Precise Intensity Tagging for Ultrashort High-Power Laser for LUXE

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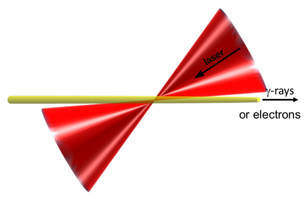
Introduction

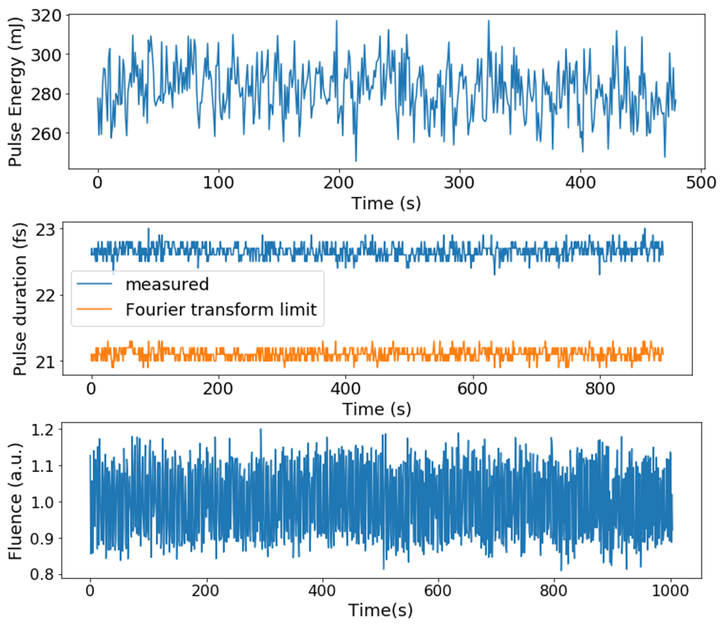
The LUXE (Laser Und XFEL Experiment) project at DESY Hamburg aims to measure processes in the strong-field quantum electrodynamics regime with high precision by colliding electrons or a high-energy photon beam with a high-power, tightly focused laser beam at a repetition rate of 1Hz. Simulations [1] predict that the probability of pair production responds highly non-linearly to the laser strength parameter. Consequently, small variations in the laser intensity lead to significant variations in the experimental observables.



The required precision will be achieved by intensity tagging through precise measurements on the relative variation of intensity on a shot-by-shot basis, with an ultimate aim to monitor the shot-to-shot fluctuations with a precision below 1%. We present the results of a non-linear intensity tagging method, which provides a measure of the laser intensity by comparing the fundamental to a non-linear copy of the laser focal spot from a thin non-linear crystal. This method provides a reference to crosscheck the intensity fluctuations derived from independent measurements of energy, duration, and fluence.

Stability of JETI200 Laser

JETI200 is a Ti:sapphire laser system in Helmholtz Institute Jena, Germany. It can achieve 200 TW peak power and pulse duration down to 17 fs. The on-target energy is over 5 J at the repetition rate of 10 Hz.



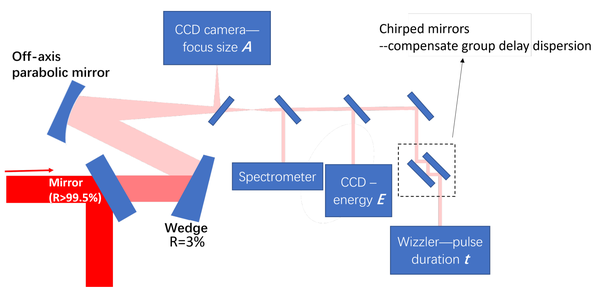
Pulse energy (with Titan 600mJ) with mean value 282 mJ and rms 0.4%

Pulse duration with mean value 22.6 fs and rms 0.4%

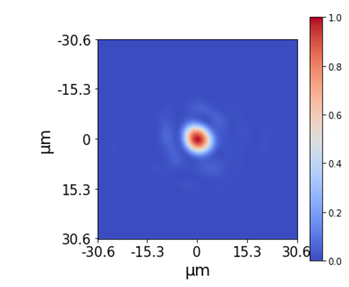
Peak fluence of focus with rms 10%, which dominates the intensity fluctuation, mainly due to air currents disturbance, etc.

Figure: The stability of JETI200 parameters, measured at 1 Hz.

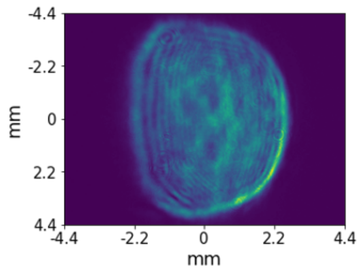
Intensity Diagnostic: Full on-shot beam characterization



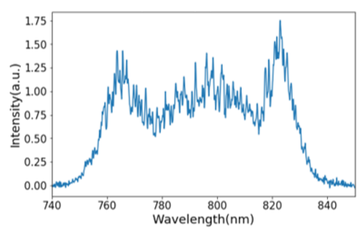
The intensity diagnostic system setup is designed according to the equation of laser pulse intensity I, $I = \frac{E}{tA}$. The leak light through a high-reflection mirror (R>99.5%) is further attenuated by a glass wedge (R=3%). OAP focuses the beam with $f/5$. A beam-splitter separates a portion of the laser and then CCD camera records the focus image. The second CCD takes picture of the near-field and the spectrum is measured simultaneously by a spectrometer, in order to calibrate the energy of different wavelengths. Wizzler is the device that measures pulse duration and spectral phase, before which, a pair of chirped mirrors compensate GDD mainly caused by the thick mirror.



Focus spot near diffraction limit

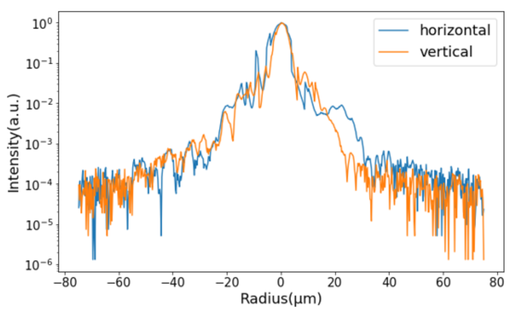


Near field image

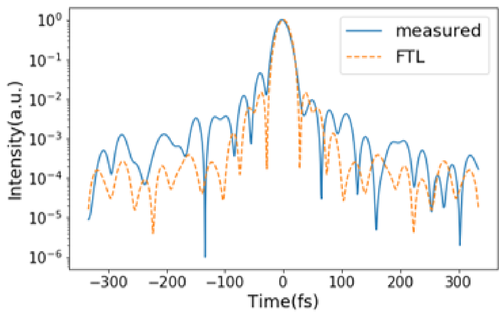


Pulse spectrum taken simultaneously with NF image

The shot noise precision is $\sqrt{C}/C$, where C is the count number. A camera with 16-bit depth can achieve precision 10^{-5}.



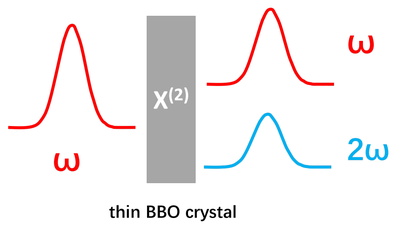
Focus spatial profile. The energy within FWHM takes about 40%. The integrated energy outside the main pulse over a large radius is also significant.



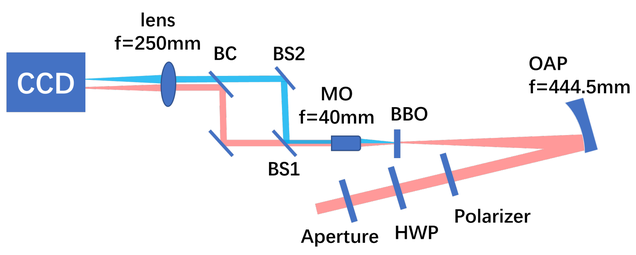
Temporal profile in log scale. Similarly, although the main pulse takes most energy, the integral of energy over a longer time is not negligible.

Non-linear Intensity Tagging

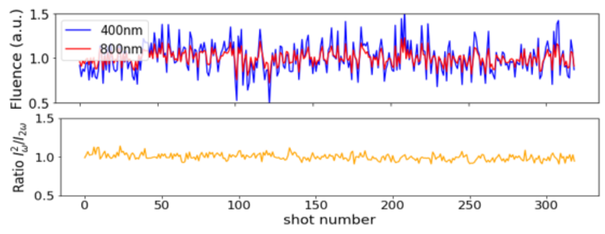
Second harmonic generation (SHG) is a nonlinear process that doubles the frequency of the incident laser. Within a certain range, the intensity of the 2nd harmonic laser beam $I_{2\omega}$ is proportional to the square of the intensity of the fundamental I_ω. The ratio $I_{2\omega}/I_\omega^2$ can be a reference to cross-check the pulse intensity.



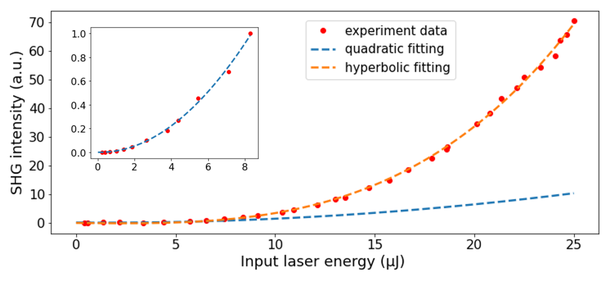
scheme of a thin SHG crystal, which converts the incident fundamental wave with wavelength ω to the second order with 2ω.



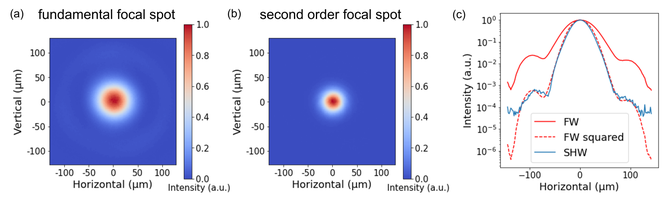
The experiment setup of non-linear intensity tagging. A non-linear copy of focus is produced by the thin BBO crystal at the focal position. The fundamental and the second-order focal spots are imaged to a CCD camera simultaneously and captured in one frame.



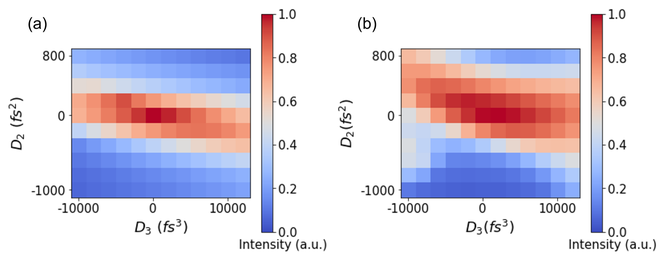
Peak fluence stability with RMS(400nm) = 13.2%, RMS(800nm) = 6.6% and RMS(ratio) = 4%



The response of the second order focus peak fluence to the input laser pulse energy. When the energy is under 8 μJ (equivalent to peak fluence $10^{14} W/cm^2$ in our setup), the ratio is quadratic. It turns into a hyperbolic relationship when the peak fluence exceeds this threshold value.



(a) The focal spot in transverse mode.
(b) The non-linear copy of the focus in (a).
(c) The plot of focus spatial profile in log scale. — is the fluence of the fundamental focus and — the 2ω. --- is the square of — and it perfectly overlaps with —.



(a)Experimental results of second-order beam peak fluence with altered temporal profiles by introducing different chirping values to the spectral phase.
(b)Calculated results of second-order beam peak fluence according to the relation $I_{2\omega} \propto I_\omega^2 \propto 1/\tau^2$. τ, the pulse duration.

Nonlinear intensity tagging works in a limited intensity range, and only for pulses with a well-defined temporal profile.

Conclusion

- LUXE precisely measures processes in the SF-QED regime. To achieve this goal, laser intensity must be diagnosed with precision $< 1\%$.
- Laser focus is not distorted by interaction in LUXE enables precise laser diagnostic after interaction.
- The focus at the interaction point can be directly imaged to the diagnostic system with acceptable aberration.
- The diagnostic system can monitor shot-to-shot intensity with precision $< 1\%$.
- SHG process provides a reference to cross-check laser intensity.

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References

LUXE CDR, arXiv:2102.02032 [hep-ex]

HI JENA Helmholtz Institute Jena

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