Investigating the stability of a GeV-class laser wakefield accelerator using few-cycle shadowgraphy and polarimetry

Alexander Sävert

Helmholtz-Institute Jena

Institute of Optics and Quantum Electronics, FSU Jena

EAAC, 16th September 2019

Acknowledgement

seit 1558

HI Jena
Helmholtz-Institut Jena

Maria Reuter, Maria Leier, Malte C. Kaluza

Imperial College London

Kristjan Poder, Jason M. Cole, Stuart P.D. Mangles, Zulfikar Najmudin

mpipks

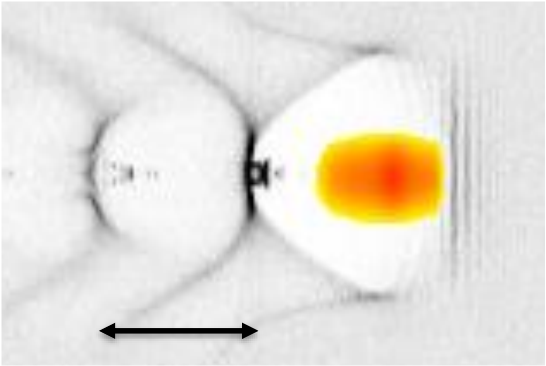
Evangelos Siminos

université de BORDEAUX

Stefan Skupin

Fundamentals of Few Cycle Microscopy

Spatial resolution

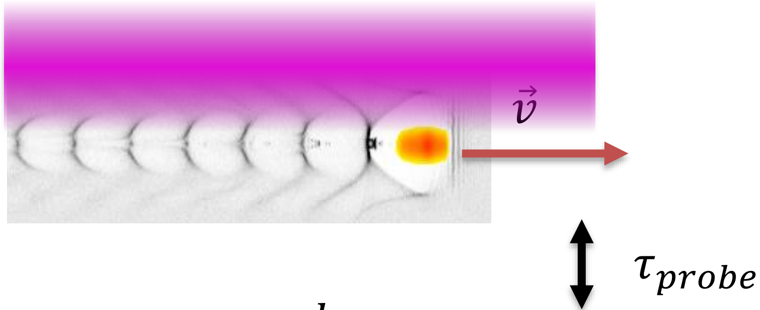


$d \approx 10\ \mu m\ @\ n_e = 10^{19} cm^{-3}$

$$d = \frac{\lambda_{probe}}{n \sin \alpha}$$

Microscope

Temporal resolution



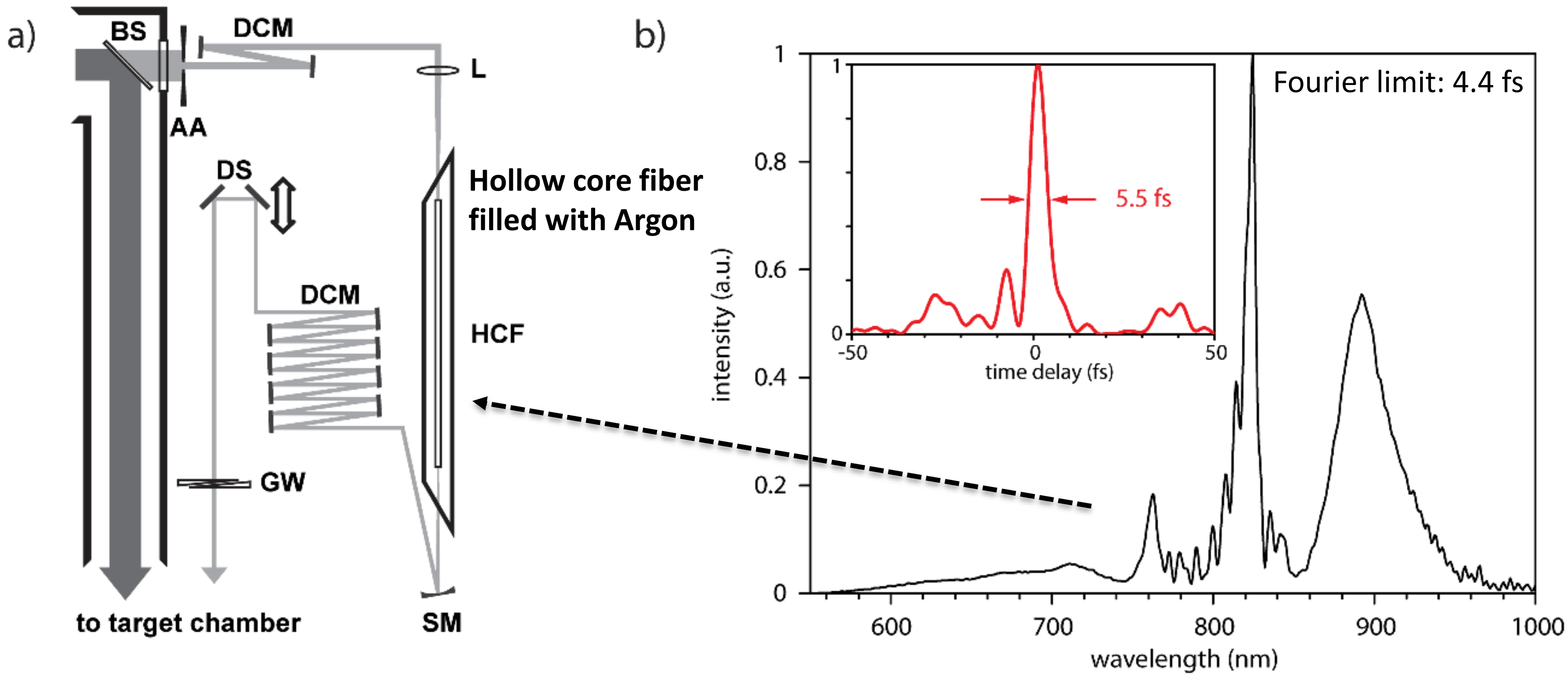
$$\tau_{probe} < \frac{d/_4}{\vec{v}}$$

$$\tau_{probe} < \frac{2.5\ \mu m}{c} \approx 9\ \text{fs}$$

(Single)Few-Cycle Probe pulses

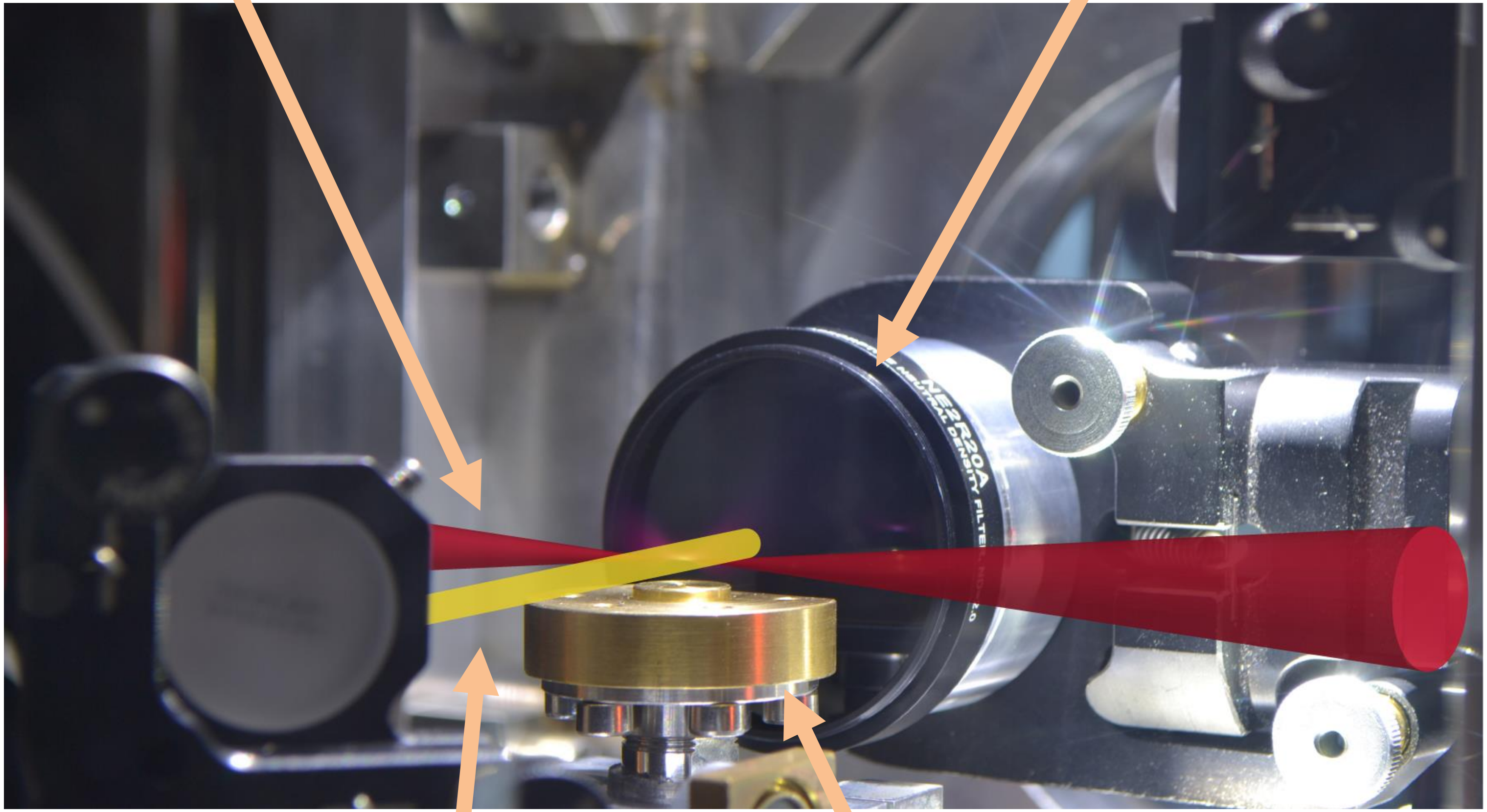
HI JENA
Helmholtz Institute Jena

Few Cycle Probe Beamline @JETi40 & JETi200



M.B. Schwab, A.Sävert., *et al.*, Appl. Phys. Lett. **103**, 191118 (2013)

Few Cycle Microscopy @JETi40

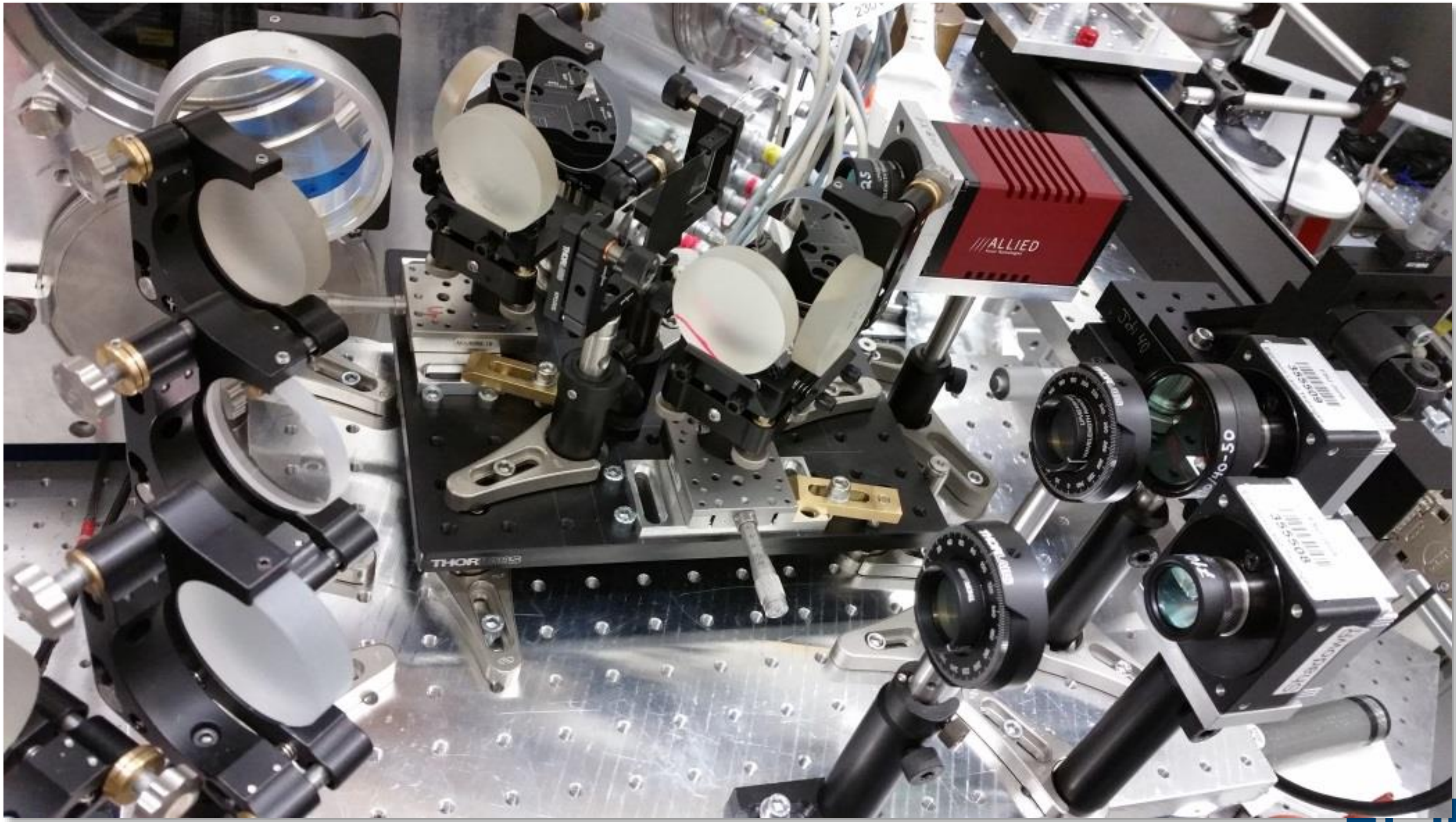


M.B. Schwab *et al.*, APL **103**, 191118 (2013)
A. Sävert et al. PRL **115**, 055002 (2015)

HI JENA
Helmholtz Institute Jena

Diagnostics

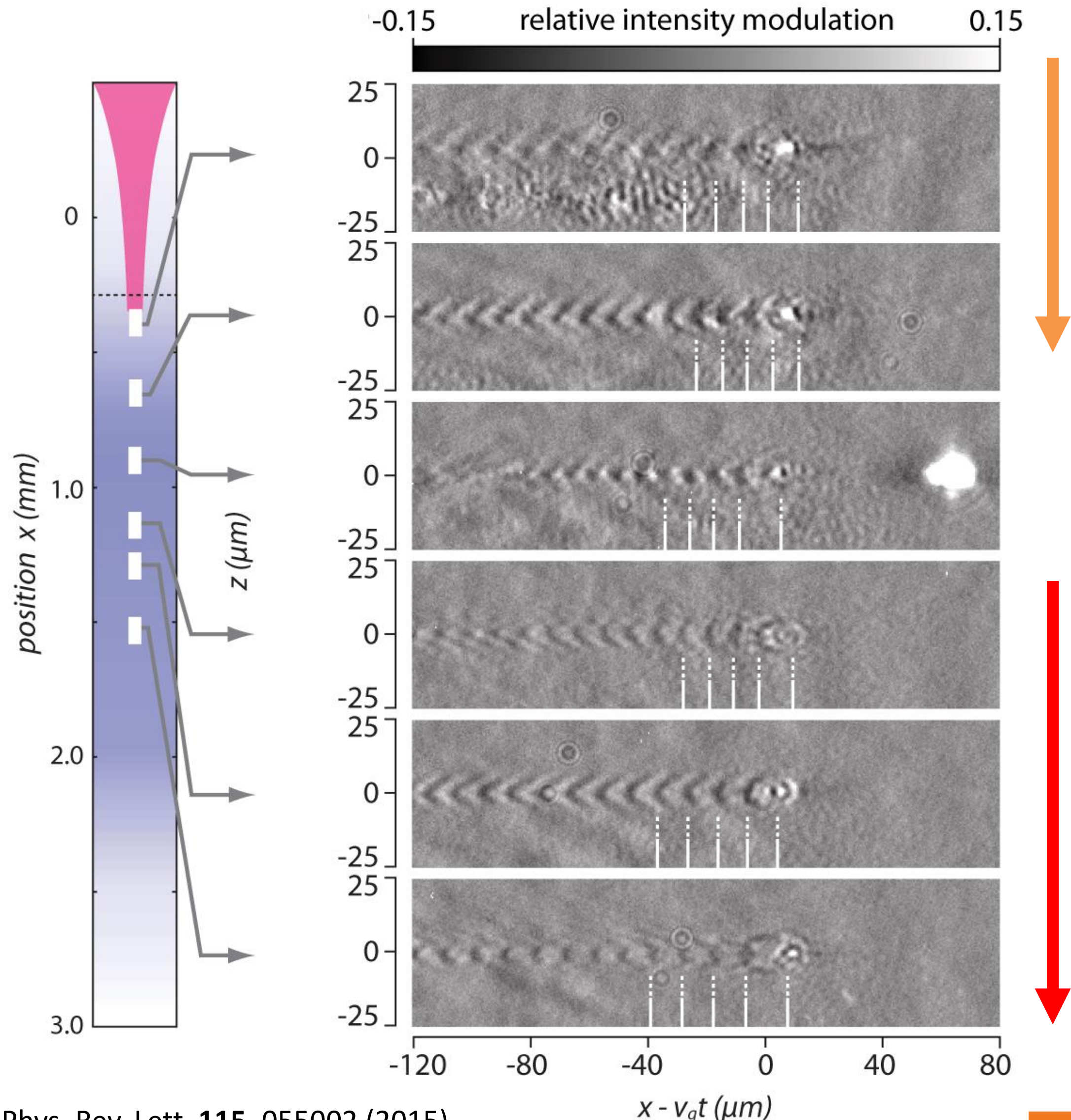
Detailed measurement as input for simulation



Interferometer & 2-channel system
(Shadowgraphy, polarimetry, temporal filtering)

HI JENA
Helmholtz Institute Jena

Shadowgraphy Plasma wave evolution



transverse focussing

(self) injection

acceleration

A. Sävert *et al.* Phys. Rev. Lett. **115**, 055002 (2015)

HI JENA
Helmholtz Institute Jena

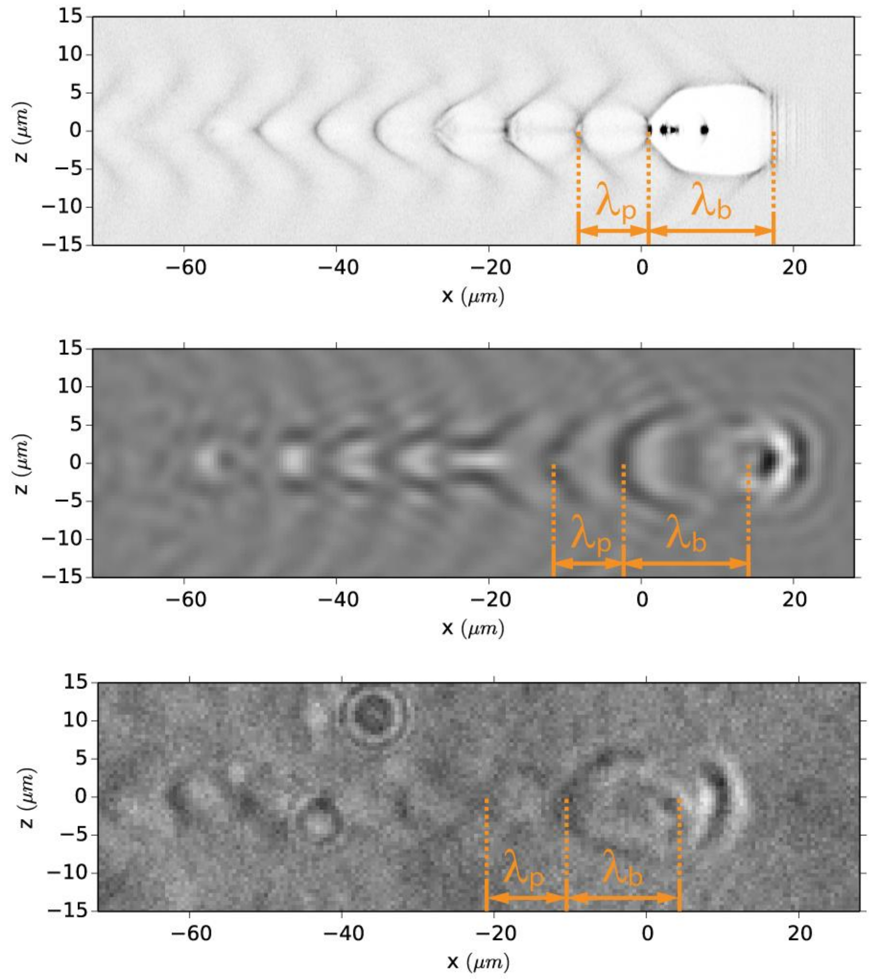
Synthetic Diagnostics

Snap shot of the 3D simulation after 1.2 mm propagation

electron density

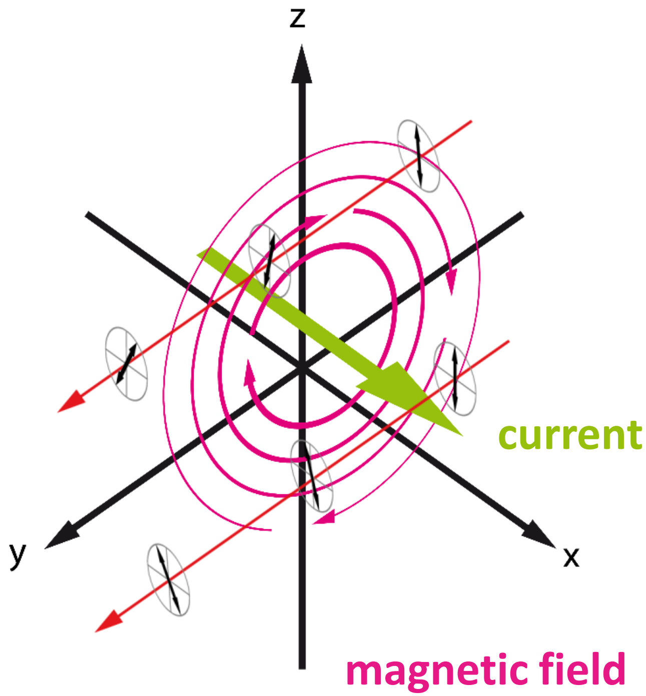
computed shadowgram

experiment

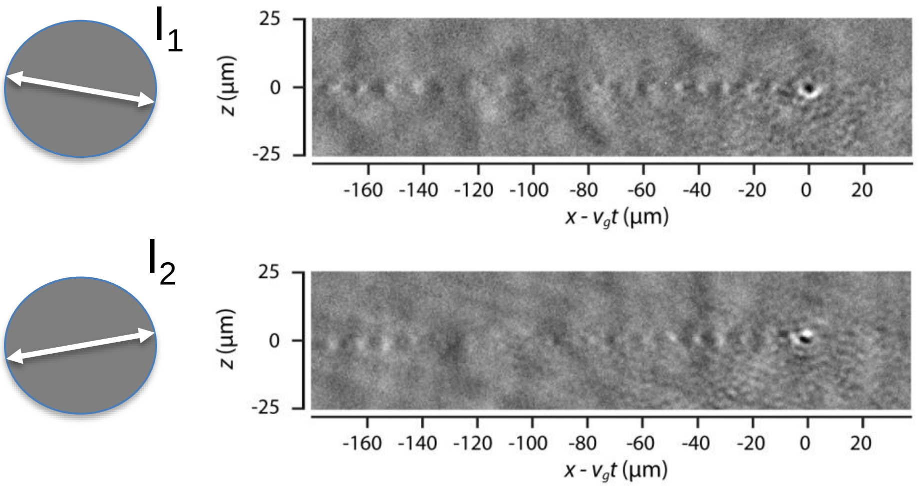


E. Siminos *et al.* PPCF. 58 065004 (2016)

Characterizing magnetic fields - Faraday effect

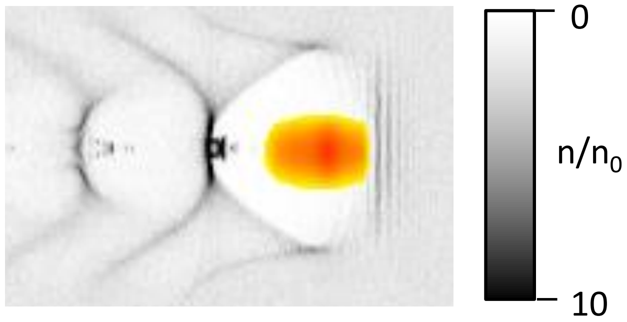


Split the beam and rotate polarizers in opposite direction.



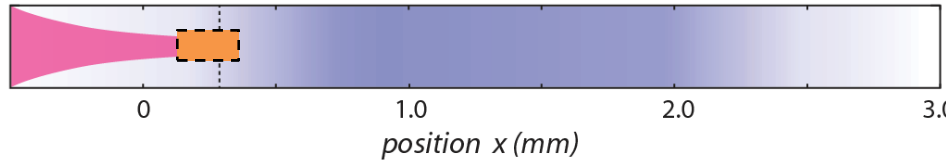
Azimuthal magnetic fields
of the electron bunch and bubble
rotate the probe beam´s polarization.

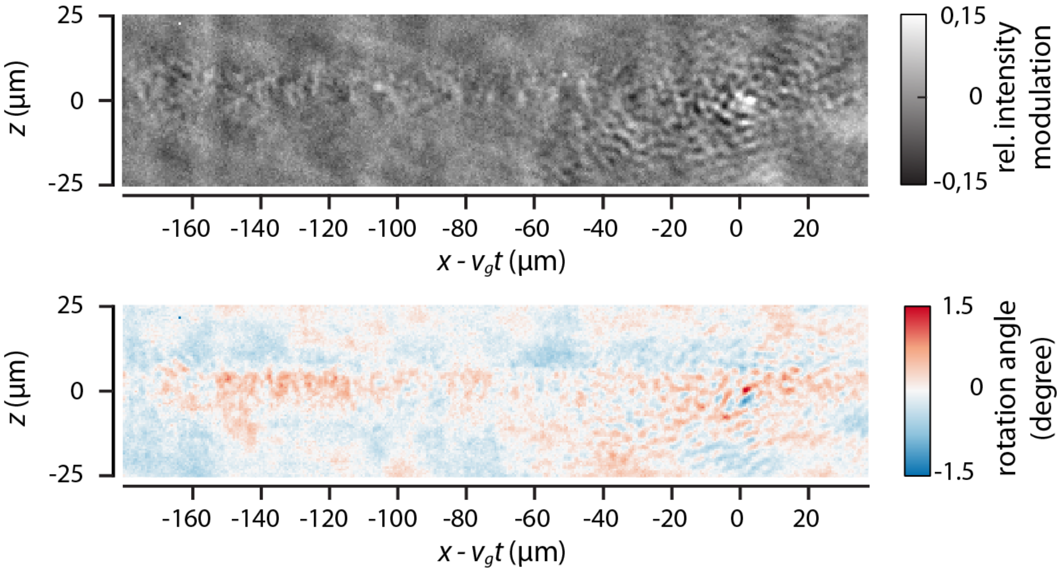
$$\varphi_{rot} = \frac{\mathrm{e}}{2\mathrm{m_e c}} \int \frac{n_e(\vec{r})}{n_{cr}} \vec{B}(\vec{r}) \cdot \frac{\vec{k}_{probe}}{k_{probe}} ds$$

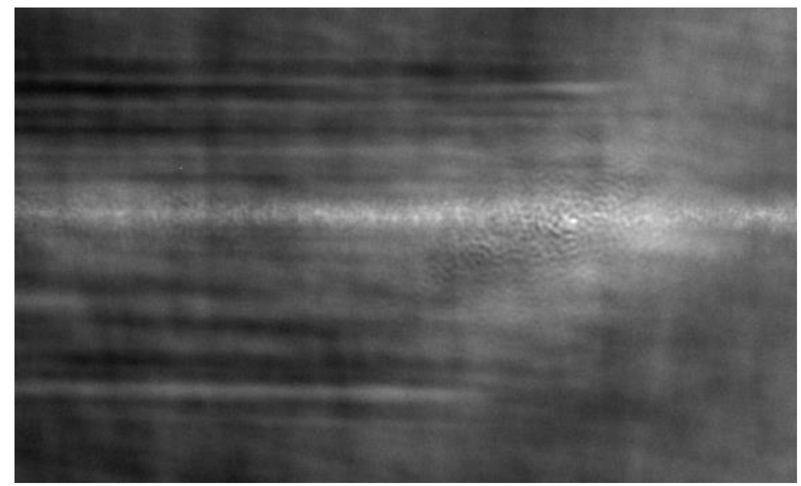


Few Cycle Microscopy: Polarimetry - temporal evolution

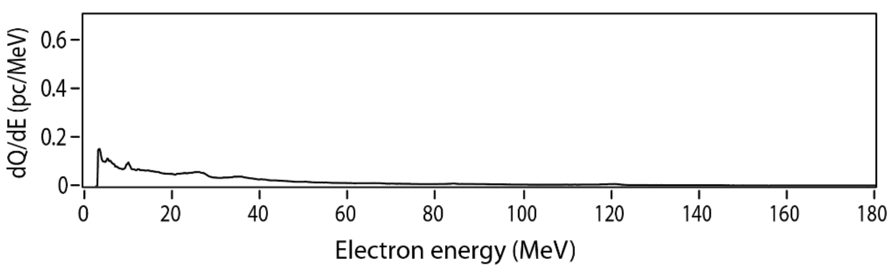
JETi40: F/10 focusing, a_0=1.7
$n_e = 1.3\text{x}10^{19}$ cm^{-3}





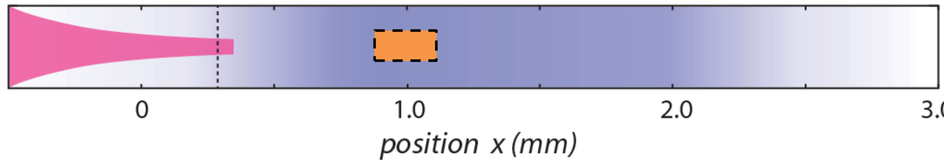


Cross Phase Modulation between pump and probe increases the noise.

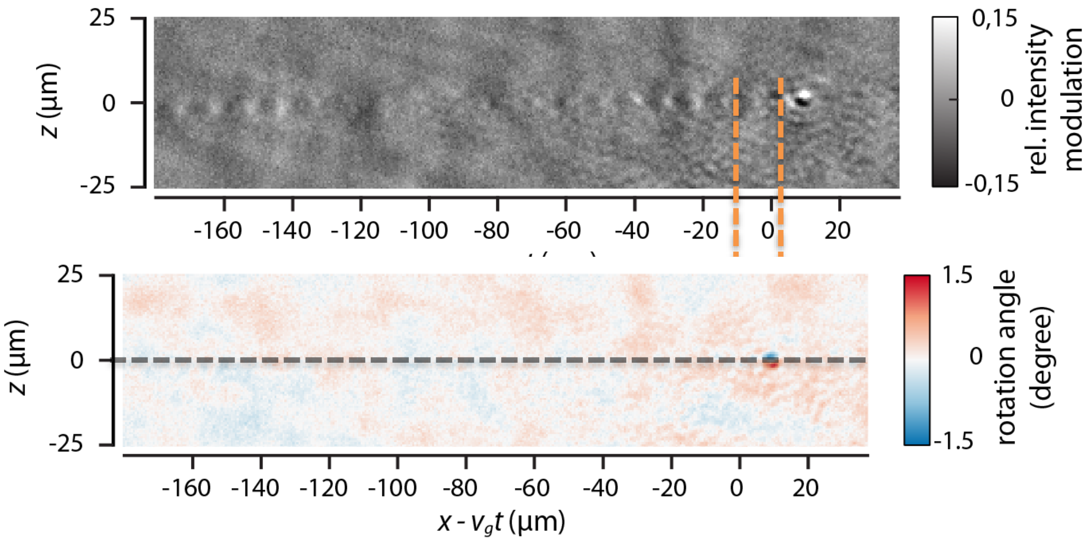


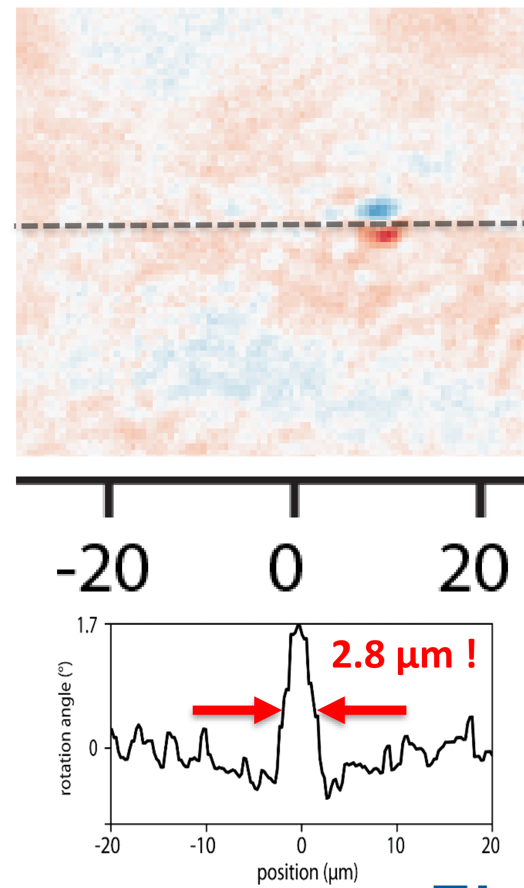
HI JENA
Helmholtz Institute Jena

Few Cycle Microscopy: Polarimetry - temporal evolution



first plasma period (bubble)



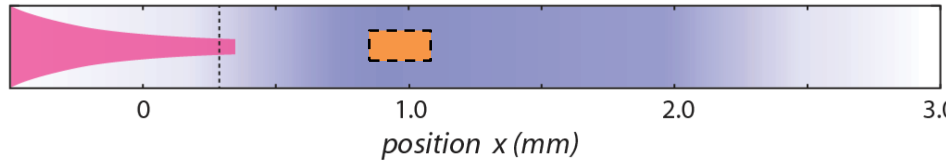


Measurement of femto-scale magnetic fields

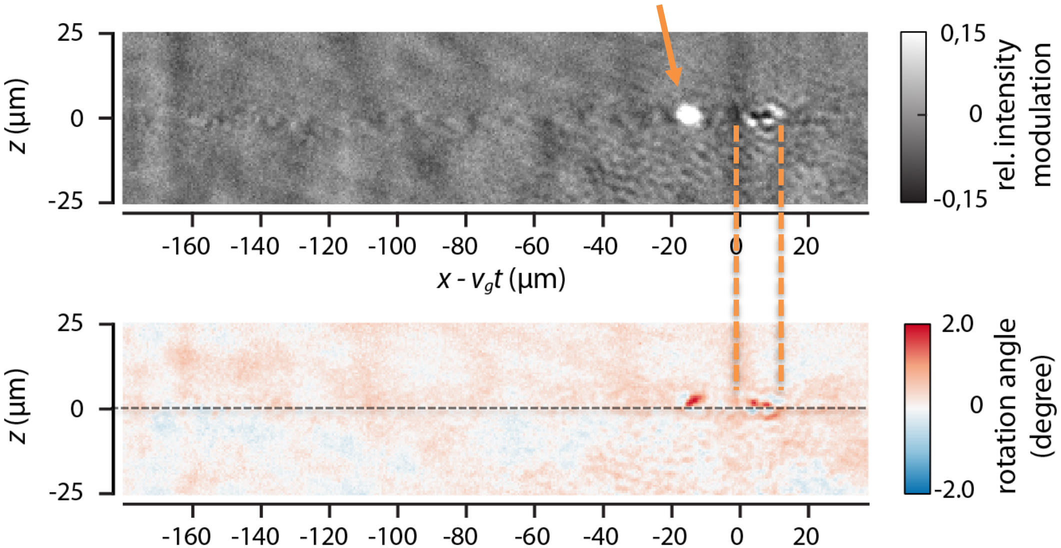
$\tau_{rot} \approx 9.5\ \mathrm{fs}$

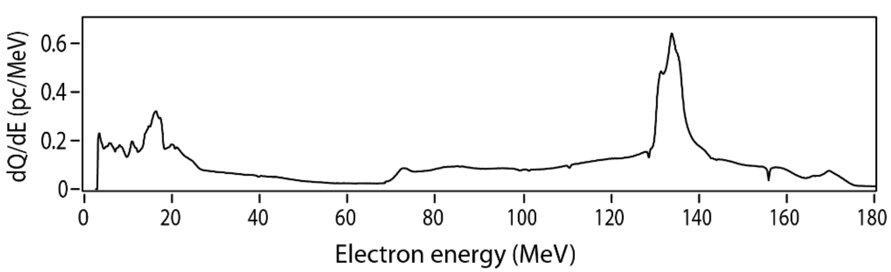
HI JENA
Helmholtz Institute Jena

FC Polarimetry: Temporal evolution

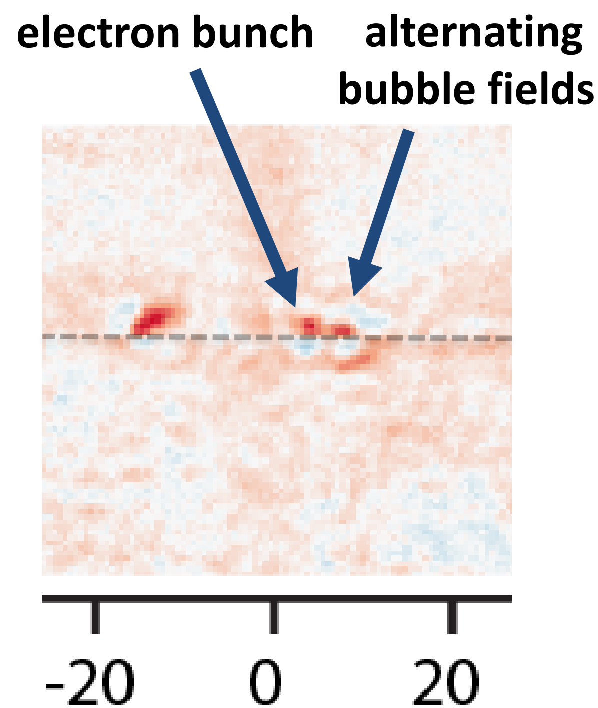


wavebreaking radiation – point of injection





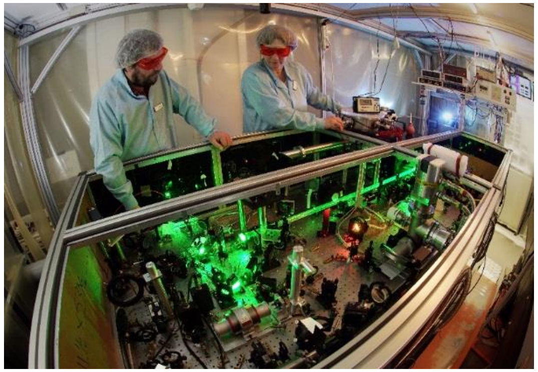
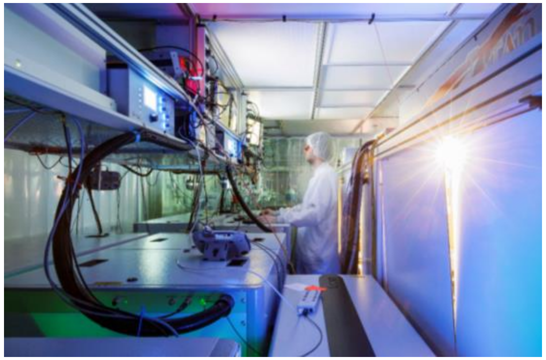
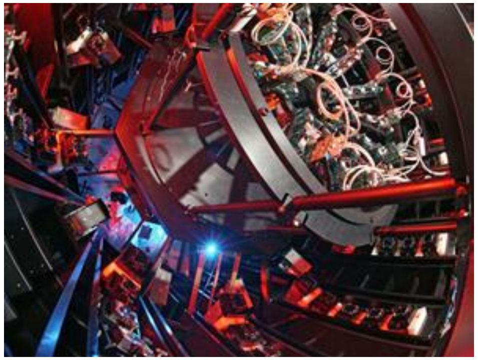
14 pC



Lu scaling: depletion ca. 1.4 mm, we see injection @ 1 mm, dephasing from there ca. 0,4 mm -> 120 MeV expected.

HI JENA
Helmholtz Institute Jena

Outlook

JETi40	JETi200	Polaris
		

JETi40

Wavelength:	800 nm
Energy on target:	0.8 J
Pulse duration:	27 fs
Peak power:	30 TW
Repetition rate:	10 Hz

Emax ≤ 200 MeV

JETi200

Wavelength:	800 nm
Energy on target:	5 J
Pulse duration:	17 fs
Peak power:	300 TW
Repetition rate:	5 Hz

Emax > 950 MeV

Polaris

Wavelength:	1030 nm
Energy on target:	17 J (54 J)
Pulse duration:	100 fs
Peak power:	170 TW
Repetition rate:	1/50 Hz

Emax ~ 190 MeV

Conclusion

- Few Cycle Microscopy recording Shadowgrams and Polarograms gives a deep insight into plasma wakefield acceleration
- Tracking the position of electron bunches in the plasma and the evolution of the plasma wakefield
- Completely non-invasive, real time diagnostic which opens the path to feedback loops (including plasma parameters)
- Everything scales: Lower plasma densitiy requires SWIR/MIR/THz few cycle probe pulses, which are available.