Advanced Plasma Diagnostics and Laser Development

Accelerator Research and Development ARD
A program by the Helmholtz association

JÜLICH FORSCHUNGSZENTRUM

GSI

KIT Karlsruhe Institute of Technology

DESY

HZB Helmholtz Zentrum Berlin

HZDR

HI Jena
Helmholtz Institute Jena

Malte C. Kaluza
Helmholtz-Institute Jena,
Friedrich-Schiller-University Jena
for the ATHENA team

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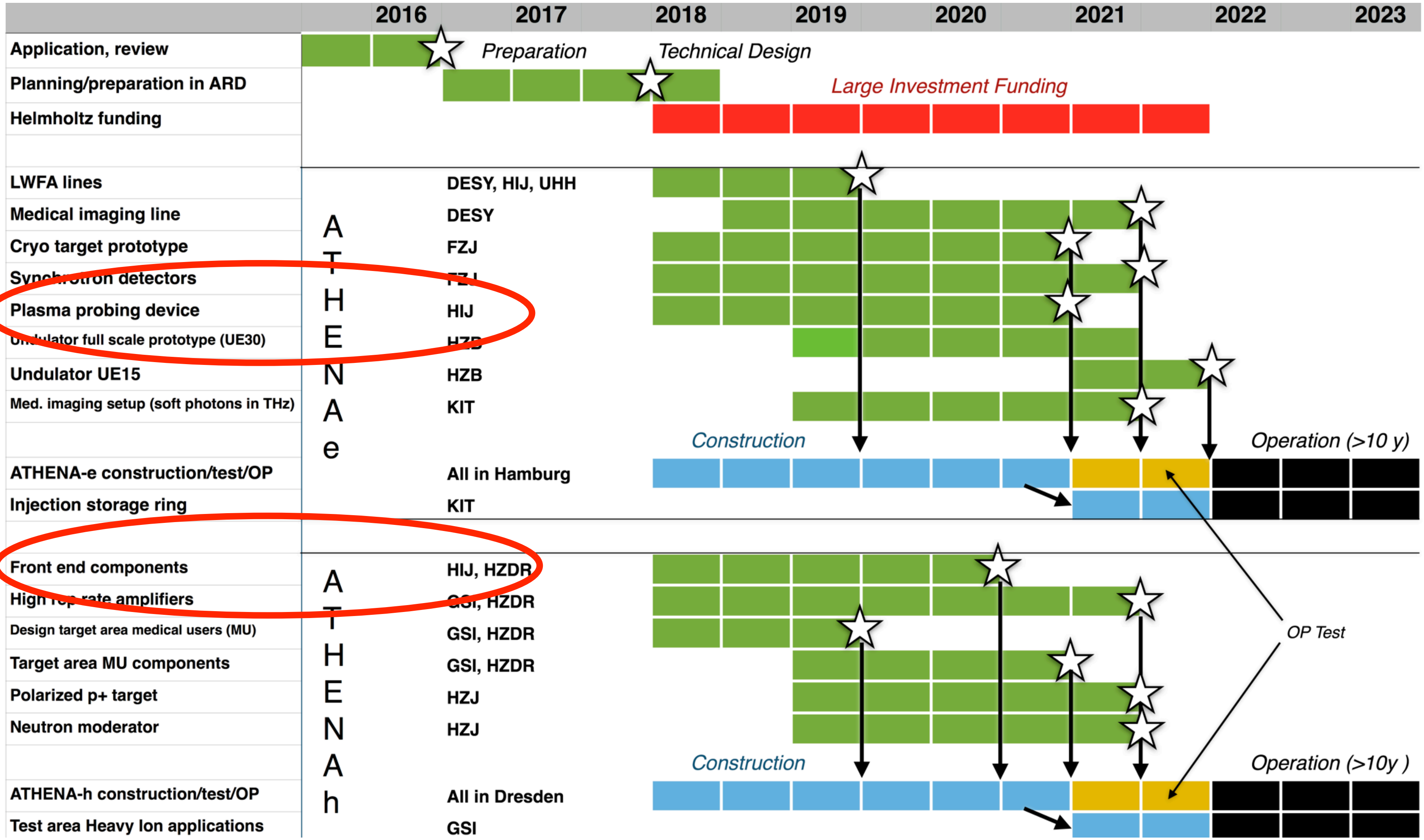
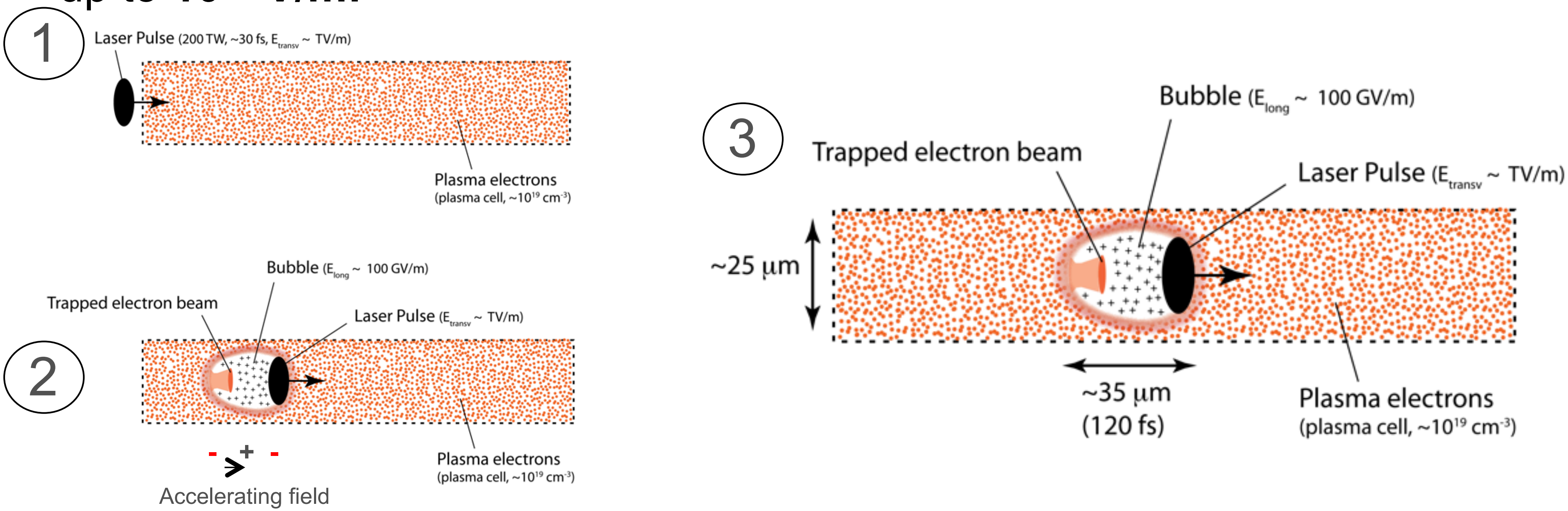
ATHENA-timeline



ATHENA$_e$: how does a plasma e-accelerator work?

High-intensity laser ^pulses have oscillating transverse fields of 10^{12} V/m. They can generate plasma waves with quasi-static longitudinal fields with up to **10^{11} V/m!**

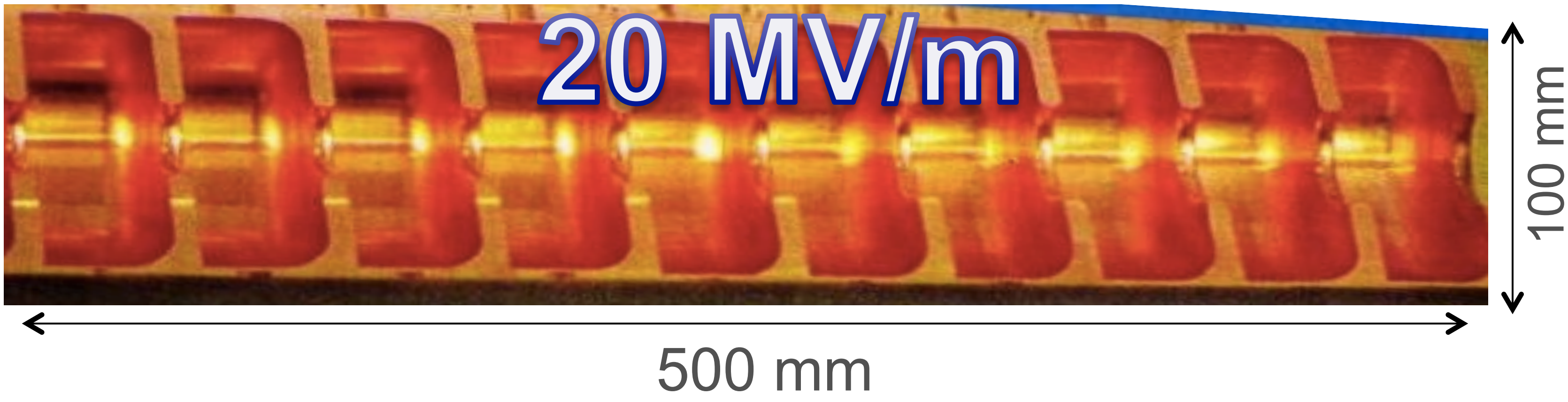


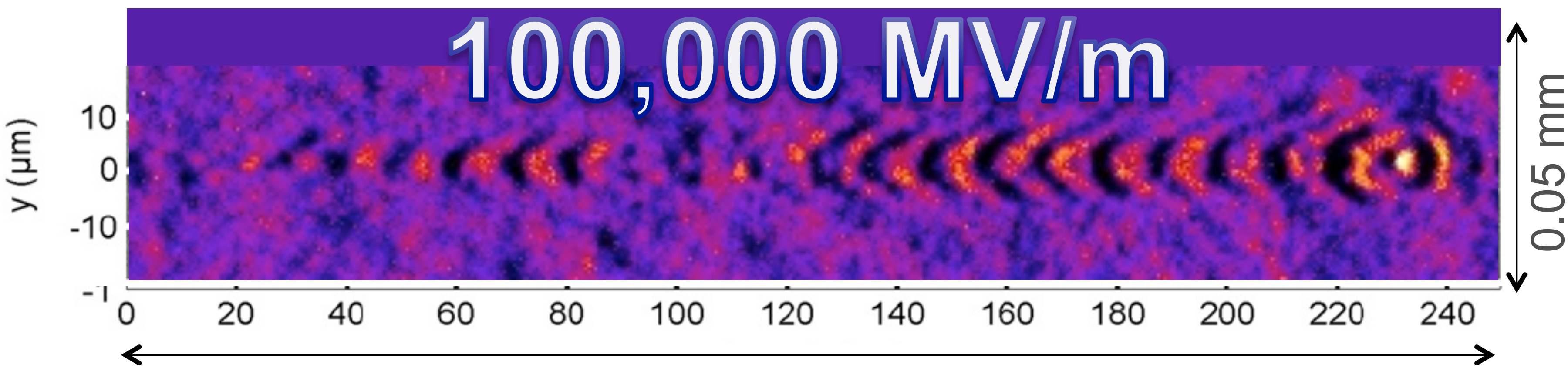
- Electrons accelerated by plasma wave over mm...cm up to GeV energies.
- Electron pulses can be used as a driver, too.
- Increase electron energies: use lower plasma densities.
- Optimize electron pulses: detailed insight into accelerator

Conventional vs. plasma-based accelerators

Metallic (Cu) S band Linac structure

Powered by micro-waves





0.25 mm

APPLIED PHYSICS LETTERS **103**, 191118 (2013)

Few-cycle optical probe-pulse for investigation of relativistic laser-plasma interactions

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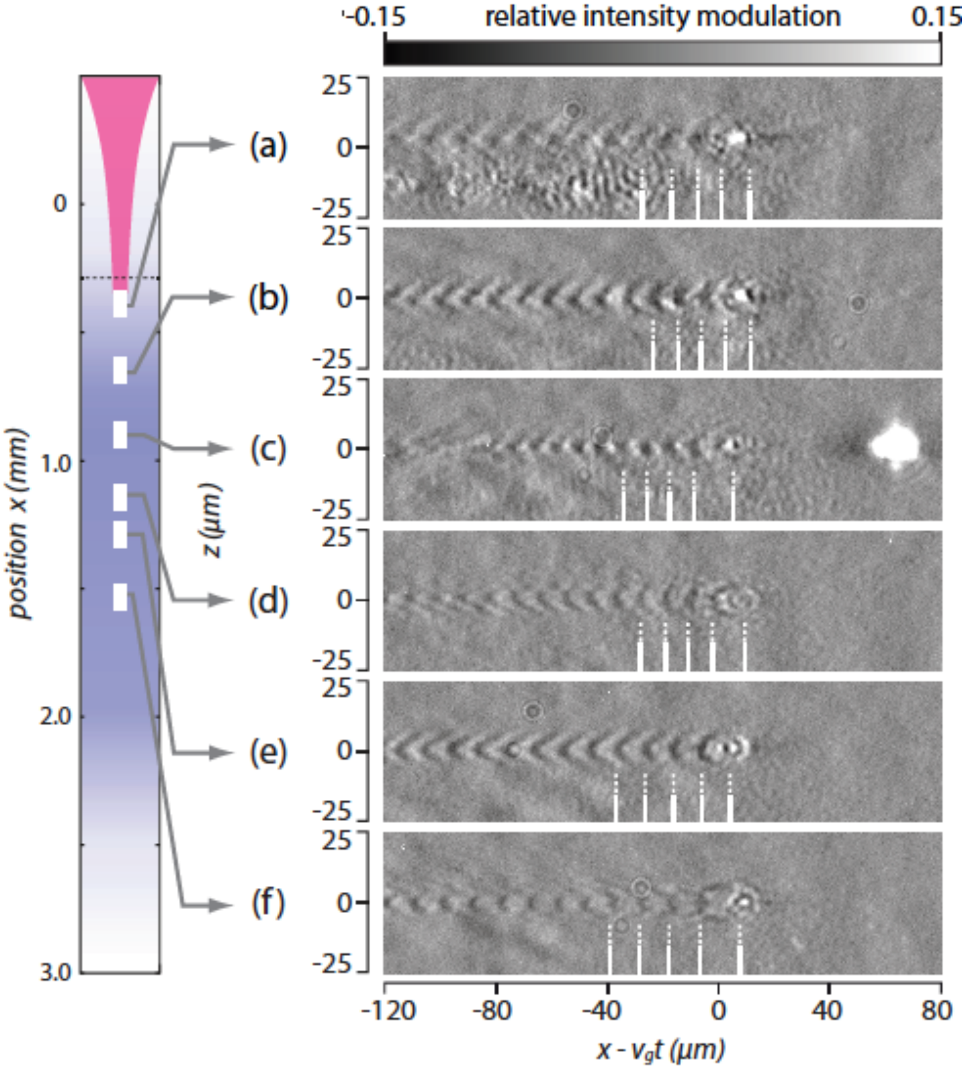
Ultra-fast probing of plasma electron-accelerators

So far:

First high-resolution images of dynamics in **laser-driven** plasma-electron accelerator

Future plans for ATHENA$_e$:

Modify probing tools to fit low-density **beam-driven** plasma-electron accelerator @ SINBAD

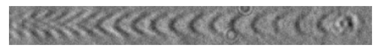


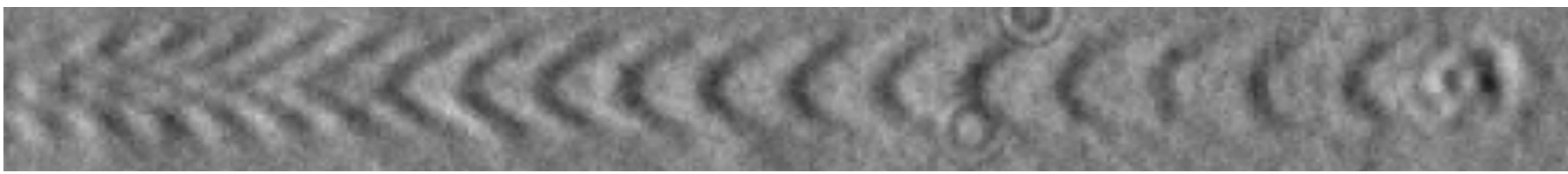
A. Sävert *et al.*, submitted (2014)

Ultra-fast probing of plasma electron-accelerators

So far: high-resolution probing possible at moderate densities n_e only

- when reducing n_e





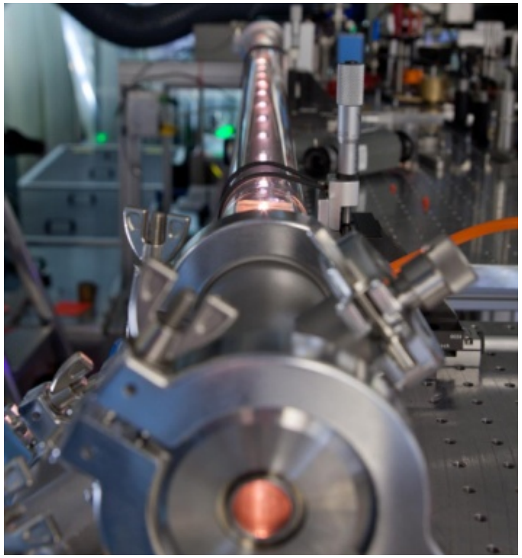
- diagnostics‘ sensitivity ~ $\lambda_{pr}/\lambda_{pl}$

⇒ use synchronized **few-cycle mid-IR pulses,**
adapt diagnostic components (lenses, cameras, polarizers,...)

Generation of suitable probe pulses

near-IR: λ_{pr} @ 800 nm

spectr. broadening
+ compression



synchr. few-cycle, **near-IR probe**

$n_e = 0.5...1\times10^{19} cm^{-3}$

mid-IR: $2\ \mu m \leq \lambda_{pr} \leq 10\ \mu m$

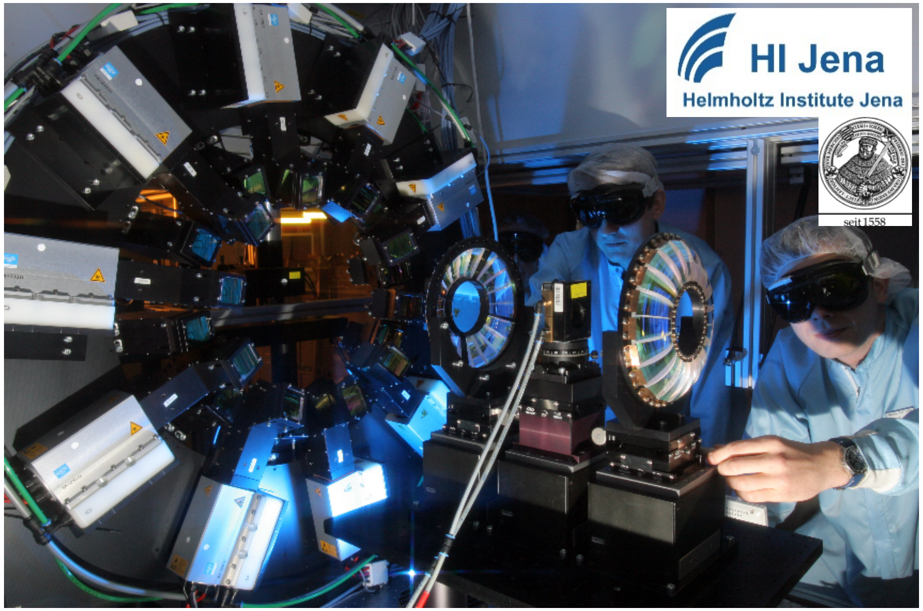
shift λ_{pr} + spectr. broadening
+ compression

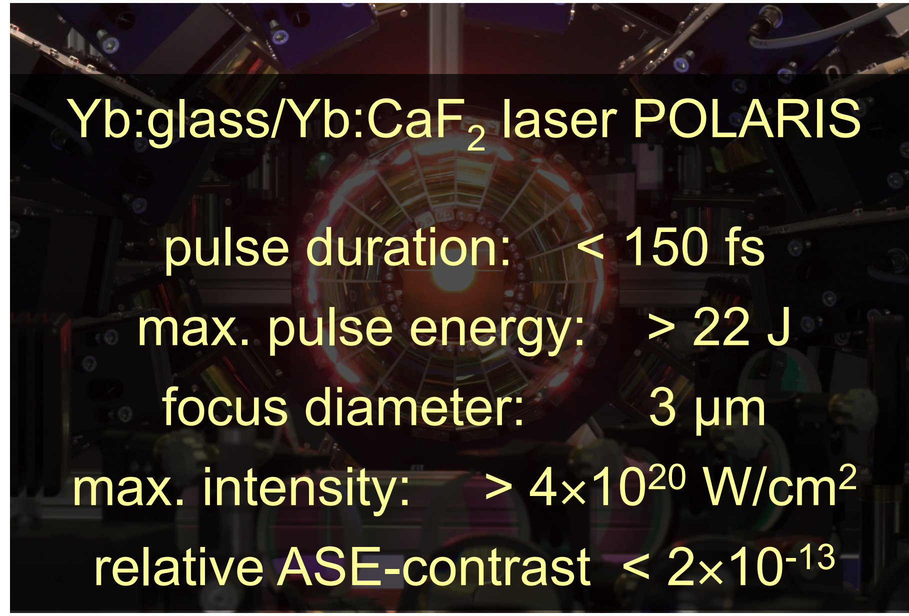
synchr. few-cycle, **mid-IR probe**

$n_e = 3x10^{16}...1\times10^{18} cm^{-3}$

M. Schwab *et al.*, APL **103,** 191118 (2013)

High-power laser development at HI-Jena





Contributions for ATHENA$_h$:

- Front-end components for ultra-high pulse contrast
- Methods for variable focusing of laser pulses

M. Hornung *et al.,* Opt. Lett. **38,** 1718 (2013)
H. Liebetrau *et al.,* Opt. Expr. **22,** 024776 (2014)
M. Hornung *et al.,* HPLSE **2,** e20 (2014)
S. Keppler *et al.,* Opt. Expr. **22,** 11228 (2014)
A. Kessler *et al.,* Opt. Lett. **39,** 1333 (2014)

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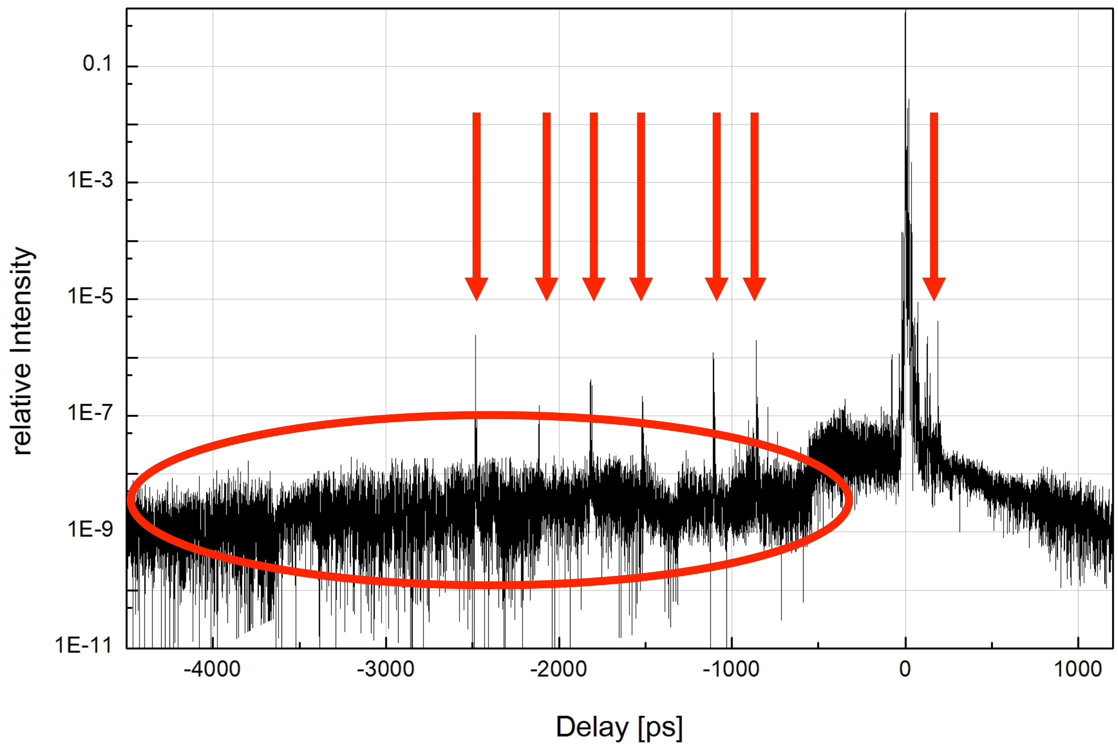
Laser development – Front-end components

Laser pulse contrast: crucial parameter for particle acceleration

Sources of contrast deterioration:

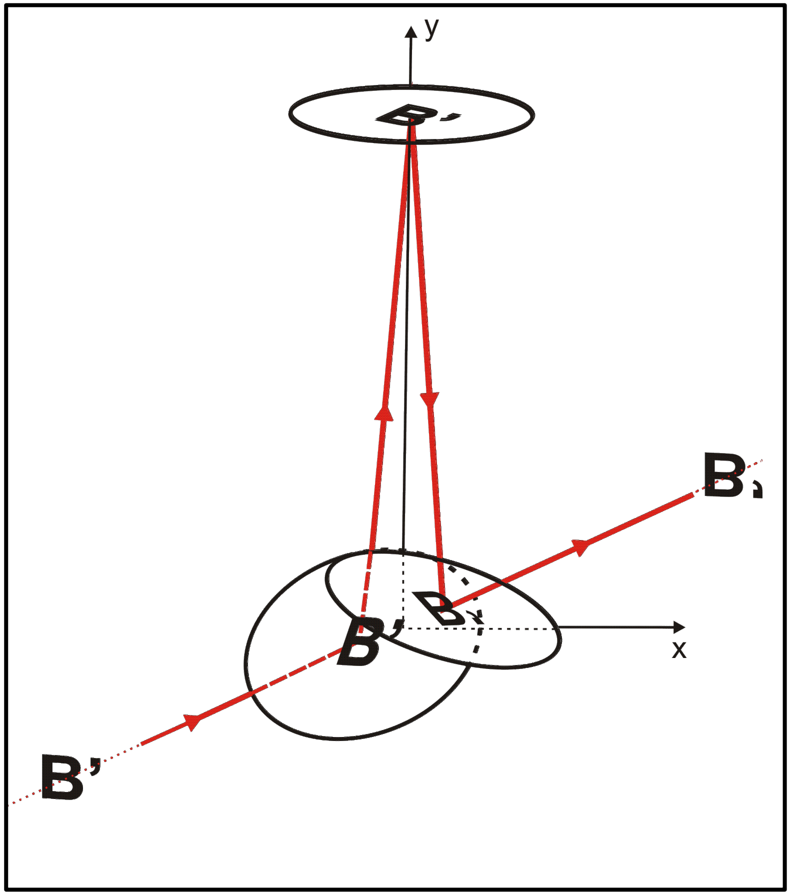


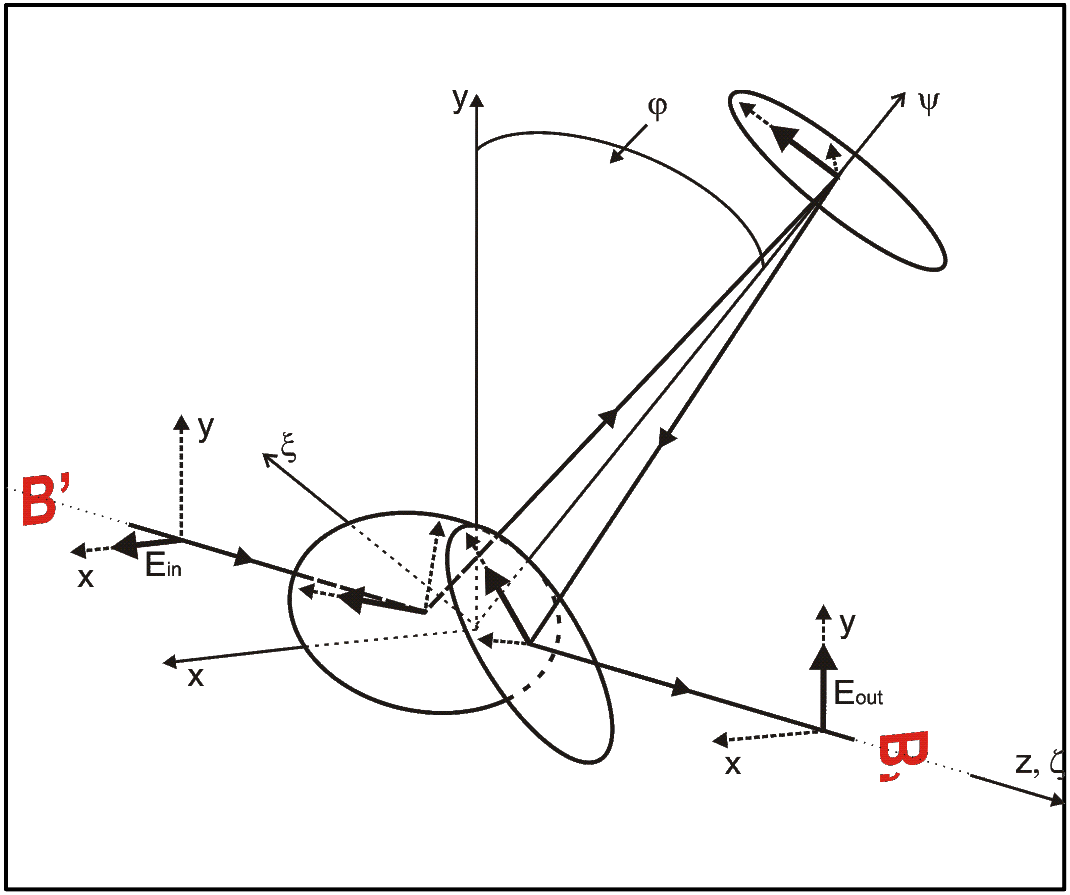
- Short pulse replica (short pre- and post-pulses)
- Amplified spontaneous emission (ASE)

Laser development – Front-end components

Avoid short post- and prepulses:

replace all transmissive wave plates by reflective ones





S. Keppler *et al.*, Opt. Expr. **20,** 20742 (2012)

Laser development – Front-end components

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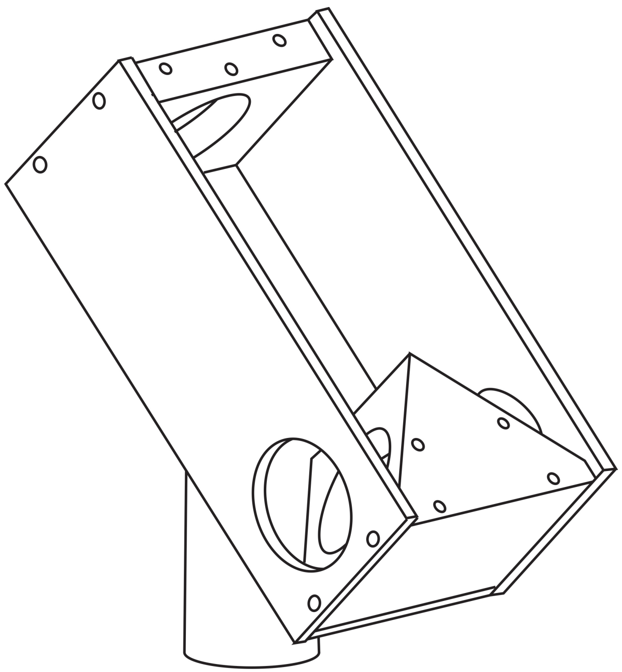
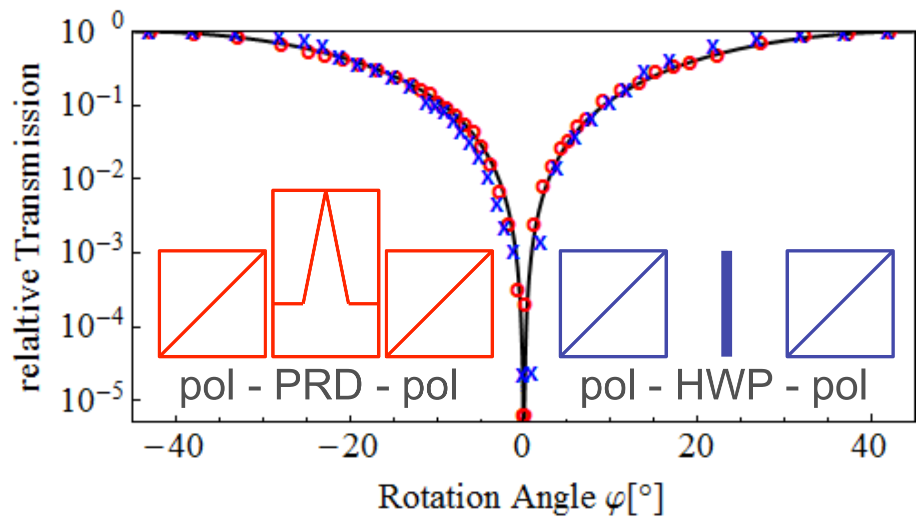




Scalable, broad-band solution to be implemented into PEnELOPE.

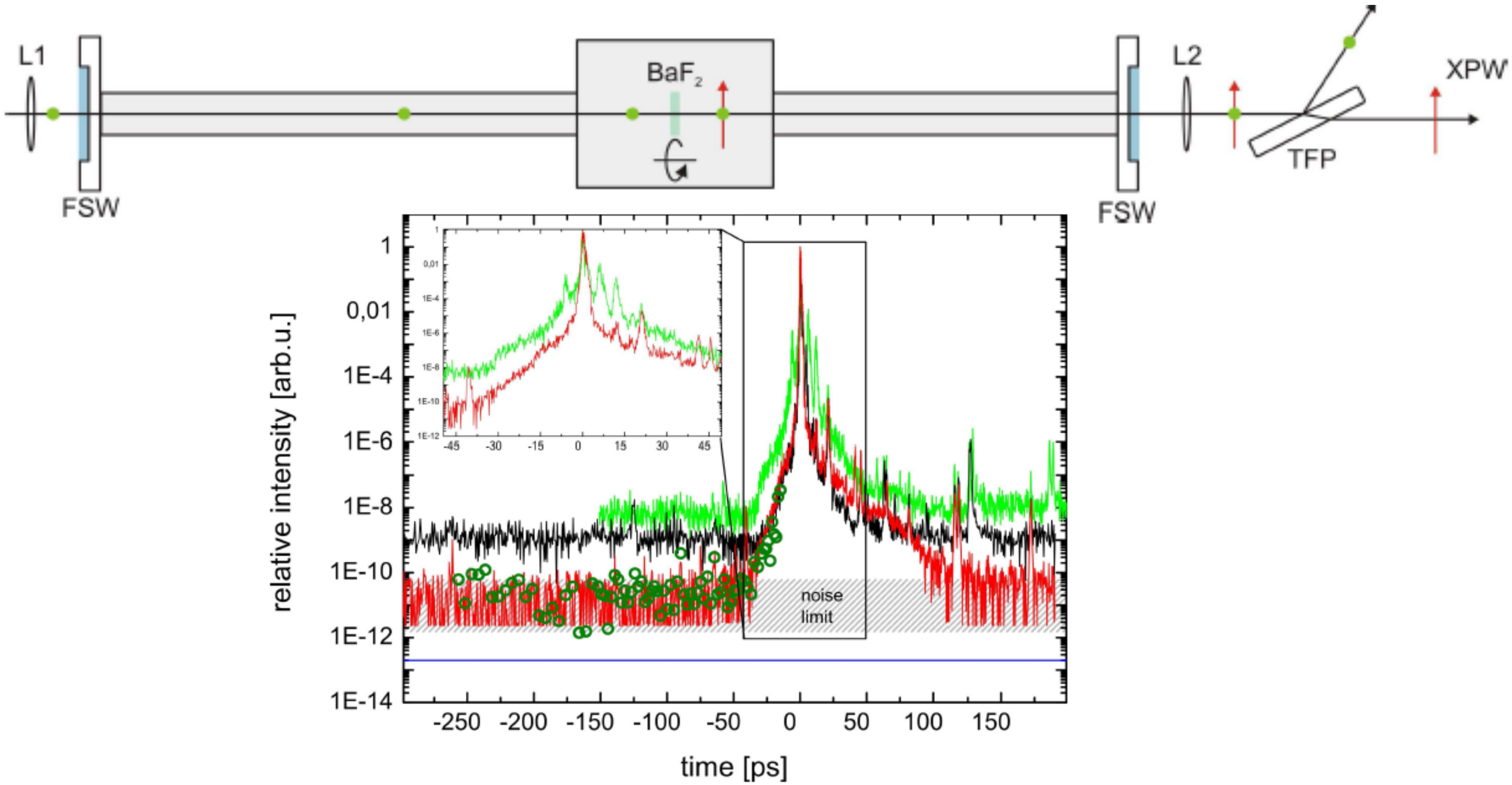
Works for λ/2- and λ/4-wave plates.

S. Keppler *et al.*, Opt. Expr. **20,** 20742 (2012)

Laser development – Front-end components

Reduce ASE-level:

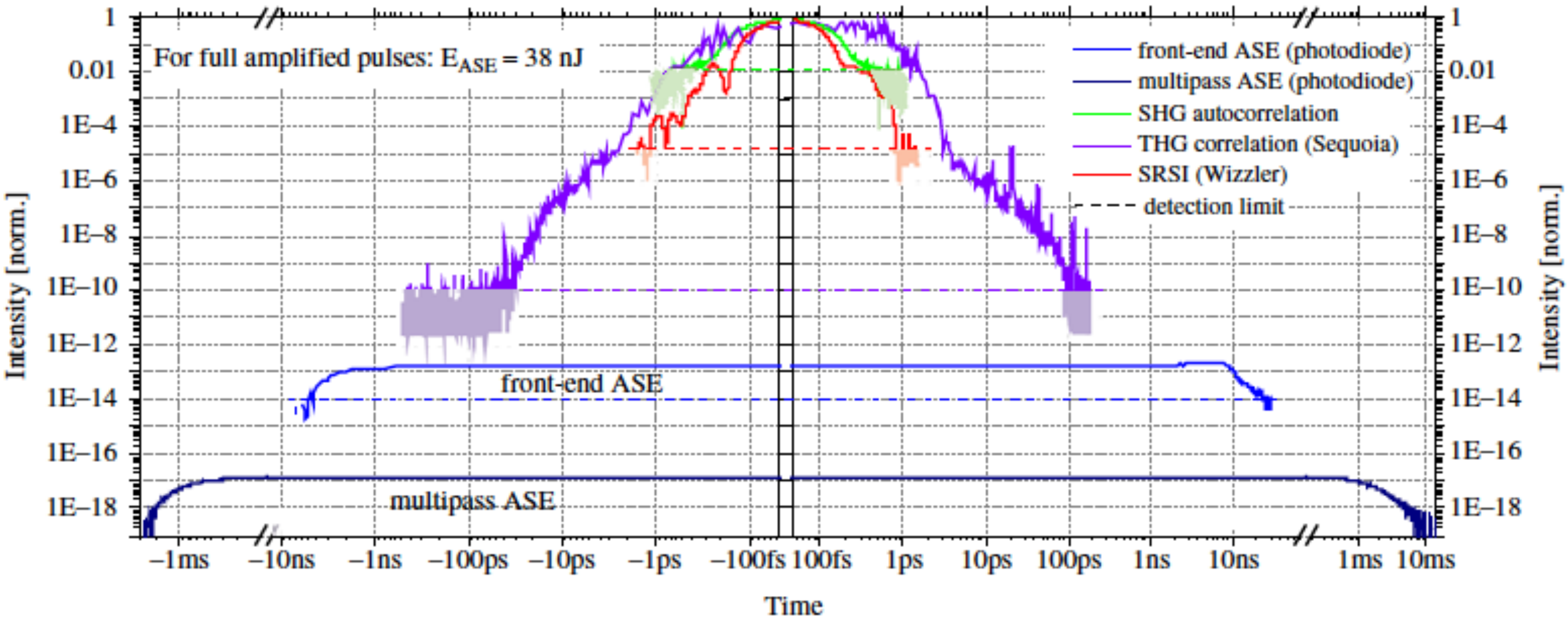
Double-CPA system + XPW



H. Liebetrau *et al.,* Opt. Expr. **22,** 024776 (2014)

Laser development – Front-end components

Contrast enhancement for POLARIS @ HI-Jena:



POLARIS: currently best contrast for diode-pumped systems worldwide

Suitable front-end components to be developed by HI-Jena for PEnELOPE/ATHENA$_h$.

M. Hornung *et al.,* Opt. Lett. **38,** 1718 (2013)
M. Hornung *et al.,* HPLSE **2,** e20 (2014)

Laser development – Variable focusing

Usual approach:

Use adaptive optics + wavefront sensor:

⇒ smallest focus + highest intensity

Depending on application:

Adaptive optics + generic algorithm

⇒ different focal spot shapes,

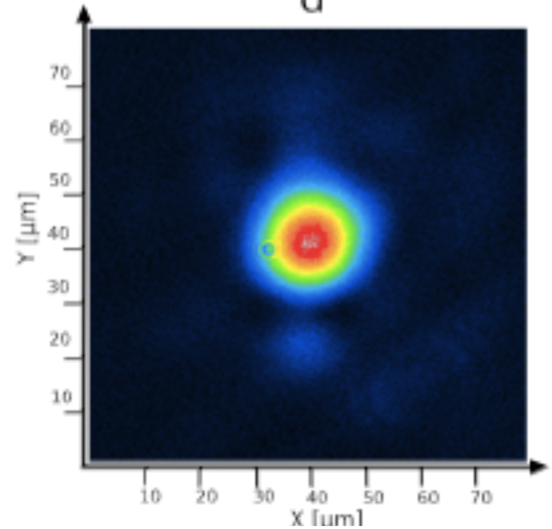
e.g. satellite focus,

double focus

or other shapes, e.g. flat-top or doughnut

⇒ optimization for several ion- or electron acceleration scenarios

d



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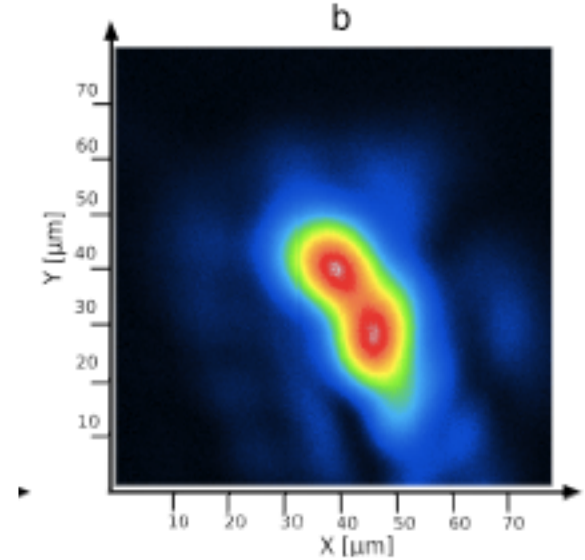

M. Hornung *et al.*, Opt. Lett. **38,** 1718 (2013)

Summary

HI-Jena will

- Develop and deliver ultra-short probing tools for low-density plasma electron accelerators at $ATHENA_e$
- Contribute to development of laser-plasma electron injector at KIT
- High-power laser components for ultra-high contrast and variable focusability for laser ion-accelerator at $ATHENA_h$