Relativistic Laser-Matter-Interaction

Research fields for the HED Instrument at the European XFEL with instrumentation from the HIBEF User-Consortium

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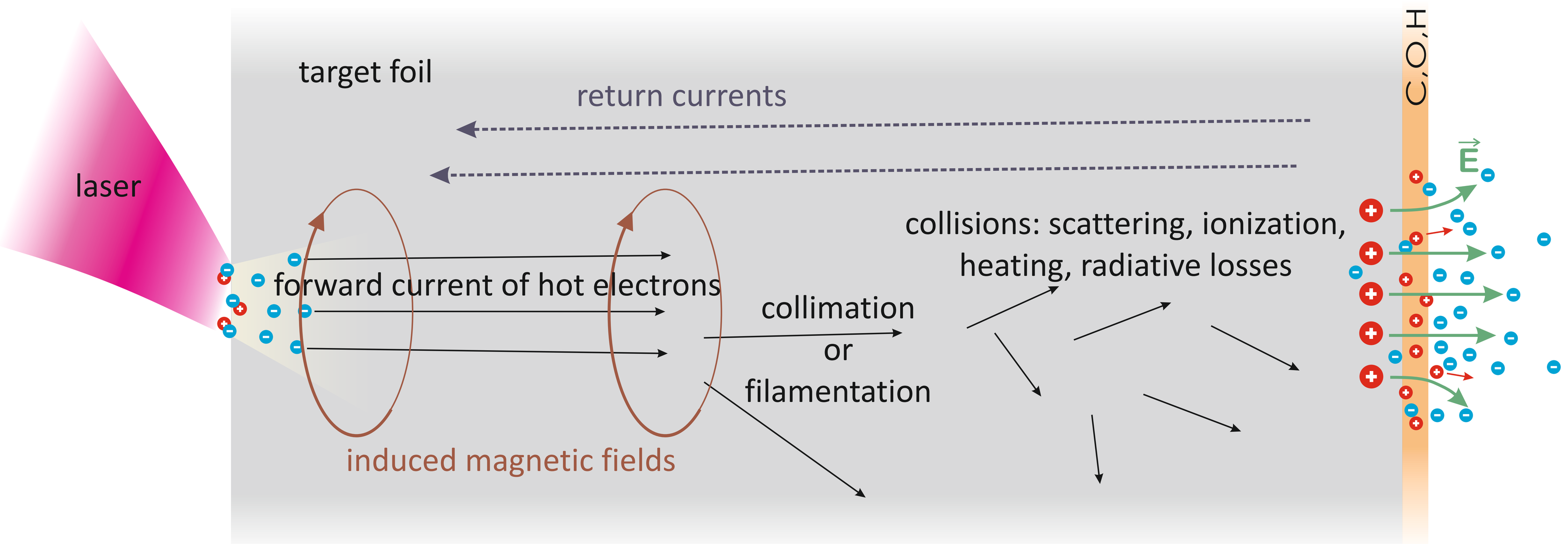
High-Power Laser-Matter-Interaction

Primary effect:
Electron acceleration at target foil front side with a short-pulse multi-TW laser. This generates electrons up to MeV‘s of energy and >>1 kA/µm² currents.



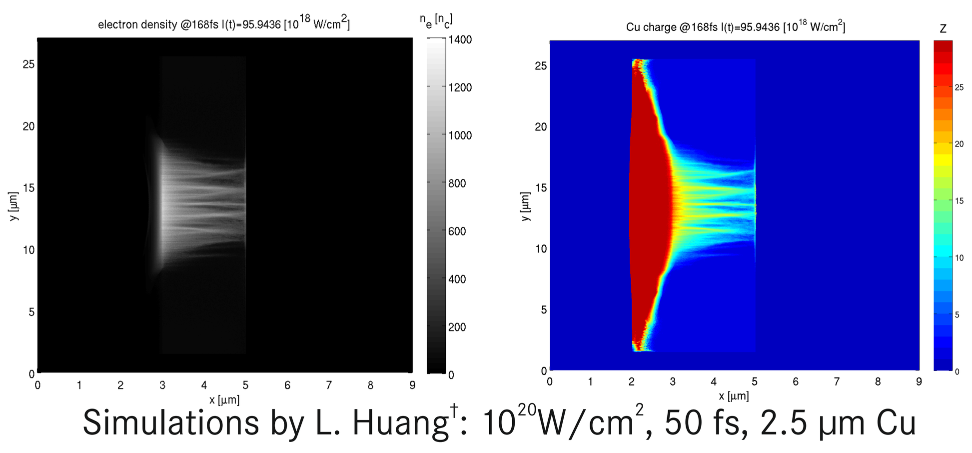
Secondary effects:
- TNSA proton / ion beams
- THz pulse generation
- Kα X-ray source
- Bremsstrahlung up to γ–rays

Side-effects:
- spatial modulation of laser-plasma interface (critical density surface) at target front surface
- harmonics emitted from coherent electron motion, up into XUV domain and down to sub-fs duration

Intermediate processes - electron transport at extreme conditions:
- self-generation of magnetic fields up to kT, collisional ionization and changes of resistivity
- electron beam filamentation or collimation
- target heating to keV at solid density
- diffusion of the magnetic fields, ...

Coherent imaging of ionization dynamics in solid-density plasma

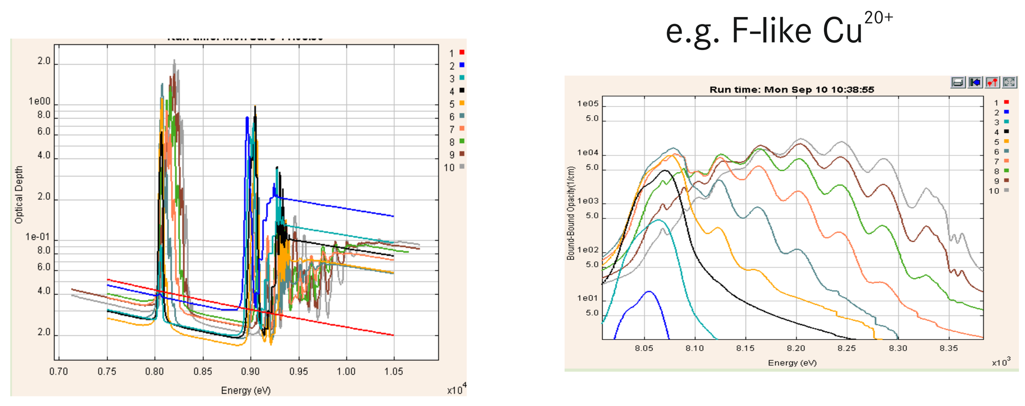
Early-time free electron density is related to local ionization Z*



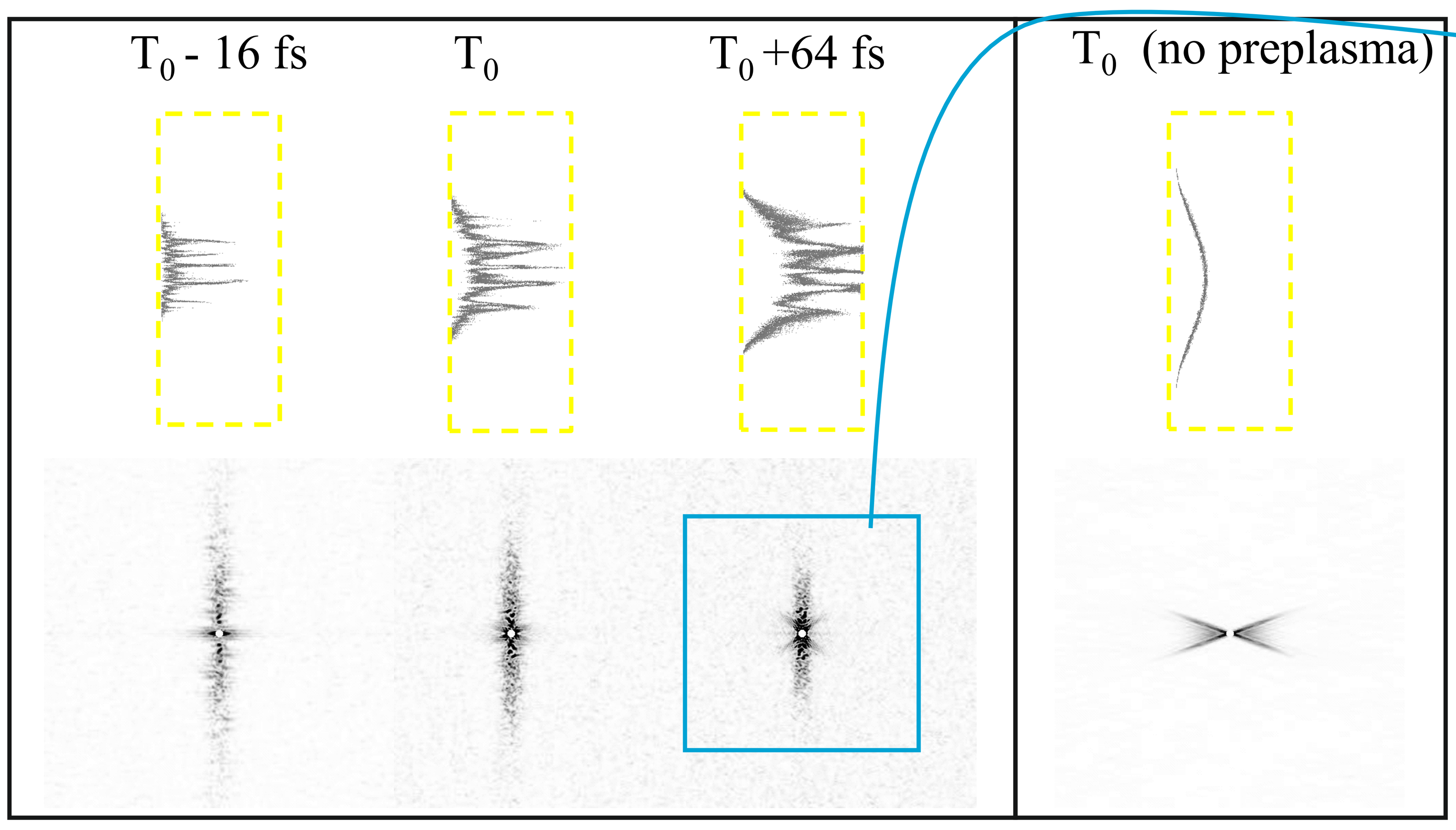
Simulations by L. Huang†: 10^{20} W/cm², 50 fs, 2.5 µm Cu

Specific charge state Z* can be coherently imaged by tuning XFEL to specific line

e.g. F-like Cu^{20+}



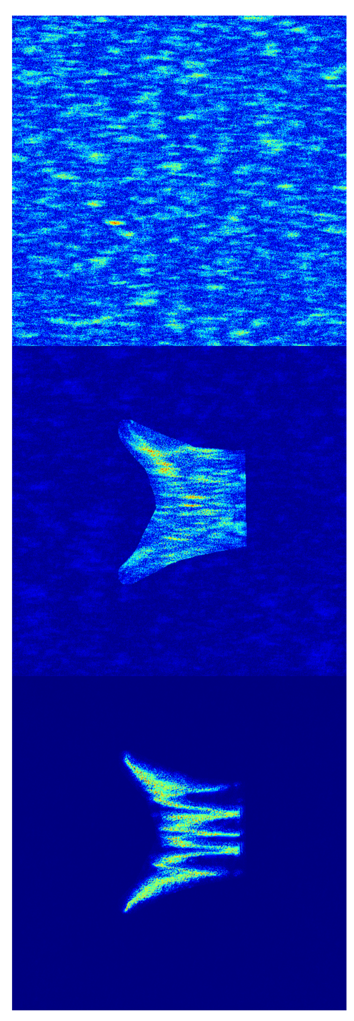
Time-resolved SAXS for charge state Z*



Simulations of scattering signal by Ch. Gutt‡

†: is also with Shanghai Institute of Optics and Fine Mechanics
‡: is with DESY

Reconstruction by iterative phase retrieval



i = 0

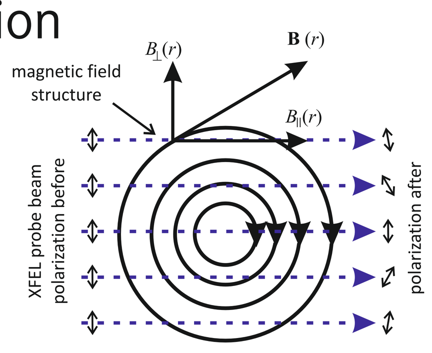
i = 10^1

i = 10^3

Measuring self-generated magnetic fields via Faraday rotation

Faraday effect in plasma
Rotation of plane of polarization

$$\phi_{\mathrm{rot}} = \frac{e_0}{2\,c\,m_e}\int \frac{n_e(\mathbf{r})}{n_c}\,\mathbf{B}(\mathbf{r})\cdot\frac{\mathbf{k}}{|\mathbf{k}|}\,\mathrm{d}s$$

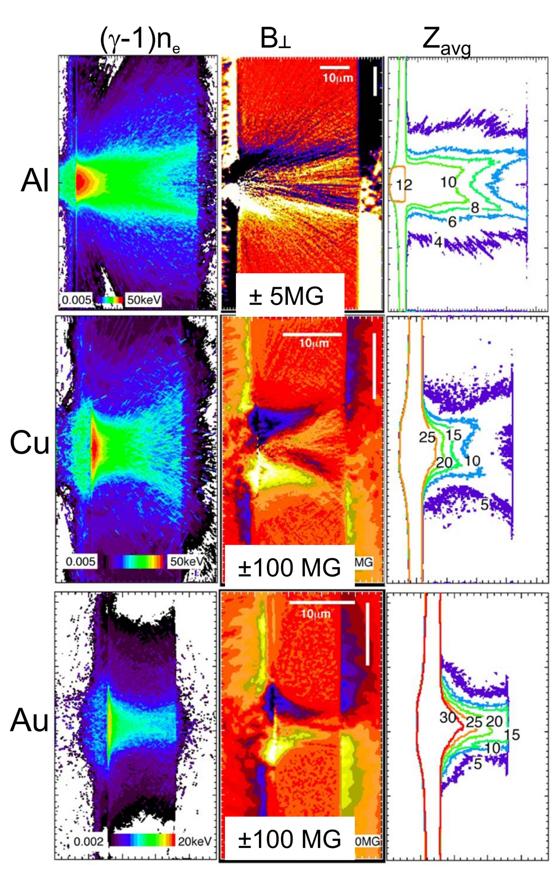


Requirements
- initially linearly polarized collimated beam
- wavelength that can penetrate solid-density plasma
- propagation somehow parallel to B-fields,

→ **XFEL beam is ideal choice**

Shown in underdense laser-plasma interactions
- Kaluza et al. Phys. Rev. Lett. **105** 11 (2010)
- Buck et al. Nat. Phys. **7** 7 (2011)

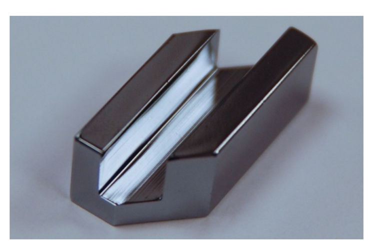
Simulations show magnetic fields up to 10 kT with radial dimensions of about 5 µm.



- magnetic fields up to 10 kT, depending on target material
- interplay with ionization dynamics and thus resistivity gradients can allow for electron beam collimation (Cu, Au)l

Simulations by Sentoku et al.
Phys. Rev. Lett. **107** (2011)

Channel-cut crystals
- X-ray polarizers for 4 – 15 keV
- max. extinction ~10^{-8}
- max. transmission ~ 0.4



[Marx et al. Opt. Comm. **284** (2011)]

Estimates for 4 keV photon energy
- 1 kT / 5 µm radius / Al gives 10^{-4} rad rotation
- 10 kT / 5 µm / Cu gives a few mrad rotation

Observables
- hot electron beam formation can be traced
- beam divergence can be measured
- occurence of beam collimation can be inferred

SIOM