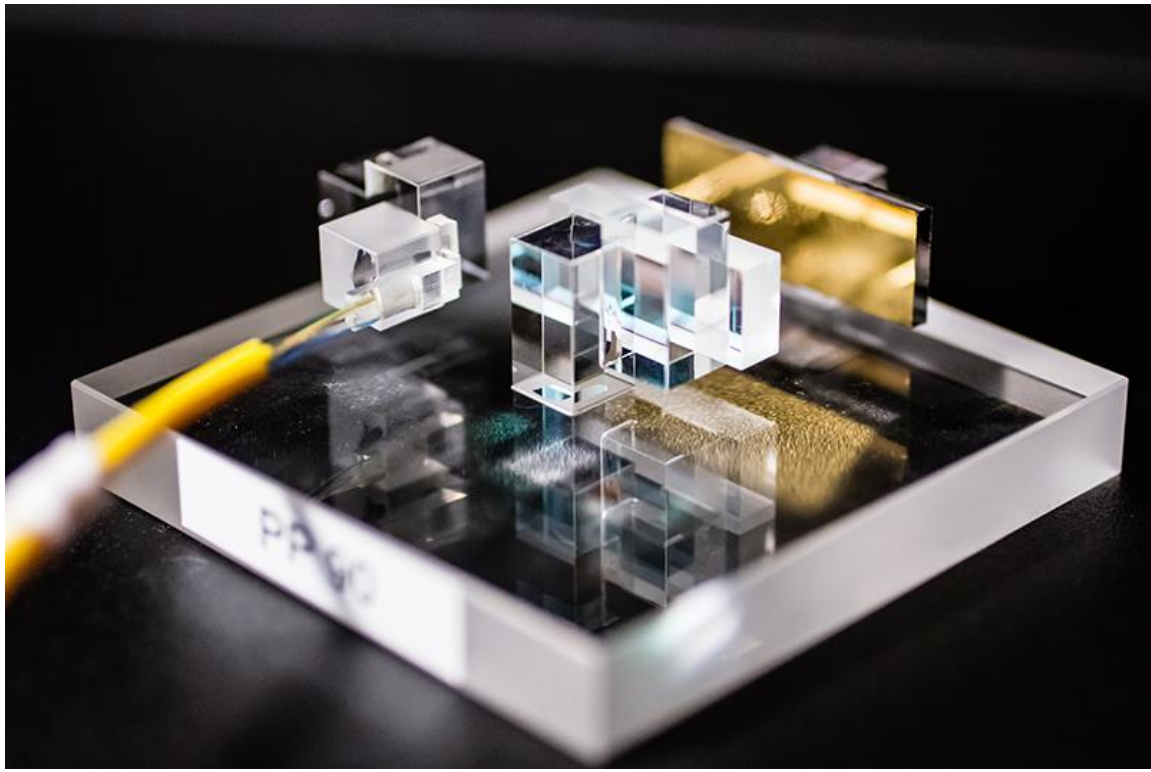
Transition length ***/5***

IFSW

C. Jacquard, Microprocessing with a multi-plane light conversion beam shaper and a femtosecond laser at 515nm, SPIE Photonics West - (2023)

cailabs
SHAPING THE LIGHT

- Beam-Shaping of Ultra-Short Pulse lasers
- **Tackling micromachining challenges with beam-shaping**
  - Process speed
  - Manufacturing precision
  - **Fiber delivery**
- Conclusion



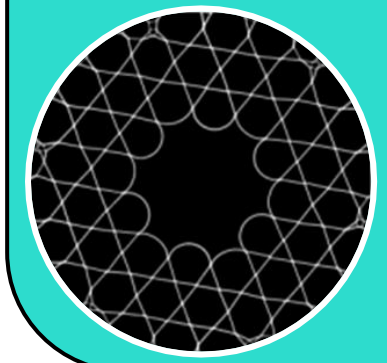
Tackeling µ-machining challenges with beam shaping – Fiber delivery

Robust hollow core fiber coupling with **/16** depointing thanks to mode-cleaning

CANUNDA BY CAILABS

Injection in a hollow core fiber …

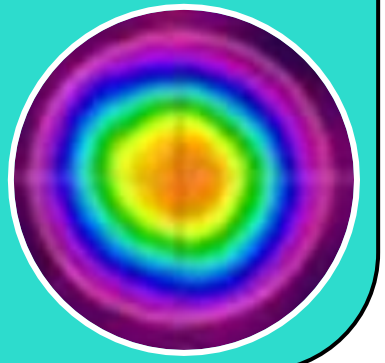
- Hollow-core Photonics Cristal Fiber
- 1030nm
- 15µJ / pulse



… with a stabilized Gaussian beam

in the processing plane :

- $Tilt_{in}$ 160µrad → $Tilt_{out}$ <10µrad & <1.5% power loss
- 93% coupling efficiency



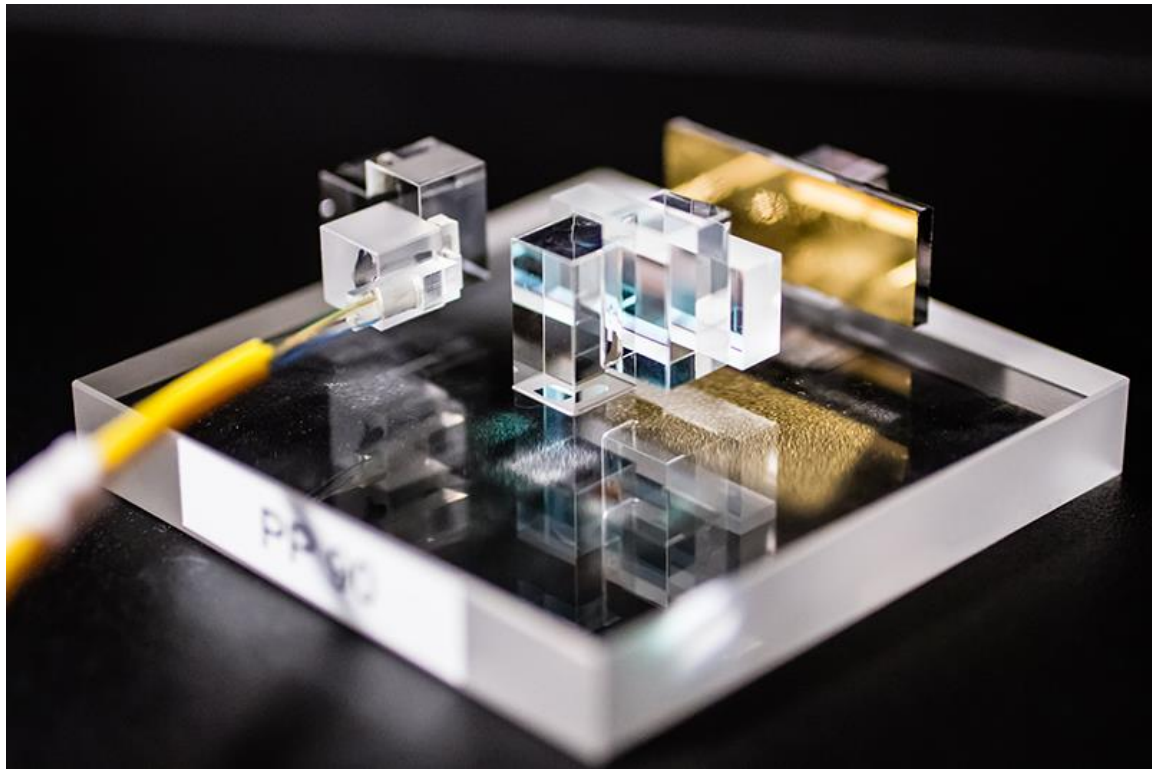
Depointing **/16**

GLOphotonics
The Hollow-Core PCF and Photonic MicroCell™ Company

B. Beaudou et al., Study Of Pointing Stabilization Unit for Femtosecond Fiber Beam Delivery System, LIM (2021)

cailabs
SHAPING THE LIGHT

- Beam-Shaping of Ultra-Short Pulse lasers
- Tackling micromachining challenges with beam-shaping
- **Conclusion**



Take home message #1 /4

Thank you to all our partners

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ALPhA NOV Optics & Lasers Technology Center

Ollscoil na Gaillimhe University of Galway

Amplitude

IFSW

MANUTECH

Take home message #2 /4

There are many ways to shape beams & right criteria are key

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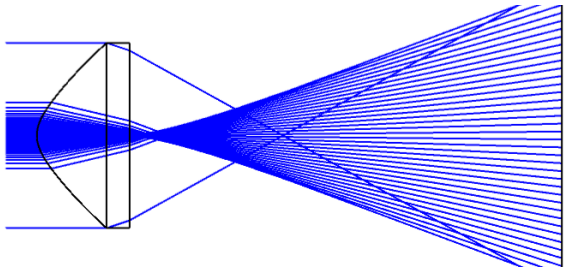
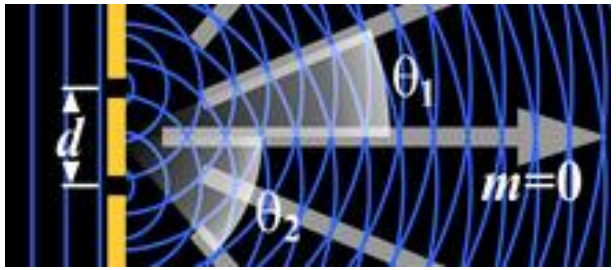
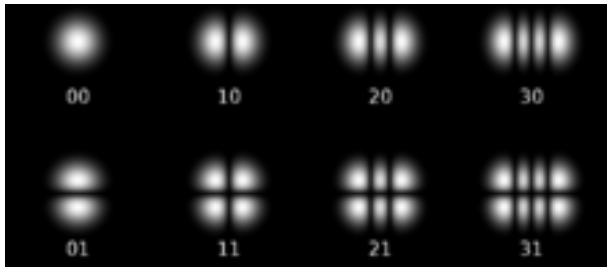
Ray tracing

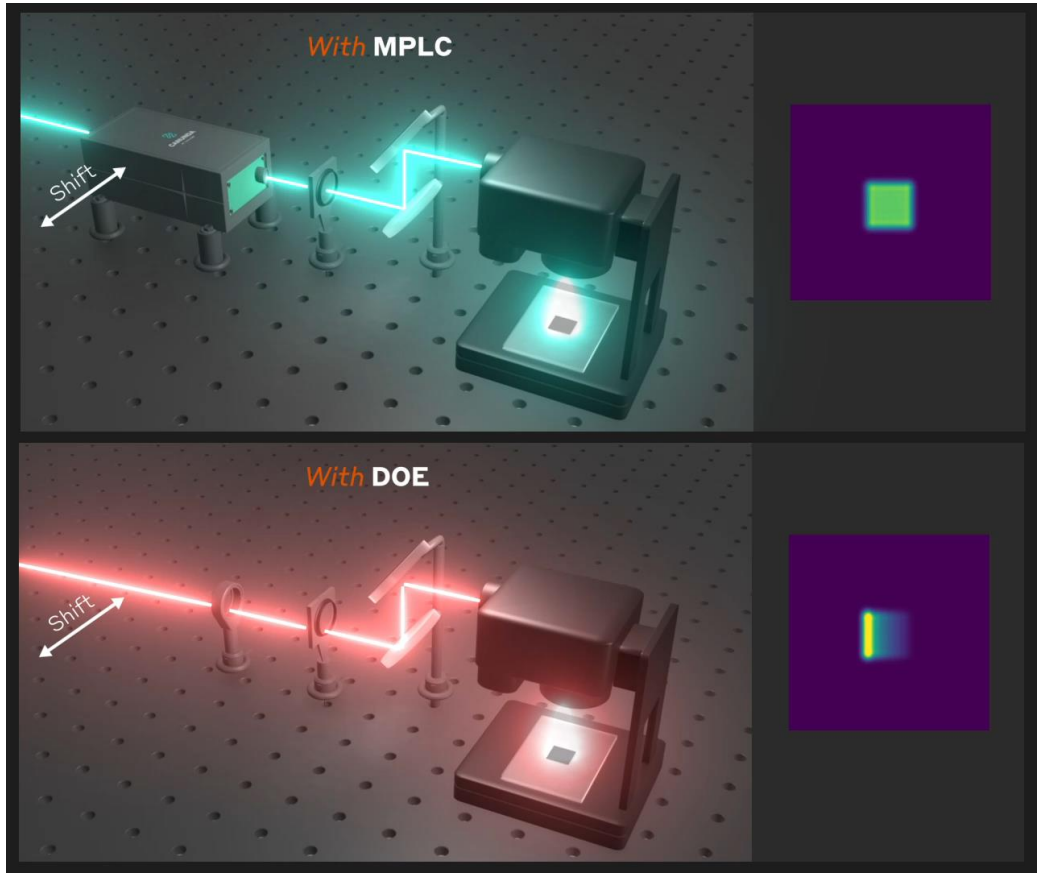


Diffraction



Mode propagation





Take home message #3 /4

Possiblities of beam-shaping are broad – Think out of the box !

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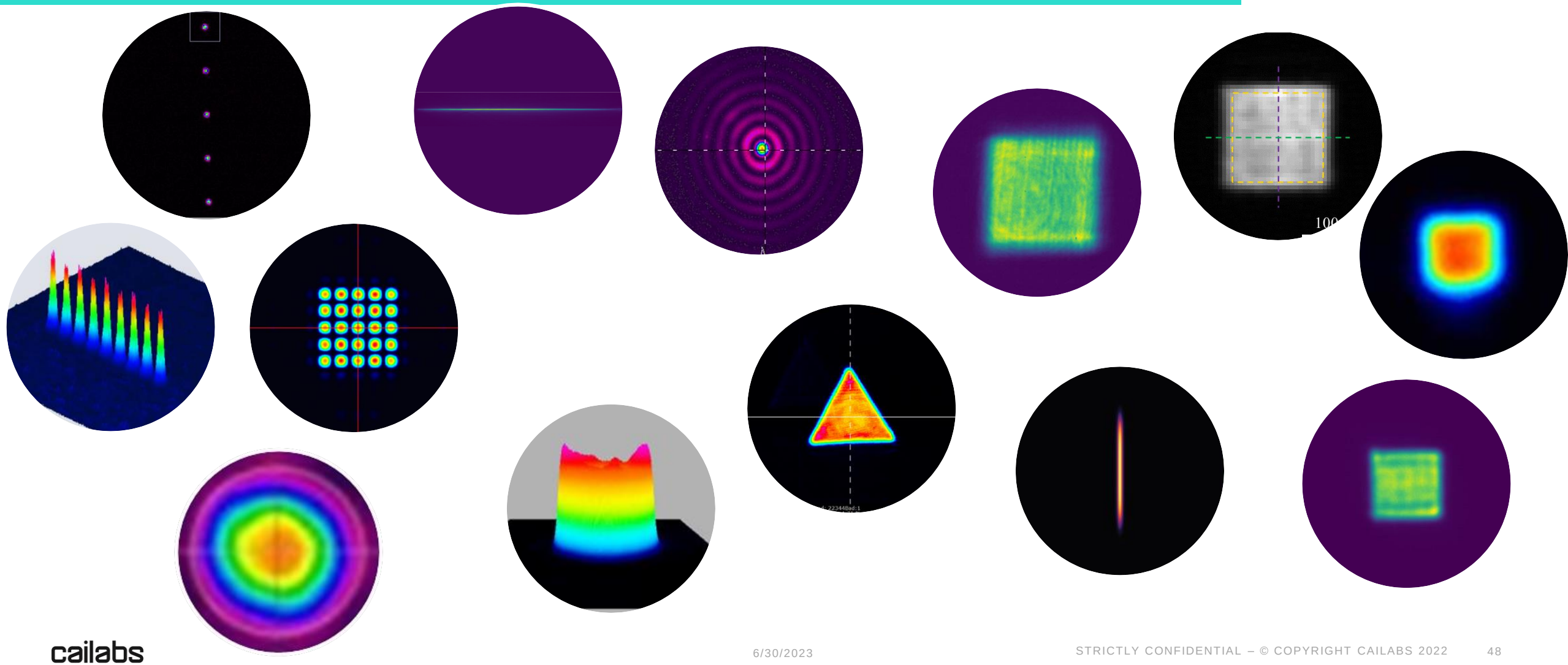

Take home message #4 /4

Tackling µ-machining challenges has been achieved with beam-shaping

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Homogeneity **/5**

Bessel profile **x2** closer to theory

Maximum positinoning precision **x4**

Channels width **/2**

Transition length **/5**

Removed coated width **-20%**

Depth of Field **x4**

Depointing **/16**

Ablation efficiency **x2**

Process speed **+42%**

Process speed **x20**

Process speed **x2.5**

Process speed **x5**

Welding speed **x9**

Process speed **x10**

Cailabs at Laser World of Photonics

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WLT LiM 2023

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Cailabs 6 presentations at Laser in Manufacturing

The LIM team, look for us !

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Cailabs at Laser World of Photonics

LASER World of PHOTONICS

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Meet us at our booth A3-268

& at the LWOP trade show events :

10th year anniversary Brunch

Busbar Laser Welding **live demonstration**

June 28th 11AM – A3-268

EPIC EUROPEAN PHOTONICS INDUSTRY CONSORTIUM

EPIC meeting

Ultrafast Laser Processing

June 28th 10AM

Electro Optics

Forum Laser Materials Processing

Electro optics live interview : Frontiers in ultrafast laser manufacturing

June 29th 12AM – B3-160

Fraunhofer ILT

TRUMPF

Forum Laser Materials Processing

Additive Manufacturing News from the 3D printing of metallic components **panel**

June 29th 4:30PM – B3-160

We are hiring, join us !

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(and many more open positions in other product lines)

Link to our website with job offers

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Thank you for your attention

ivan@cailabs.com