



Competitiveness Operational Programme (COP)  
**Extreme Light Infrastructure - Nuclear Physics  
(ELI-NP) – Phase II**

# Space-Time Coupling in Ultrashort Laser Pulses at ELI-NP

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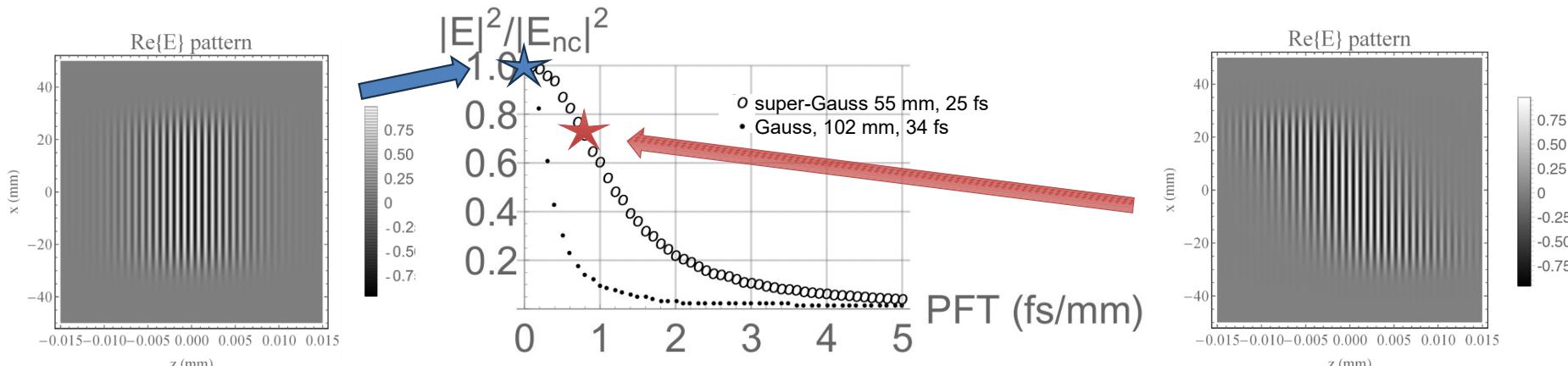
1. Motivation
2. Signatures of Space-Time Distortions
3. Measuring Laser Space-Time Coupling
4. Compressor Alignment and Control of the Space-Time Coupling
5. Conclusion and Outlook

# 1. Motivation

- Small laser beams, narrow band, decouple:  $E(\vec{r}, t) = E(\vec{r}) \cdot E(t)$
- Large beam diameters, broad bandwidths:
  - different  $E(\vec{r})$  for  $\forall$  moment in time
  - different  $E(t)$  for  $\forall$  position in space
- chromatic aberrations + time dependence
- non-homogeneous optics
- misalignments

• E.g. linear STC: Pulse Front Tilt

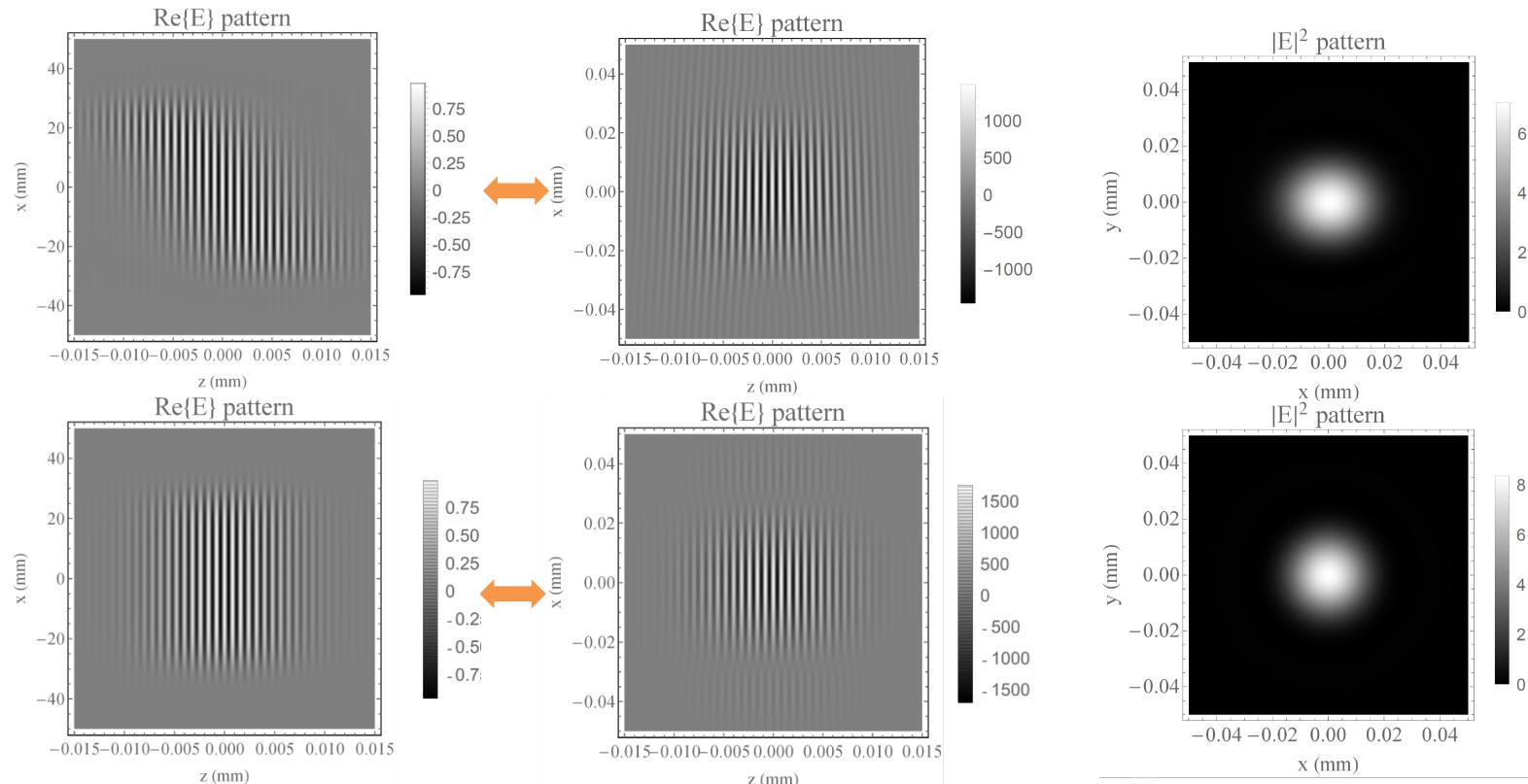
- arrival time  $\tau_0(x) = \xi x$



A-M Talpozi and D Ursescu, "Propagation of ultrashort laser fields with spatiotemporal couplings using Gabor's Gaussian complex decomposition," J. Opt. Soc. Am. A 39, 267-278 (2022)

## 2. Signatures of Space-Time Distortions

- STC in collimated field (NF)  $\longleftrightarrow$  specific STC in the focus (FF)
  - e.g. Pulse Front Tilt in NF  $\longleftrightarrow$  Spatial Chirp (SPC) in FF

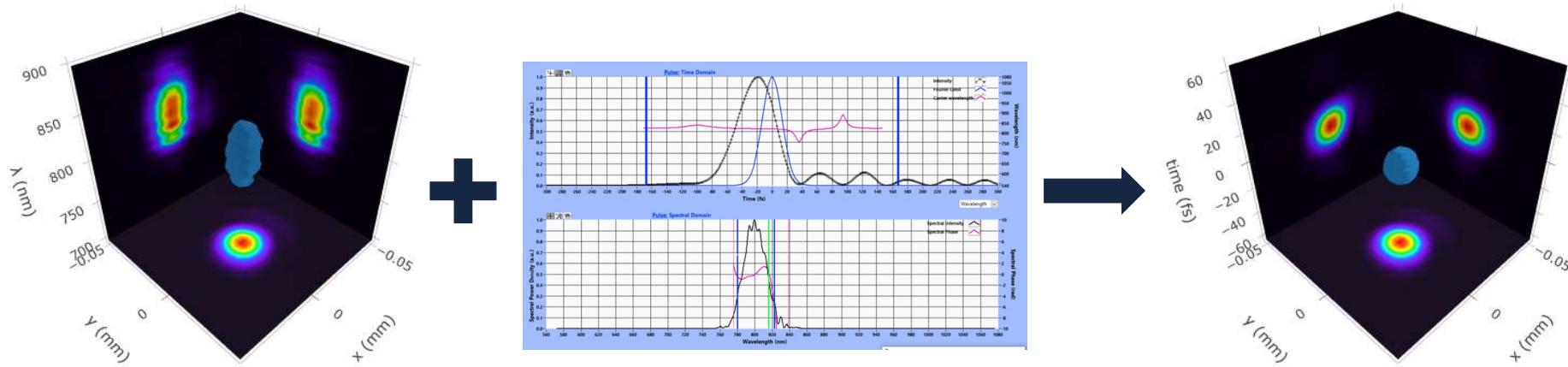
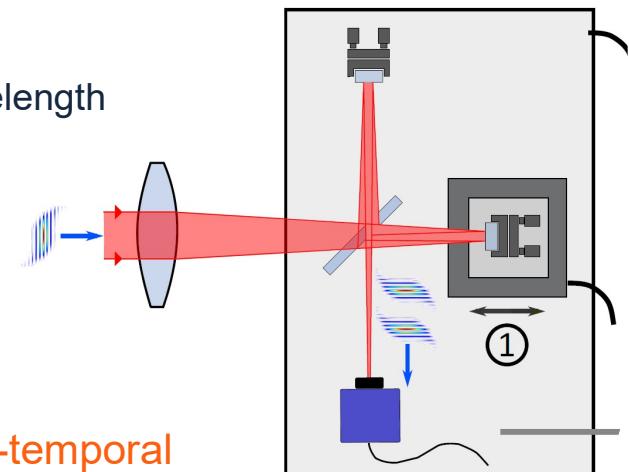


SPC in focus provides elongated beam profile:  
 ➤ can observe this effect with a normal camera

### 3. Measuring Laser Space-Time Coupling

- Use simple diagnostics:
  - FF camera to check elongation - different from astigmatism
  - camera and narrow band filters to check focal spot shifts with the wavelength
  - Inverted field autocorrelator
- Use complex techniques: INSIGHT
  - Scanning, Fourier transform spectroscopy
  - Michelson interferometer @laser focal region
  - iterative algorithm for the reconstruction (**Gerchberg-Saxton**)
  - spatio-spectral (INSIGHT) + spectral phase (SPIDER) = spatio-temporal

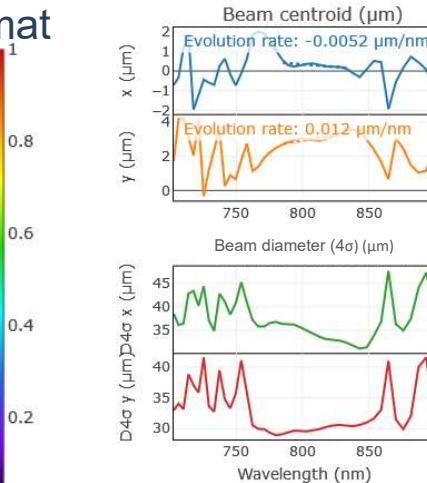
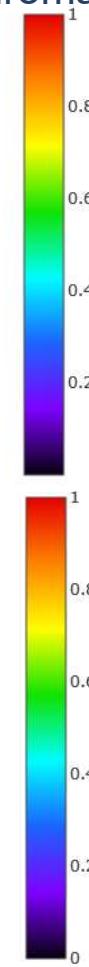
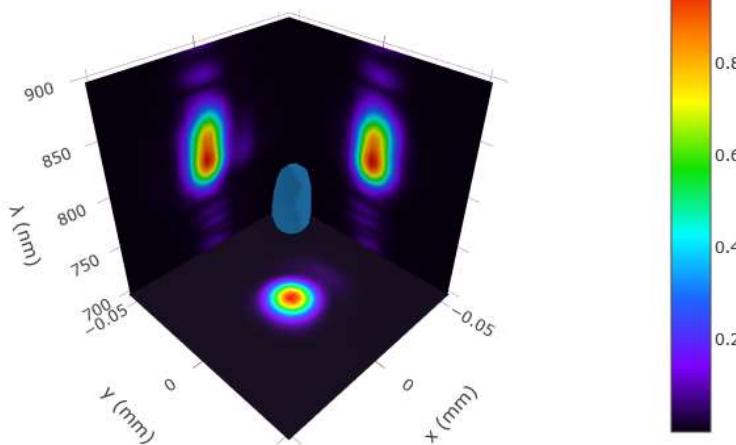
Picture from A Borot and F Quéré,  
Opt. Express 26, 26444-26461 (2018)



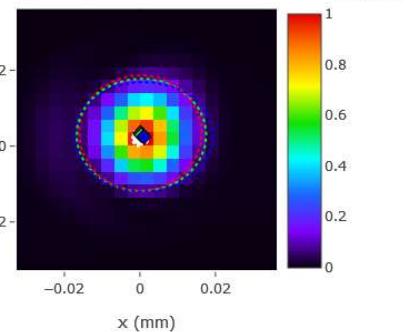
### 3. Measuring Laser Space-Time Coupling @ AVESTA

20 fs, 800 nm, 8.5 mm beam focused with 250 mm achromat

**no wedge**

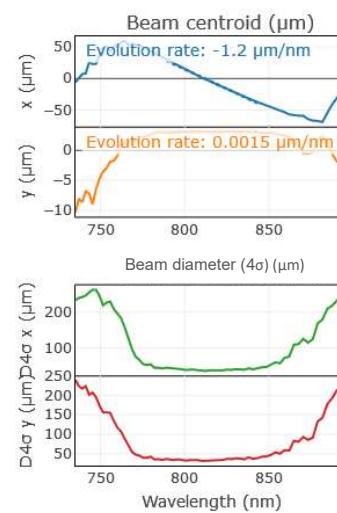
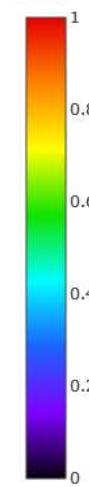
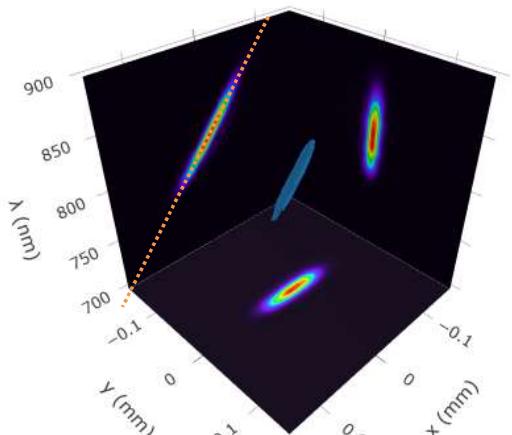


(Red, Green and Blue):  
Beam centroid and width ( $D4\sigma$ )  
for 3 wavelengths.  
(White): Beam centroid trace

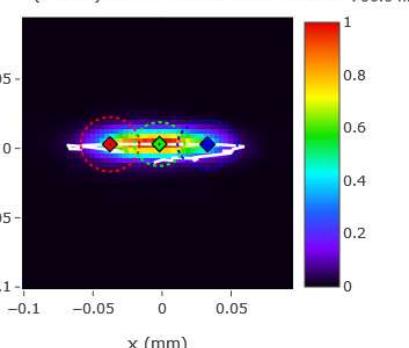


**5° wedge**

**Spatial chirp  
in focus**



(Red, Green and Blue):  
Beam centroid and width ( $D4\sigma$ )  
for 3 wavelengths.  
(White): Beam centroid trace

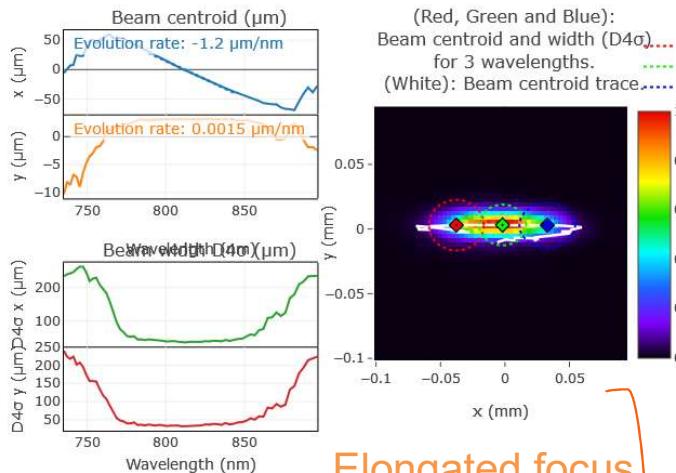


**Elongated focus**

Team: M. Talposi, V. Iancu

### 3. Measuring Laser Space-Time Coupling: comparison with the simulation code

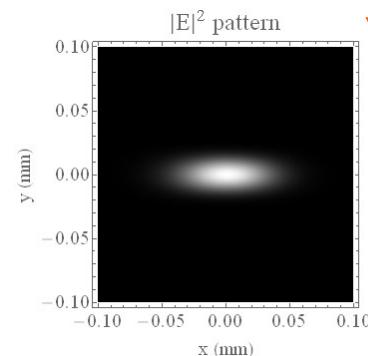
#### Measured @ AVESTA



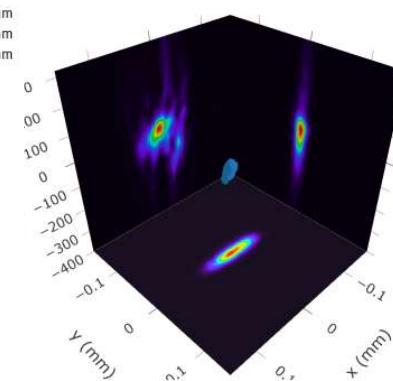
Elongated focus

Simulation AVESTA osc., Gaussian 8.5 mm, PFT, focused with 250 mm optics

Fused silica  
5° wedge  $\Rightarrow$   
AGC = 3.24  
mrad/PHz  $\Rightarrow$   
PFT =  $2\pi/\lambda \cdot \text{AGC}$   
= 25 fs/mm  
  
Z Horvath, et al,  
"Dispersed femtosecond  
pulses in the vicinity of  
the focus," Opt. Comm.  
111, 478 - 482 (1994)

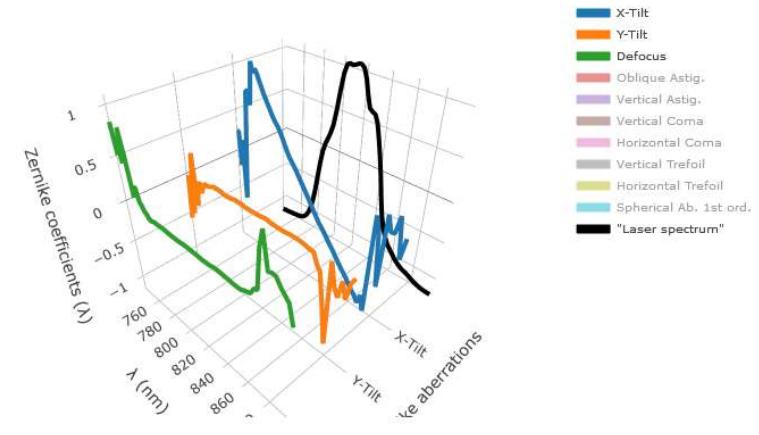


Calculated.  $Dx = 0.100 \text{ mm}$ ,  $Dy = 0.033 \text{ mm}$ .



No PFT in the focus

Spectral evolution of the Zernike aberrations ( $\lambda$ ):  
Pupil size  $\phi = 11.4 \text{ mm}$

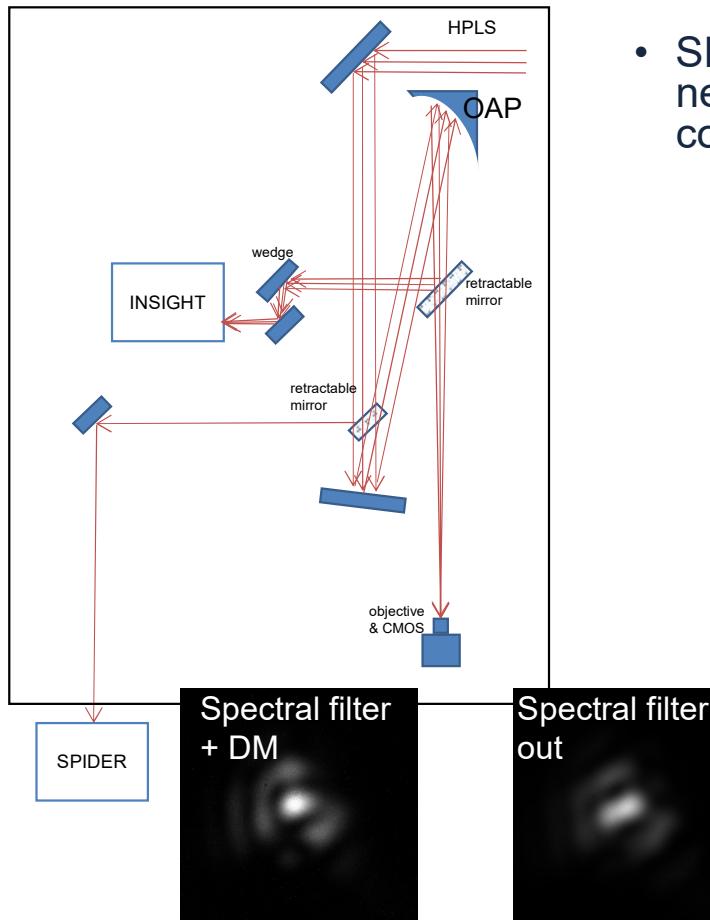


Angular chirp in NF

Measured.  $Dx = 0.110 \text{ mm}$ ,  $Dy = 0.026 \text{ mm}$

## 4. Compressor Alignment and Control of the Space-Time Coupling @ HPLS

- HPLS @E4,100 TW beamline. Nominal: 25 fs, 800 nm, 55 mm diameter. OAP:  $f = 1.5$  m



- SPC in FF is given by PFT/AGC in NF: need to optimize the alignment of the compressor diffraction grating G2
  - 2 degrees of freedom: Grooves and Angle

Team: M. Talposi, S. Popa, V. Iancu, Y. Nakamiya, D. Matei, G. Bleotu, L. Neagu, A. Lazar, G. Cojocaru, A. Toma, A. Dumitru, S. Norbaev, D. Ursescu

## 4. Compressor Alignment and Control of the Space-Time Coupling: Results



Before STC optimization

HPLS E4, OAP  $f = 1.5$  m,  
at focus, with Deformable  
Mirror (DM) optimization

~ 3 mrad Grooves  
~ 0.15 mrad Angle  
misalignment



After STC optimization

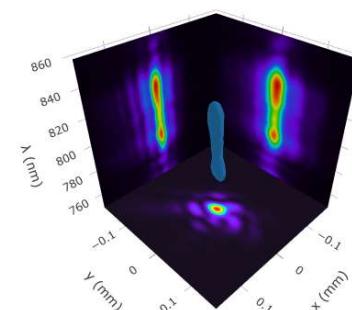
Plots courtesy of Y. Nakamiya. Team work: M. Talposi, S. Popa, V. Iancu, Y. Nakamiya, D. Matei, G. Bleotu, L. Neagu, G. Cojocaru, A. Toma, A. Dumitru, A. Lazar, S. Norbaev, D. Ursescu

**Focal spot decrease by 2.3: from 39 um to 24 um on x-axis and from 38 um to 27 um on y-axis**

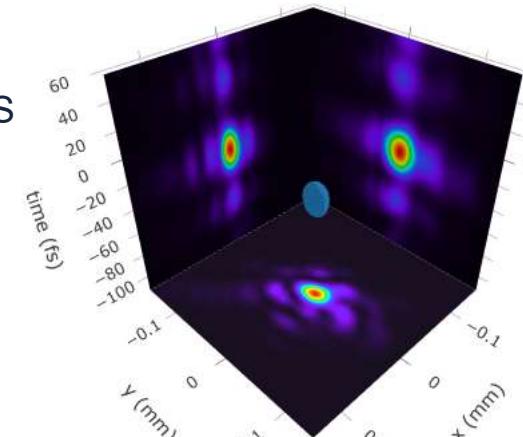
**Estimated irradiance (intensity) increase: up to 1 order of magnitude (additional ND1)**

## 6. Conclusion and Outlook

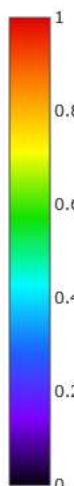
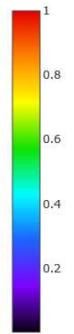
- **Developed simulation code for STC**
- **Validated through INSIGHT measurements**
- **Improved focus quality and intensity of HPLS @E4**
- **Provided plan for operating the laser**
  - Need of compressor gratings alignment optimization, periodically
  - Provided angle calibration for motor steps
- **Future**
  - Evaluate angle misalignment - PFT - SPC - intensity values for HPLS beamlines (data analysis & simulations)
  - On-going upgrade of INSIGHT (broadband) for Spectral Broadening
  - Purchase single-shot measurement device (e.g. STRIPED-FISH)



3D  $E(x,y,\lambda)$



3D  $E(x,y,t)$





EUROPEAN UNION



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Thank you for your  
attention!

