# The Quest for the perfect focus for high power density XUV and X-Ray beams: Experience from FLASH

**ACTOP08**
**Trieste 2008**

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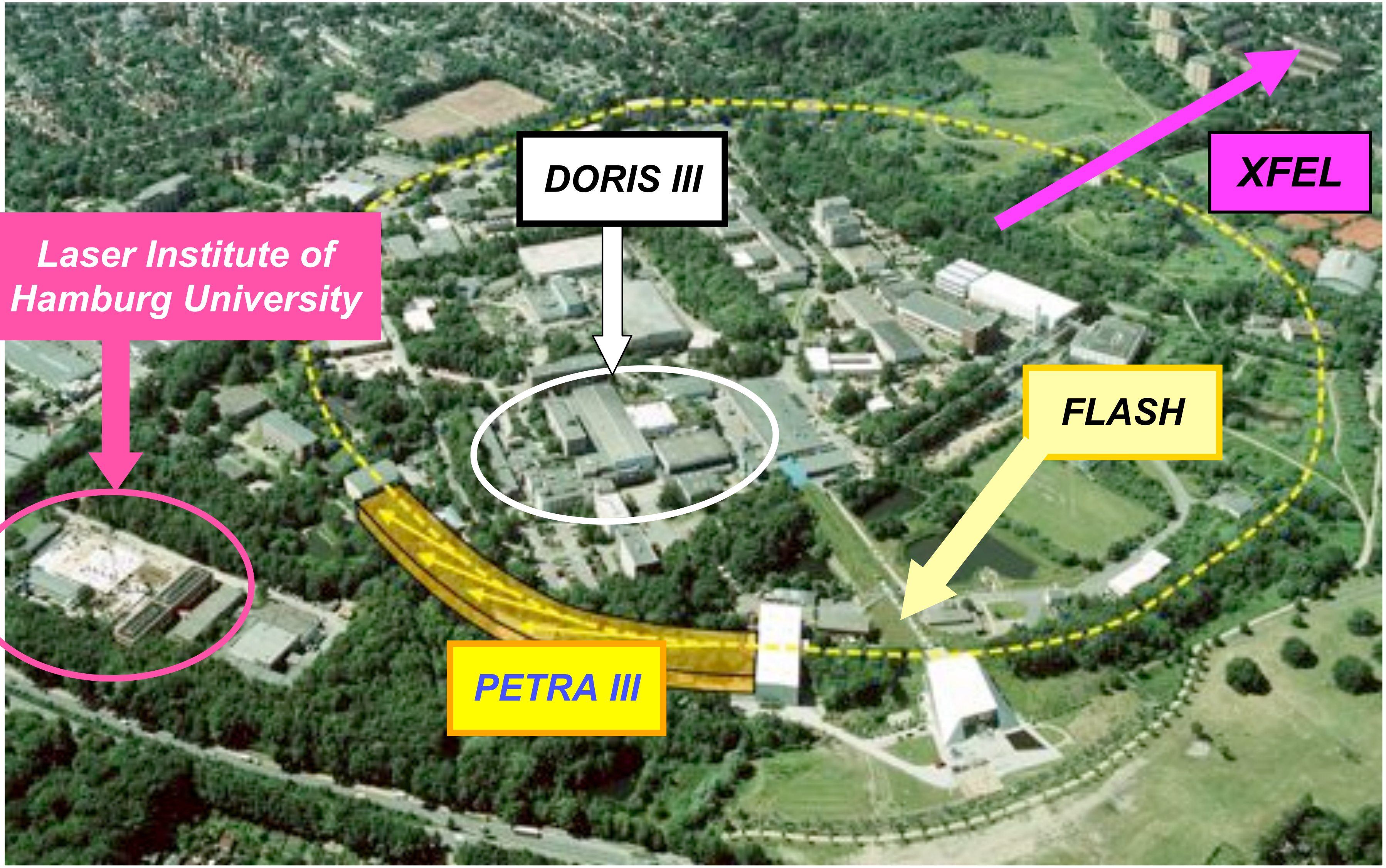
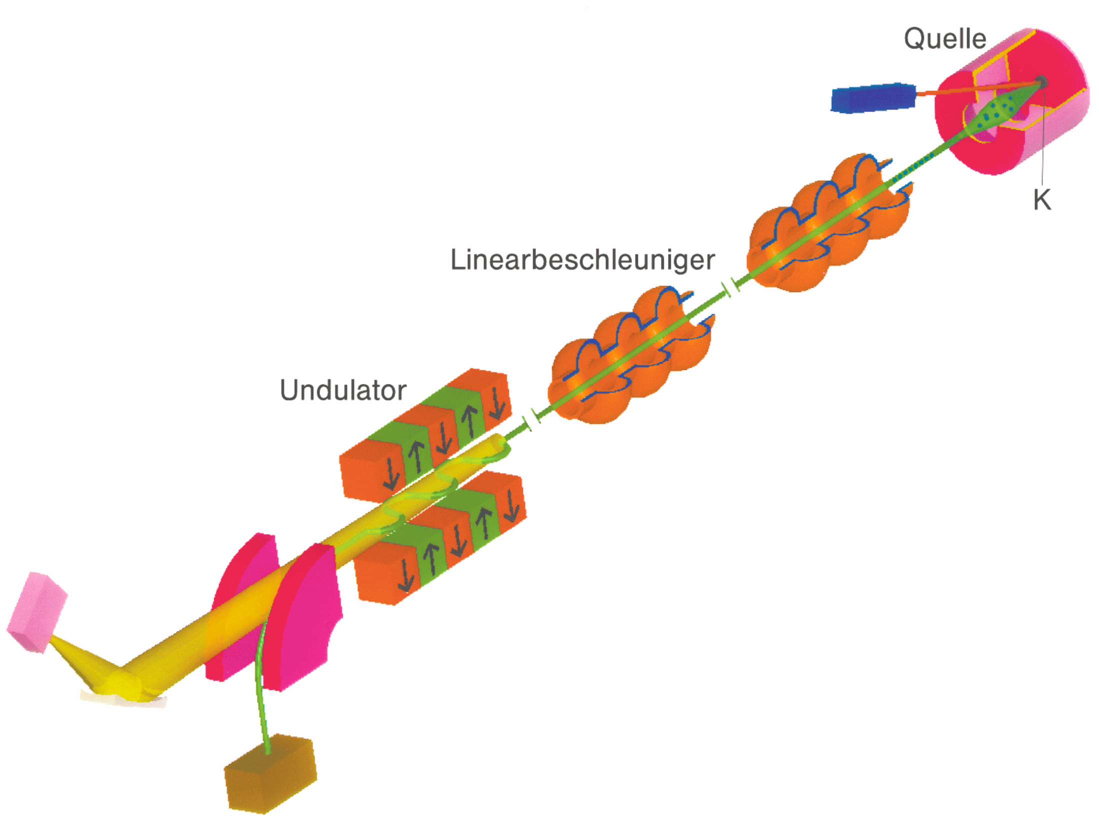
# Research with photons at DESY



# *FLASH = Free-electron LASer in Hamburg*


**LINAC driven SASE free electron laser**



# Outline

- **Status of FLASH**
- **Layout of the user facility**
- **What do user need to perform successful experiments at FELs?**
- **Summary and outlook**

# Status of FLASH

# *Current performance of FLASH*

***Wavelength range (fundamental):***
***6.9-48 nm***

***FEL harmonics (@6.9 nm):***
***3 rd : 2.3 nm (270 eV)***
***5 rd : 1.4 nm (450 eV)***

***Spectral width (FWHM):***
***0.5-1 %***

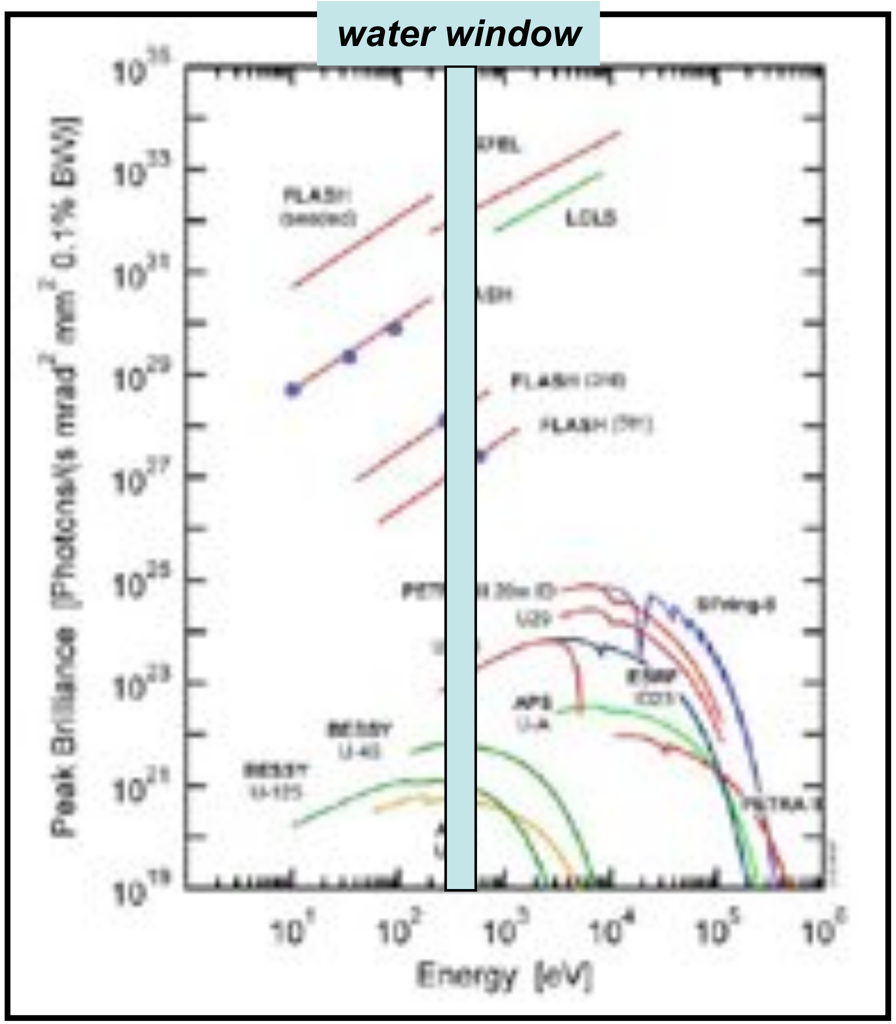
***Pulse energy:***
***up to 100 µJ (average),***
***170 µJ (peak)***

***Pulse duration (FWHM):***
***10-50 fs***

***Peak power (fundamental):***
***5 GW***

***Average power (fundamental):***
***up to 100 mW***

***Peak brilliance:***
***up to $5 \times 10^{29}$***

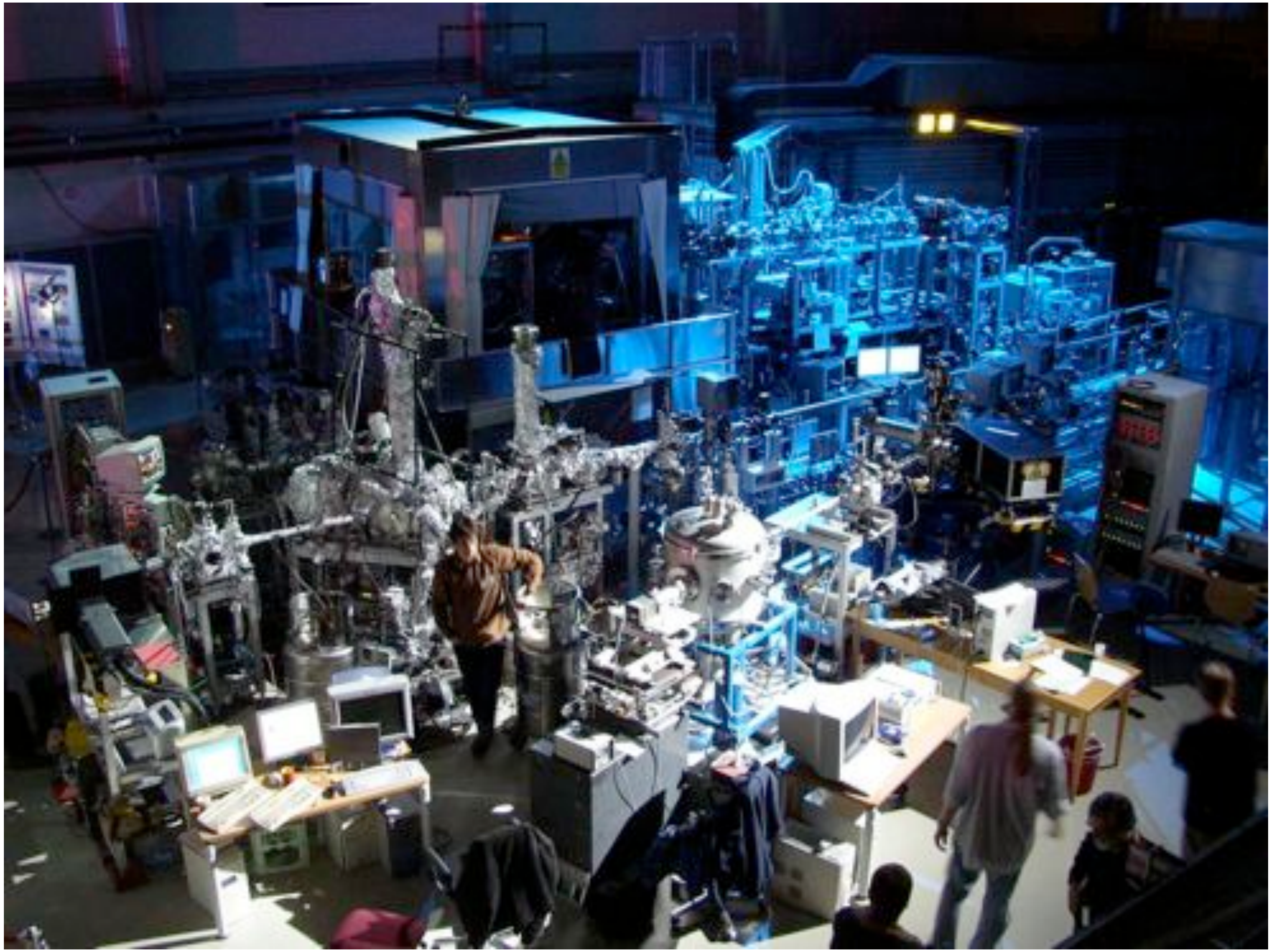



***peak brilliance***

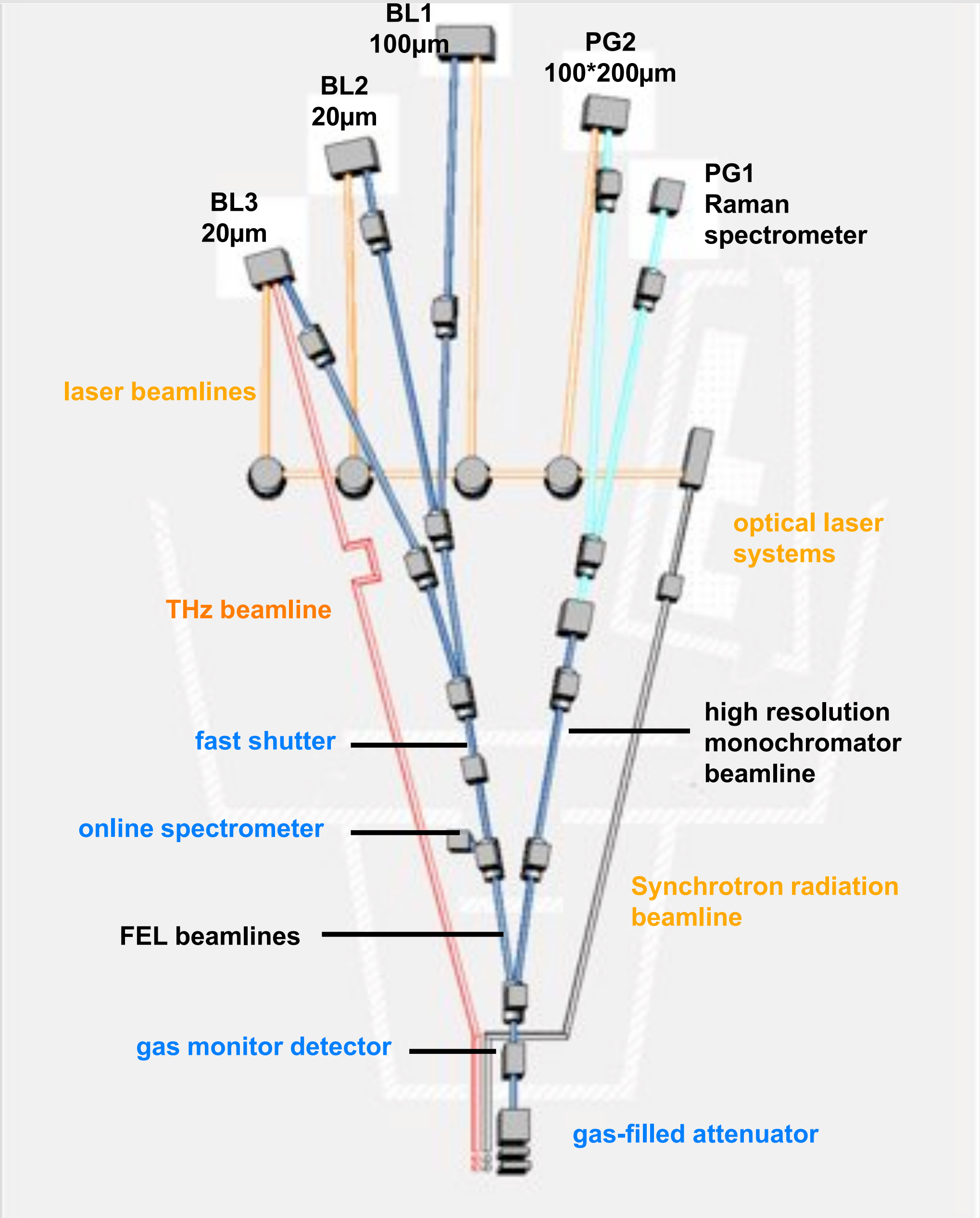
# *Current Research Areas*

- **Femtosecond time-resolved experiments**
  - synchronisation FEL - optical laser (*Drescher, Meyer*)
  - pump-probe expts. on atoms and molecules (*Meyer, Drescher*)
  - sum-frequency generation (*Starke*)
- **Interaction of ultra-intense XUV pulses with matter**
  - multiphoton excitation of atoms, molecules, clusters… (*Richter, Becker, Moshammer, Möller*)
  - creation and characterisaton of dense plasmas (*Lee et al.*)
  - imaging of biological samples (*Hajdu/Chapman*)
- **Investigation of extremely dilute samples**
  - photodissociation of molecular ions (*Wolf*)
  - highly charged ions (*Crespo*)
  - mass selected clusters (*Meiwes-Broer*)
- **Investigation of surfaces and solids**
  - XUV laser desorption *(Zacharias)*
  - surface dynamics (*Föhlisch*)
  - luminescence under FEL radiation (*Kirm*)
  - meV-resolution photon and photoelectron spectroscopy of surfaces and solids with nm resolution (*Kipp*)

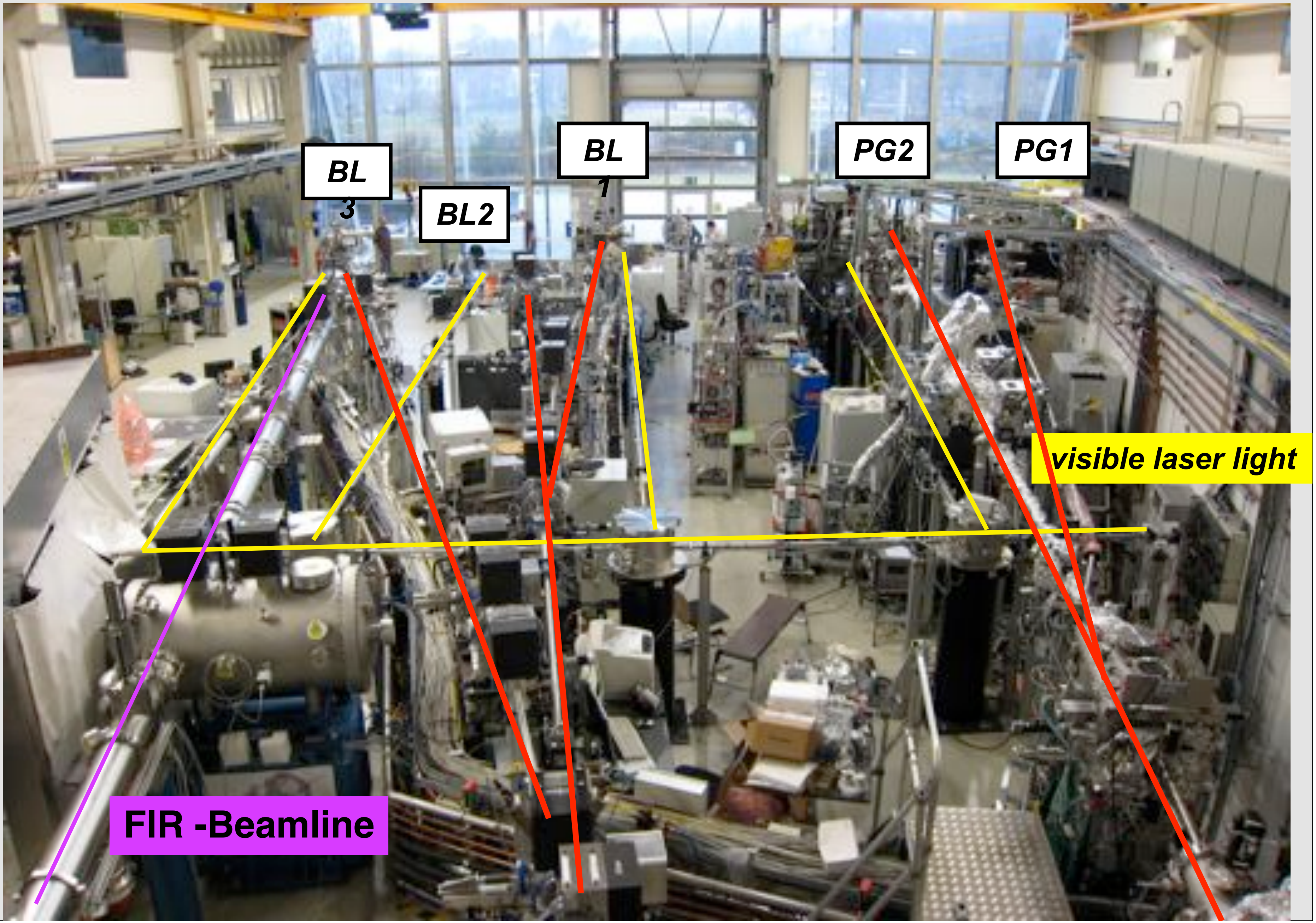
# Layout of the experimental hall



# Experimental area of FLASH



# FLASH experimental hall



# Beam distribution optics

**Plane mirror -> beam distribution**

**Toroidal & ellipsoidal mirror -> focusing**

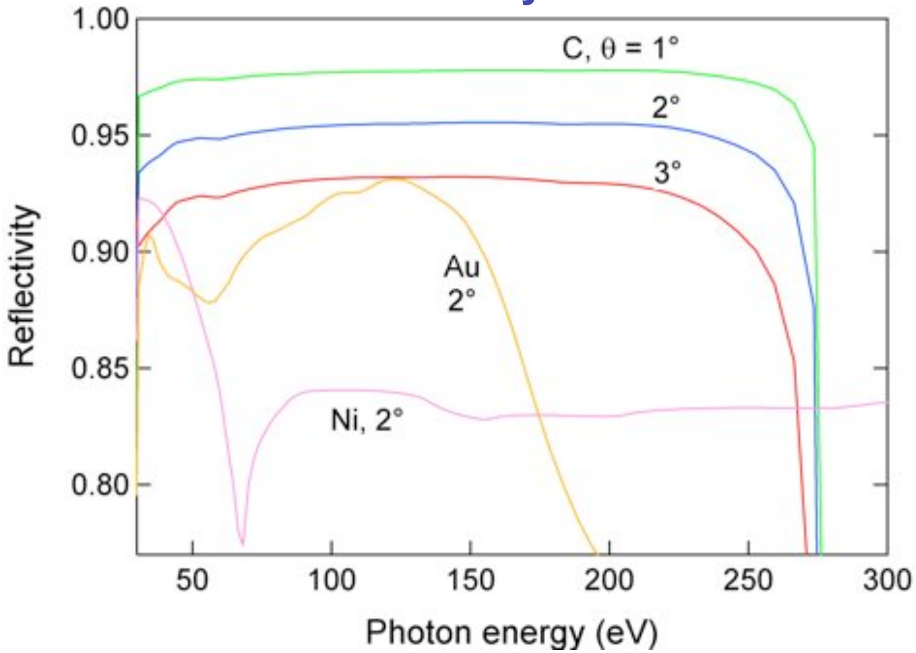
**Substrate: Si**

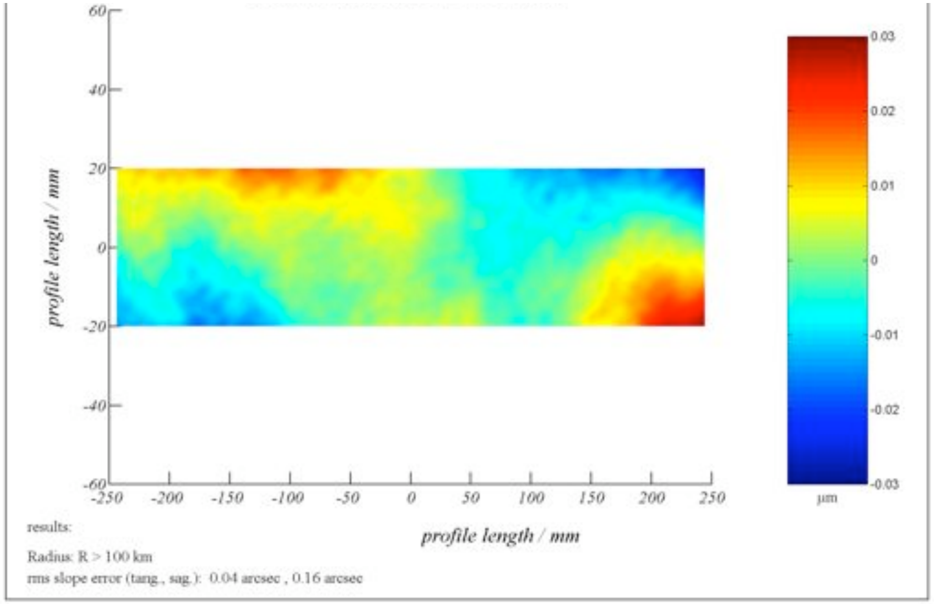
**Mirror dim.: 50 cm x 6 cm**

**Coating: C for the fundamental**

| Properties | Specification | Results |
|---|---|---|
| Geometry | Radius >20km | R>230km |
| Slope error | tangential: 0.1" rms<br>sagittal: 0.2" rms | 0.070" rms<br>0.122" rms |

## Reflectivity



# What do the users need to perform successfully experiments at FELs?

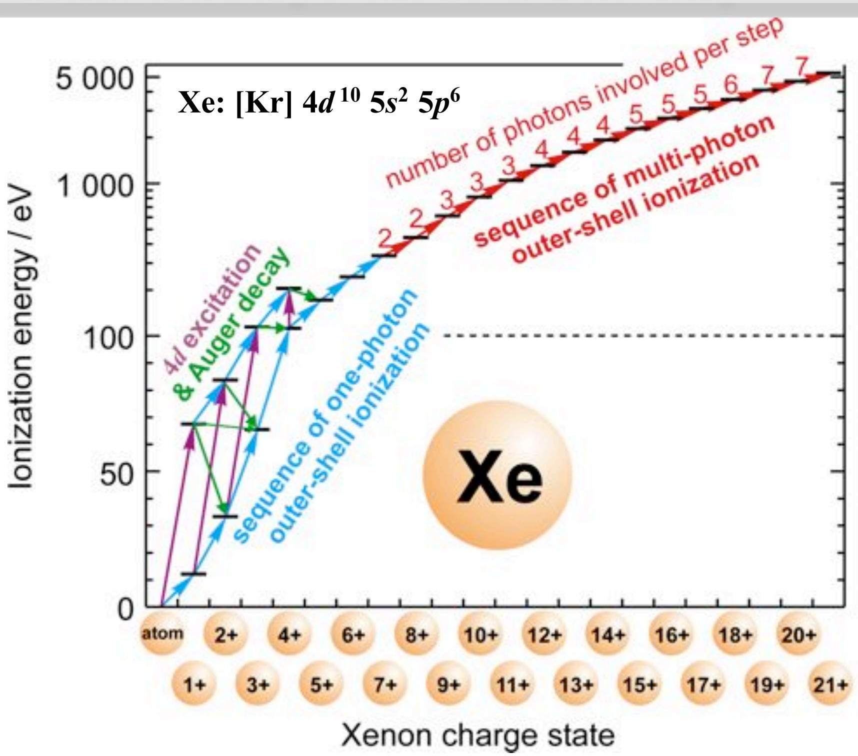
Example:

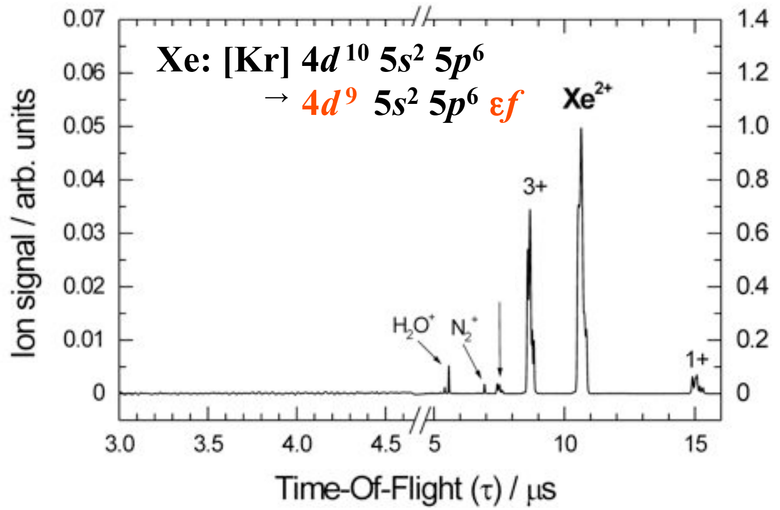
*Photoelectric effect at ultrahigh intensities*

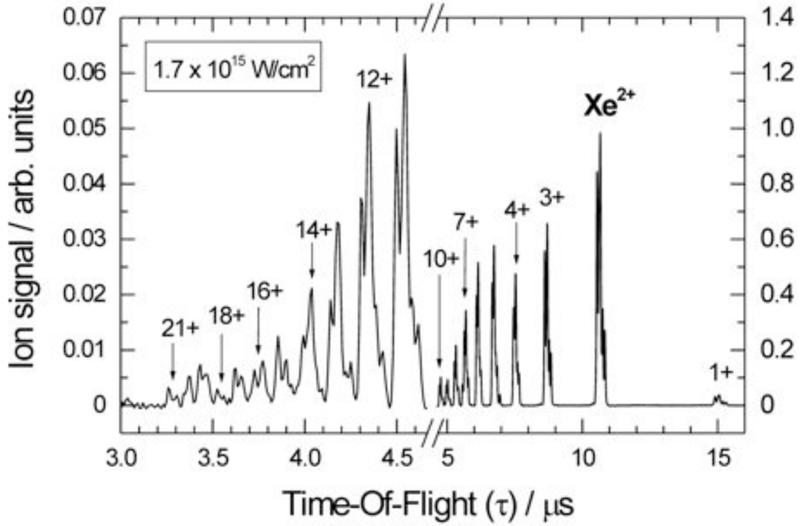
A.A. Sorokin, S.V. Bobashev, T. Feigl,
K. Tiedtke, H. Wabnitz, and M. Richter,
*Phys. Rev. Lett. 99, 213002 (2007)*

# Ion time-of-flight spectroscopy in a peta watt focus of spherical ML mirror at 13nm (92eV)

**The irradiance determine the physics:**
- Pulse energy (GMD)
- Pulse length (temporal distribution)
- Focus size (lateral distribution)



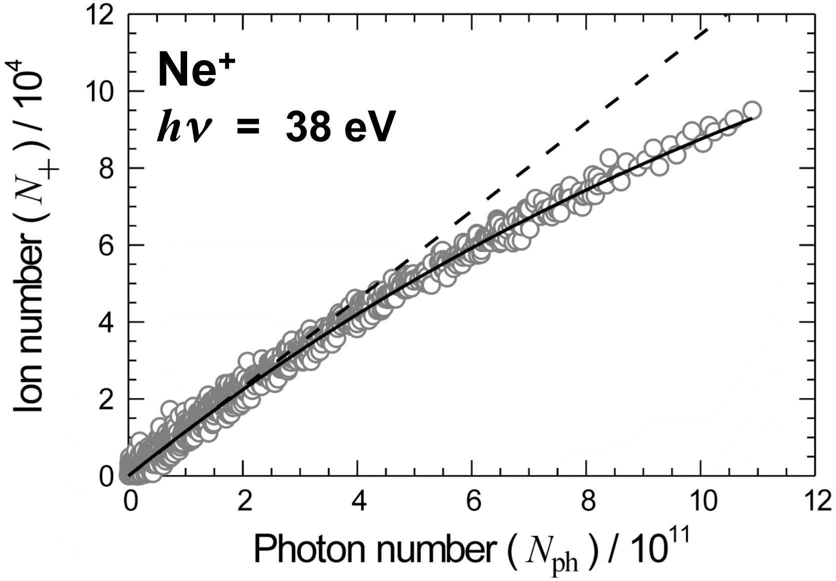

*Photoelectric effect at ultrahigh intensities*

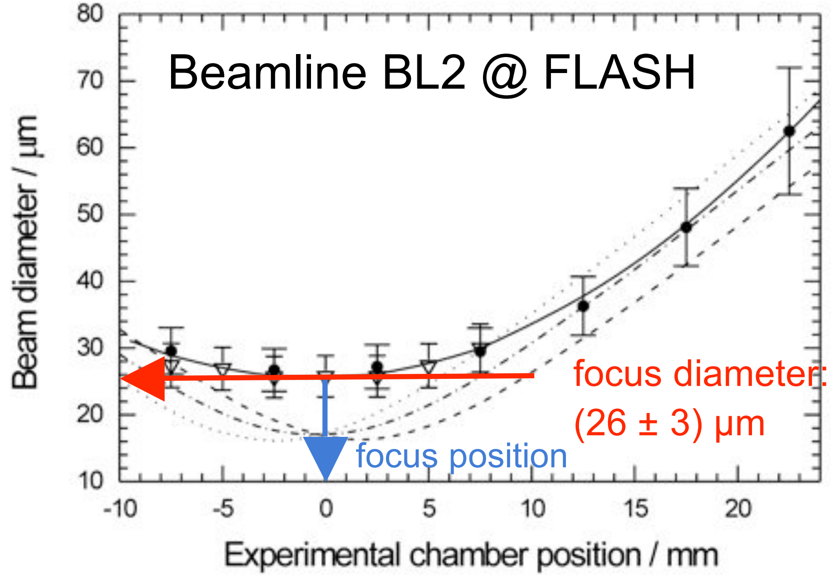
A.A. Sorokin, S.V. Bobashev, T. Feigl, K. Tiedtke, H. Wabnitz, and M. Richter, *Phys. Rev. Lett. 99, 213002 (2007)*

# Lateral intensity distribution / Focus determination

# Lateral intensity - Focus determination

Saturation of ion signals due to vanishing targets: Determination
of FEL beam size and waist



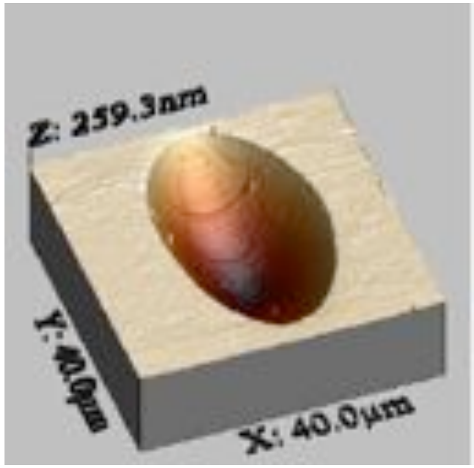

$$N_+(N_{ph}) = N\left(1 - e^{-\sigma \frac{N_{ph}}{A}}\right)$$

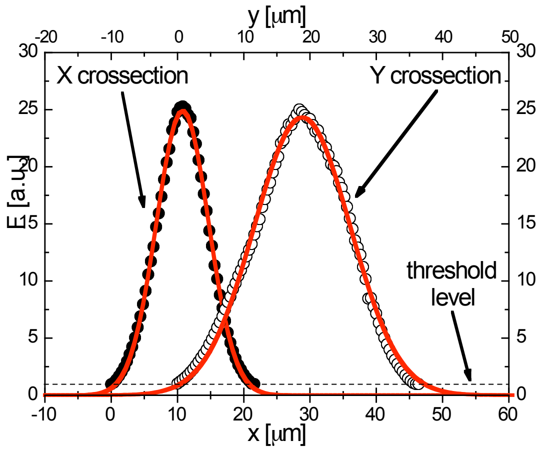
fit →

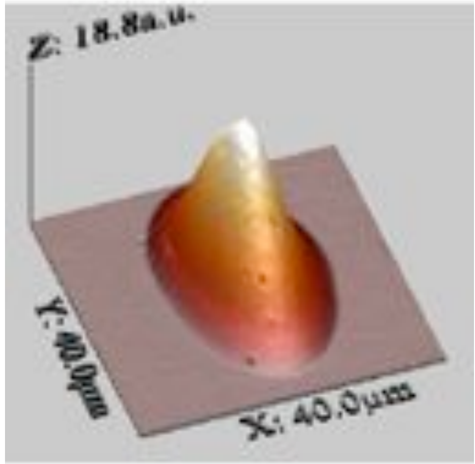
cross section σ is known
photon number $N_{ph}$ is measured
beam cross section $A$ is derived

A.A. Sorokin et al., Appl. Phys. Lett. **89**, 221114 (2006)

## Method based on ablation of PMMA
## →Single-Shot Determination
(but post mortem)

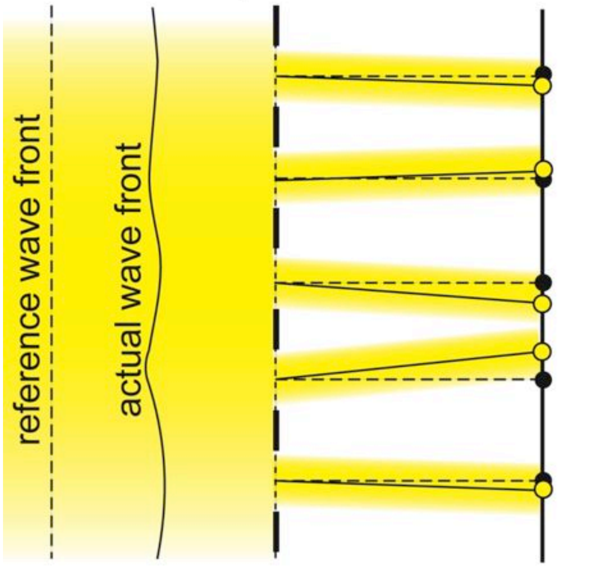


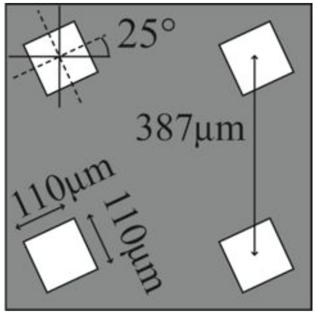




Chalupsky et al., Opt. Express, **15**, 6036 (2007)

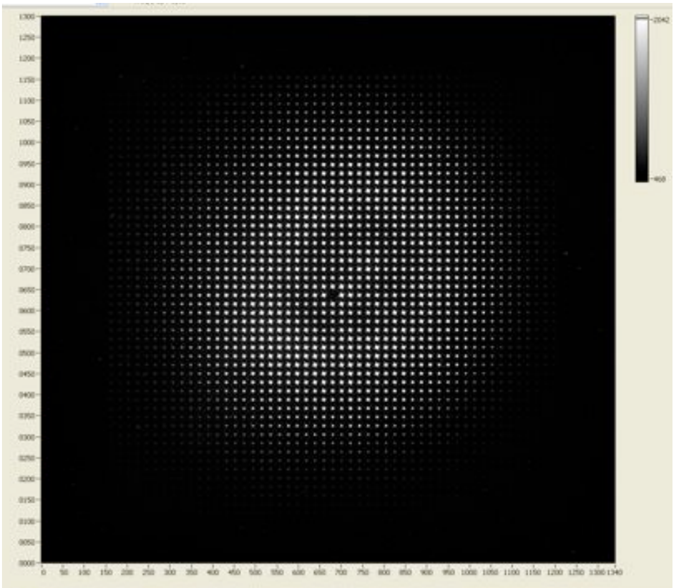
## More convenient approach:
## Wavefront sensor



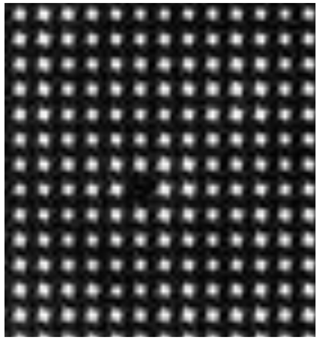

**Wave front sensor**
**soft- and hardware by Imagine Optic**
**CCD: field of view = 19.5 x 19.5 mm**
**1340 x 1300 pixels**
**Hartmann plate: 51 x 51 quadratic holes**
**tilted by 25° to prevent**
**interference of adjacent holes**




**camera image**



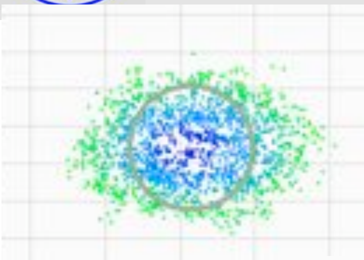
**camera image zoom**



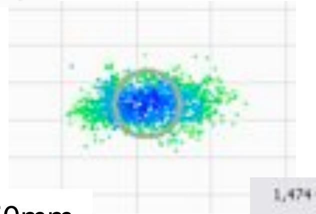
**The actual beam is compared to a perfect spherical wave**

**Courtesy Pascal Mercère, SOLEIL**

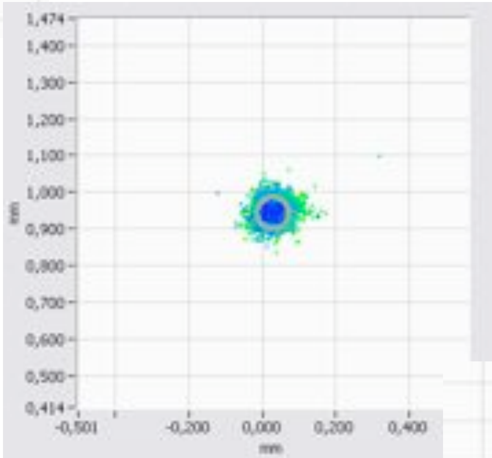
# Before adjusting ellipsoidal mirror of BL2



defocus 100mm
radius 164.9µm

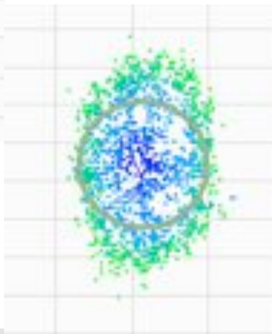


defocus 50mm
radius 87.8µm

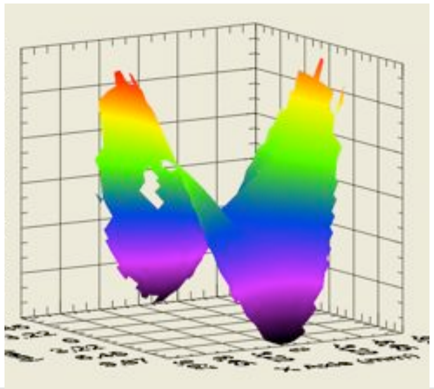


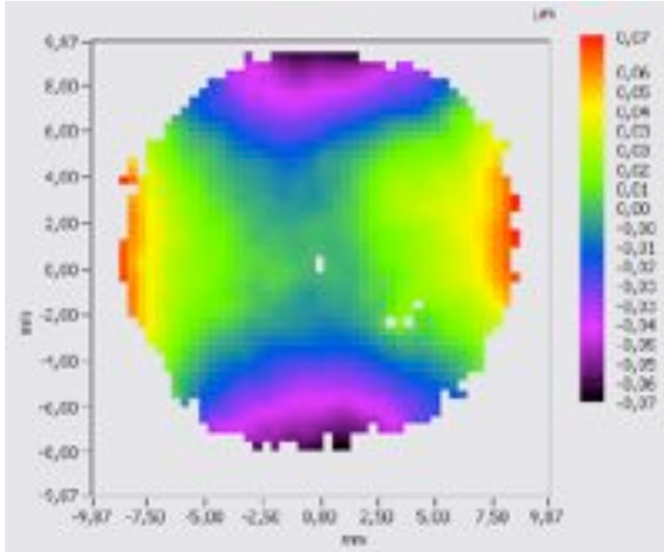
**defocus 0mm**
**radius 42.3µm**

defocus -50mm
radius 88.9µm



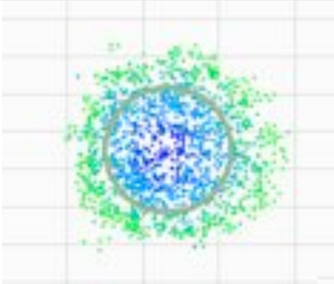
defocus -100mm
radius 166.0µm





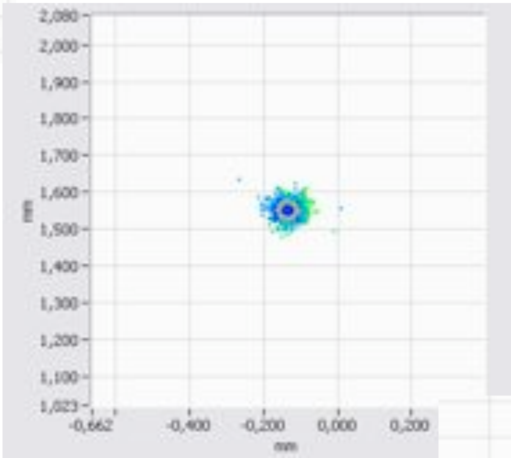
**Rotation: 0 Yaw: 0**
**PV: 110nm  rms: 22nm @ 27 nm**
**→ λ/1**

# After adjustment of BL2

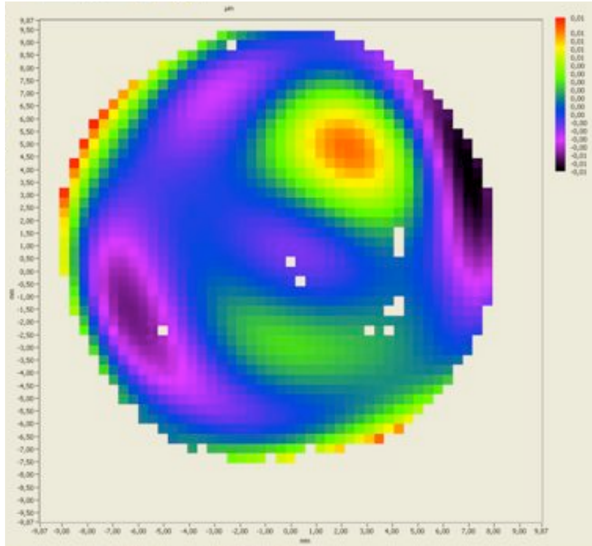


**defocus 100mm**
**radius 165µm**

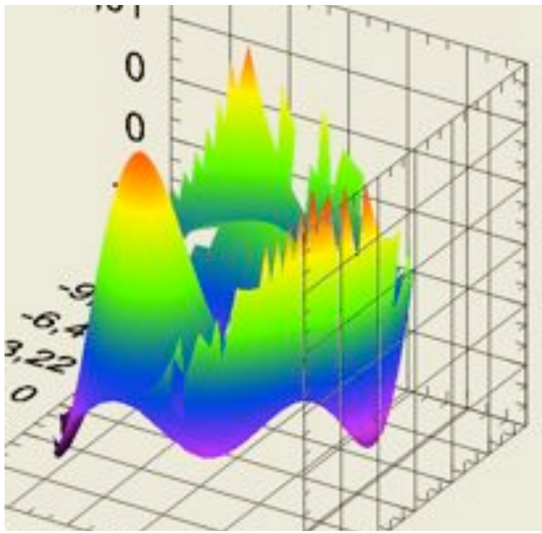
**defocus 50mm**
**radius 84.1µm**

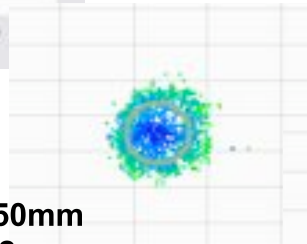



**defocus 0mm**
**radius 24.1µm**

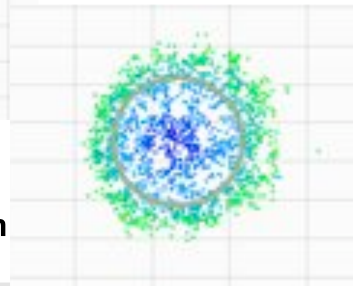


**Rotation: 45000 Yaw: -0.01**
**PV: 18 nm  rms: 3 nm @ 27 nm**
**→ λ/9**





**defocus -50mm**
**radius 85.2µm**

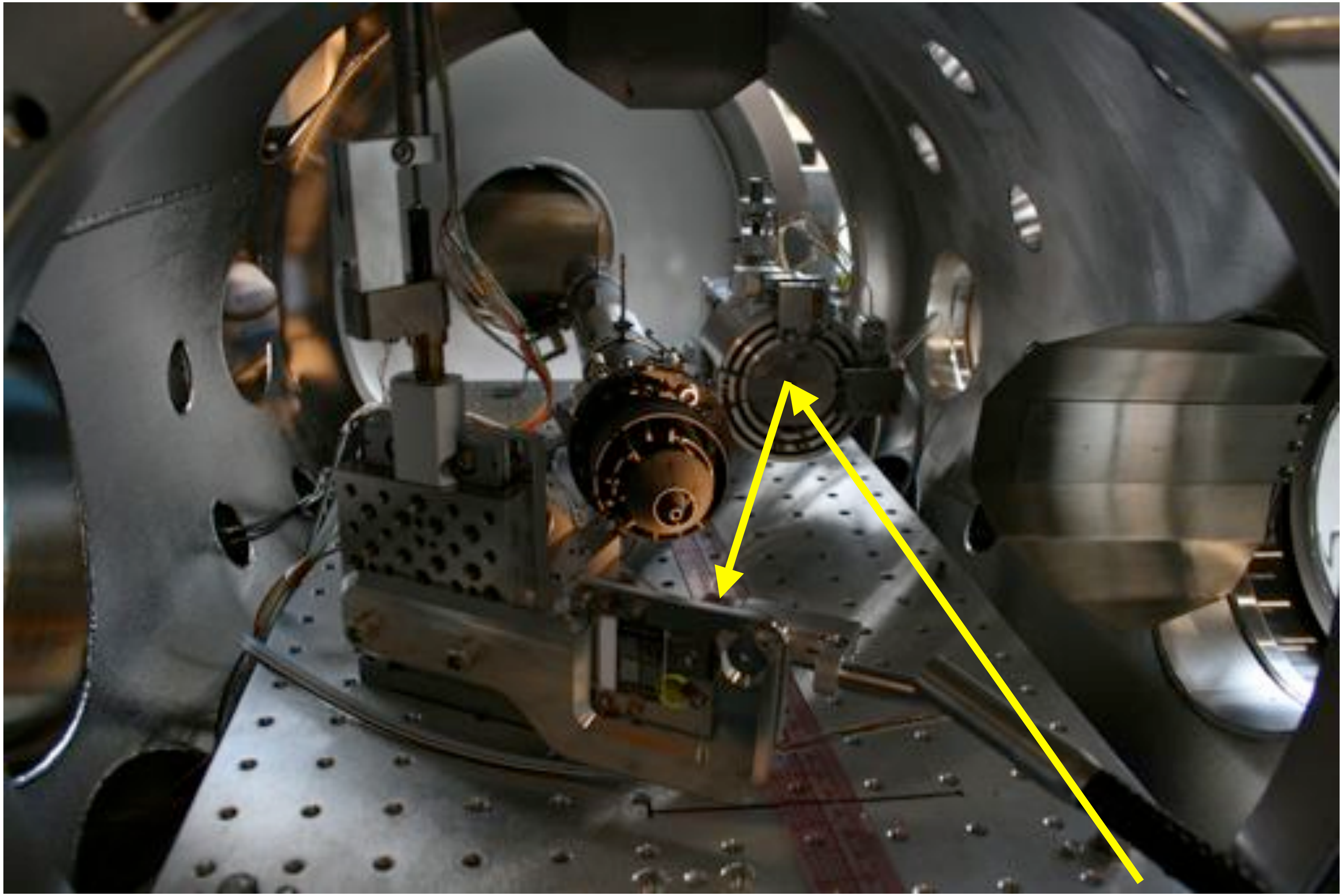


**defocus -100mm**
**radius 166µm**

# Experience with an off-axis parabola

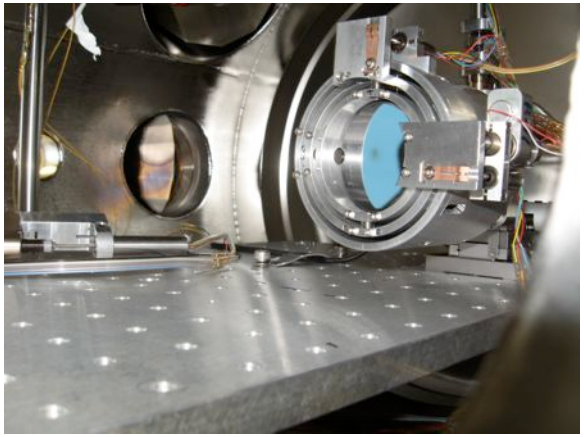
# *Focusing Flash with an Off-Axis Parabola*

**Courtesy S. Toleikis, DESY**



# *Focusing Flash with an Off-Axis Parabola*

Courtesy S. Toleikis, DESY

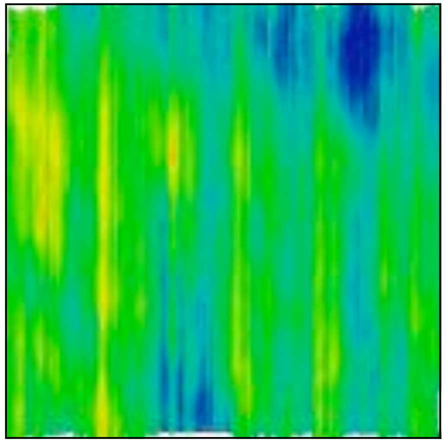


**Off-Axis Parabola (OAP):**

- **Off-axis angle: 21.8°**
- **Focal length: 268.94 mm**
- **Initial prediction for OAP with ML coating for 13.5 nm with no height errors indicates ≤1 µm focal spots**

**Beamtime in February 2007 failed due to bad surface quality:**

- Striations were introduced in OAP during polishing
- Zygo interferometer image shows the pattern
- RMS height error over 1 $cm^2$ is 1.6 nm



**Comparison of the measured PMMA damage pattern with simulations using measured surface profile of the OAP**

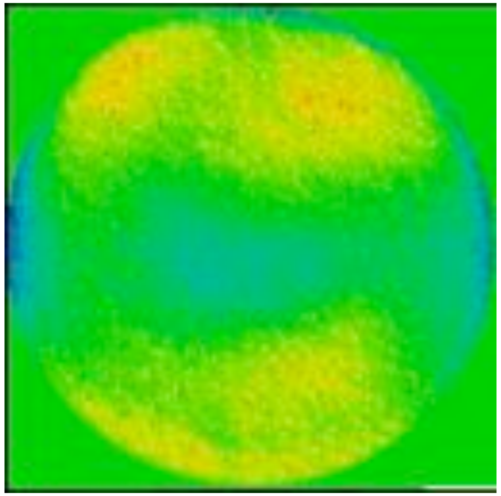
PMMA data

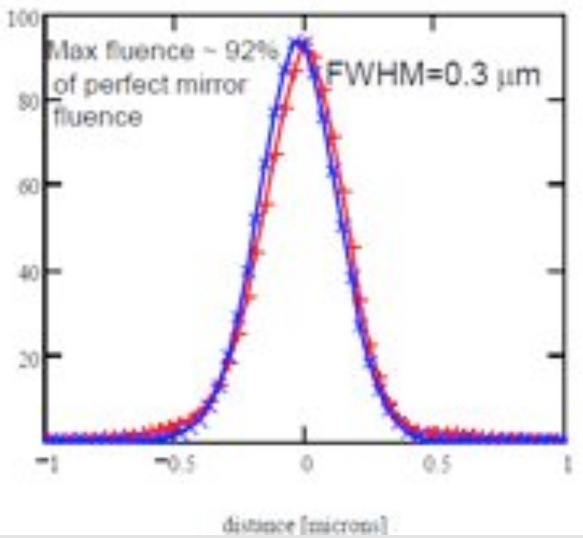
Simulation

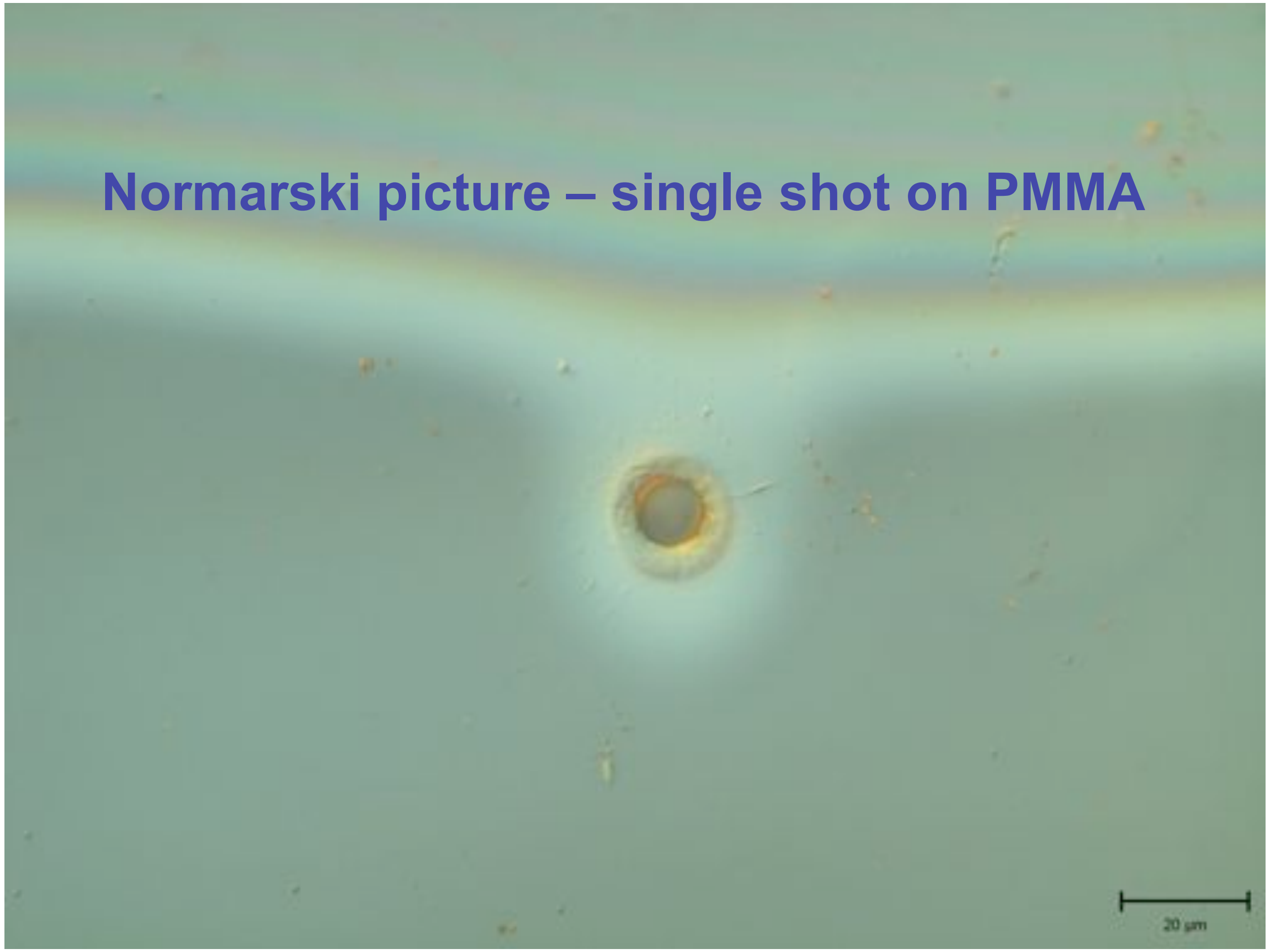
# *Focusing Flash with an Off-Axis Parabola*

Courtesy S. Toleikis, DESY

**Repolished by ASML: -> now RMS height error is 0.3 nm**

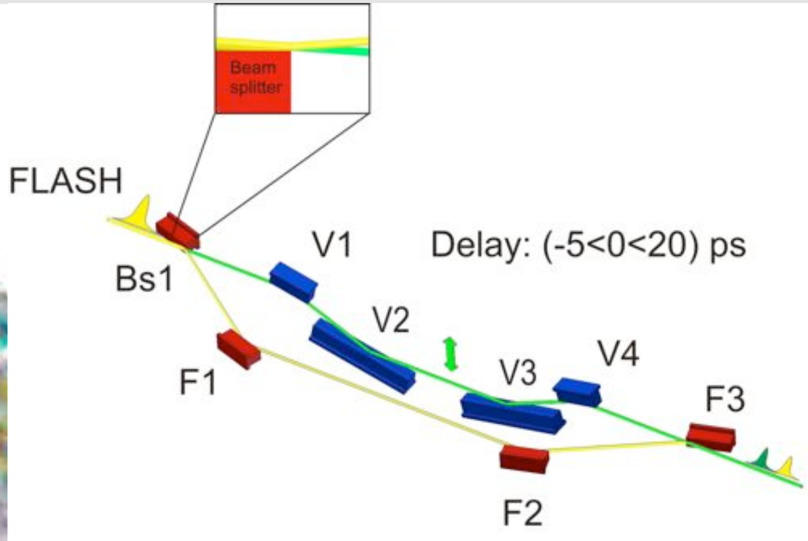


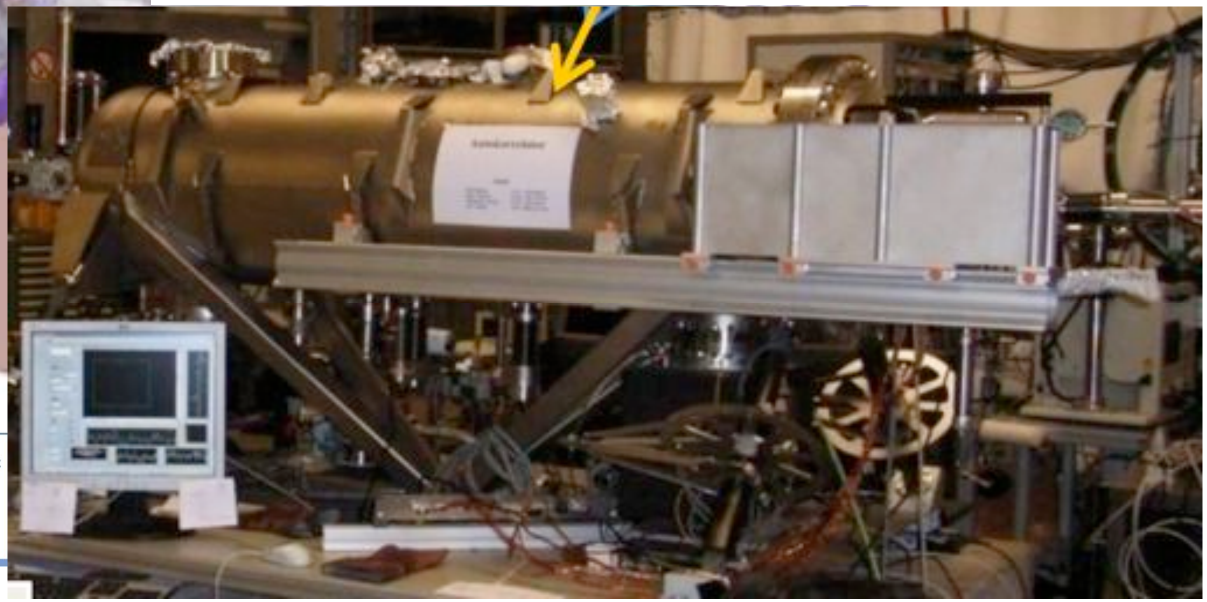


# Temporal intensity distribution

# Temporal coherence and pulse duration
# Two Autocorrelator set-ups

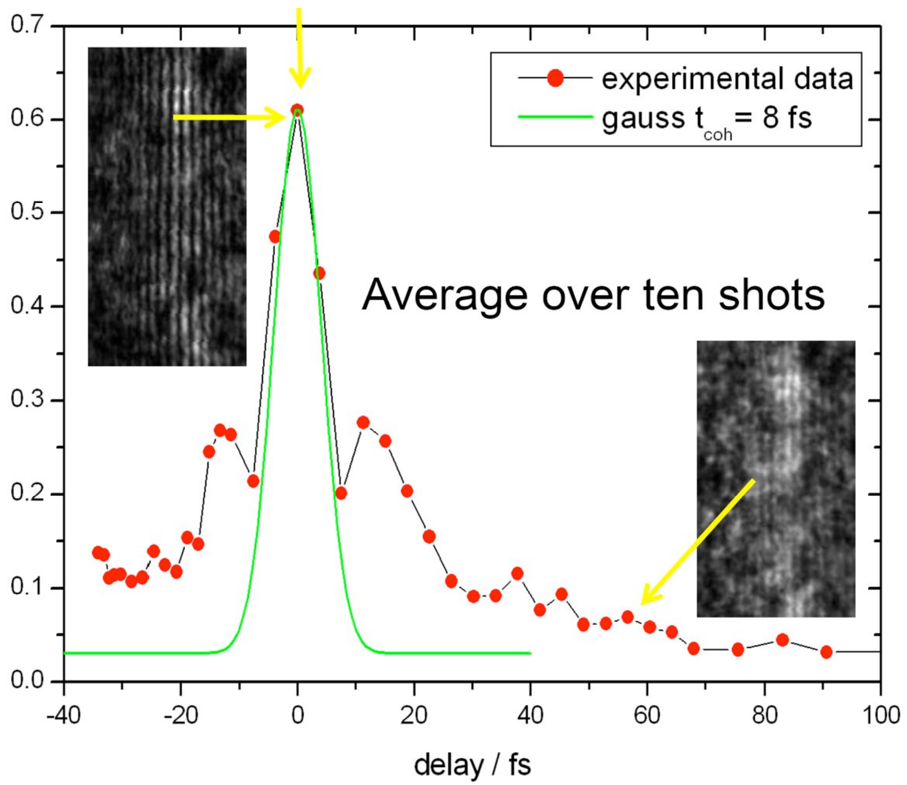


The FEL radiation is split and directed under grazing incidence over a set of fixed and a set of position-variable mirrors, respectively, before being recombined.

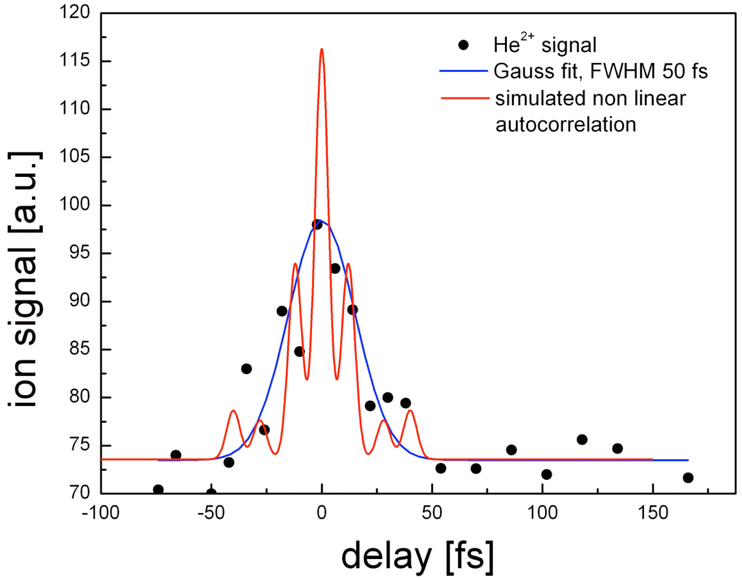
*R. Mitzner, H. Zacharias et al. 2008*

## Temporal coherence




Fringe visibility as a function of
path difference between two beams

## Pulse duration with nonlinear autocorrelation




Nonresonant two-photon double ionization of He

R. Mitzner, H. Zacharias et al. 2008

# Summary / Outlook

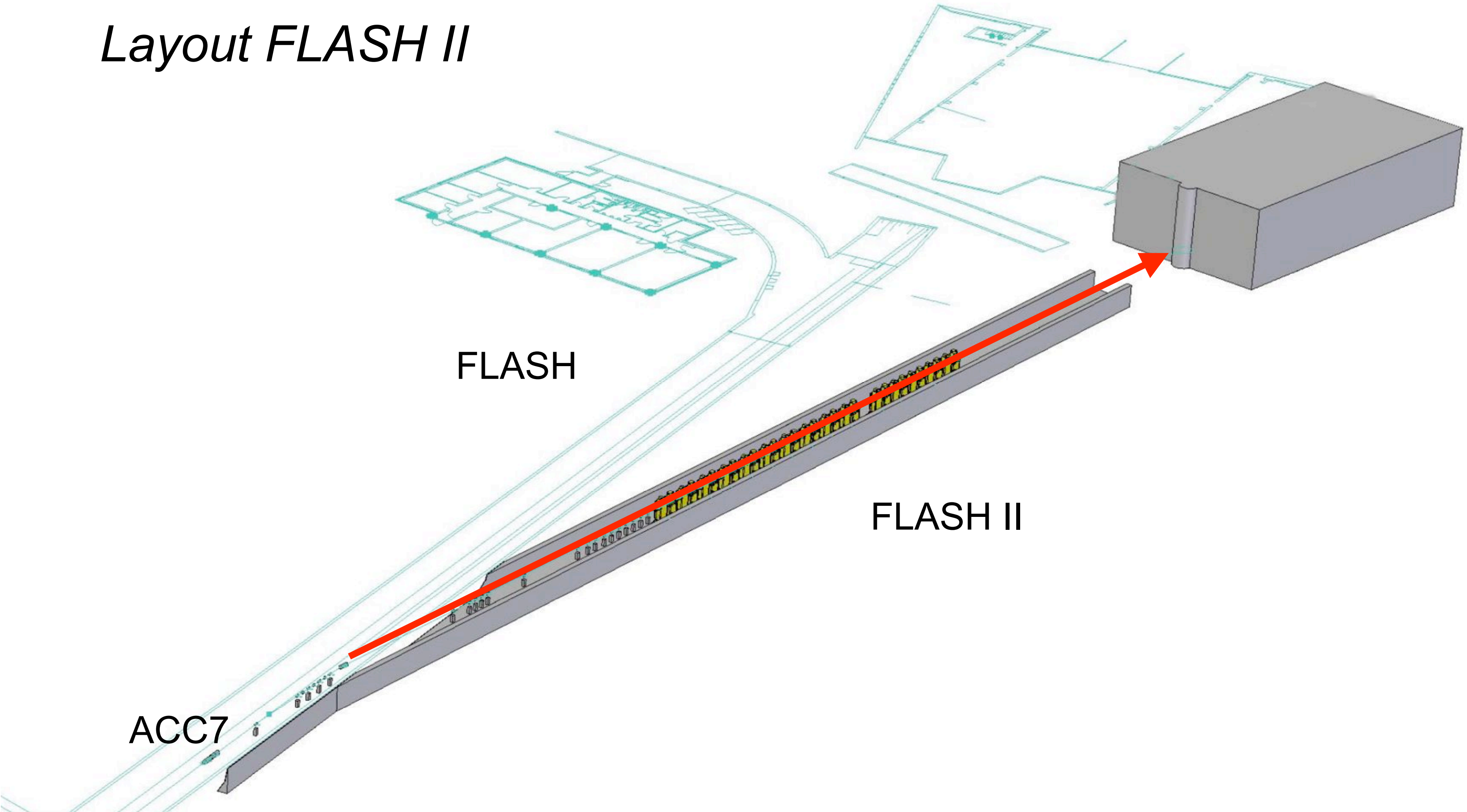
*The essential techniques for FEL beam distribution and diagnostics are available:*

- Intensity monitor, beam position monitors, gas attenuator, VLS
- Ellipsoidal, torodial mirrors to focus down to 20 -100 µm
- Techniques to determine the lateral distribution in the focus

- but more R&D is needed to
  - improve and optimise beam delivery (e.g. multilayer for different wavelengths, filter to get rid of the fundamental)
  - improve the focusing schemes (OAP, KB systems)
  - improve alignment tools (wavefront sensor)

# Outlook

*Layout FLASH II*



# The FLASH Team

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BESSY, Berlin
University of Münster
CNR-INFM, Padova
LASER Lab Göttingen

# Thanks for your attention!