K-B active optics system optimization through wavefront sensor measurements at Fermi@Elettra FEL

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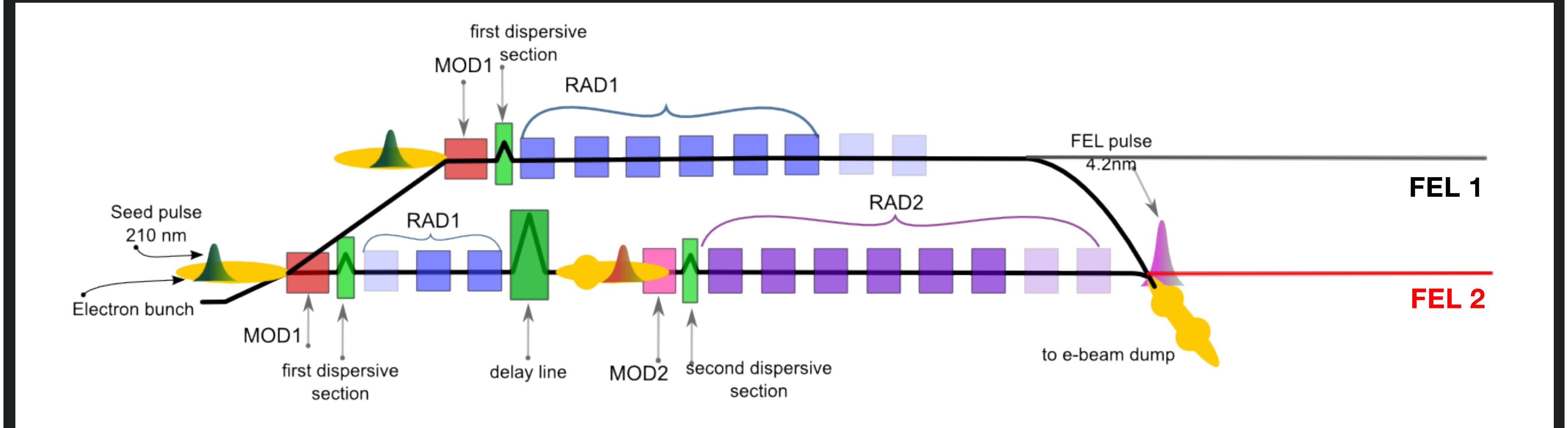
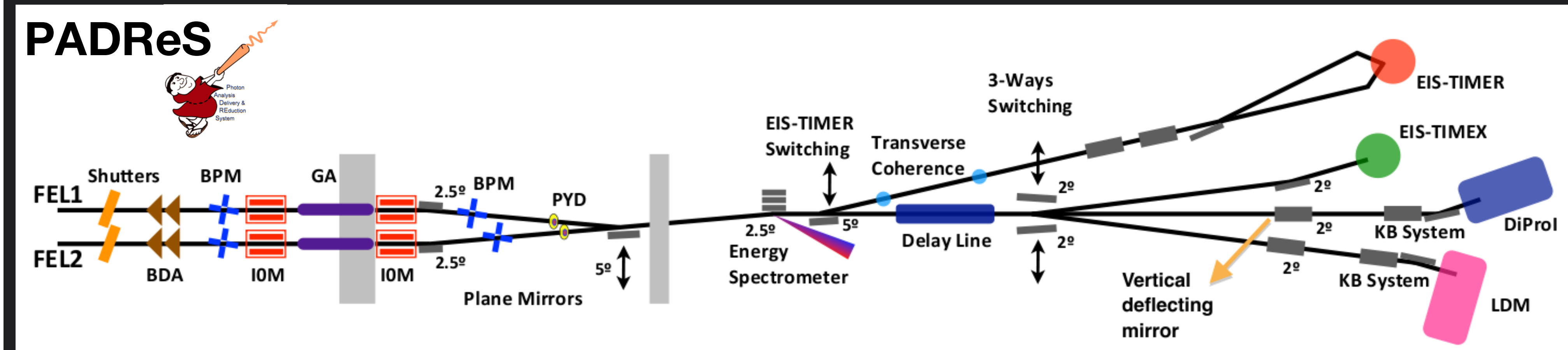
Photon
Analysis
Delivery &
REduction
System

FERMI@Elettra seeded FEL

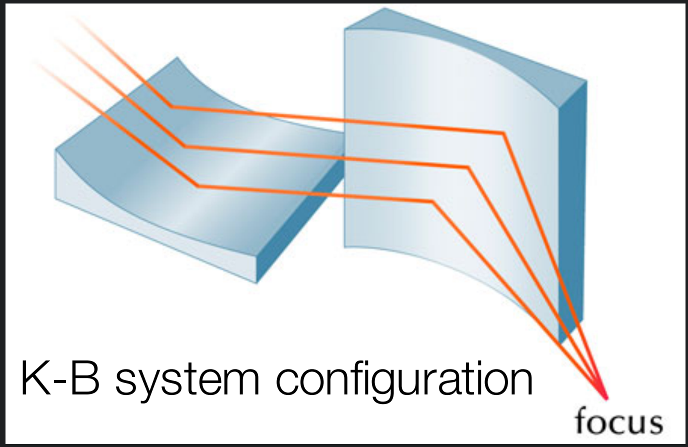


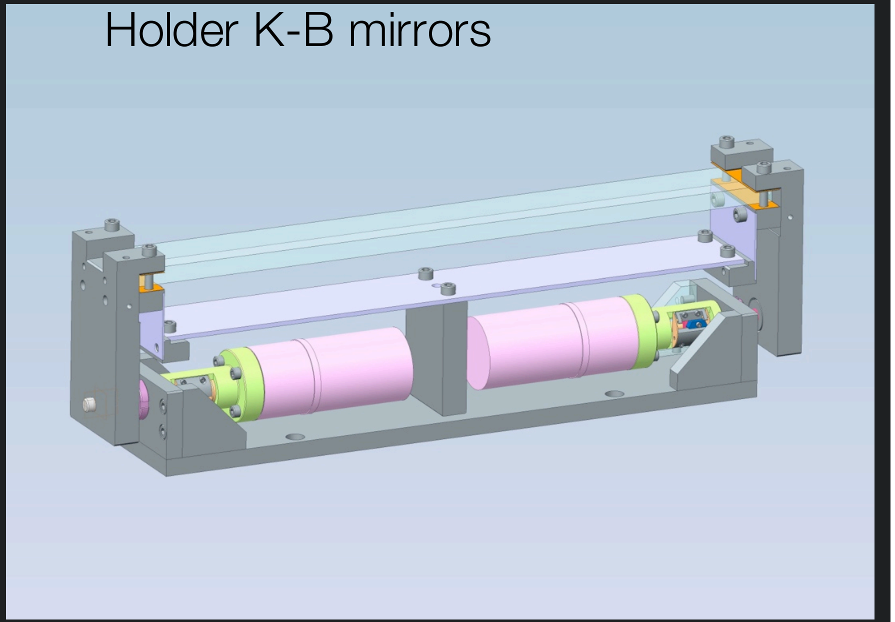
- **FEL 1 from ~100 nm down to 20 nm** - source distance (to spectrometer) 57.5 m
  Divergence σ(μrad) = 1.25 λ(nm) - Source dimension = 60 μm (sigma)

- **FEL 2 from 20 nm down to ~4 nm** - source distance (to spectrometer) 49.8 m
  Divergence σ(μrad) = 1.5 λ(nm) - Source dimension = 123 μm (sigma)



K-B active optic system - DiProl

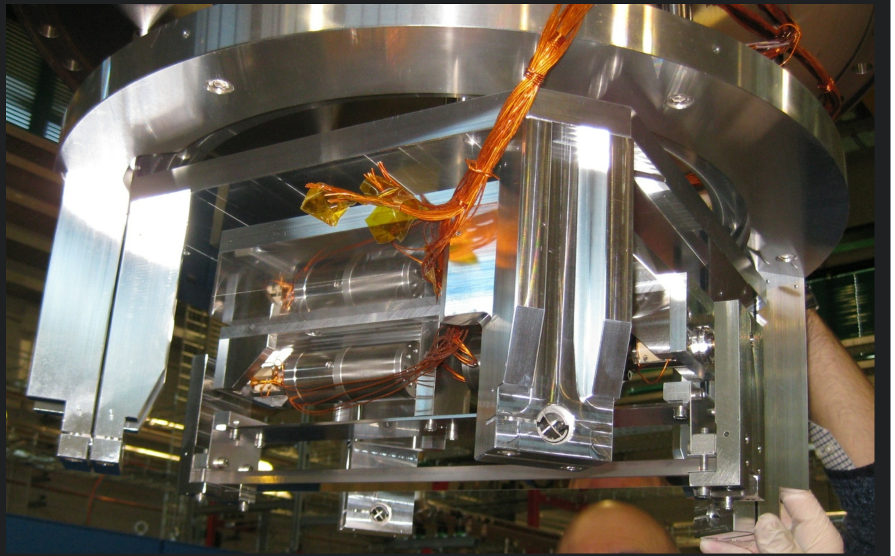




End-stations need high flux - great demagnification

K-B system advantages

- Decoupling vertical and horizontal beam components
- It is hard to realize thick ellipsoidal mirrors with this demanding demagnification



- ## K-B bendable system advantages

- Focalization of the 2 sources at different distance with the same couple of mirrors

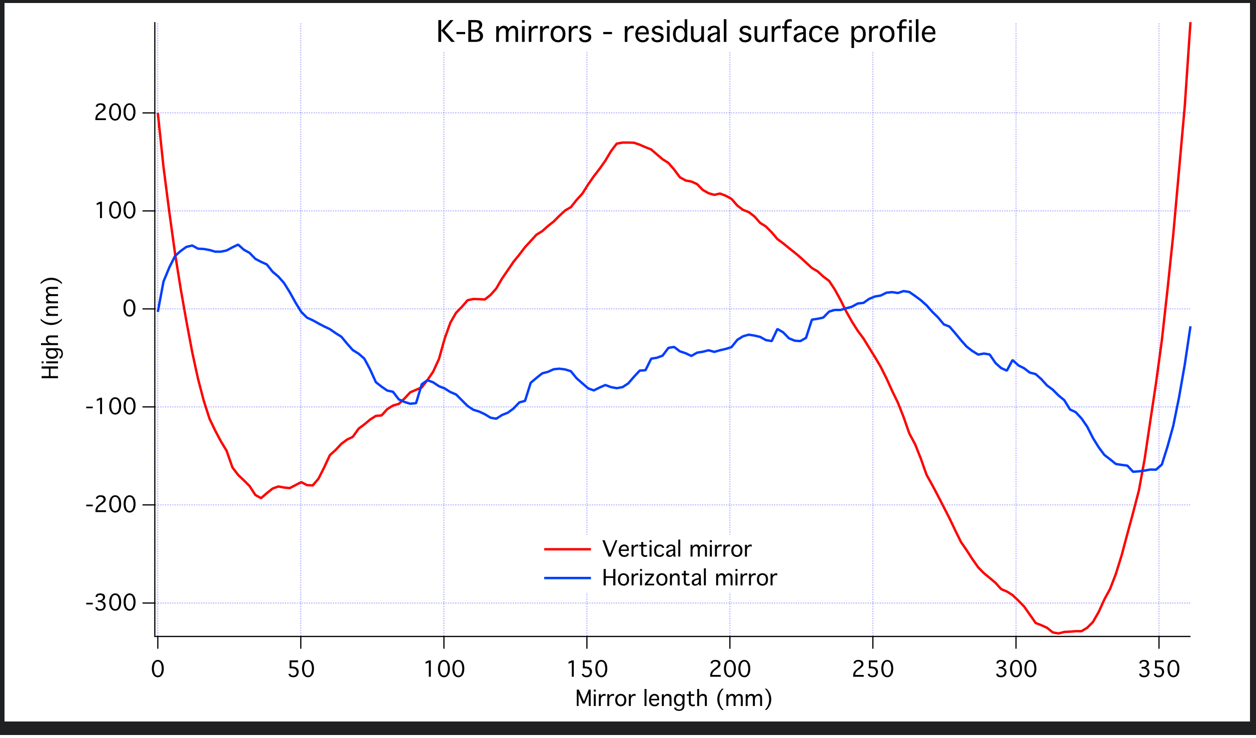
. Improvement of the FEL beam wave-front

K-B active optic system - DiProl

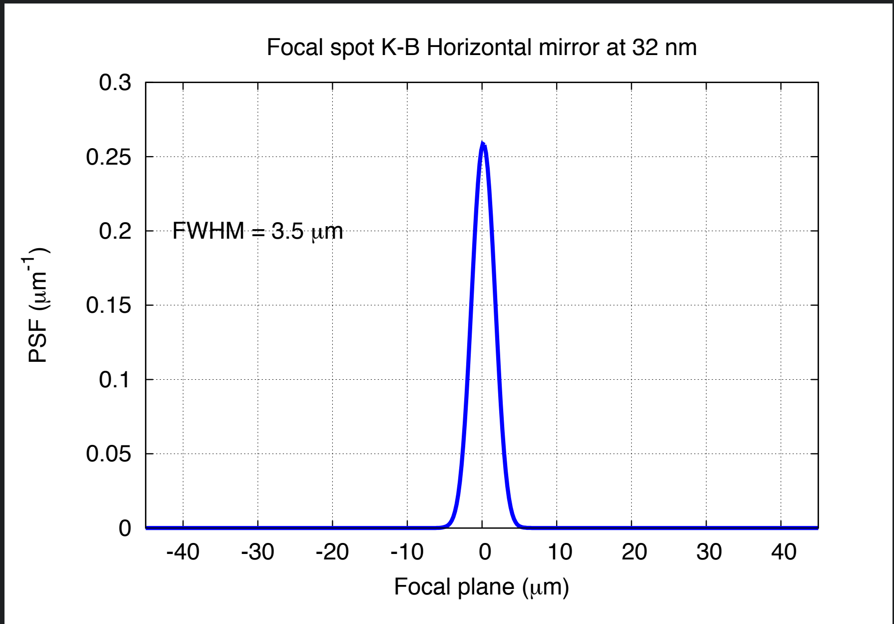
Profile surface characterization with Long Trace Profiler

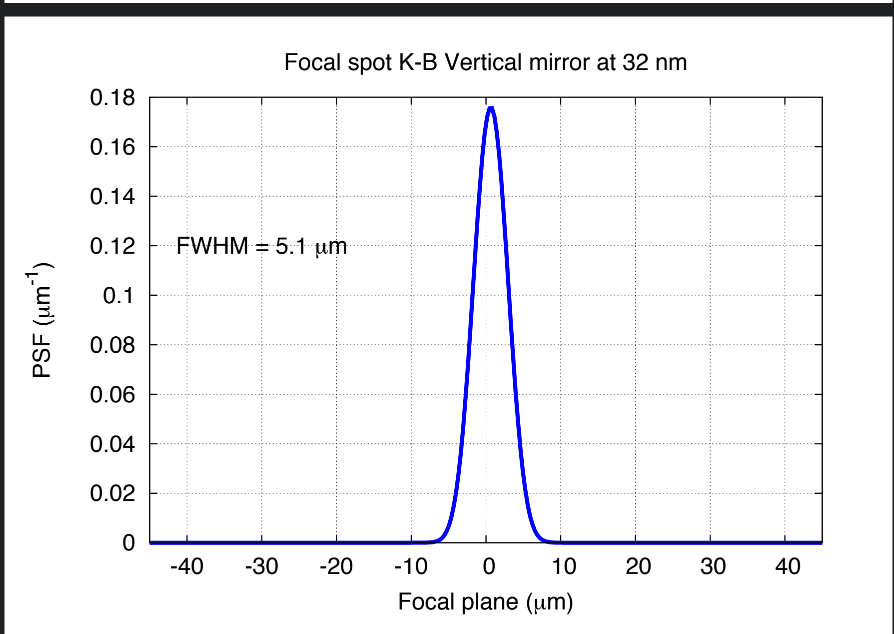
- **LTP profile measurements 1mm step**
- **Best possible profile reached through the Adaptive Correction Tool software**
- **Measurements with Zygo interferometer and AFM - rms under specifications (<3A spatial range 2µm - 0.5mm)**
- **Proof of the system stability**

K-B Vertical and Horizontal mirrors - residual surface profile



Focal spot simulations with WISE[1]- DiProI

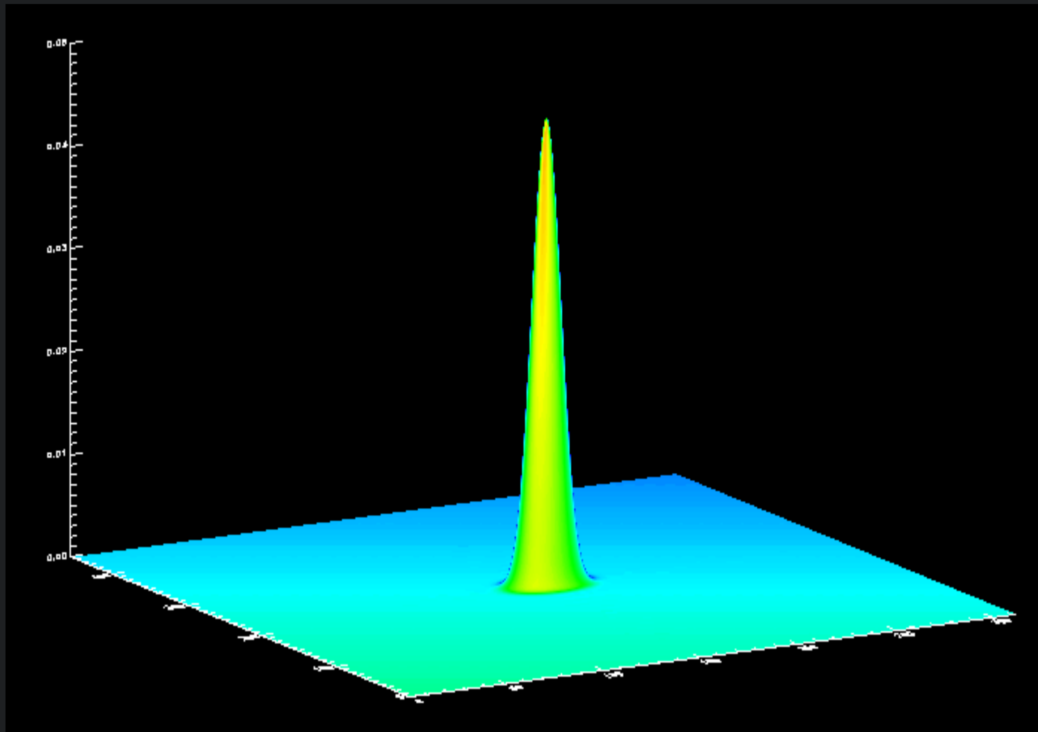




32 (37) nm wavelength

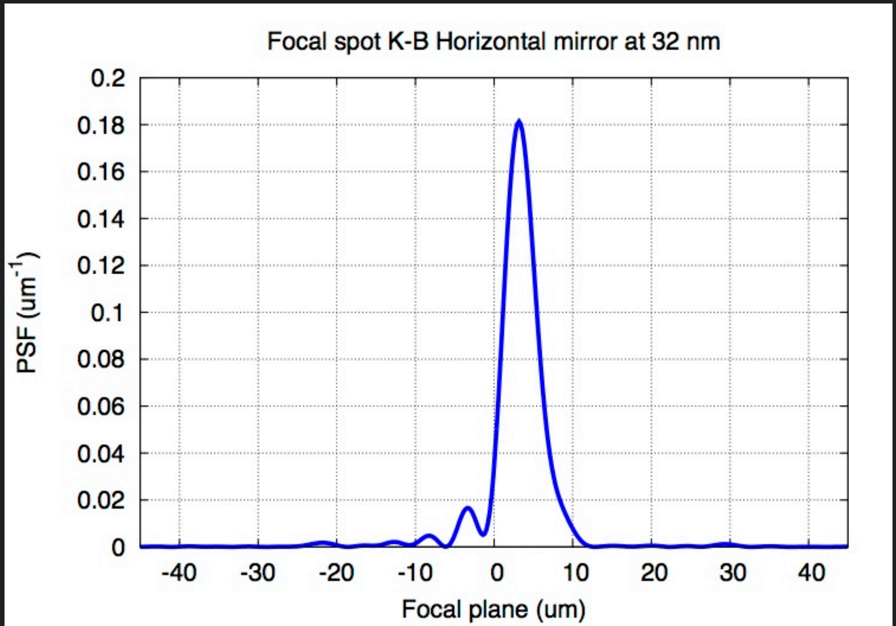
- K-B horizontal ideal mirrors
  FWHM = 3.5 (4.1) μm

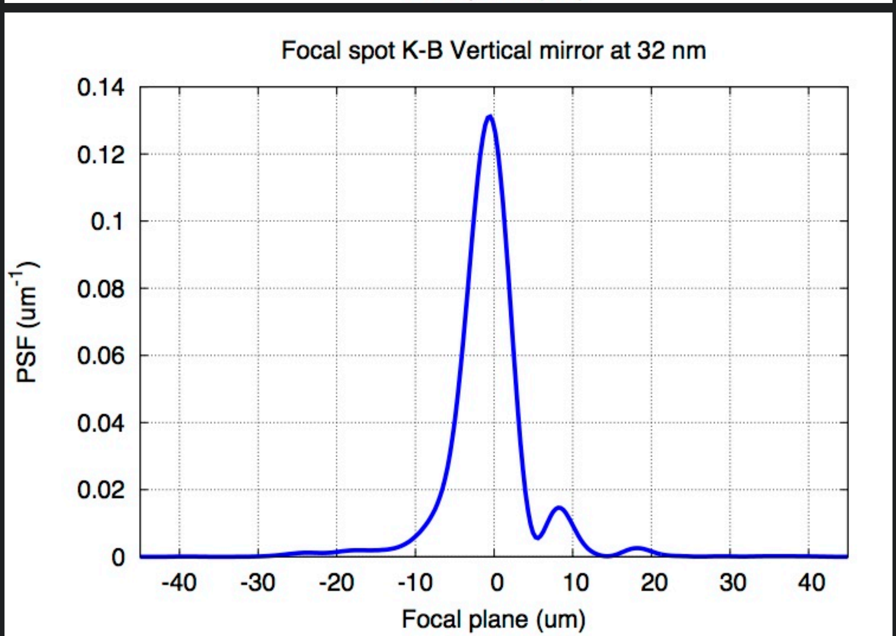
- K-B vertical ideal mirrors
  FWHM= 5.1 (5.9) μm



(1) L. Raimondi, D. Spiga, SPIE Proc., 8147 (2011)

Focal spot simulations with WISE[(1)]- DiProl

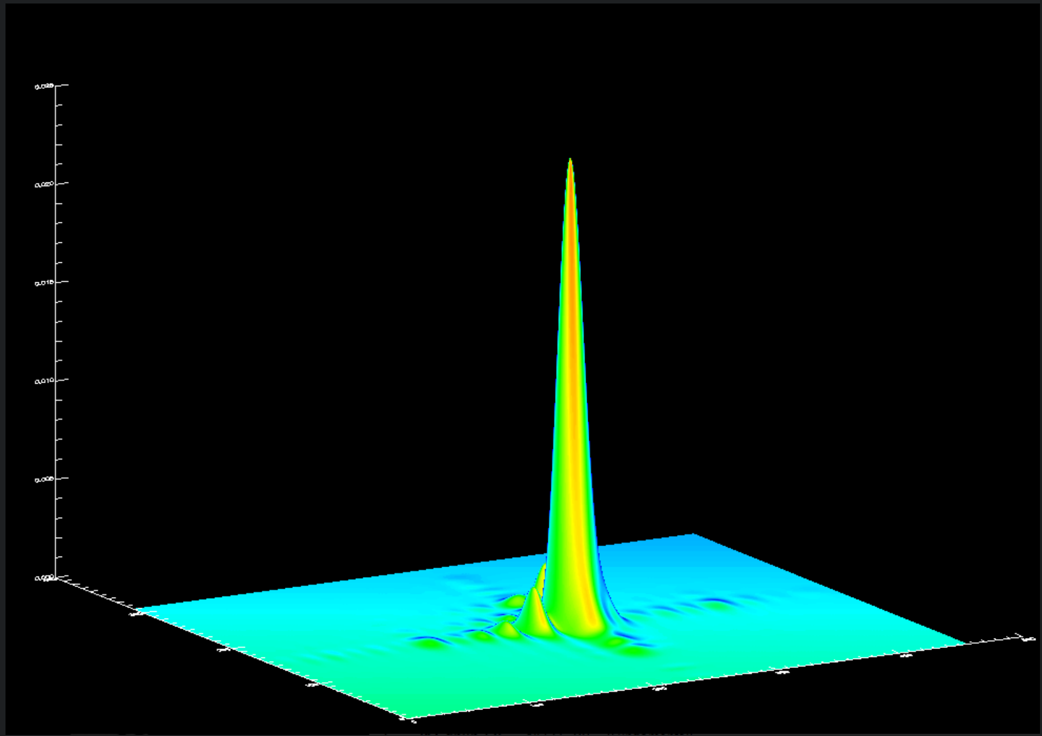




32 (37) nm wavelenght

- K-B horizontal best focus
  FWHM = 4.4 (5.1) μm

- K-B vertical best focus
  FWHM = 5.8 (6.0) μm



(1) L. Raimondi, D. Spiga, SPIE Proc., 8147 (2011)

Focal spot measurements - DiProl

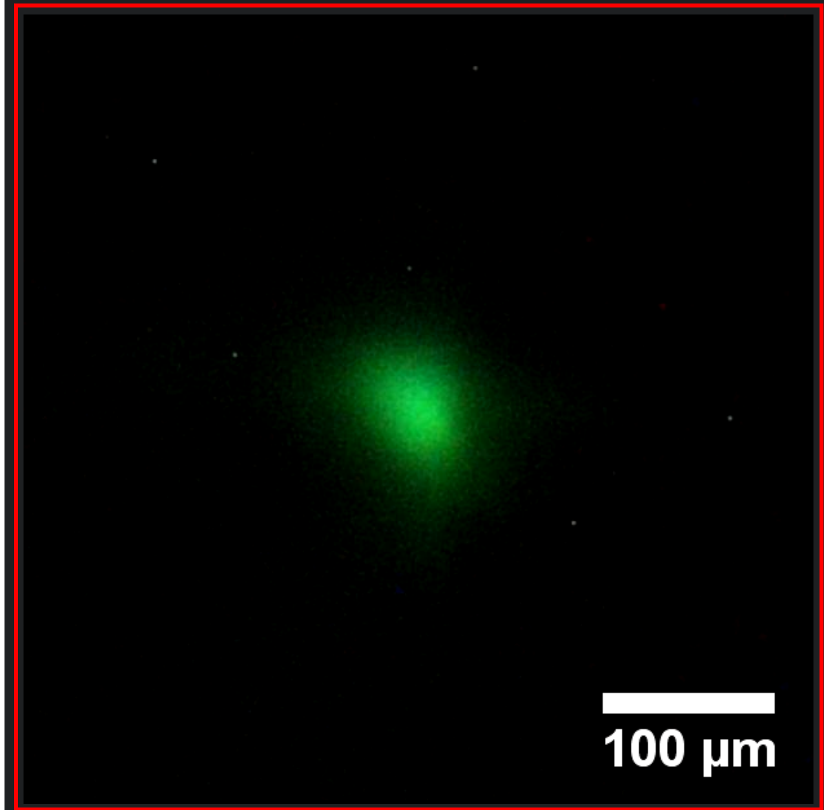
Phosphorus screen

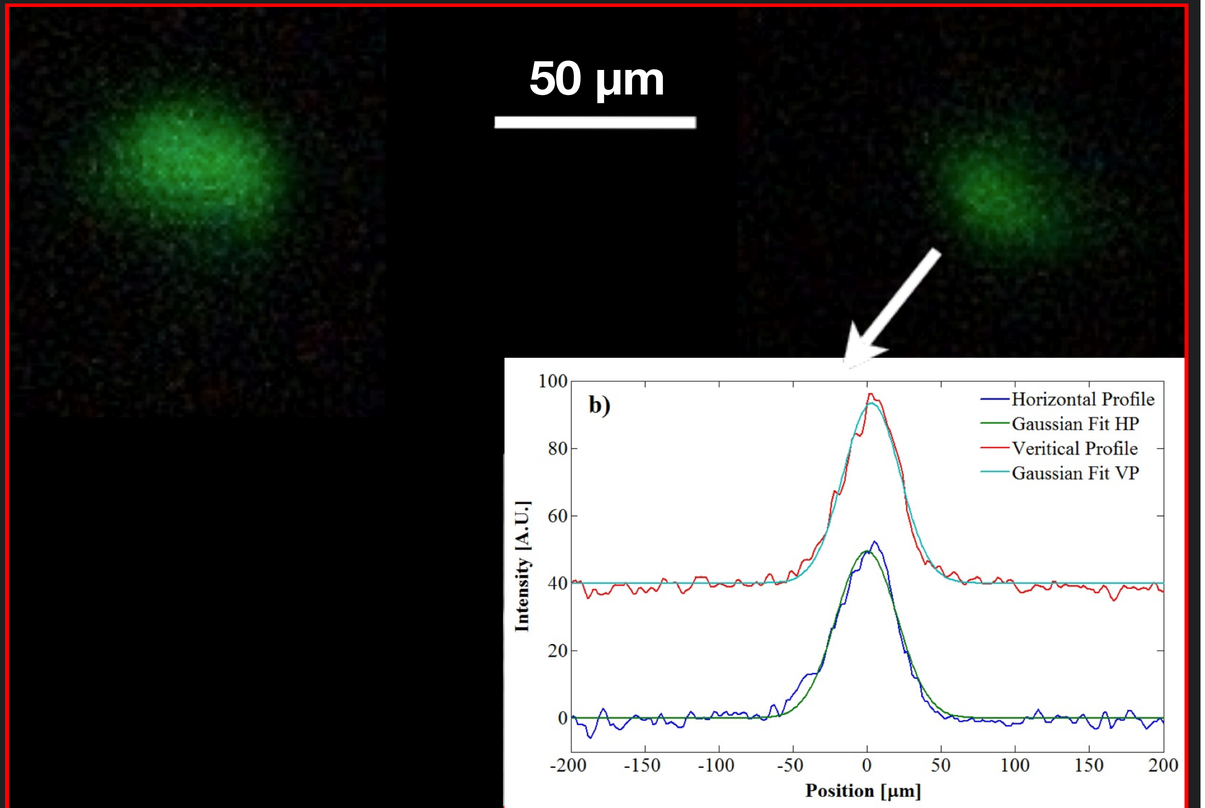
First phase

- rough angle alignment
- optimized mirror bending
- best spot achieved on Phosphorus screen $FWHM_{32nm}$=60x70 µm

Second phase

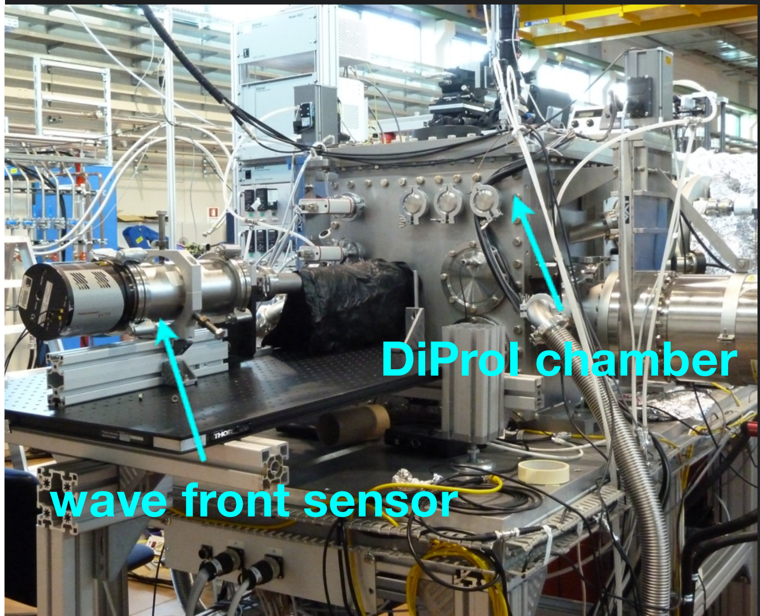
- refine angle alignment
- optimized mirror bending
- best spot achieved on Phosphorus screen $FWHM_{32nm}$=40x42 µm



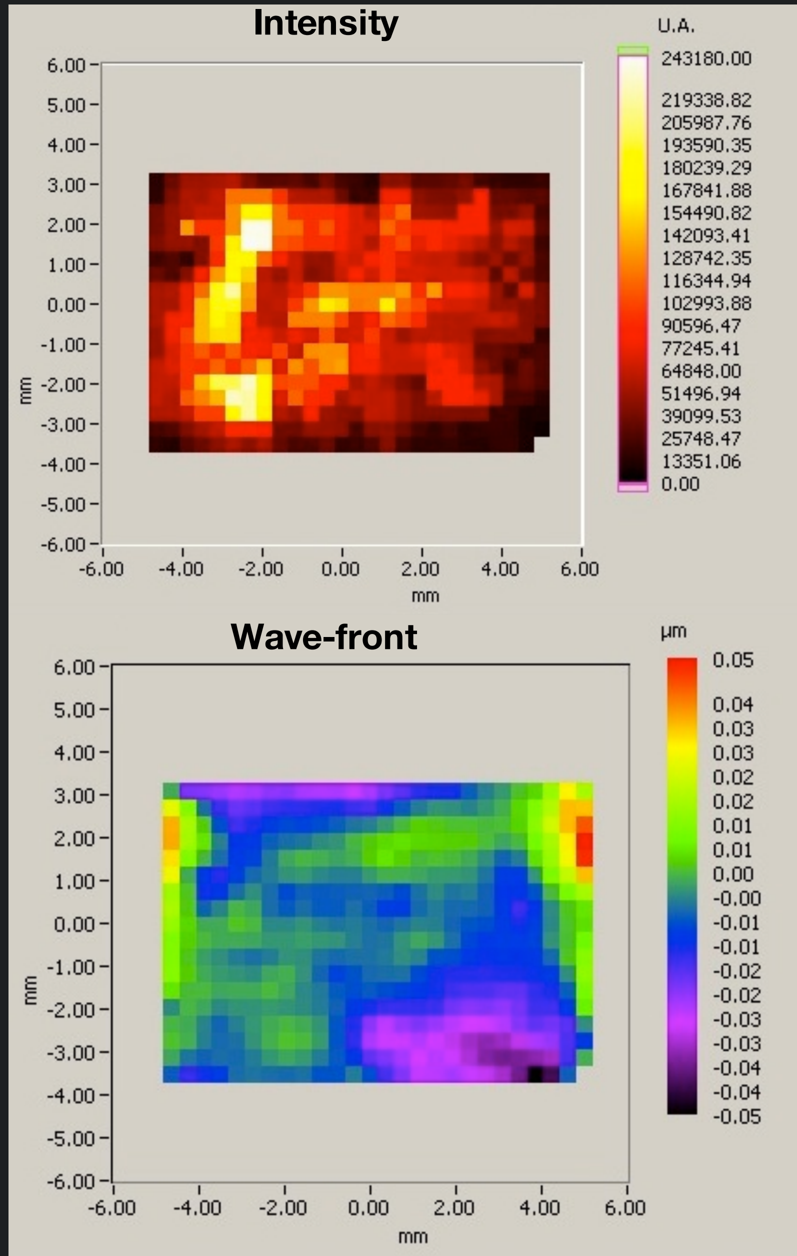


Focal spot measurements at DiProl end-station

Wave-front sensor measurements (instrument by Imagine Optics)



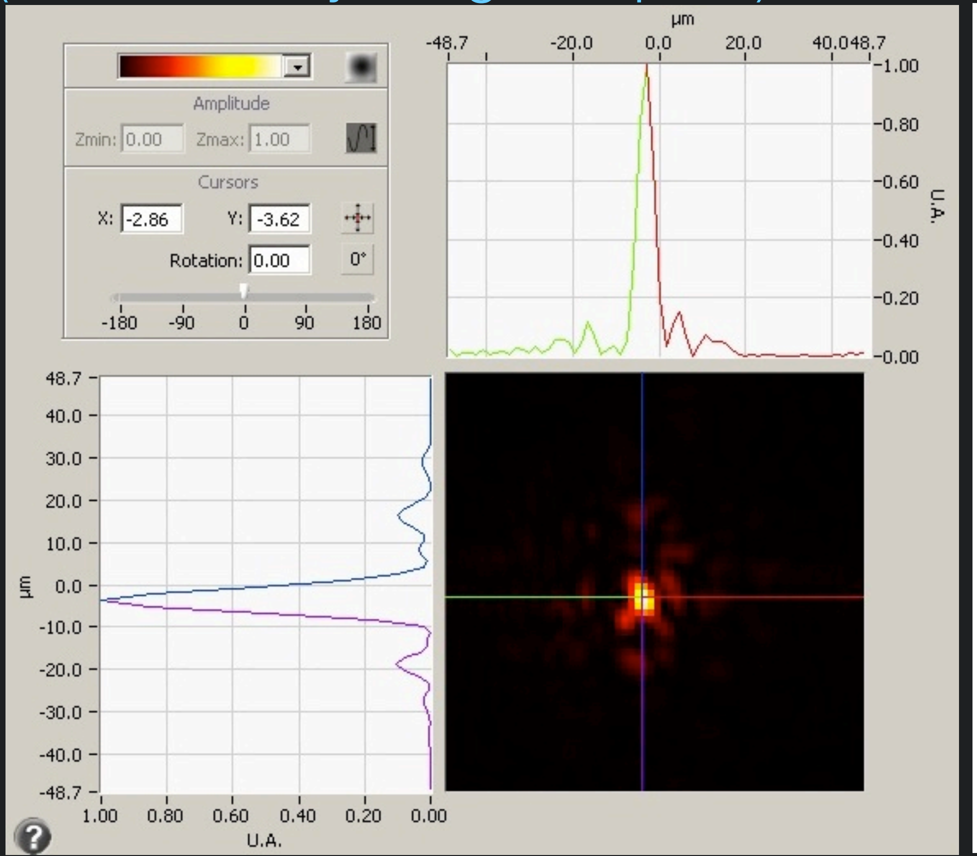
- **FEL 1 wavelength - 32.5 nm**
- **WFS field of view 13x13 mm**
  pine-hole array - d=75µm p=250µm
- **measuring of Intensity and wave front at 1m out of nominal focus**
- **reconstruction of the spot in focal plane**
- **rms wavefront of best spot 0.37 λ**

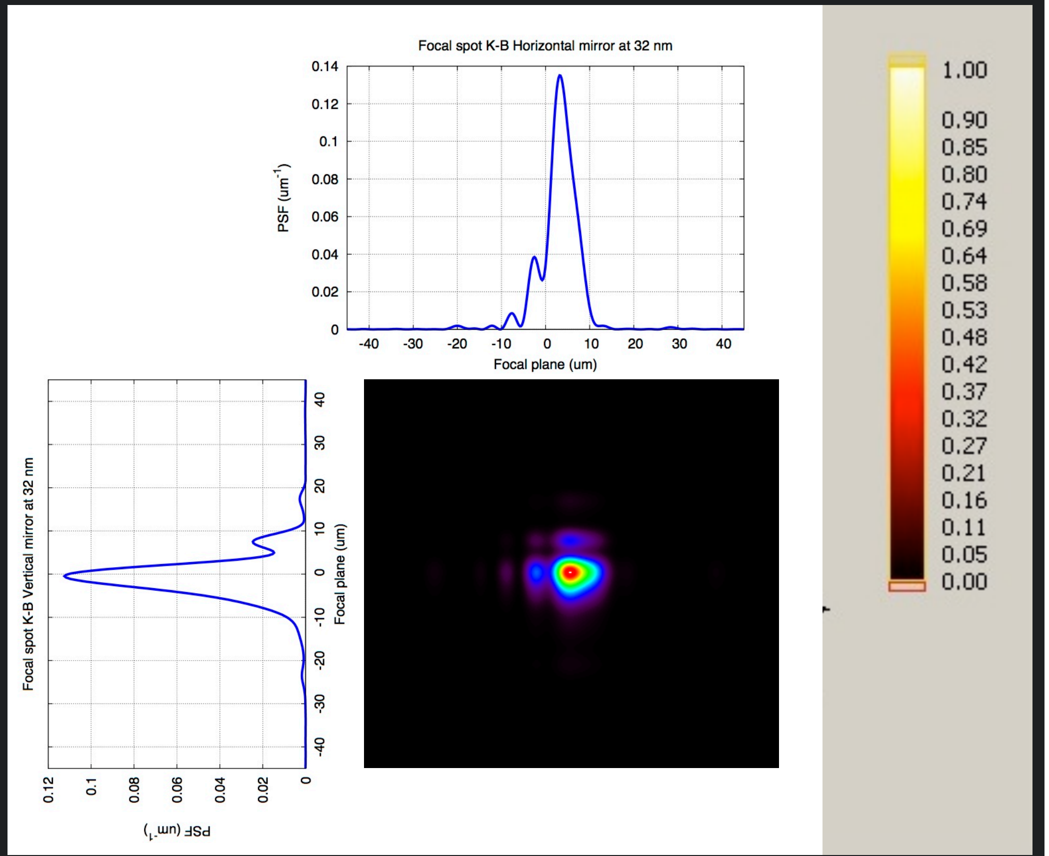


Focal spot measurements - DiProl

Wave-front sensor measurements (instrument by Imagine Optics)

WISE code simulations



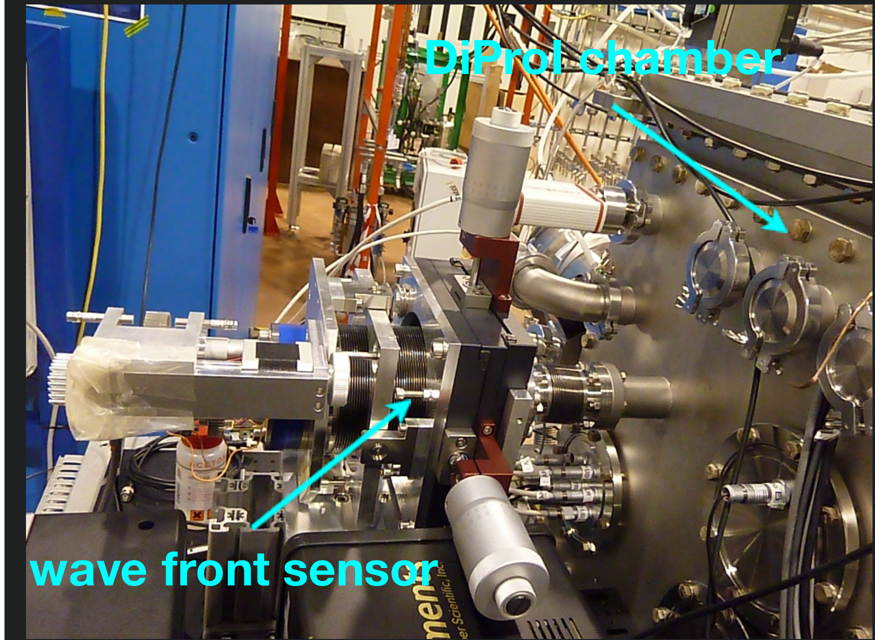


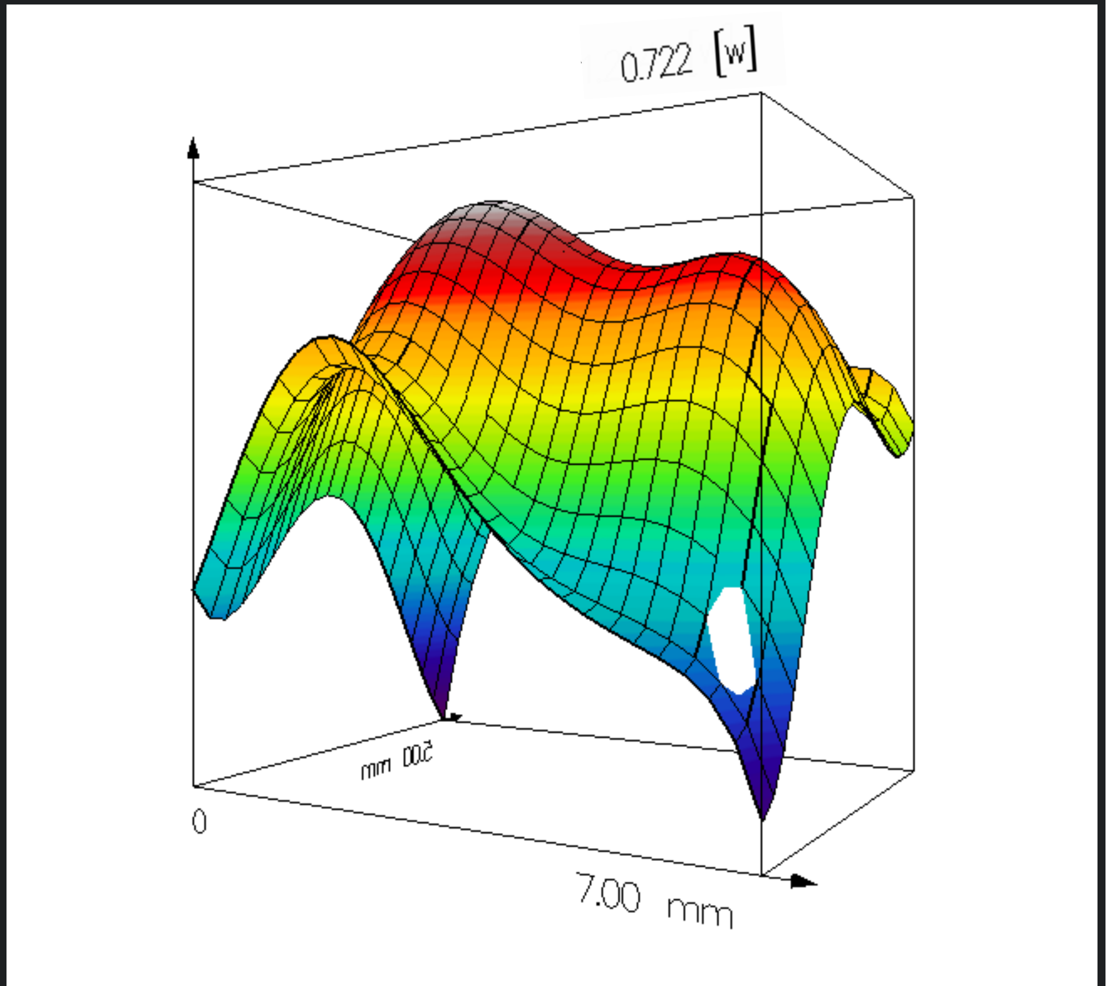
- **FEL 1**
- **wavelength - 32 nm**
- **Ideal mirrors at 32 nm spot-size $\boxed{\text{FWHM} = 3.5\text{x}5.1\ \mu\text{m}}$**
- **Best spot-size measured with WFS (imagine Optics) $\boxed{\text{FWHM} = 5\text{x}8\ \mu\text{m}}$**

- **Spot-size simulated with Fresnel diffraction at the common best focus (-1mm from the nominal focus) $\boxed{\text{FWHM} = 5.0\text{x}7.7\ \mu\text{m}}$**

Focal spot measurements at DiProl end-station

Wave-front sensor measurements (instrument by LLG, DESY)

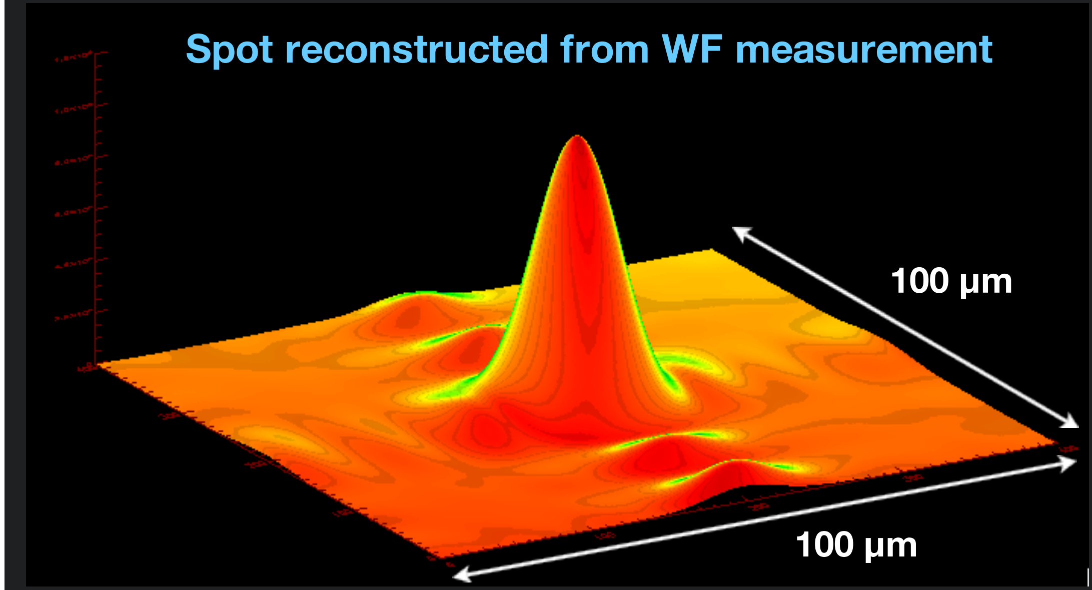


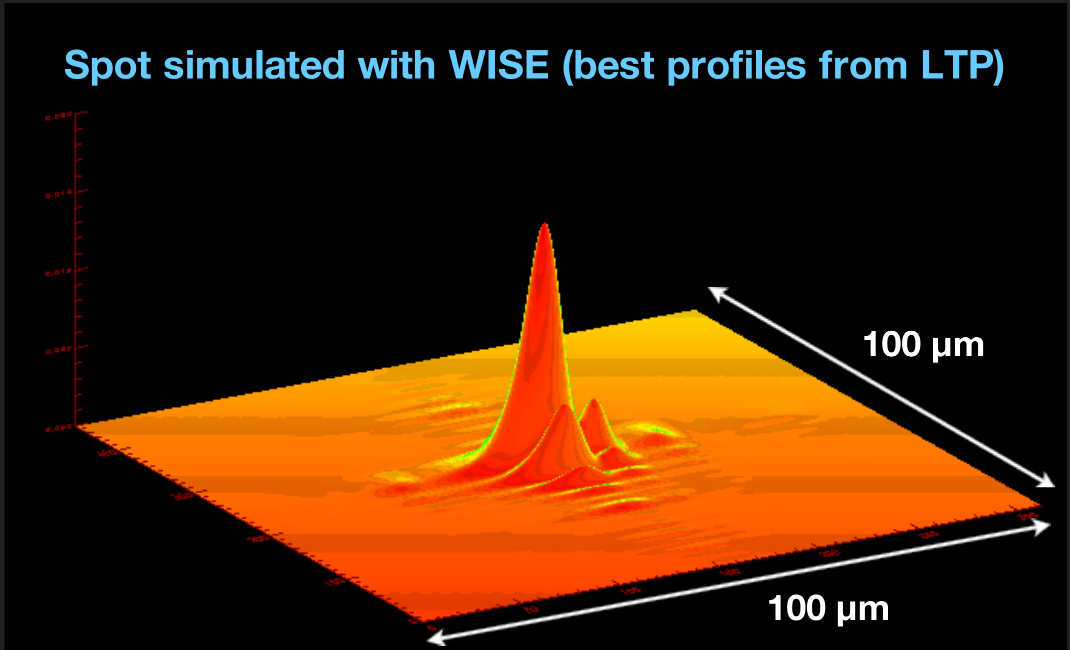


- **FEL 1 wavelength - 37.2 nm**
- **WFS field of view 6x8 mm**
  pine-hole array - d=75µm p=250µm
- **measuring of Intensity and wave**
  front at 917 mm out of nominal focus
- **wavefront rms of 0.51 λ**

Focal spot measurements at DiProl end-station

Wave front sensor measurements (instrument by LLG, DESY)

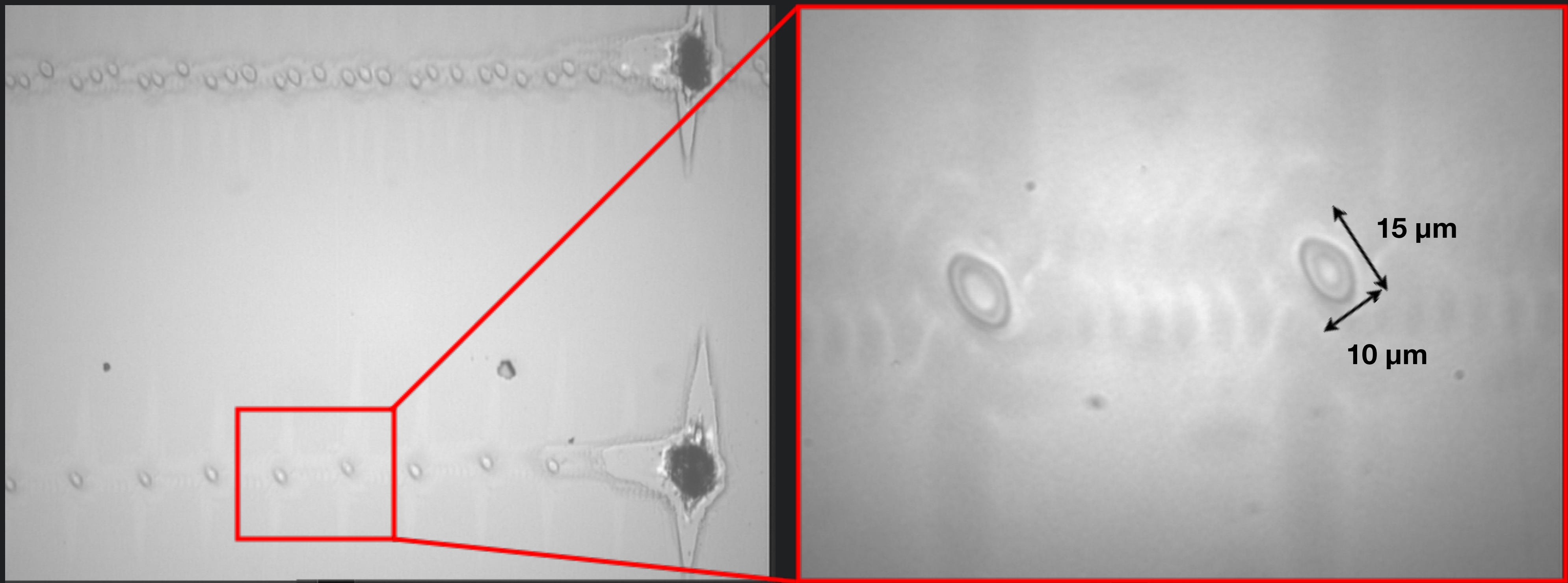




- **FEL 1**
- **wavelength - 37.2 nm**
- **diffraction limit spot-size**
  FWHM = 4.1 x 5.9 µm
- **Best spot-size measured with WFS (LLG-DESY)**
  FWHM = 10 x 13.5 µm
- **Spot-size simulated with WISE at the common best focus (best profiles from LTP measurements)**
  FWHM = 5.2 x 8.0 µm

Focal spot measurements at DiProl end-station

PMMA ablation measurements (related to the best spot) Optical microscope

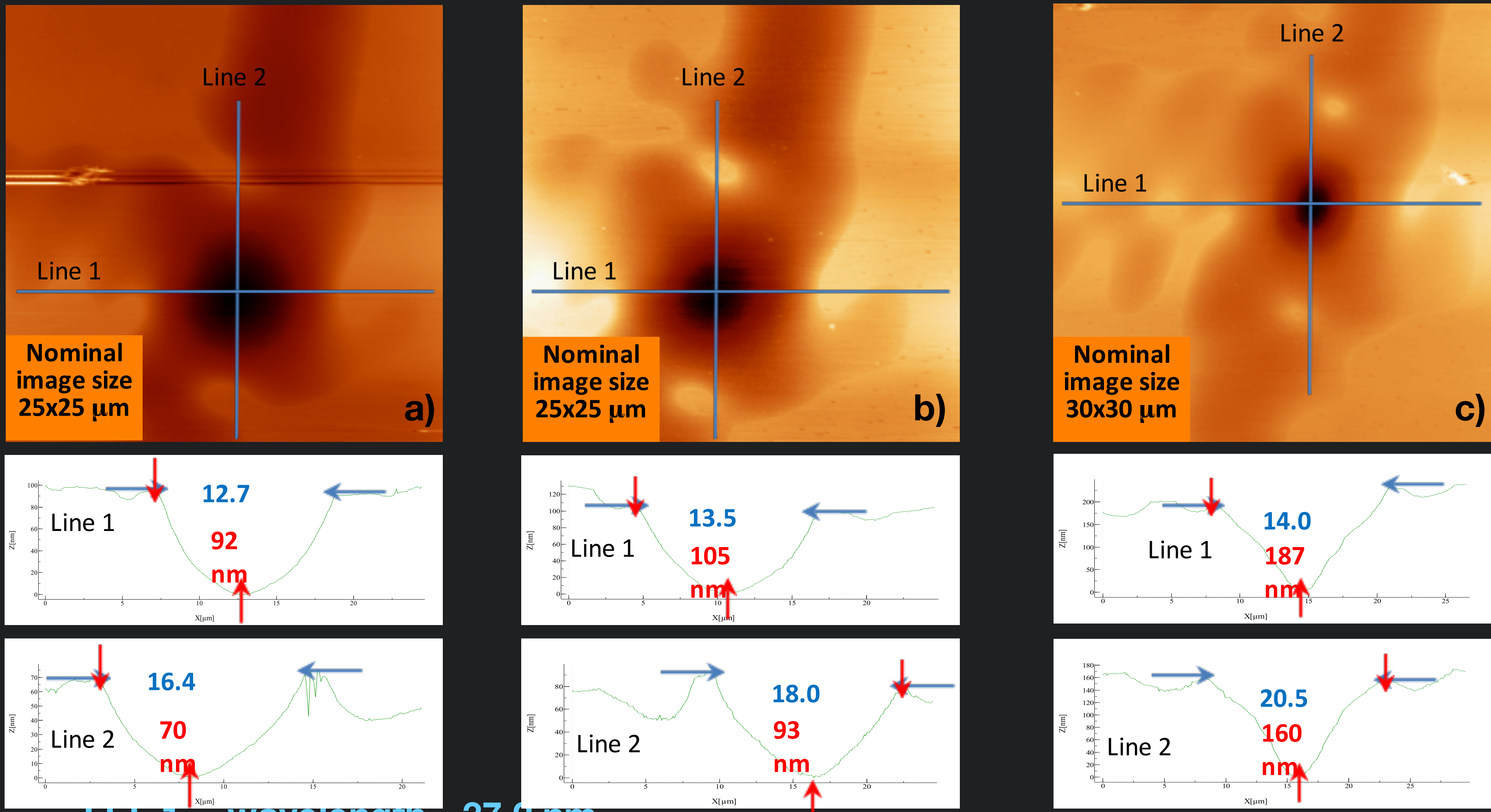


Shot to shot PMMA ablation series observed with optical microscope 100X

- **FEL 1**
- **wavelength - 37.2 nm**
- **Ablations on PMMA with FEL intensity estimated on focal spot 2 µJ**
- **Estimation of the peak width ~ 10 x 15 µm**

Focal spot measurements at DiProl end-station

PMMA ablation measurements (related to the best spot) AFM



- FEL 1 - wavelength - 37.2 nm
- Intensity estimated on focal spot: a) 0.85 µJ - b) 1.25 µJ - c) 2.0 µJ
- Chalupski analysis still in progress
- Ablations on PMMA (500nm thickness) Spot-size estimation FWHM ~ 10x13 µm

Focal spot measurements - DiProl

SUMMARY

- **Ideal mirrors spot-size**
  $FWHM_{32nm}$ = 3.5x5.1 µm $FWHM_{37nm}$ = 4.1x5.9 µm

- **Best spot-size measured with WFS (Imagine Optics) at 32 nm**
  $FWHM_{32nm}$ = 5x8 µm

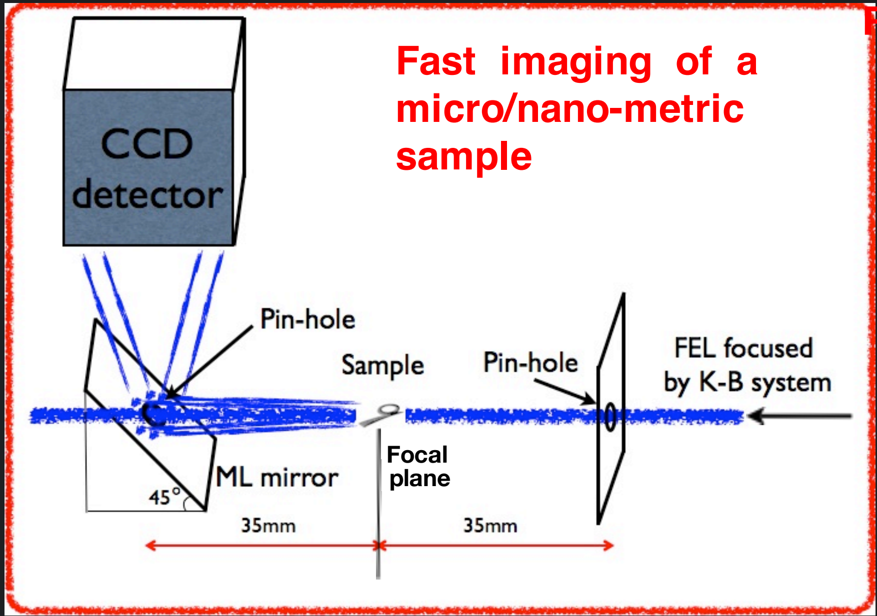
- **Spot-size simulated with WISE code**
  $FWHM_{32nm}$ = 5.0x7.7 µm

- **Best spot-size measured with WFS (LLG-DESY) at 37 nm**
  $FWHM_{37nm}$ = 10x13.5 µm

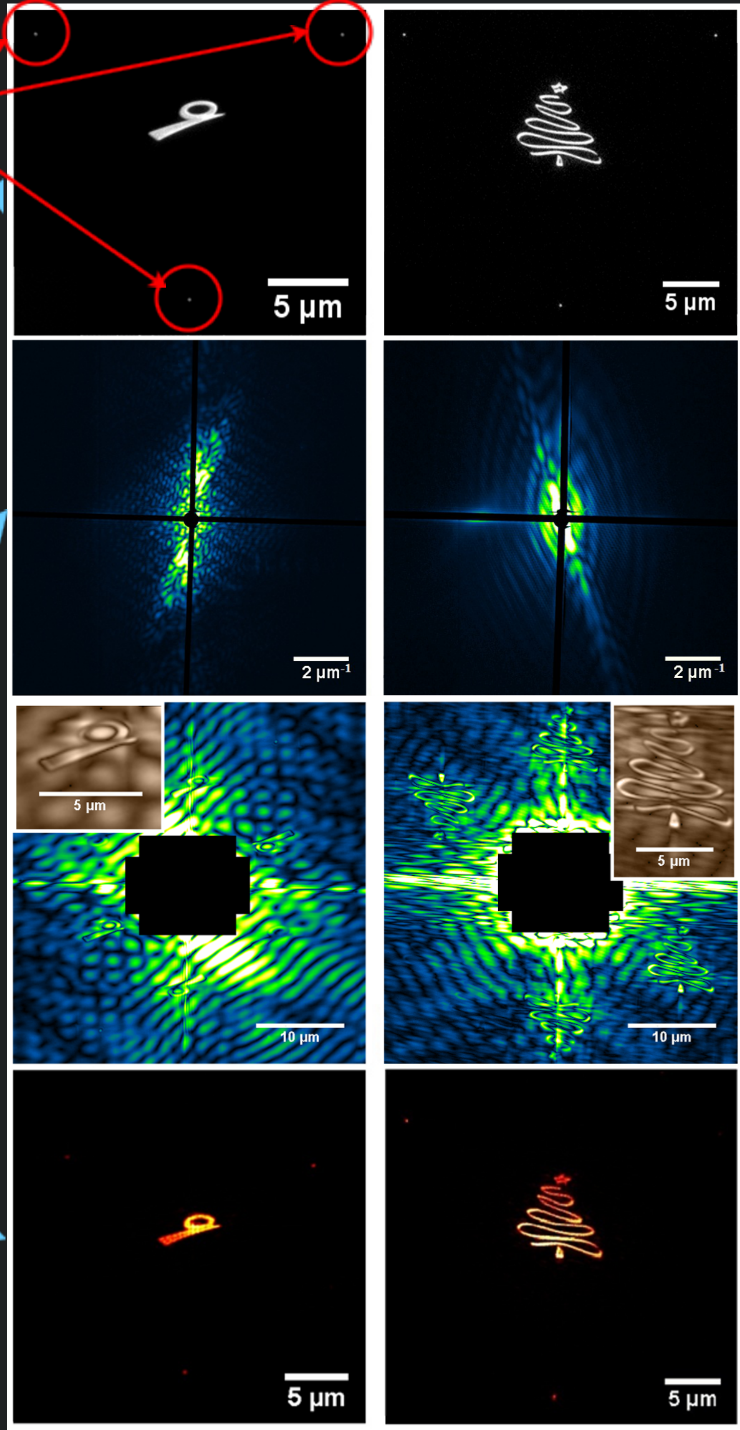
- **Spot-size simulated with WISE code**
  $FWHM_{37nm}$ = 5.2x8.0 µm

- **Spot-size measured on PMMA ablation (DESY campaign) at 37nm**
  $FWHM_{37nm}$ = 10x13 µm

DiProl experiments



Reference pin-holes



Sample

Diffraction pattern FEL pulse 20 μJ at 32.5 nm

Reconstruction object

Fourier transform of the collected data

Phase retrieving using computational algorithm

Involved people: H.N.Chapman (CFEL) J.Hajdu (Univ Upsala) M.Bogan (Pulse Stanford) and DiProl Team

From more details see F.Capotondi poster - this conference

Conclusions

- **Through both wave-front sensors we improve the alignment of all angles and we went further in the optimization of the mirror shape:**
  - **with Imagine Optics WFS at 32 nm, we obtained a focal spot (reconstructed via software) with $FWHM_{32nm}$ = 5x8 μm**
  - **with LLG, DESY WFS at 37 nm, we obtained a focal spot (reconstructed via software) with $FWHM_{37nm}$ = 10x13.5 μm**
- **Thanks to the simulations computed with WISE code we can say that these optimizations have led the system performances very close to the limit of the mechanical system. The simulations of the best profiles measured at LTP provide: $FWHM_{32nm}$ = 4.4x5.8 μm and $FWHM_{37nm}$ = 5.1x6.0 μm**
- **AFM analysis of PMMA ablation measurements related to the best spot obtained in the LLG, DESY WFS campaign returns a spot size $FMHM_{37nm}$=10x13μm in agreement with the WFS reconstruction**
- **These results confirm how essential is this instrument for a bendable K-B system like ours, used both as a diagnostic and as a tool for the active optics optimization**

People involved in this work:

- L.Raimondi, N.Mahne, C.Svetina and M.Zangrando – PADReS
- F.Capotondi, E.Pedersoli, M.Kiskinova – DiProI
- B. Mahieu, G. De Ninno, C. Spezzani, E. Allaria, M. Trovò, E. Ferrari – FERMI team
- D.Cocco – SLAC
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- P. Zeitoun, G. Dovillaire, G. Lambert, W.Boutu, H. Merdji, A. I. Gonzalez, D.Gauthier – CEA + LOA + IMAGINE OPTIC

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