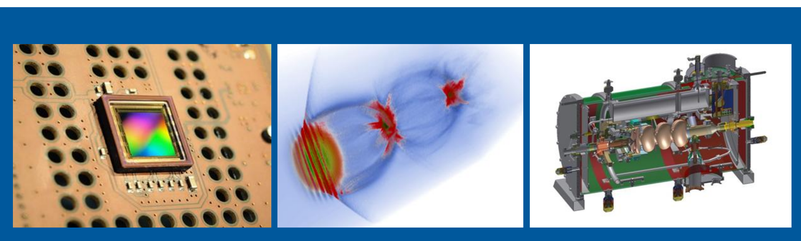
Programme Matter and Technologies

Laser wakefield acceleration and ultrafast diagnostics



ARD-ST4 Novel Acceleration Concepts

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Motivation

- **A compact electron accelerator**
- **Fast 3D multi-scale simulation**
- **Advanced metrology methods**

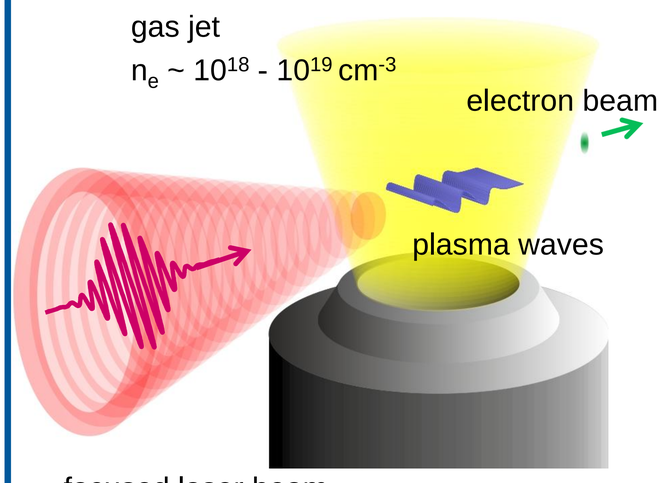
Exploration of extremely high acceleration gradient in plasmas

Investigation of laser-plasma acceleration physics with real-time experiment-simulation feedback

- Studies of injection and acceleration mechanisms for better control on beam parameters
- Characterization of 6D phase-space beam distribution as required for certain applications

LWFA as a compact electron accelerator

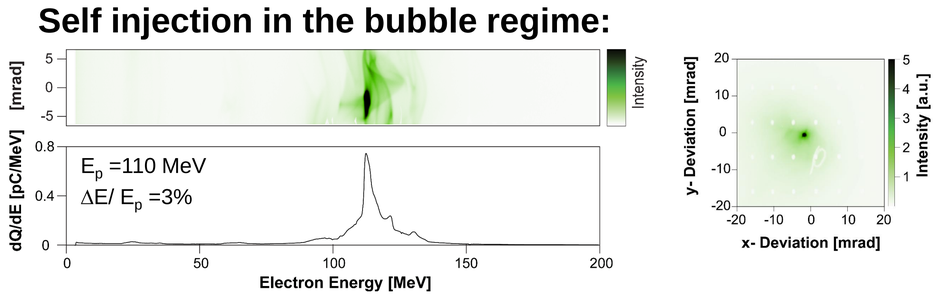
- **High acceleration gradient in plasma (~100 GV/m)**
- **Unique electron bunch properties:** High peak current (~kA), ultra-short duration (< 5 fs), ultra-small size (~1-3 μm), low transverse emittance (< 1π mm-mrad)



focused laser beam

DRACO laser (30 fs, 1.4 J pulse)
JETi laser (30 fs, 0.8J pulse)
I_p~ 10^{19} W/cm^2

Self injection in the bubble regime:



Challenges

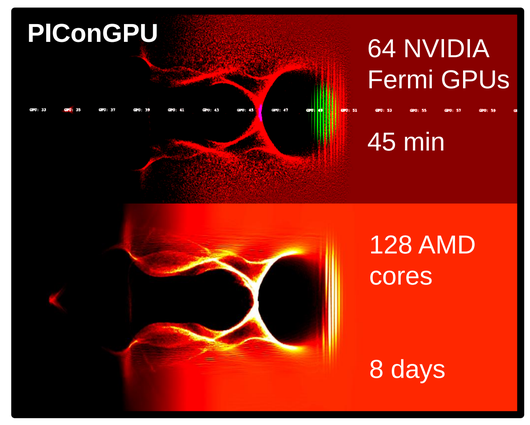
- To understand electron injection and acceleration mechanisms which influence beam parameters.
- To characterize the plasma accelerating structure and generated bunch which are a few μm in size.

Simulations

Ultrafast diagnostic techniques

PIC code on GPUs

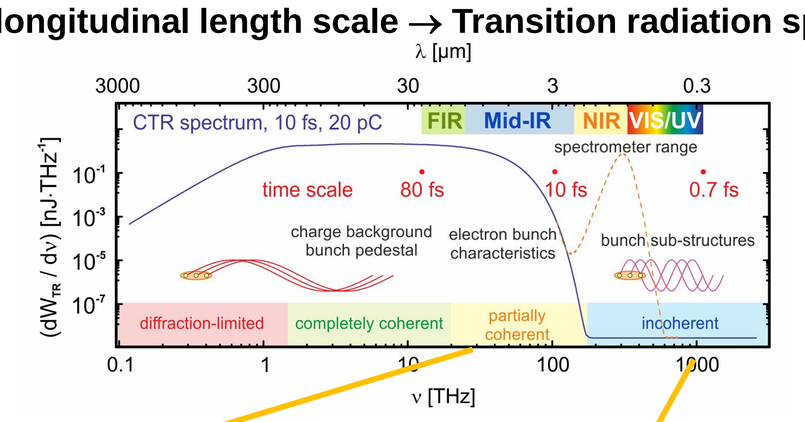
- Relativistic 3D3V code
- Highly scalable (7 Pflops @TITAN, Oak Ridge)
- 3D live visualization
- Open source
- Calculates far-field radiation from all electrons in plasma (full spectrum including coherent properties)



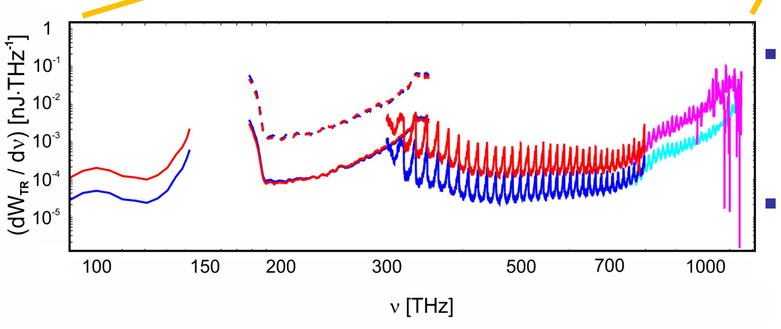
480x480x3070 Cells, 2.8 x 10^9 macro particles, 30000 time steps

Coherent THz spectroscopy for single-shot femtosecond bunch duration diagnostic

- **PIC simulations → sub 10 fs electron bunch with fine structures**
- **Bunch longitudinal length scale → Transition radiation spectral coherence**



Detection threshold curve of an optical spectrometer @ HZDR



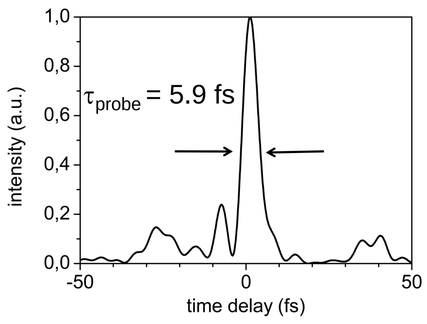
- Q ≥ 20 pC, incoherent-partially coherent spectral range
- E_{bunch} ≥ 100 MeV, minimize spatial coherent

Features:

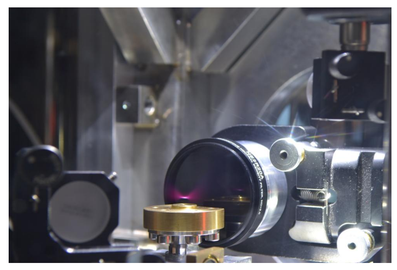
- Single-shot capability
- Sub-femtosecond resolution
- Covers from UV (200 nm) to FIR (12 μm) (upgrade to 24 μm for detection of multiple injections)

Ultra-short probing of plasma wakefields: laser-electron accelerators under the microscope

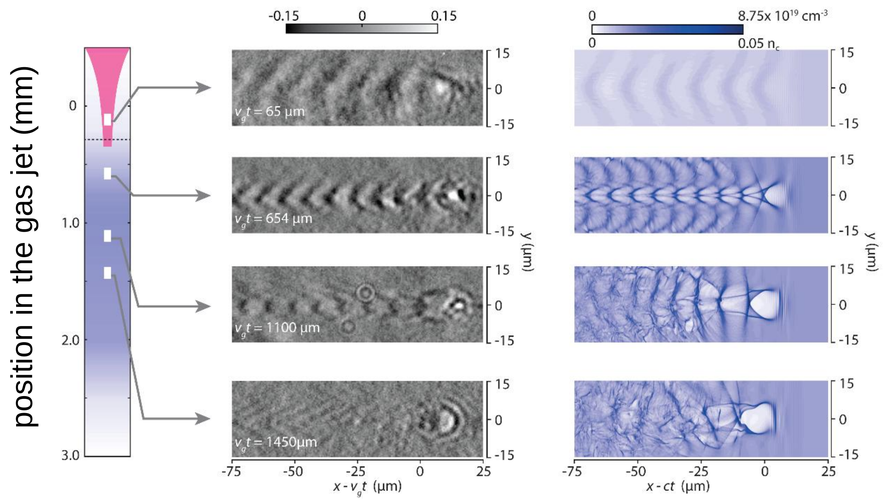
Probing plasma waves → sub-10 fs laser pulse combined with a few μm spatial imaging resolution



- Synchronized, few-cycle probe pulse at JETI-system @ HI-Jena
- Optical imaging system with ~1 μm resolution



- Interferometry, shadowgraphy, polarimetry for in situ characterization of the acceleration
- Enable quantitative comparison to PIC simulations



Snap-shots of the plasma waves — PIC simulations

Summary

- Single-shot broadband IR spectrometers: resolve fs sub-structrure on LWFA electron bunches, applicable to RF accelerator beams, compact (1 m x 0.6 m footprint), transportable to other Helmholtz labs
- Probing plasma waves technique: detailed insight into acceleration dynamics in plasma, suitable for laser- and beam-driven plasma accelerators, easy to copy at other Helmholtz labs
- Ultrafast diagnostics: in connection to ARD-ST3

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