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Friedrich Schiller University

Friedrich-Schiller-Universität Jena

Proposal for the Installation of a Few-Cycle Probe Pulse Unit at Apollon

Malte C. Kaluza
Institute of Optics and Quantum Electronics, FSU Jena, Germany
Helmholtz-Institute Jena

Thanks to all collaborators

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Friedrich-Schiller-Universität
HELMHOLTZ GEMEINSCHAFT
Helmholtz-Institut Jena

A. Sävert, M.B. Schwab, M. Leier, M. Reuter, M. Schnell, A. Kawshik, D. Ullmann, O. Jäckel, F. Ronneberger, B. Beleites, C. Spielmann, G.G. Paulus, M. Zepf
Institute of Optics and Quantum Electronics, Friedrich-Schiller-University Jena, Helmholtz-Institute Jena

MPQ

A. Buck, K. Schmid, C.M.S. Sears, J.M. Mikhailowa, F. Krausz, L. Veisz
Max-Planck-Institute of Quantum Optics, Garching

Imperial College London

S.P.D. Mangles, K. Poder, J. Cole, Z. Najmudin
Imperial College London, UK

mpipks

E. Siminos, S. Skupin
Max-Planck-Institute of the Physics of Complex Systems, Dresden

Benefits and requirements for probe pulses for high-intensity experiments at Apollon

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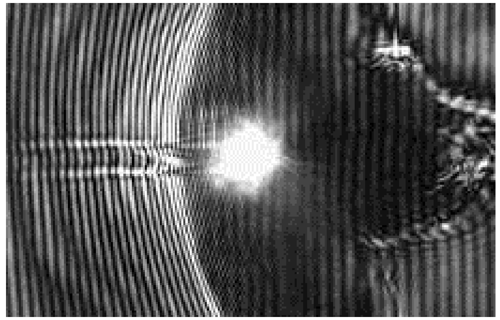
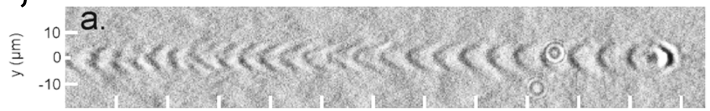
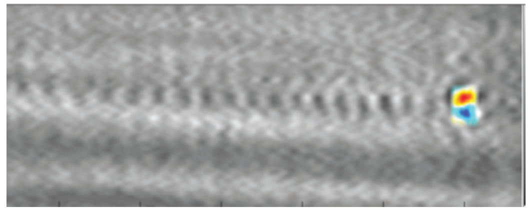
Synchronized electro-magnetic probe pulses for laser-plasma interactions:



- ⇒ study interaction @ high spatial&temporal resolution
- ⇒ monitor e^-- and ion-acceleration on-line: plasma wave, sheath field, target deformation,...
- ⇒ visualize instabilities (incl. evolution?)

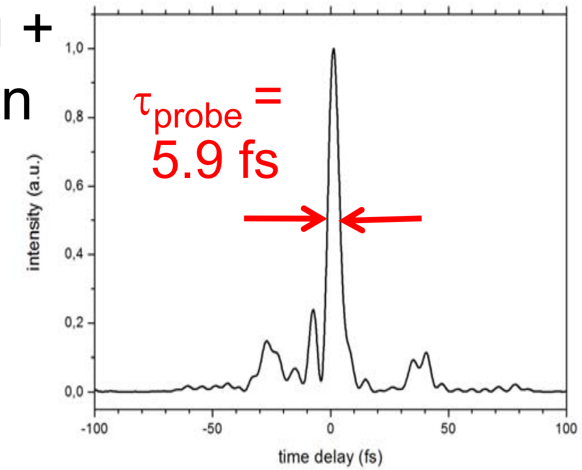


- ⇒ determine internal structure of e^--bunches, control their position in the plasma via Faraday effect



Provide synchronized probe pulses for each target area

- shorten to few-cycle duration (spectral broadening + pulse compression) ⇒ increase temporal resolution
- shift λ_{probe} to mid-IR (2…10 µm) ⇒ optimize probe's sensitivity at low n_e
- shift λ_{probe} away from main pulse's harmonics ⇒ suppression of plasma emission



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Generation of synchronized few-cycle probe pulses

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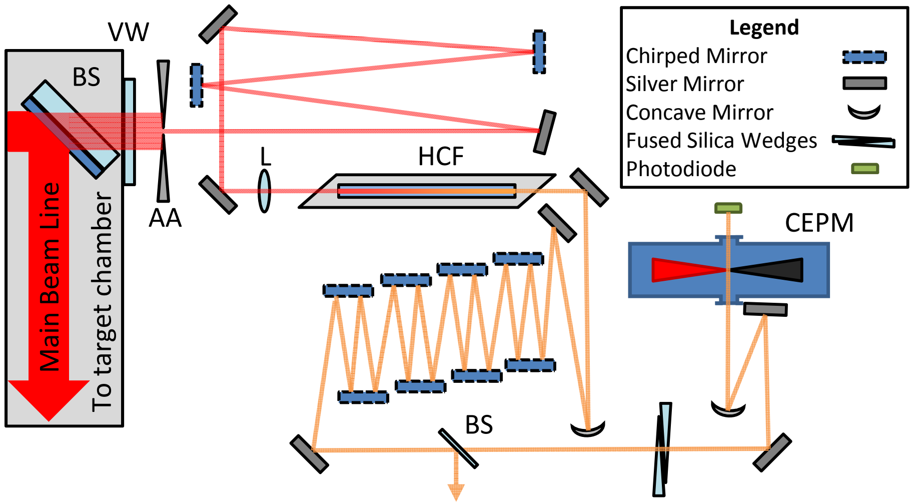
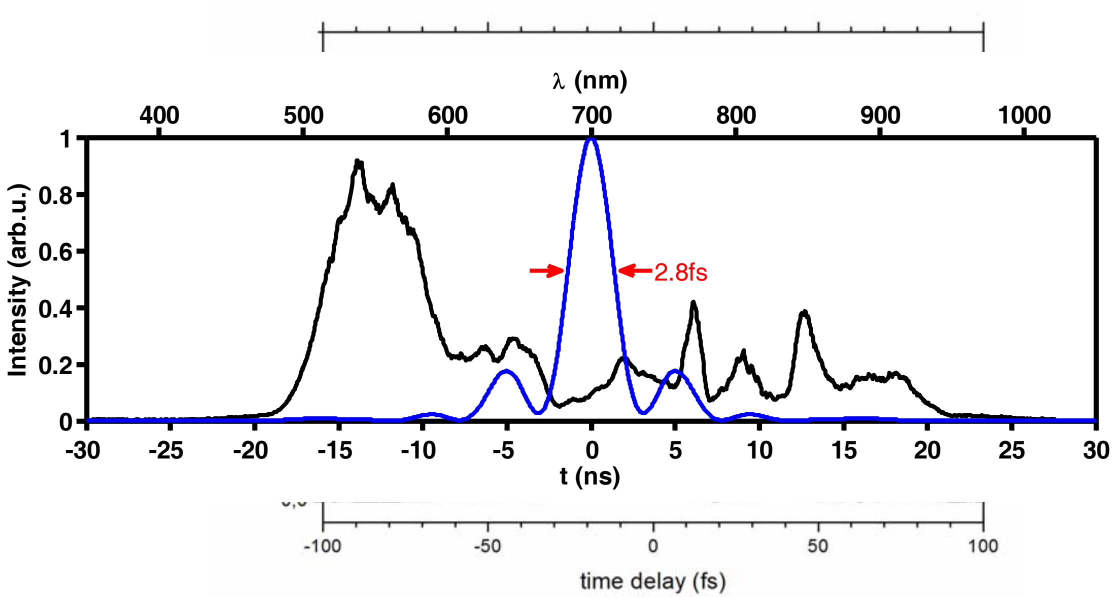
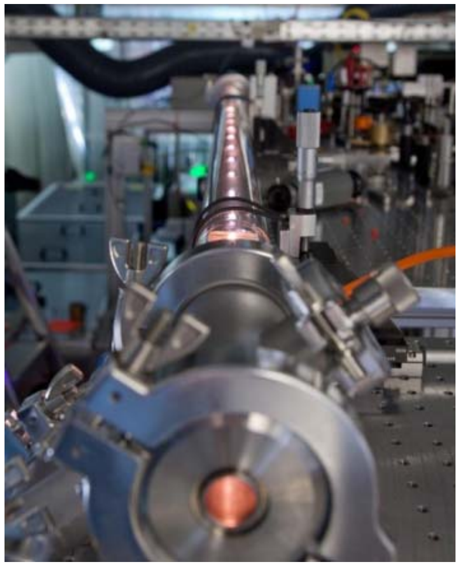
- Few-cycle probe pulse generation via frequency-broadening







input pulses from JETI: 32 fs, ~1 mJ

⇒ (5.9±0.4) fs @ 300 μJ, (2.8±0.4) fs @ 200 μJ

⇒ sufficient for shadowgraphy, Faraday-rotation, interferometry, …

M. Schwab *et al.*, Applied Physics Letters **103,** 191118 (2013)
D. Adolph *et al.*, submitted to Optics Express (2015)

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Probing underdense interactions:
Laser wakefield acceleration of electrons

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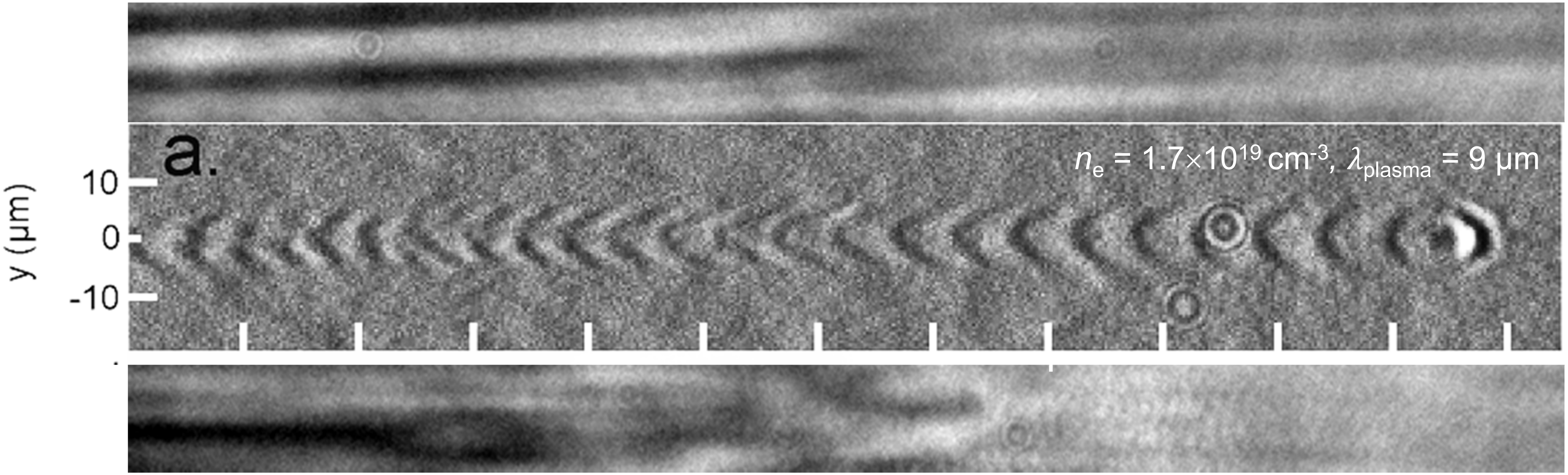
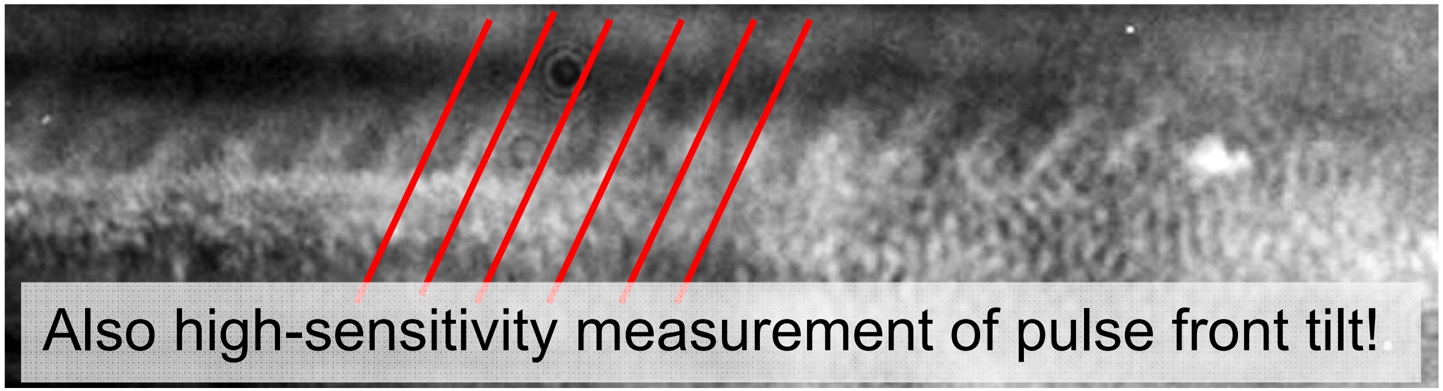


High-resolution (µm and fs) visualization of plasma wave and its evolution



M. Schwab *et al.*, Applied Physics Letters **103,** 191118 (2013)
M. Schnell *et al.*, Nature Communications **4,** 2421 (2013)
A. Sävert *et al.*, Physical Review Letters **115,** 055002 (2015)

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Probing underdense interactions: Laser wakefield acceleration of electrons

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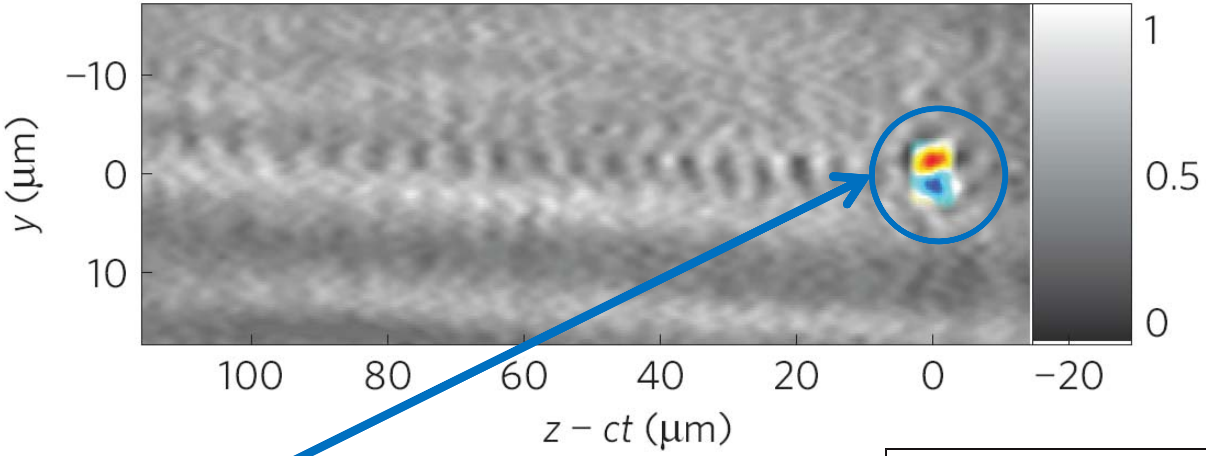
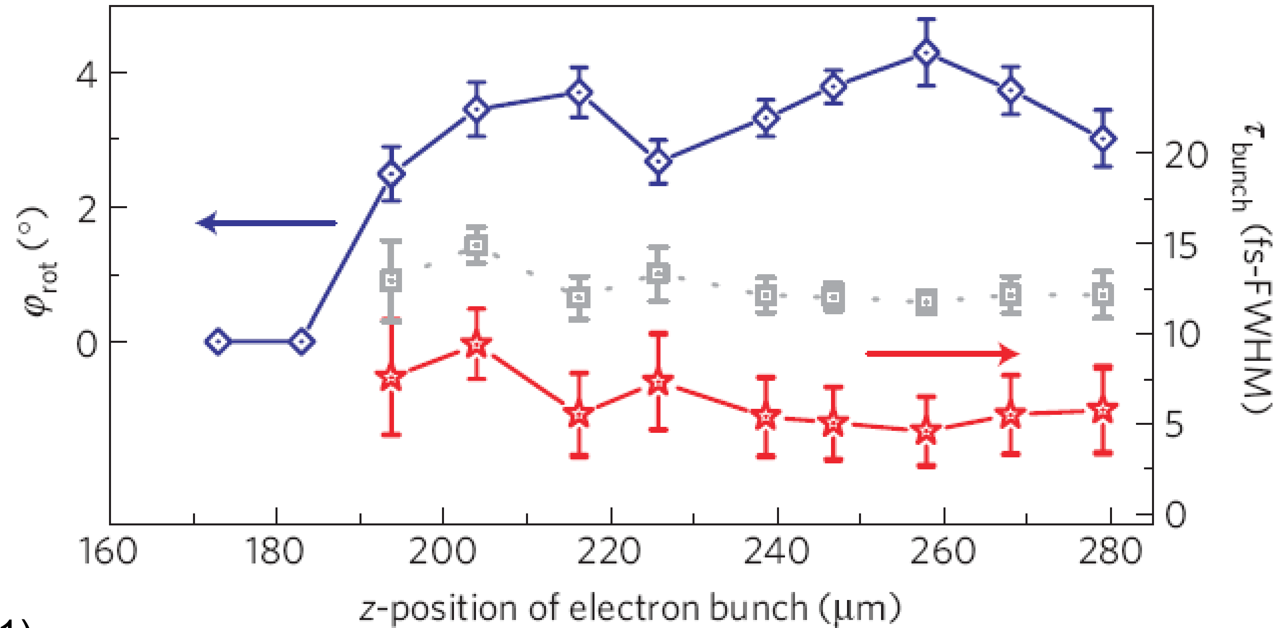


- Polarimetry:
  visualize e-bunch's B-fields via Faraday-effect:
  τ_{bunch} = (2.5±0.9) fs (r.m.s.)
- change pump-probe delay : evolution of e-bunch formation



A. Buck *et al.*, Nature Physics **7,** 543 (2011)

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Probing overdense interactions: Laser-driven ion acceleration

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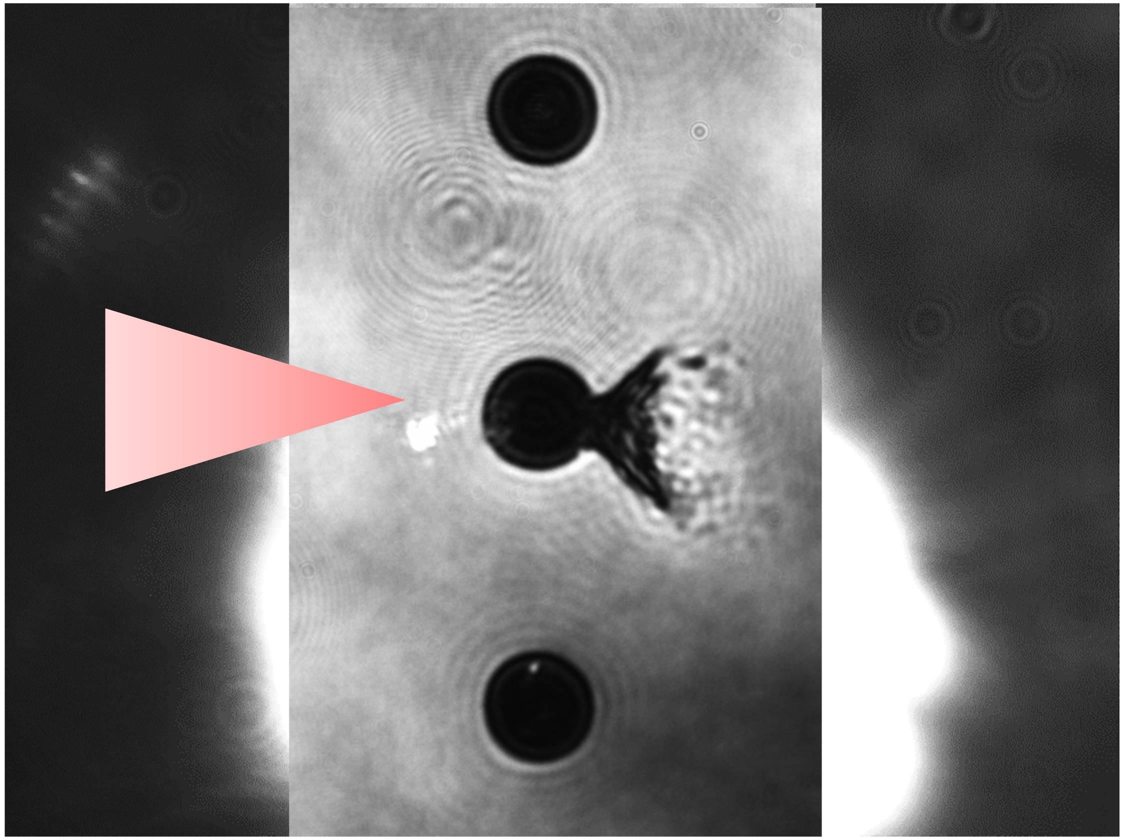


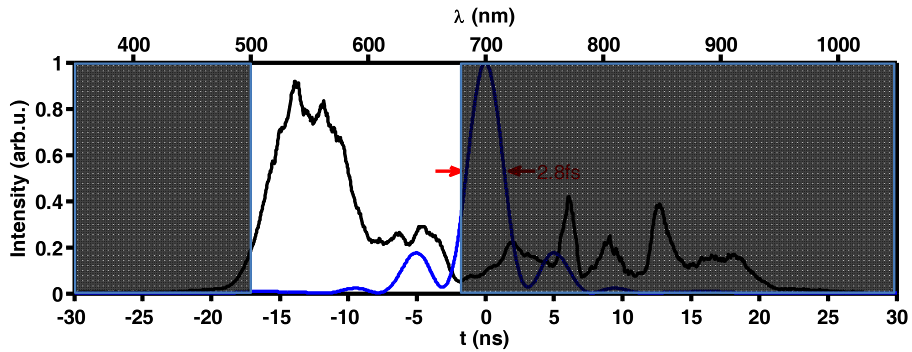
Probing of ion acceleration, e.g. using mass-limited targets:

- Plasma emission outshines probe light

Use main pulse @ 400 nm and probe pulse @ 550 nm (+ color filters)

⇒ Suppression of plasma emission

⇒ Fine details of interaction become visible



⇒ Wavelength-shifted, synchronized probe pulses required!

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Going to lower plasma densities – optimal probe wavelength required

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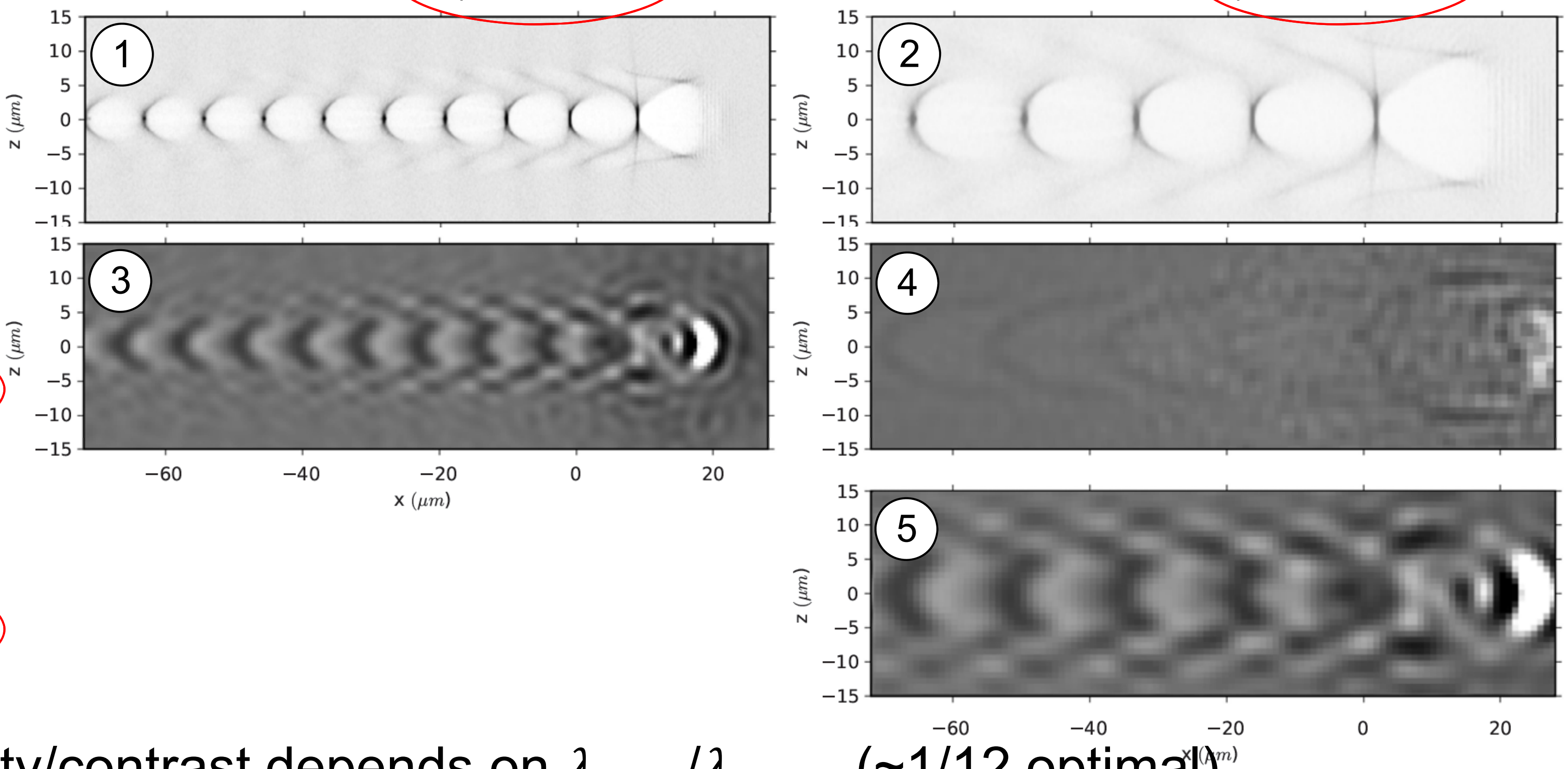
n_e = 1.7×10^{19} cm^{-3}, λ_{plasma} = 9 μm

n_e = 4.8×10^{18} cm^{-3}, λ_{plasma} = 17 μm

plasma wave, simulated with 3D-PIC

probing image, simulated for λ_{probe} = 750 nm

probing image, simulated for λ_{probe} = 1.4 μm



- Sensitivity/contrast depends on $\lambda_{probe}/\lambda_{plasma}$ (~1/12 optimal)

  ⇒ increase λ_{probe} to mid-IR (8...10 μm for $n_e \leq 10^{17}$/cm^3)
- Space and time scales of plasma wave increase similarly

  ⇒ few-cycle probe pulse in mid-IR gives similar relative resolution!

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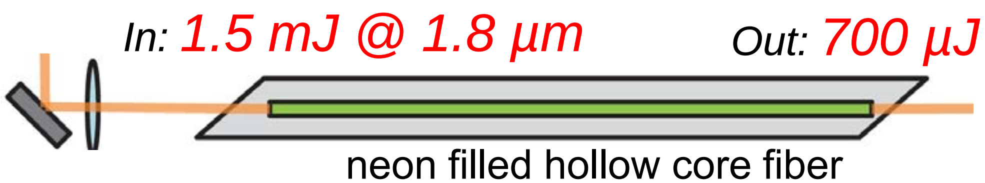
E. Siminos *et al.*, submitted (2016)

Generation of synchronized, mid-IR, few-cycle probe pulses

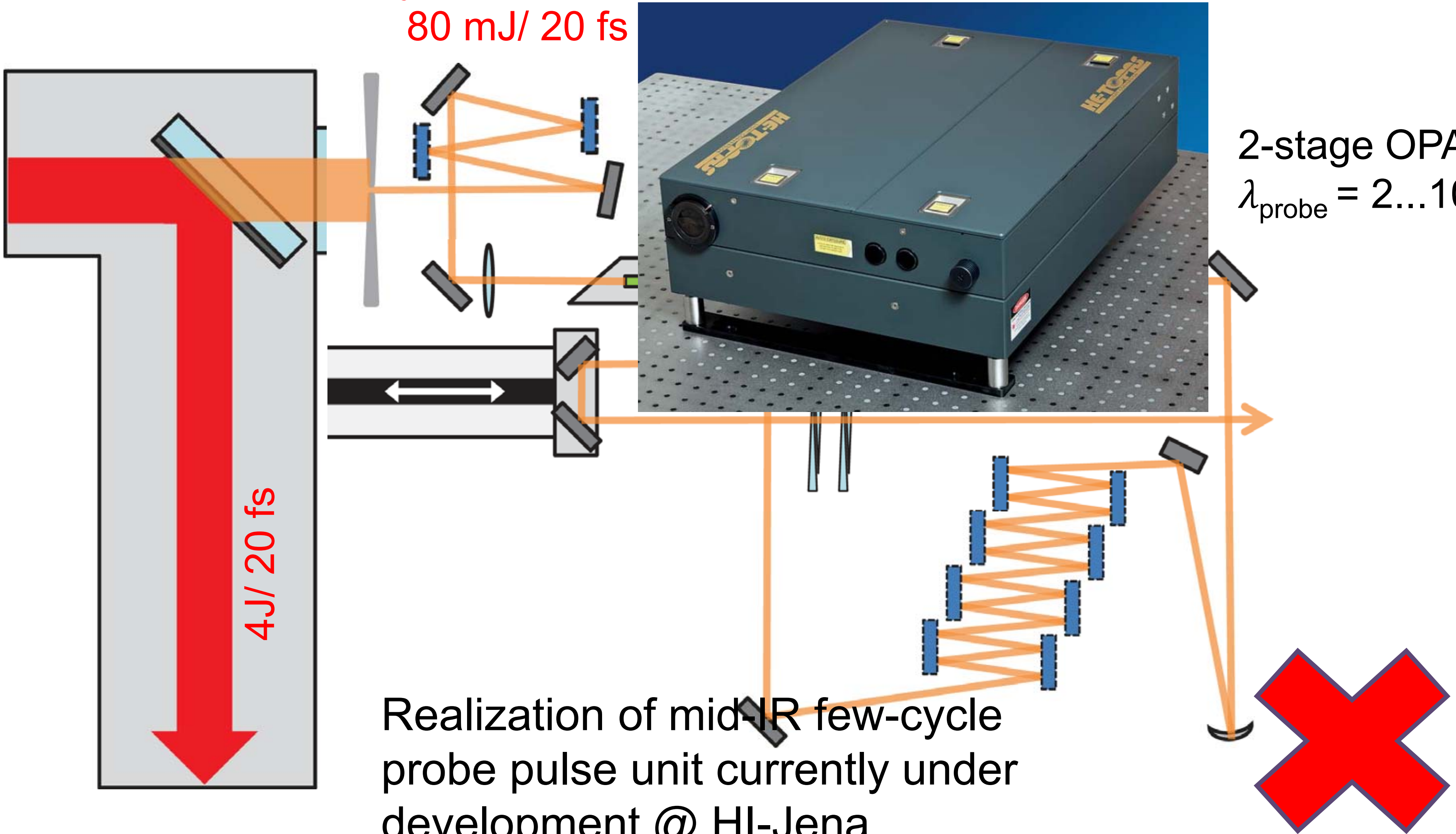
- Active frequency-shift with optical parametric amplifier

Input: 9,5 mJ/ 35 fs @ 800 nm



Compression with quartz to **11 fs** ≙ 2 optical cycles

- Active frequency-shift with optical parametric amplifier



2-stage OPA:
λ_{probe} = 2...10 µm

Realization of mid-IR few-cycle probe pulse unit currently under development @ HI-Jena.

Synchronized probe pulses for laser-plasma interactions:

⇒ powerful tool to show much more details of interaction

⇒ develop mobile probe-pulse unit to provide suitable probe pulses for each target area at Apollon

Requirements/Options:

- passive option: few mJ input + broadening (+ compression)
  - ⇒ few-cycle duration, $\lambda_{probe} \approx \lambda_{main}$, interactions @ $n_e \sim 10^{19}$ cm^{-3}
  - ⇒ $\lambda_{probe} \neq \lambda_{main}$, overdense interactions
- active option: few 10 mJ input + amplification and/or λ_{probe}-shift with OPA + compression
  - ⇒ few-cycle duration, $\lambda_{probe} \gg \lambda_{main}$, interactions @ $n_e \sim 10^{16}...10^{17}$ cm^{-3}
- adjust optical path lengths for correct delay:
  (internal optical path lengths: 3 m for passive, ~ 6 m for active option)

Thank you for your attention!