

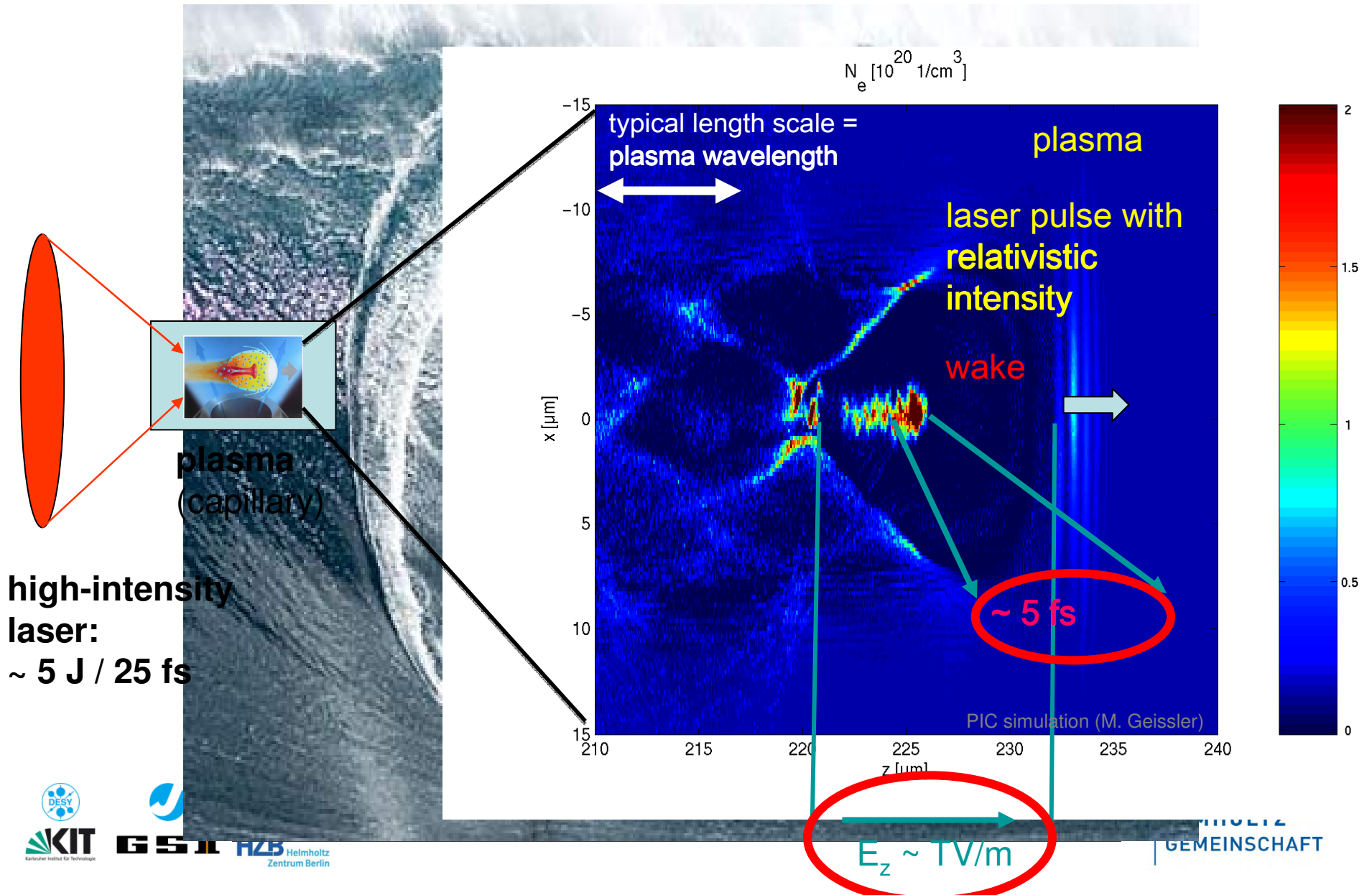
Accelerator Research and Development ARD

Topic 4: Novel Techniques for High Gradient Acceleration

Plasma Wakefield Acceleration
of
electrons

- **basics** and state-of-the-art
- **players** and **projects**

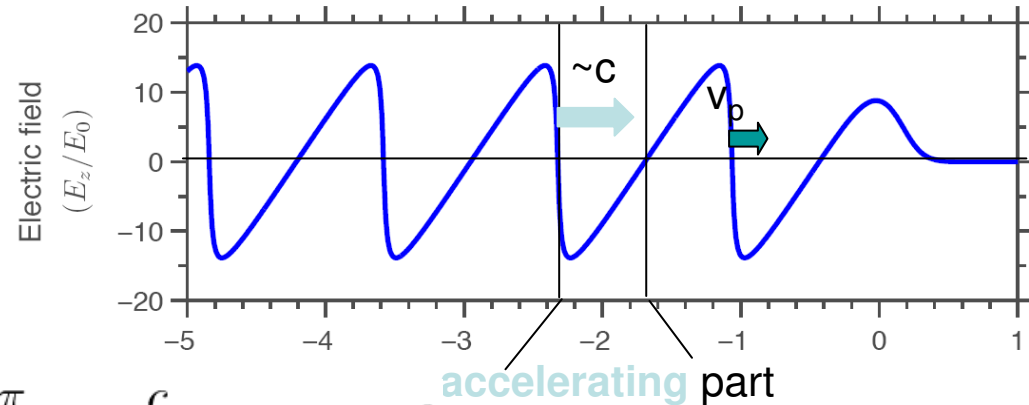
plasma wakefield acceleration: basics



maximum energy - dephasing

dephasing:

electron faster than wake

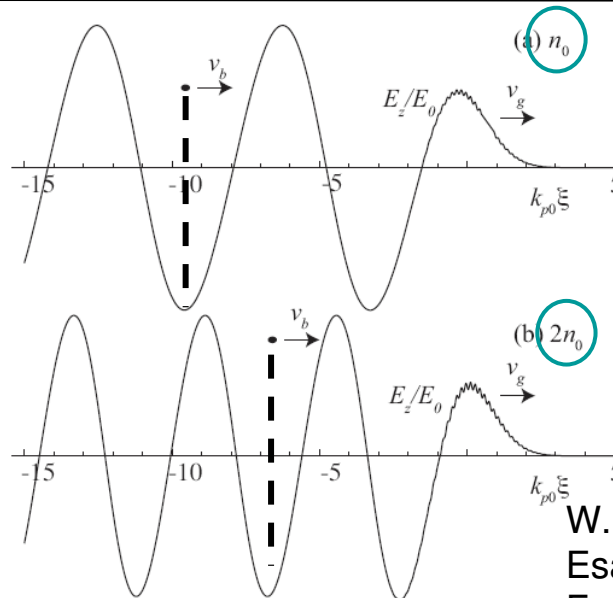


dephasing length:
$$L_d = \frac{\pi}{\omega_p} \frac{c}{(c/v_p - 1)} \simeq \lambda_p \gamma_p^2$$

maximum energy:
$$W \approx eE_m L_d \longrightarrow W_m \approx 2\pi \gamma_p^2 (E_m/E_0) mc^2$$

solution:

plasma **up**-ramp



W. Rittershofer, C. Schroeder, E. Esarey,
F. Grüner, W. Leemans; Phys. of

PWA worldwide



PWA worldwide II

LETTERS

3 GeV electron beams from a centimetre-scale accelerator

PRL 102, 124801 (2009)

PHYSICAL REVIEW LETTERS

week ending 24 APRIL 2009

week ending 27 MARCH 2009

PHYSICAL REVIEW LETTERS

Volume of Injected Electrons in a Laser-Plasma Accelerator

R. Fitour,¹ A. Specka,² H. Videau,² A. Tafzi,¹ F. ...
¹ CNRS, École Polytechnique, UMR 7639, 91761 ...
² CNRS-IN2P3, UMR 7638, 91128 ...
November 2008; published 24 April 2009

PHYSICAL REVIEW LETTERS

PRL 104, 084802 (2010)

Electron Beam

Electron Beam

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> 200 hits for „Laser-Wakefield Acceleration“ since 2005 in Web of Science

Controlled injection and a plasma wakefields by colli

Laser-driven accelerators by colliding pulses injection:
A review of simulation and experimental results^{a)}

V. Malka,^{1,b)} J. Faure,¹ C. Rechatin,¹ A. Ber
and E. Lefebvre³
¹ Laboratoire d'Optique Appliquée, École Nationale
École Polytechnique, CNRS, UMR 7639, 91761 P
² Laboratoire Leprince Ringuet, École Polytechnique
DAM, DIF, Bruyères-le-Châtel, 91297 Ar
November 2008; accepted 16

Stable generation of GeV
beams from self
channel

Laser Electron Accelerator

T. Tajima and J. M. Dawson
Department of Physics, University of California, Los Angeles, California 90024
(Received 9 March 1979)

An intense electromagnetic pulse can create a weak of plasma oscillations through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density 10^{14} W/cm² shone on plasmas of densities 10^{18} cm⁻³ can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.

500-712, Korea
of Technology (MIT), Cambridge, Massachusetts 02139, USA

Laser-driven soft-X-ray undulator source

Matthias Fuchs^{1,2}, Raphael Weingartner^{1,2}, Antonia Popp¹, Zsuzsanna Major^{1,2}, Stefan Becker², Jens Osterhoff^{1,2}, Isabella Cortie², Benno Zeitler², Rainer Hörterlein^{1,2}, George D. Tsakiris¹, Ulrich Schramm³, Tom P. Rowlands-Rees⁴, Simon M. Hooker⁴, Dietrich Habs^{1,2}, Ferenc Krausz^{1,2}, Stefan Karsch^{1,2,*} and Florian Grüner^{1,2,*}



Helmholtz
Zentrum Berlin

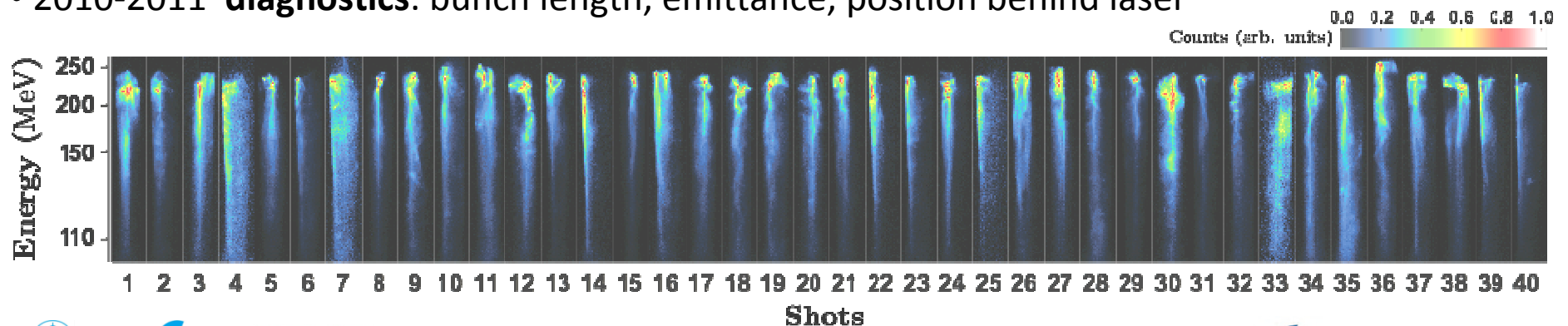
GEMEINSCHAFT

PWA history

- before 2000: **theory** on LWFA (1979), experiments with „*thermal*“ energy spectra
- 2000 theory of **bubble** acceleration (Meyer-ter-Vehn, MPQ): **needs stronger laser**
- 2004 **first** experimental results, *peaked* energy spectra (LBNL, LOA, RAL, *Nature*)
- 2006 Berkeley lab reaches **1.0 GeV** (W. Leemans et al., *Nature Physics*)
- 2008 **stability** improvement (e.g., J. Osterhoff et al., *PRL*)
- 2009 first **laser-driven soft X-ray undulator source** (F. Grüner et al., *Nature Physics*)

new injection schemes: down-ramp, counter-propagating lasers, ionization, shock-front

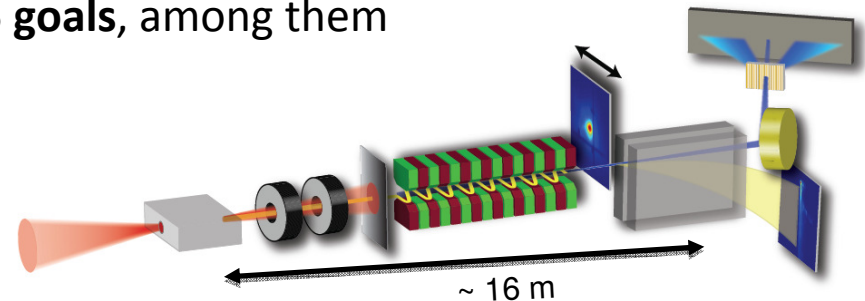
- 2010-2011 **diagnostics:** bunch length, emittance, position behind laser



perspectives

- EuroNNAc workshop @ CERN, May 2011, **top 5 goals**, among them

- „table-top“ XFEL
- 10 GeV stage
- stable operation 24/7

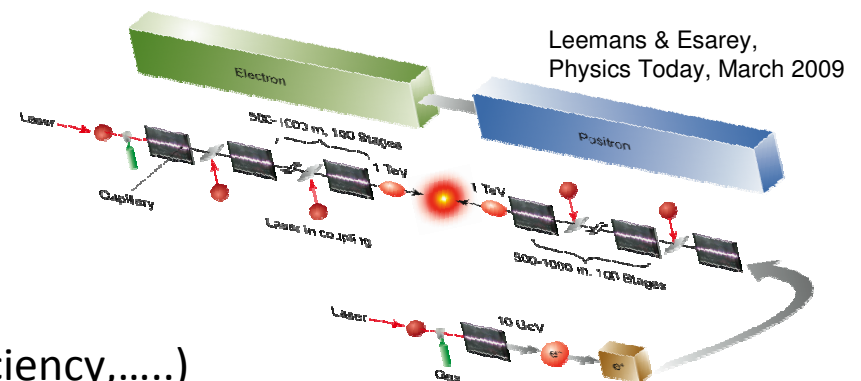


- **brilliant X-ray sources** „at home“, added values:

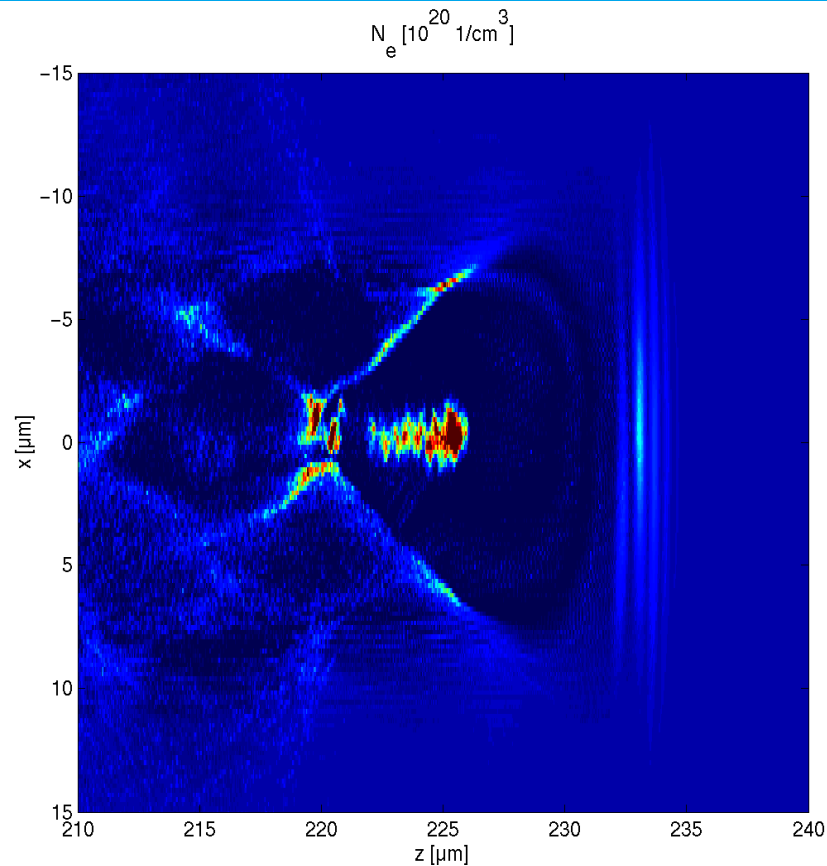
- intrinsic synchronization (driver laser, X-ray pulse, few fs)
- compact enough for hospitals: medical applications
- higher peak currents (above 20 pC/4 fs)

- **high-energy physics**

- TeV machine
- sure enough, **many** open questions (emittance growth, staging, timing/pointing for ~100 stages, efficiency,.....)



open questions



how does it all work?

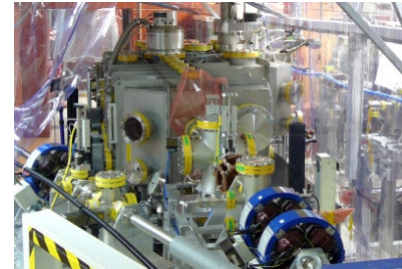
- self-consistent analytical treatments too complex → PIC codes
- PIC codes suffer from
 - idealistic modelling
 - numerical heating
 - resolution issues (space charge)
- experimental situation so far:
**initial state of electron bunch
unknown & wakefield unknown**



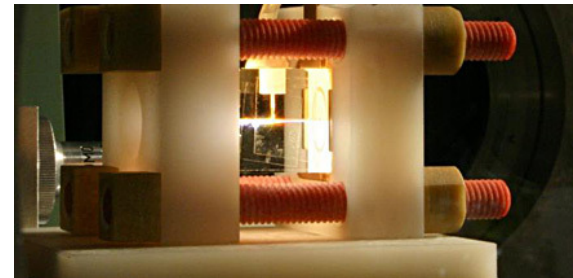
**inject well-known bunch into wakefield
→ back-calculation of wakefield**

players within Helmholtz

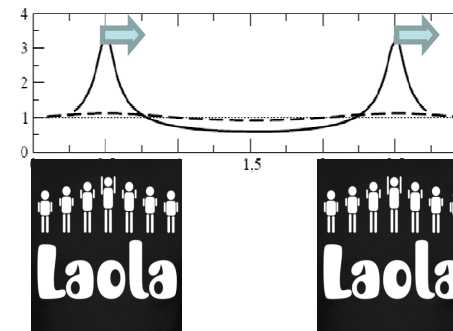
HZDR: studies of laser-plasma acceleration and diagnostics,
external injection of *ELBE*-bunches



HI+FSU Jena: new method for bunch duration measurement and
position of bunch relative to laser

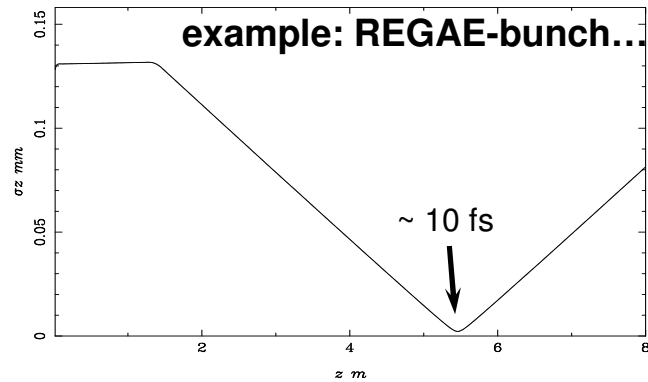


DESY + UHH → **LAOLA** = Laboratory for Laser- and beam-driven Plasma Acceleration
= combination of PWA & DESY's modern accelerators



plasma density profile

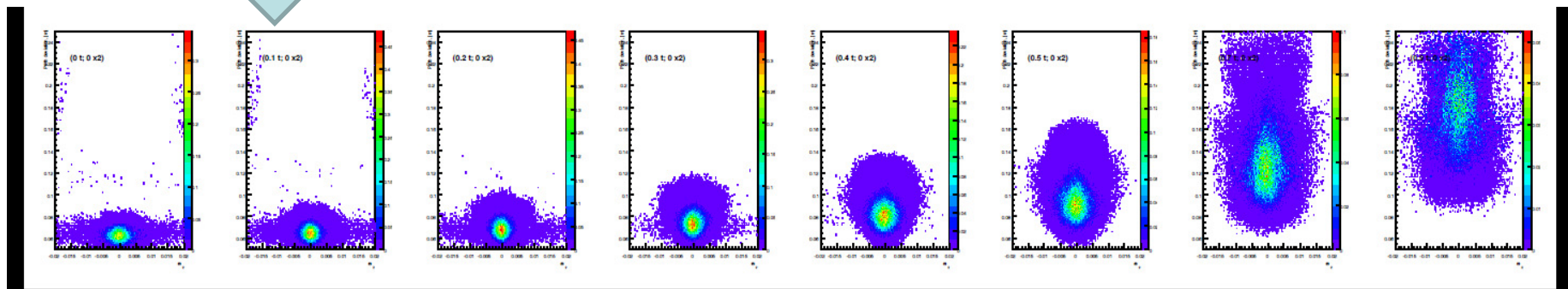
key experiment: external injection



...to be **injected** into wakefield ~ 300 fs...

...first **measurement** signal:
energy distributions dependent on timing:

requires **new** diagnostics for
timing measurements....



combining expertise within ARD

HZDR: can run laser-plasma experiments and development of new diagnostics **now**

→ bunch length, emittance, synchronisation between *ELBE*-accelerator and driver laser
(see ARD topic 3)

can study external injection with **long** beams (~ 500 fs)

→ first experiences for future experiments

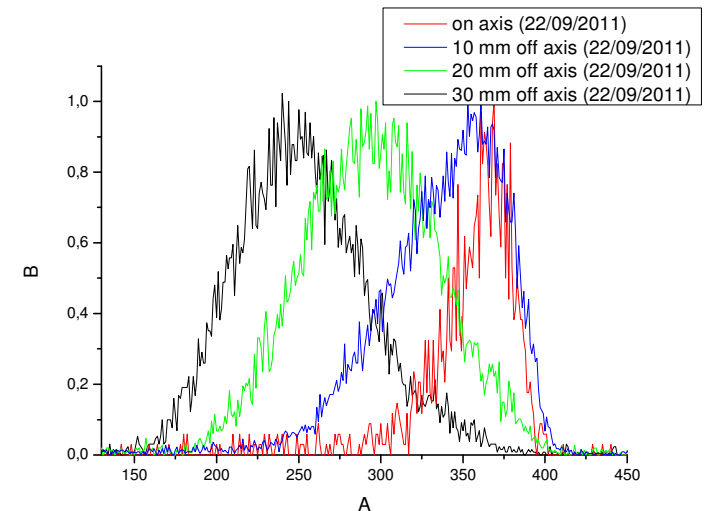
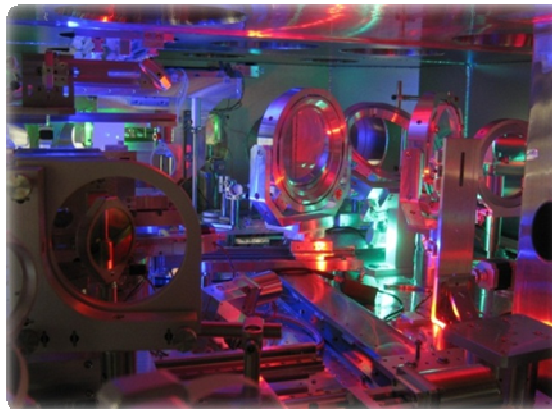
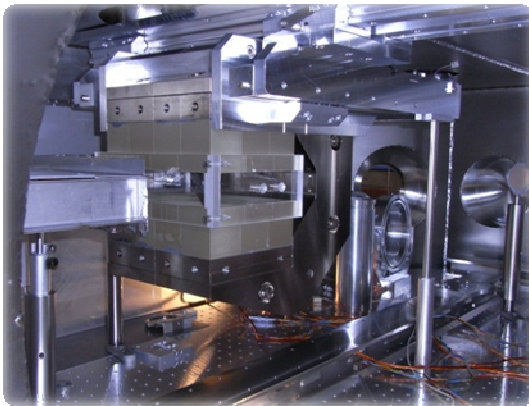
HI+FSU Jena: can develop Beam Arrival Monitors

→ measure timing between external bunch and driver laser

DESY/UHH can provide man power and expertise for experiments at HZDR, joint target developments
can later do external injection with **short** beams (~ 10 fs)

plans at HZDR

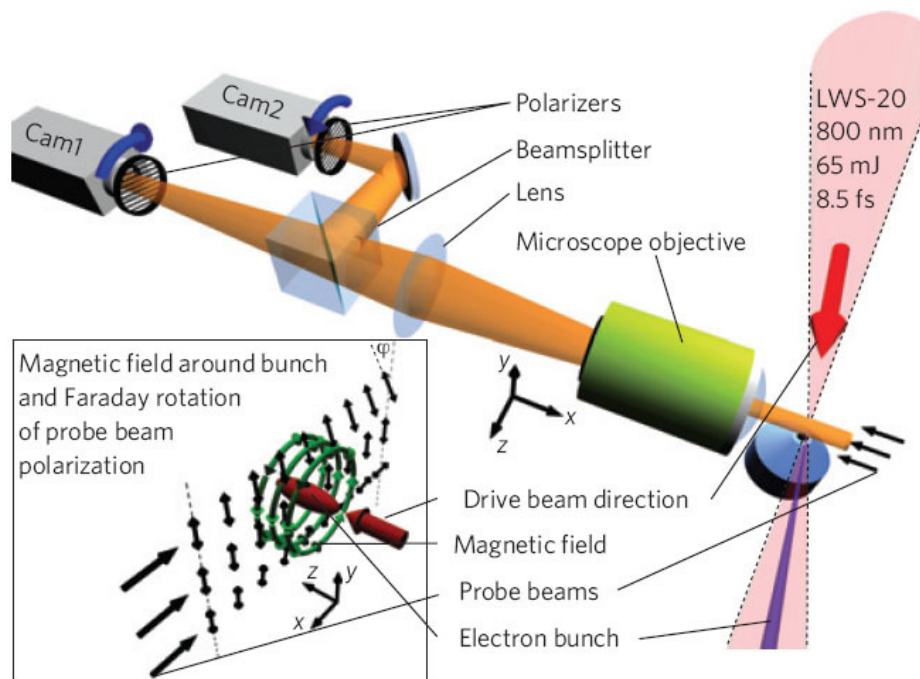
- BAMs and bunch length measurement (ARD topic 3)
- plasma target development for more stable operation
- external injection with *ELBE*-beam (longer than plasma period)



- established synchronized operation of ELBE and laser -> Thomson scattering

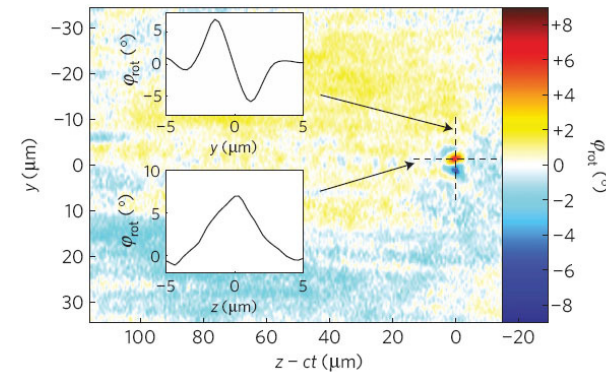
projects at HI Jena

- In-situ observation of electron acceleration (collaboration with MPQ within TR18)
- detection of electron pulse via mg. fields (Faraday-effect)

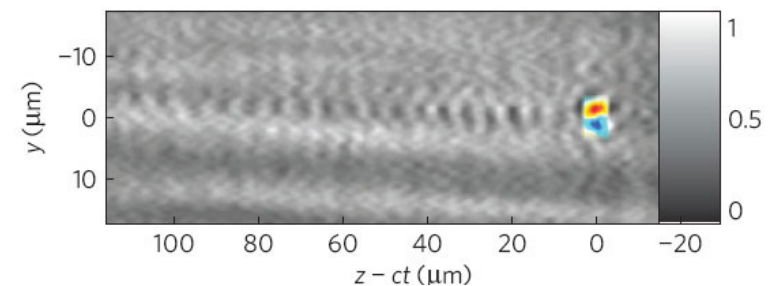


A. Buck, M. Nicolai, MCK *et al.*, Nature Physics **7**, 543 (2011)

- measurement of **electron bunch duration**:
 $\tau_e = (2.5 \pm 0.9) \text{ fs (r.m.s.)}$,



- first in-situ detection of **plasma wave**: visualize acceleration,



plans at DESY



three-labs approach for **unique** research:

now - ... **PITZ**

2013 – 2015: **REGAE** (relativistic electron gun)

2015-... : move to **FLASH**

- how to **access/control** wakefield? → study **external injection**:

- probe wakefields
- emittance growth
- staging scalability

REGAE

FLASH

- **beam-driven studies**

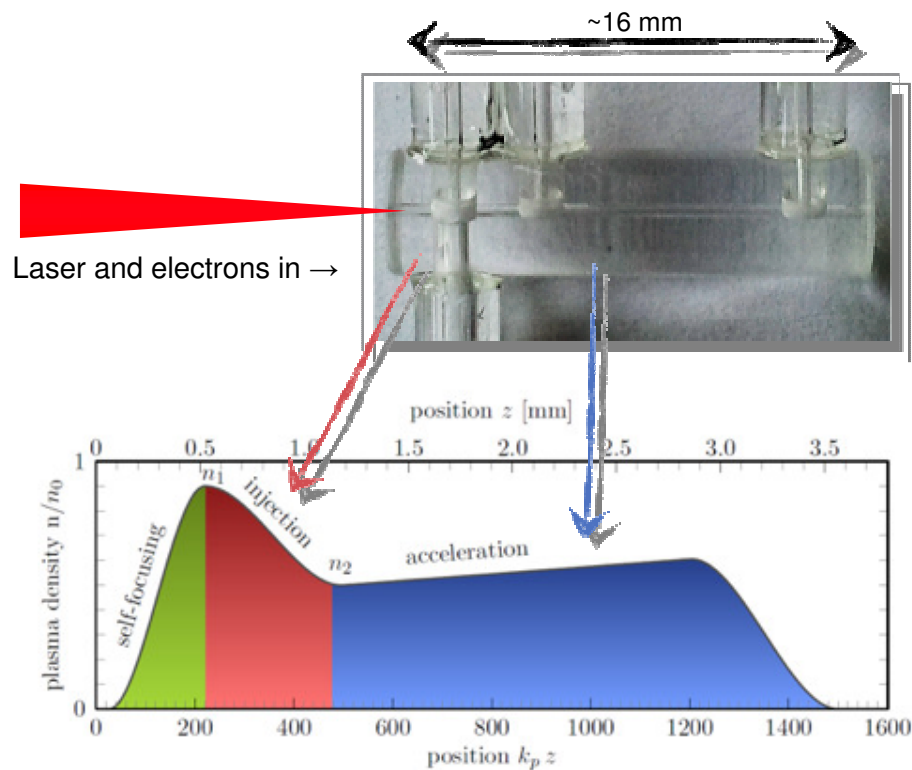
- transformer ratio
- beam self-modulation
(here w/ electrons, CERN w/ protons)

PITZ + FLASH

PITZ

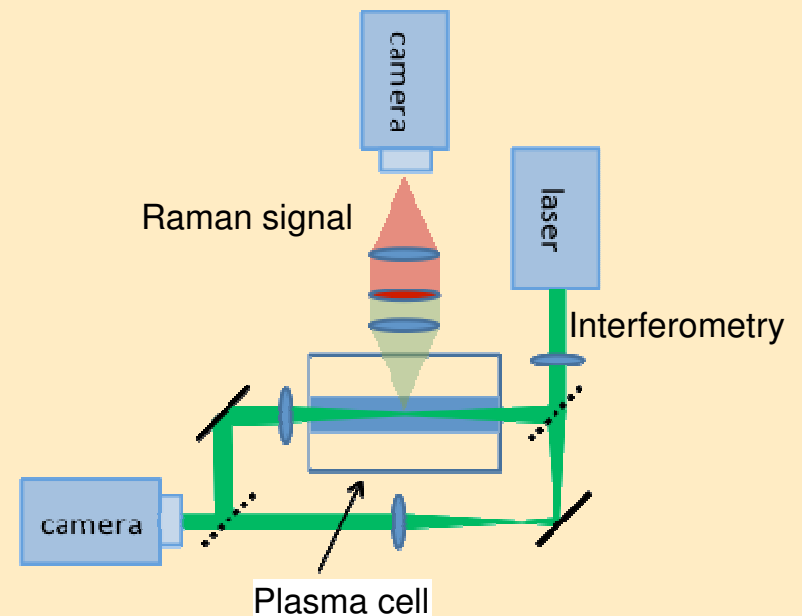
tailored plasma targets – joint project between DESY, HZDR, and HI Jena

- > tailored plasma-density profiles important to **control** acceleration process and stability
- > first test runs at HZDR + HI Jena



- > Required plasma densities for LAOLA experiments $\sim 10^{17} \text{ cm}^{-3}$, difficult to diagnose

Sensitive diagnostics being developed:



- > Density regime important for many other upcoming PWA projects (e.g. BELLA @ LBNL)

summary

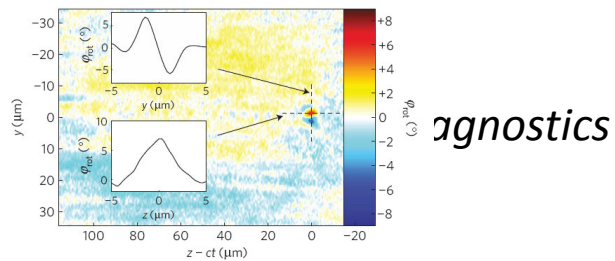
- **unique research opportunity/added value:**

combining various expertise at different Helmholtz labs

and

merging modern accelerators with plasma-wakefield accelerators

- **key experiments:**



al injection

beam-driven studies