Laser-plasma electron acceleration program

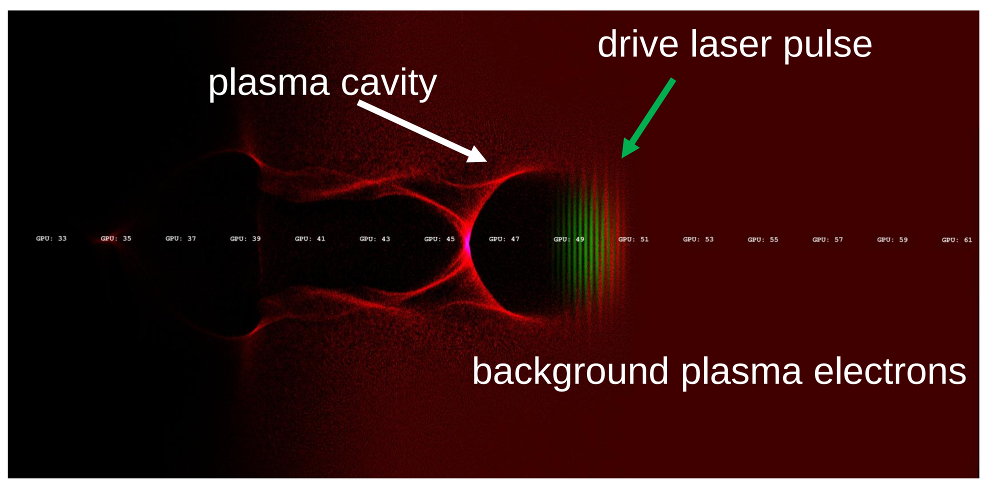
J.P. Couperus, A. Köhler, A. Jochmann, A. Debus, A. Hübl, R. Widera, M. Bussmann, T. Cowan, U. Schramm and A. Irman

Laser Particle Acceleration Division
Institute of Radiation Physics

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Motivation: Compact electron accelerator and X-ray source

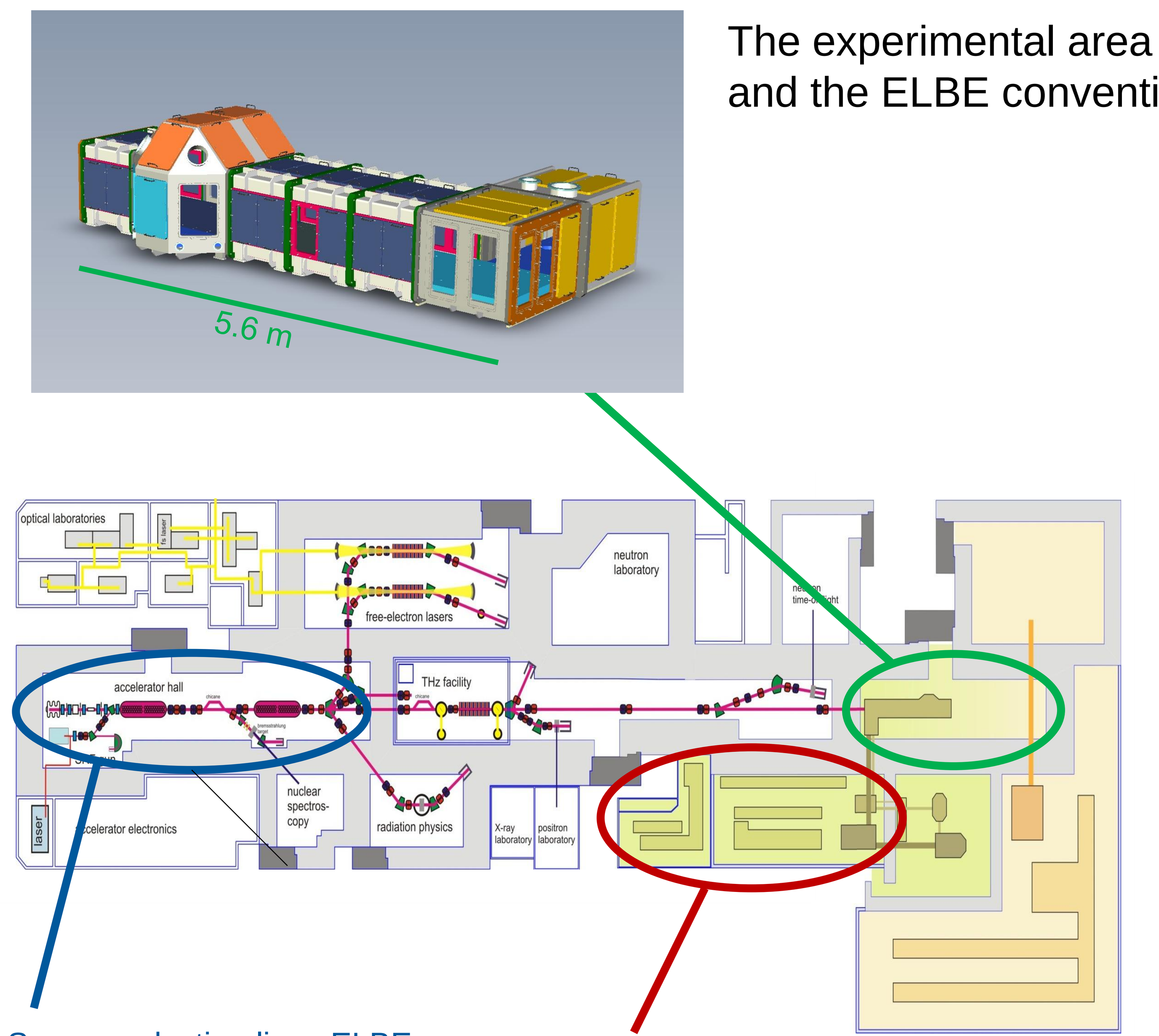
- In laser-plasma electron acceleration a high intensity ultrashort laser pulse drives plasma waves, inducing a high accelerating field gradient (~GV/m) which can accelerate electrons to high energies within a very short distance.
- A stable compact laser-driven electron accelerator can be used as a driver for unique x-ray sources via:
  - electron/laser Thomson scattering
  - betatron radiation
- For applications, e.g., ultra-fast pump-probe X-ray spectroscopy as a preparation stage for XFEL 2015, important issues are tunability, stability and scalability.



PIConGPU simulation (64 NVIDIA Fermi GPUs) of wakefield formation in the bubble regime. One 3D simulation requires only 45 minutes of simulation time.

Facility and experiments

The experimental area has access to the short-pulse high energy DRACO laser system and the ELBE conventional electron accelerator enabling both:



Superconducting linac ELBE

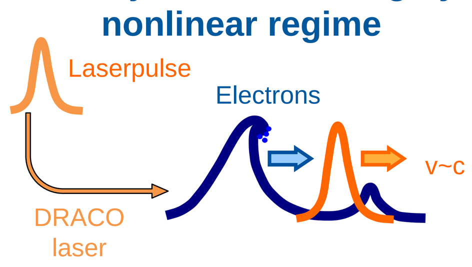
	Thermionic	SRF
pulse frequency	10 Hz	1 Hz
beam energy	24 - 30MeV	
bunch length	4 ps (FWHM)	
bunch charge	1…77 pC	1…77 pC
trans. emittance	15 π mm mrad	5 π mm mrad

150 TW Ti:Sa Laser DRACO

- λ_0 = 800 nm
- 10 Hz repetition rate
- Up to 4J on Target
- 30…500 fs pulse width (FWHM)
- Upgrade to 500 TW in 2013

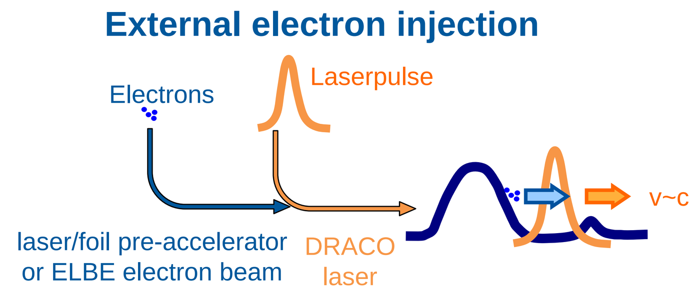
- **Laser wakefield acceleration (LWFA) experiments**
  - Improving tunability, stability and scalability to enable usage as a driver for x-ray sources

Self-injection in the highly nonlinear regime

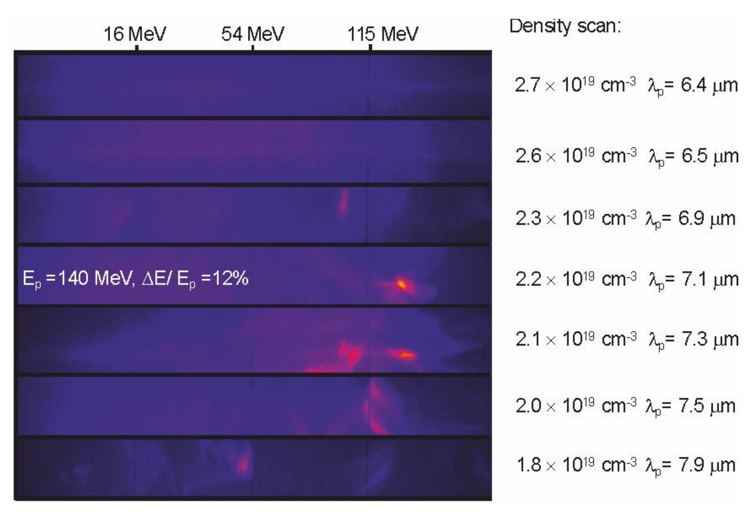


- Background plasma electrons are self-injected via wave-breaking process
- Direct access to the regime with DRACO laser parameters

External electron injection



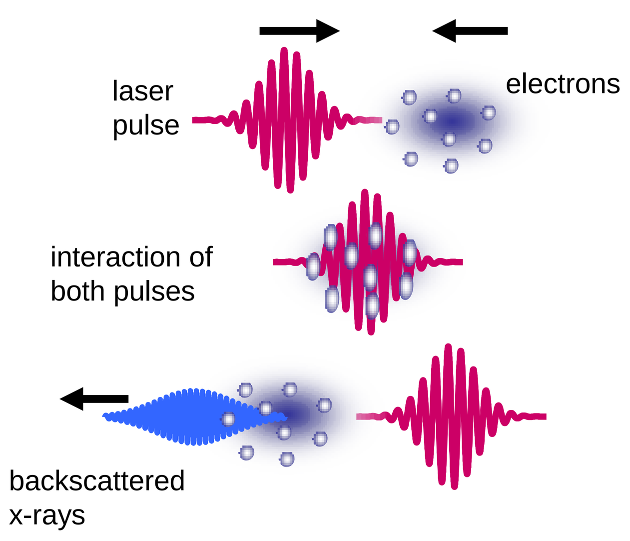
- Operate at the linear regime with lower plasma densities
- Full control over electron production and injection

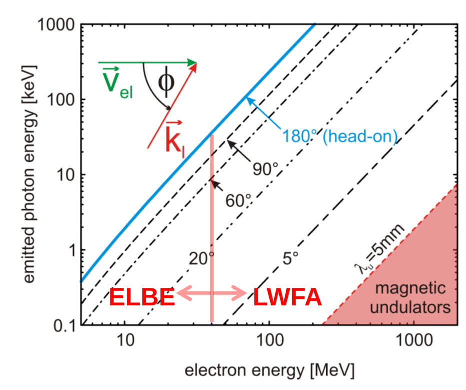


Laser-accelerated electron spectra obtained from a 750 µm axisymmetric nozzle in the highly nonlinear regime

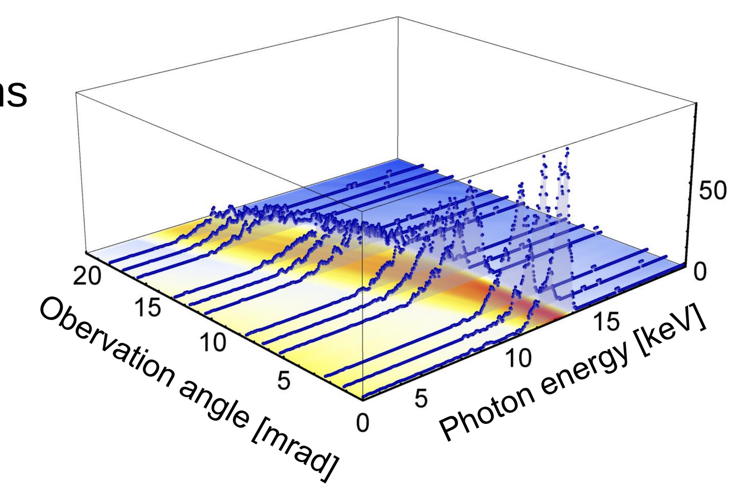
DRACO laser parameters on target:
1.4 J, 30 fs, 9 µm (radius 1/e² of intensity)
deformable mirror optimized,
3.4x10[19] Wcm[-2] (a_0=3.9)

- **Laser-Thomson backscattering experiments**
  - Scattering of DRACO photons on ELBE accelerated electrons
    - Stepping stone experiments towards fully laser driven Thomson backscattering x-ray source





$$\omega_{sc} = \frac{4\gamma^2 \cdot \omega_0}{1 + a_0^2/2 + \gamma^2\theta^2}$$



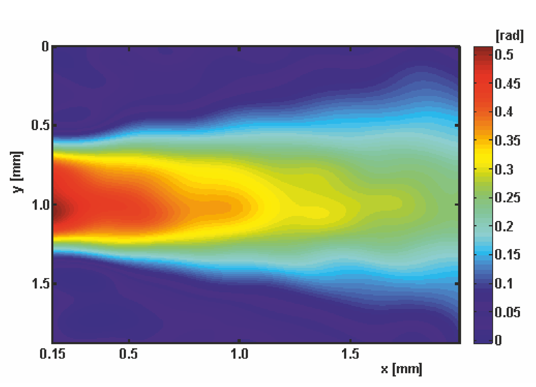
Thomson backscattered x-ray photons
Traces (data)
Base layer (simulation)

DRACO laser parameters on target:
90 mJ, 500 fs, 35 µm (FWHM), a_0=0.05
ELBE parameters on target:
77 pC, 9 π mm/mrad, 170 µm (FWHM)

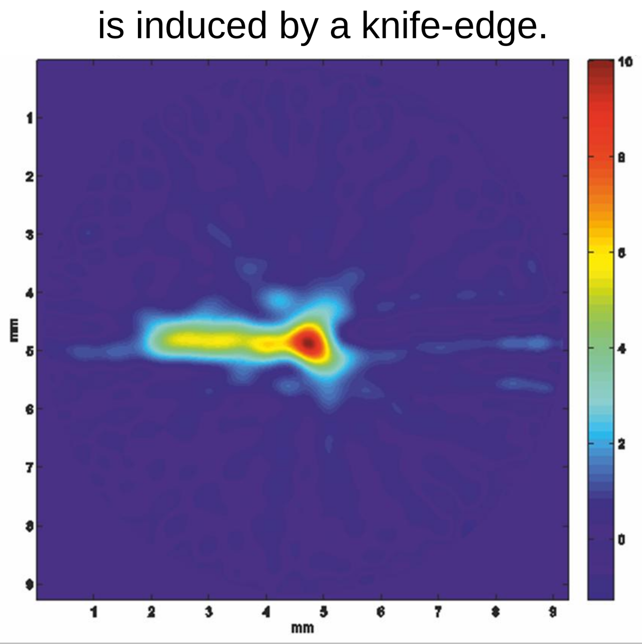
LWFA target development and characterisation

- Exact knowledge of acceleration targets for LWFA is crucial for improving electron bunch stability
- Gas-jet targets are analysed by an interferometric tomography setup, enabling precise control and adjustment of experimental parameters

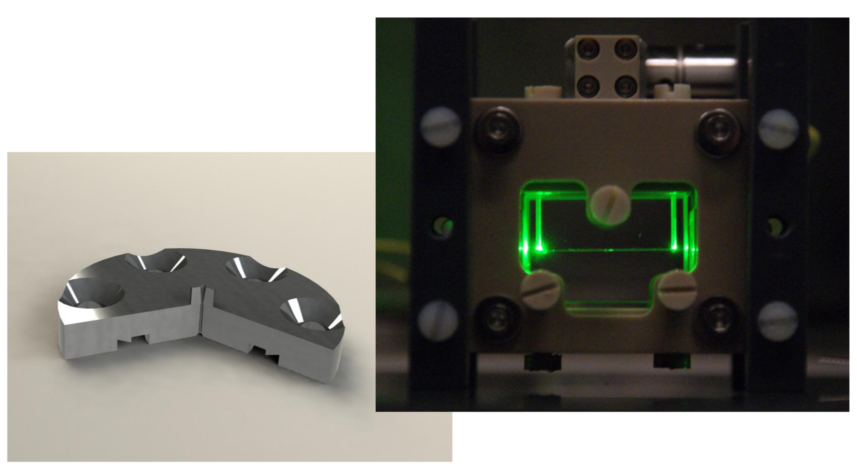
Gas density reconstruction of a 0.75 mm cylindrical de Laval nozzle gas-jet, at 70 bar helium



Gas density reconstruction of a 5 mm slit nozzle. A shock wavefront is induced by a knife-edge.

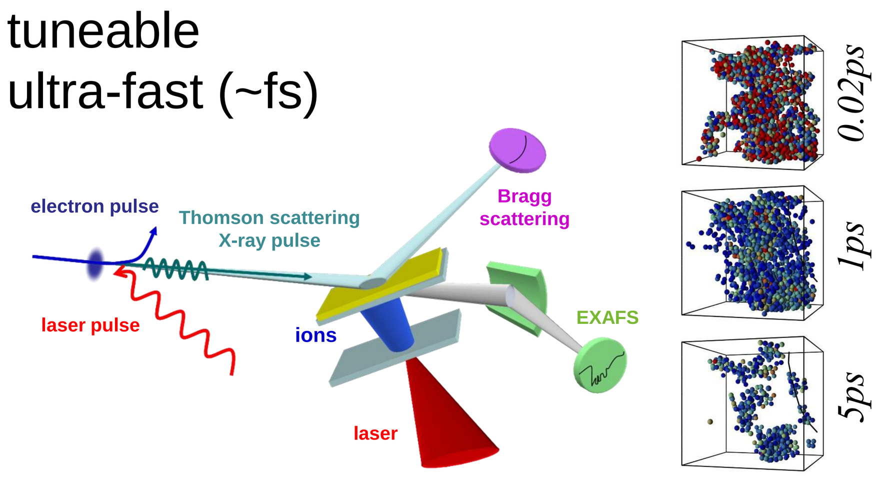


Nozzle target for high-density, short-interaction & electrical discharge capillary target for low-density, long-interaction laser wakefield electron acceleration



Outlook

- Improving tunability, stability and scalability of laser-plasma electron acceleration opens the possibility to a new X-ray source with unique characteristics:
  - finite bandwidth
  - tuneable
  - ultra-fast (~fs)



- Such a source enables new experiments such as ultra-fast pump-probe X-ray spectroscopy

Jurjen Couperus | Institute of Radiation Physics | Laser Particle Acceleration | j.couperus@hzdr.de | www.hzdr.de/fwt

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