FLASH Focus Spot Size Measurement Based on Atomic Photoionization

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The measurement of spot size in a focused FEL beam is a highly demanding task, since conventional methods, like the knife-edge or the fluorescent screen technique, are limited by the surface irradiation or even destruction due to the high intensities present in the focus. Peak irradiance levels of more than 10^{13} W cm^{-2} may occur in a spot of a few µm diameter. Moreover, due to its statistical nature, a beam of FEL radiation based on SASE principle may strongly fluctuate from shot to shot perpendicular to the propagation axis and requires spot size measurements which do not depend on beam position. Nevertheless, precise knowledge of spot size dimension and position is essential knowledge for the investigation of non-linear processes and their dependence on irradiance.

To overcome these problems, we developed a new method based on a saturation effect upon photoionization of a rare gas, which manifests itself by a sub-linear increase of the ion yield with increasing photon number per pulse. It is due to a considerable reduction of the number of target atoms within the interaction zone by ionization with a single photon pulse and becomes stronger with decreasing beam cross section. The method is indestructible and not affected by fluctuations of the beam position. Moreover, it can easily be realized in any ionization chamber by introducing a (rare) gas and detecting the photoionization signal as a function of the absolute photon number per pulse.

Our measurements have been performed at the microfocus beamline BL2 at FLASH with series of subsequent photon pulses of 25-fs duration separated by 1 µs with up to 10^{12} photons at a photon energy of 38 eV. An ellipsoidal mirror has been used for focusing. The photoionization (PI) setup consists of a vacuum chamber with a conventional time-of-flight (TOF) spectrometer.

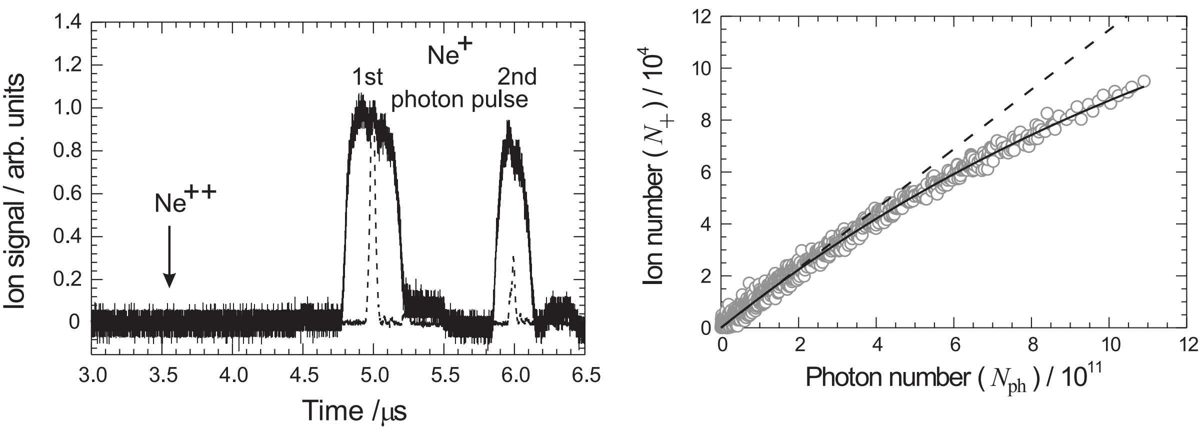

Figure 1 left: Two single-shot TOF spectra of neon (Ne) obtained from two subsequent FEL pulses, respectively, at low (dashed line) and high (solid line) numbers of ions generated per pulse.
Right: Absolute number of Ne^+ ions created per FEL pulse as a function of the absolute photon number per pulse. The solid line represents a fit curve, the dashed line depicts a linear dependency for comparison.

Neon was chosen as the target gas because at a photon energy of 38 eV, photoionization of neon is restricted to the generation of singly charged ions only but with a considerably high cross section. At the pressure around 10^{-3} Pa, the target gas is almost transparent allowing the absolute photon number per pulse to be determined online 50 cm behind the focus. For this purpose, we have used a gas-monitor detector (GMD) developed for this purpose [1]. Fig. 1 shows on the left side two TOF spectra of neon taken from two subsequent FEL pulses, respectively. The absence of any signal from doubly charged ions indicates that our measurements have not been affected by higher-order effects, such as photoionization by higher harmonics of the FEL or atomic multi-photon processes. On the right side Fig. 1 demonstrates the mentioned saturation effect for single photoionization of neon. Shown is the sub-linear dependence of the number of Ne^+ ions created per pulse on the absolute photon number per pulse. From these data, the beam size (and thus the spot diameter) can be evaluated by a fit procedure [2]. Fig. 2 summarizes the evaluation of a set of those measurements in order to find the focus position, i.e. the local minimum of the beam diameter, while moving the experimental chamber along the photon beam. The measurements have been repeated at different target gas pressure and, thus, signal intensities in order to investigate the influence of other saturation effects, e.g. due to incomplete ion collection/detection. However, below 2×10^{-3} Pa, ion detection has been confirmed to be linear and high numbers of ions generated per pulse lead to line broadening due to space charge effects and Coulomb repulsion in the respective ion spectra only (Fig. 1) whereas the beam waist measurements have not been affected by the target gas pressure (Fig. 2). As a further result, assuming a Gaussian intensity distribution, the FWHM focus diameter ($d_{FWHM} \approx 0.59 \cdot d_{2\sigma}$) at BL2 has been found to be (15 ± 2) µm with a beam divergence of about 3 mrad. Fig. 2 also shows results of ray-trace simulations. While the agreement for distances greater than 10 mm from the focus position is almost perfect, the beam diameter within the focus region seems to be slightly larger than predicted which might be explained by minor misalignment and only partially known source parameters.

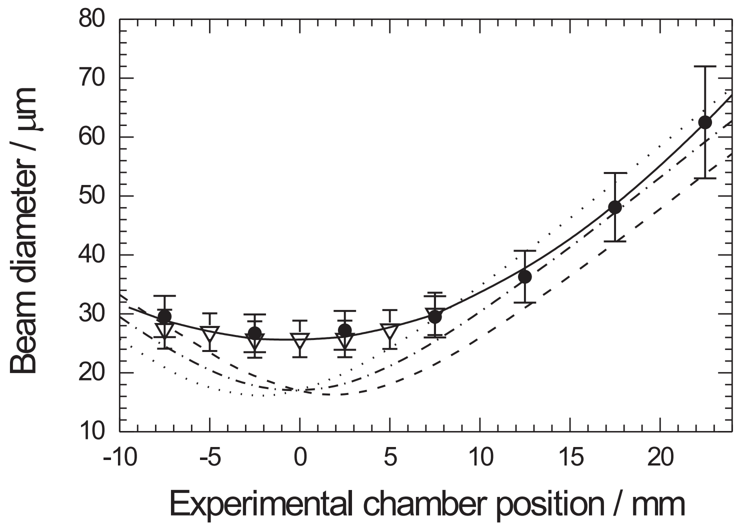

Figure 2: 2σ-value of the photon beam diameter measured at different positions of the experimental chamber along the photon beam around the focus. Data evaluation is based on saturation in the single photoionization of neon a target gas pressure of 8×10^{-4} Pa (●) and 2×10^{-3} Pa (∇). The solid line represents a polynomial fit curve. The non-solid lines display ray-trace simulation for horizontal (dashed line) and vertical direction (dotted line) and the mean of both (dashed-dotted line).

References

[1] M. Richter, A. Gottwald, U. Kroth, A.A. Sorokin, S.V. Bobashev, L.A. Shmaenok, J. Feldhaus, Ch. Gerth, B. Steeg, K. Tiedtke, and R. Treusch, Appl. Phys. Lett. 83, 2970 (2003)

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