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**

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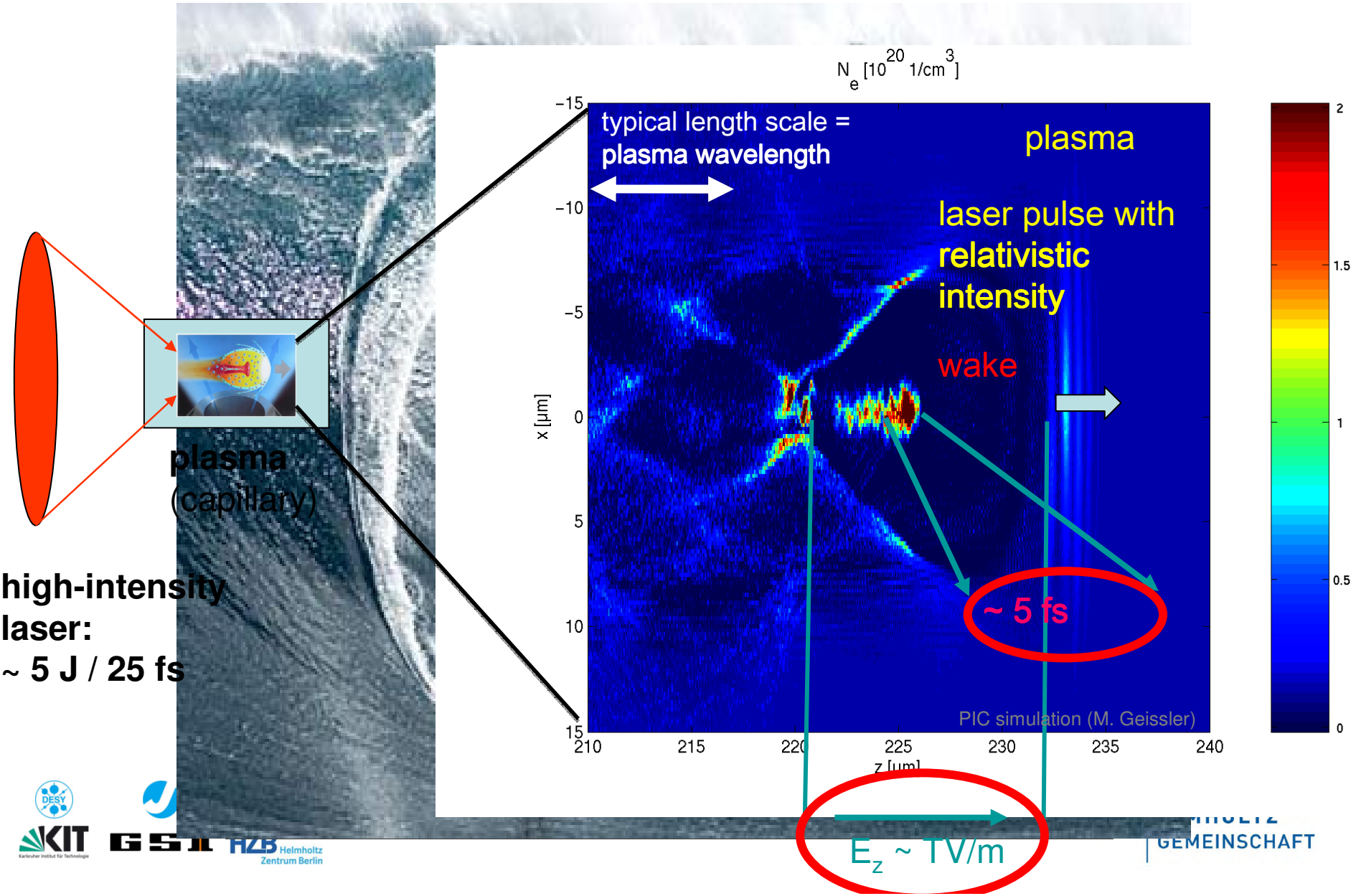
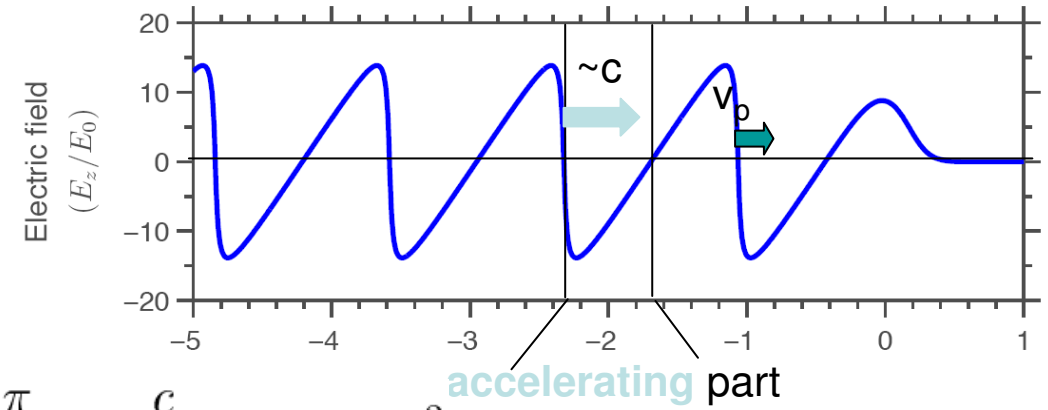
plasma wakefield acceleration: basics



maximum energy - dephasing

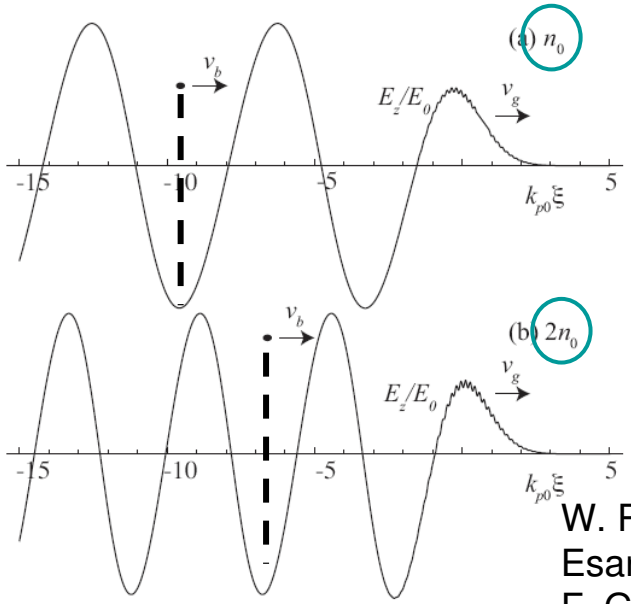
dephasing:
electron faster than wake



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

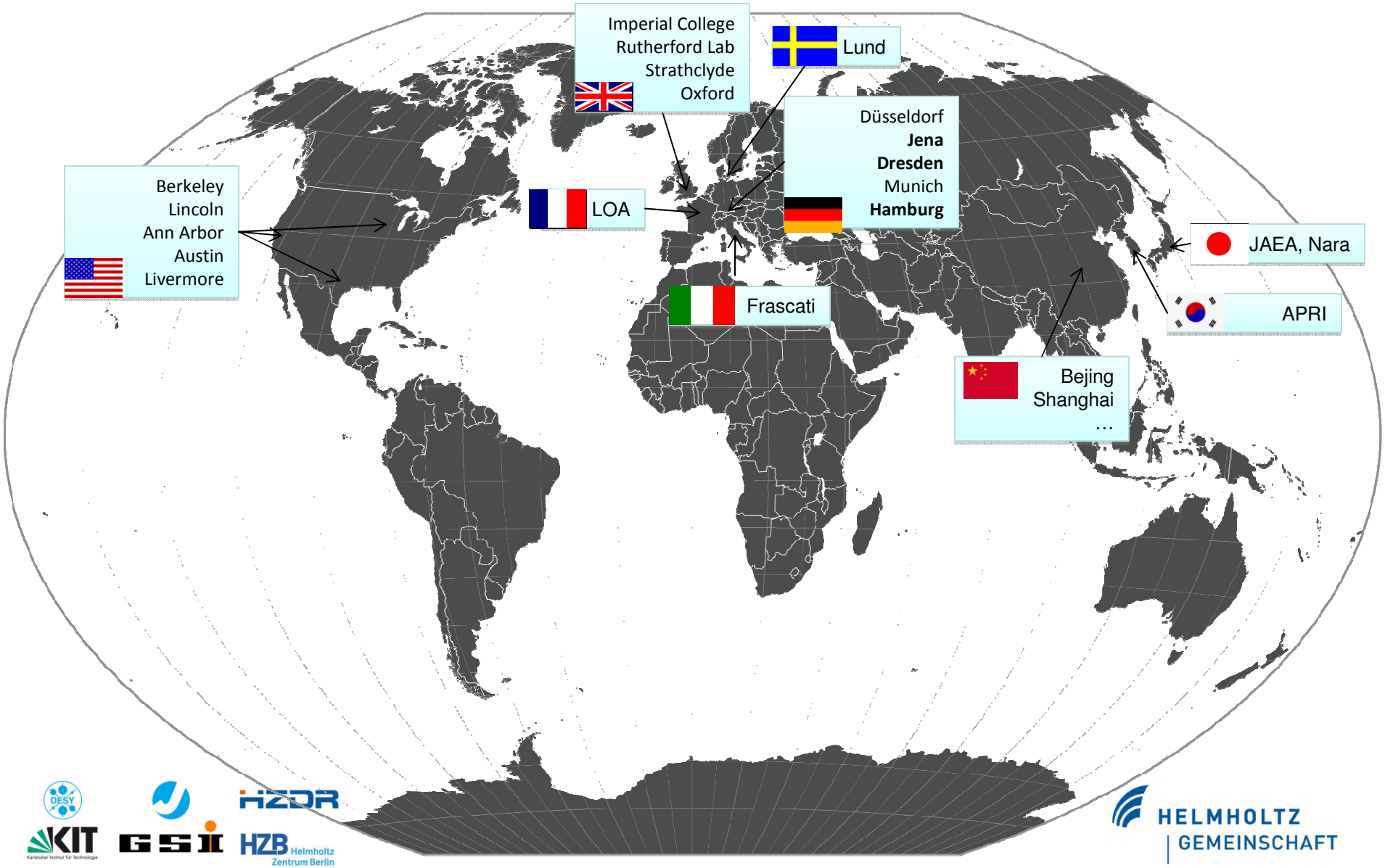
maximum energy: $$W \approx eE_m L_d \longrightarrow W_m \approx 2\pi\gamma_p^2 (E_m/E_0)mc^2$$

solution:
plasma **up**-ramp



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

PWA worldwide



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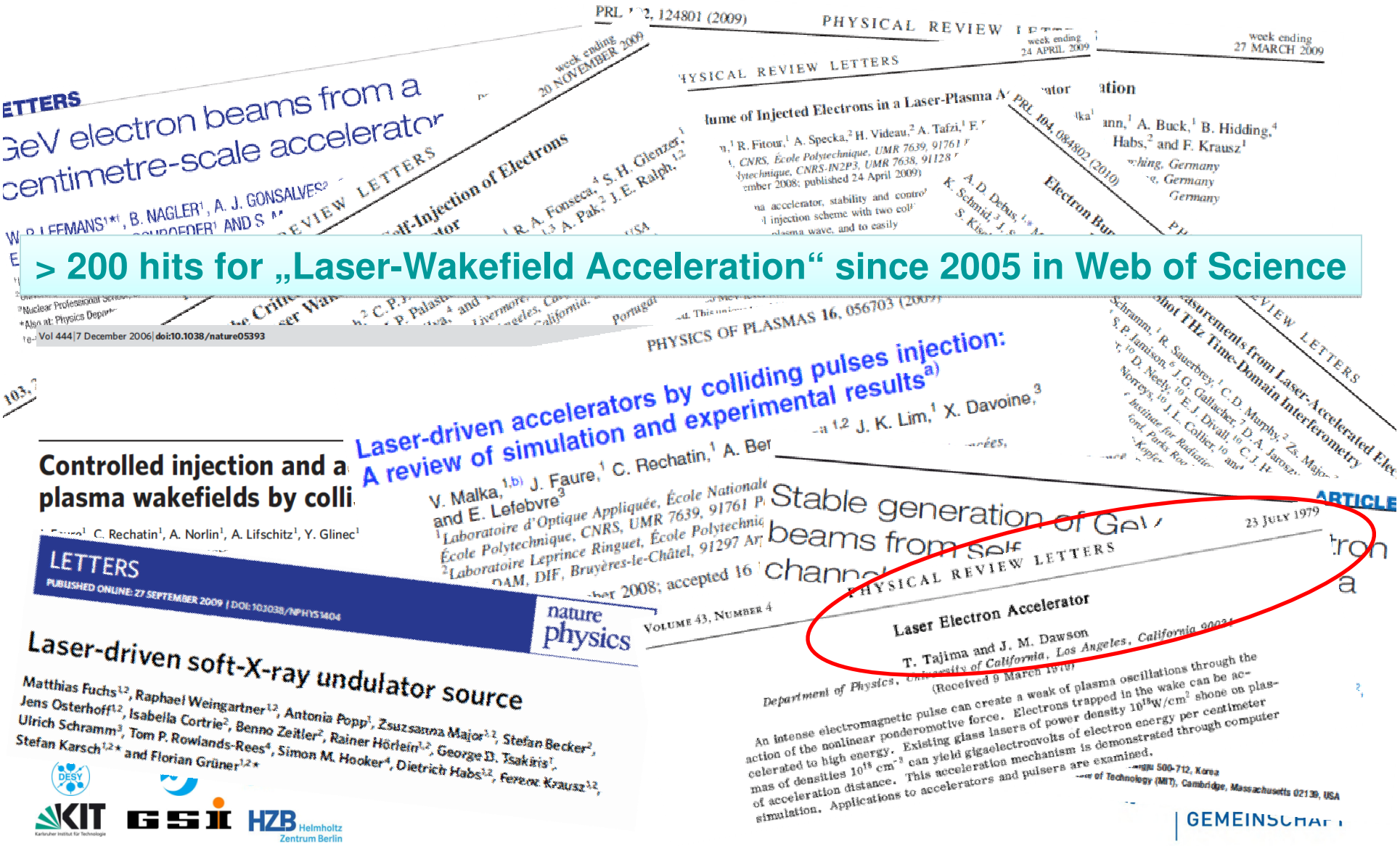
PWA worldwide II

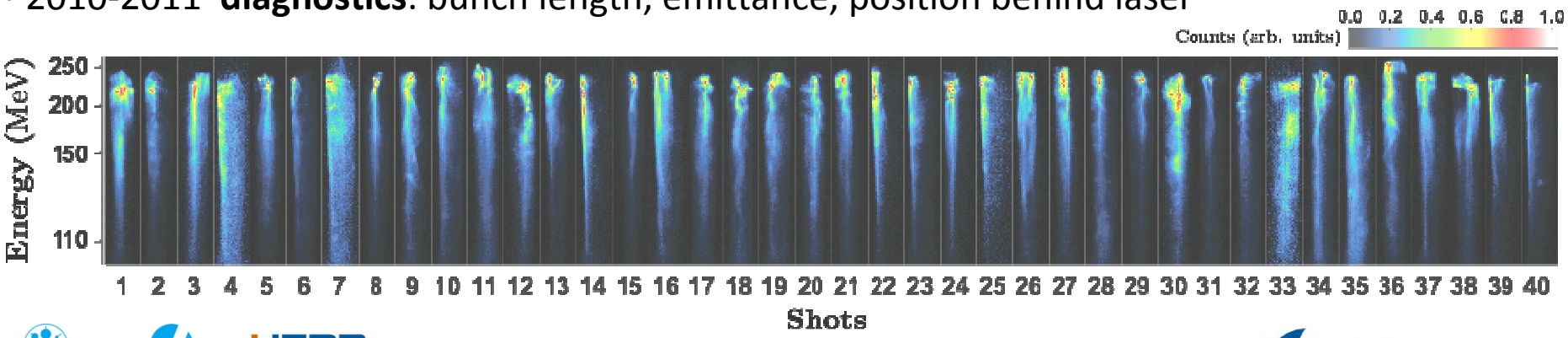


PWA history

- 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



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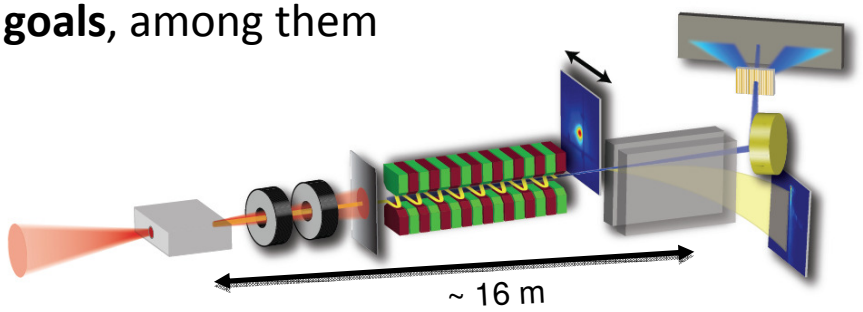
perspectives

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

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

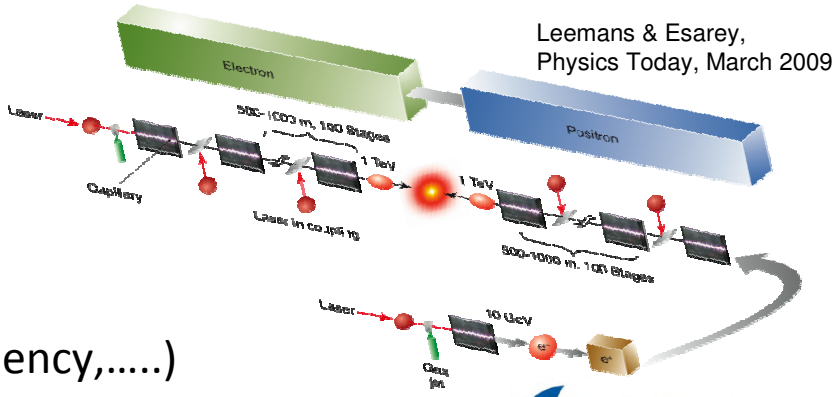


- **brilliant X-ray sources** „at home“, added values:

  - 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,.....)



Leemans & Esarey,
Physics Today, March 2009

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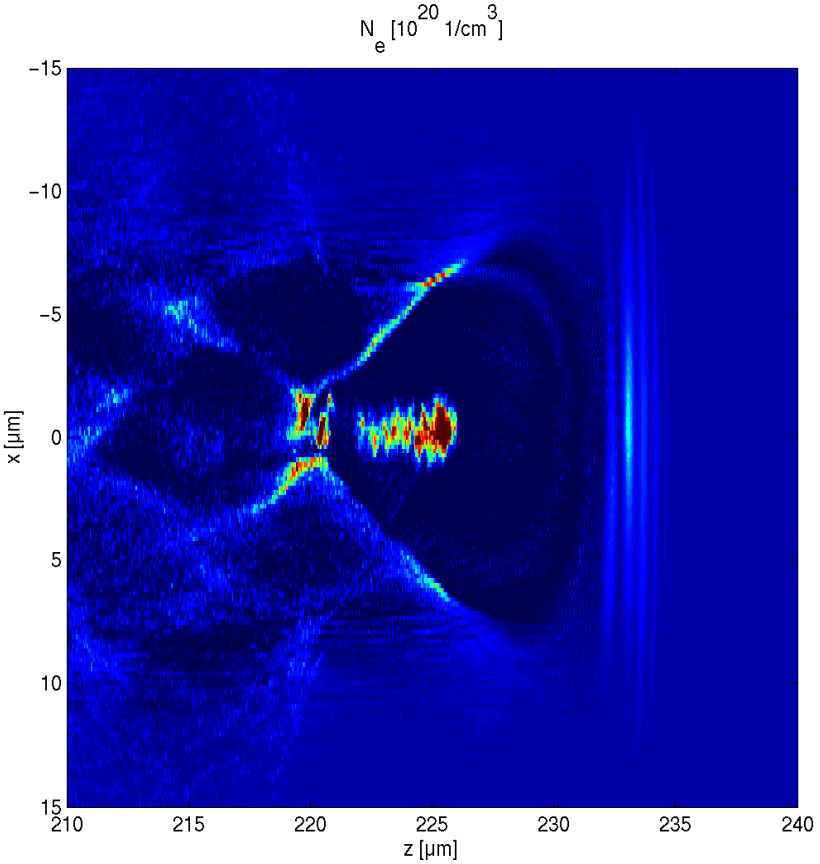
open questions



how does it all work?

- selft-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

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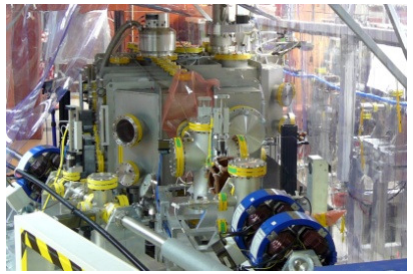
players within Helmholtz

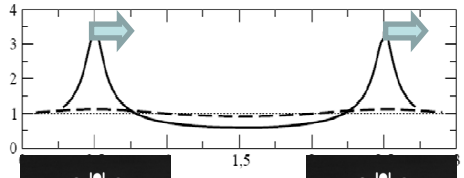
HZDR: studies of laser-plasma acceleration and diagnostics, external injection of *ELBE*-bunches



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

DESY + UHH → LAOLA = Laboratory f**o**r **L**aser- and beam-driven Plasma **A**cceleration

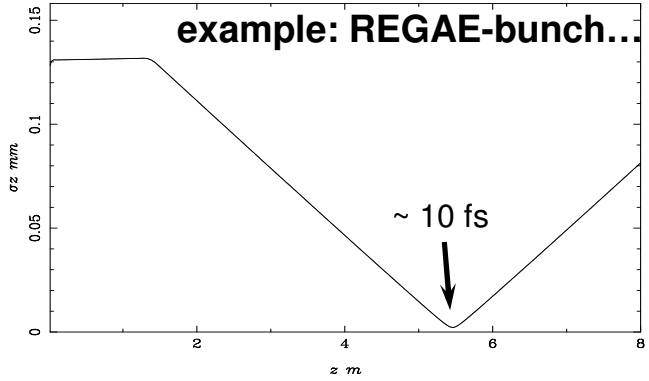
= combination of PWA & DESY's modern accelerators

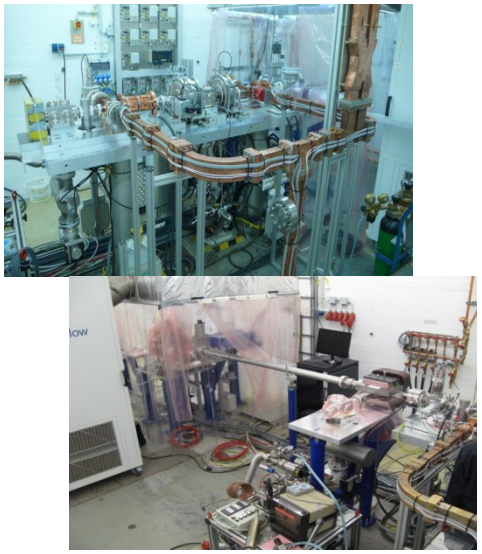


plasma density profile

Laola Laola

key experiment: external injection

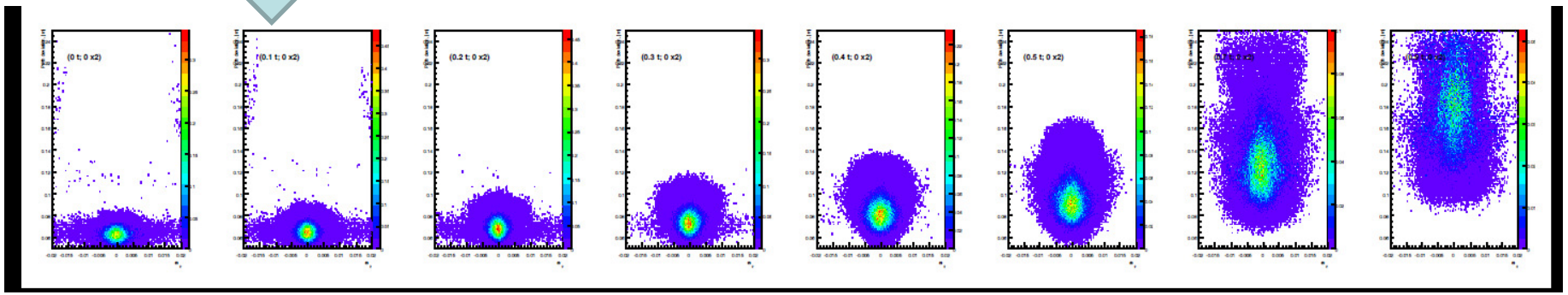




…to be **injected** into wakefield ~ 300 fs…

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

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



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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)

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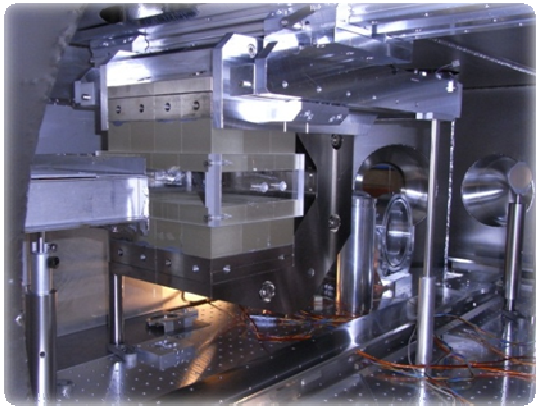
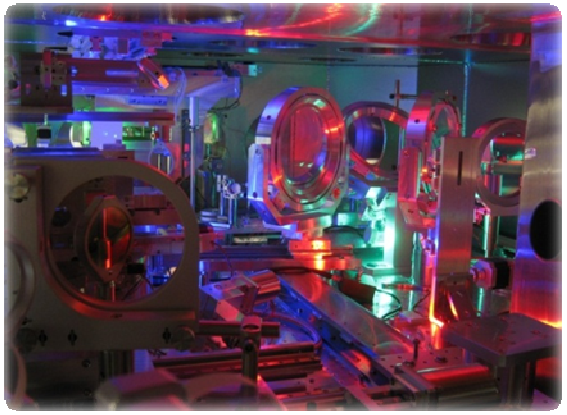
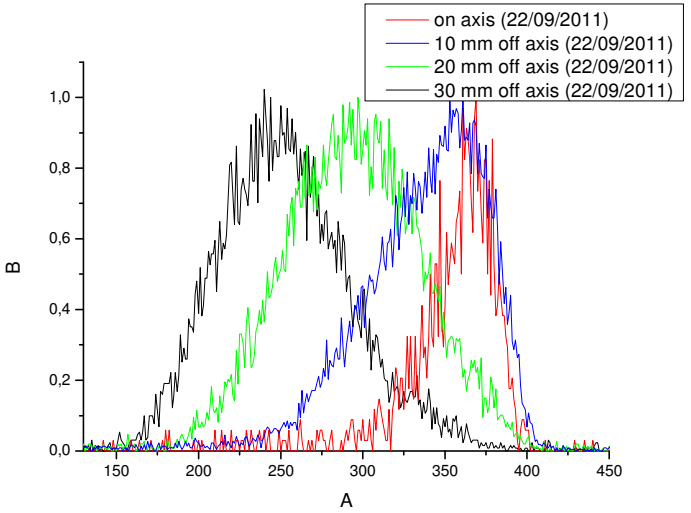
plans at HZDR

- 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

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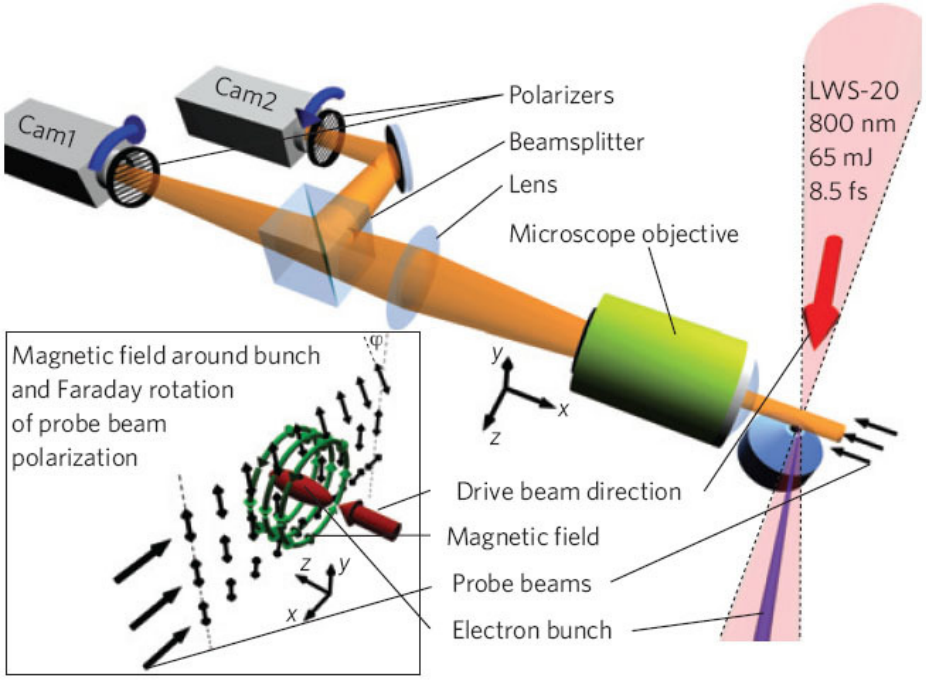
projects at HI Jena

- In-situ observation of electron acceleration (collaboration with MPQ within TR18)

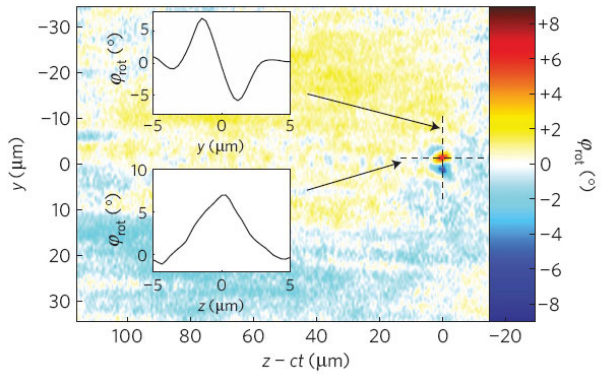
TR 18

- detection of electron pulse via mg. fields (Faraday-effect)

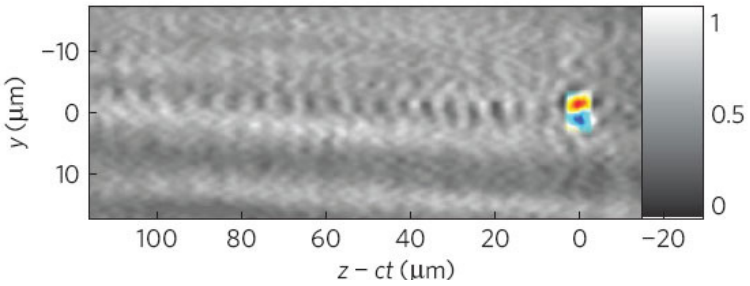


A. Buck, M. Nicolai, MCK *et al.,* Nature Physics **7,** 543 (2011)

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



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



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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

  REGAE

  - staging scalability

  FLASH

- **beam-driven studies**

  - transformer ratio

  PITZ + FLASH

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

  PITZ

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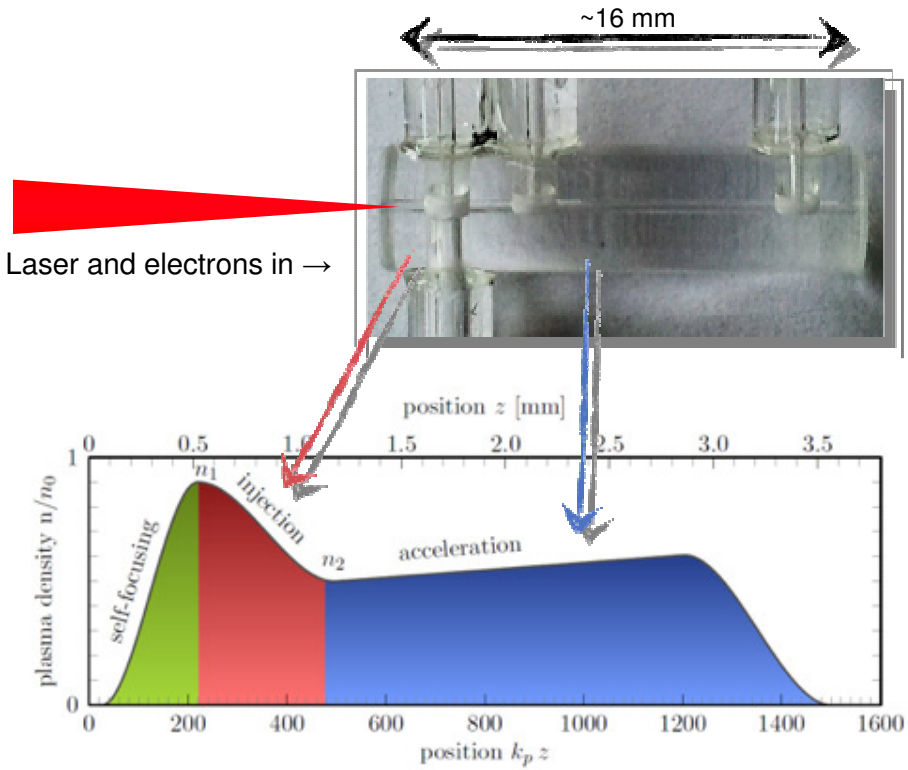
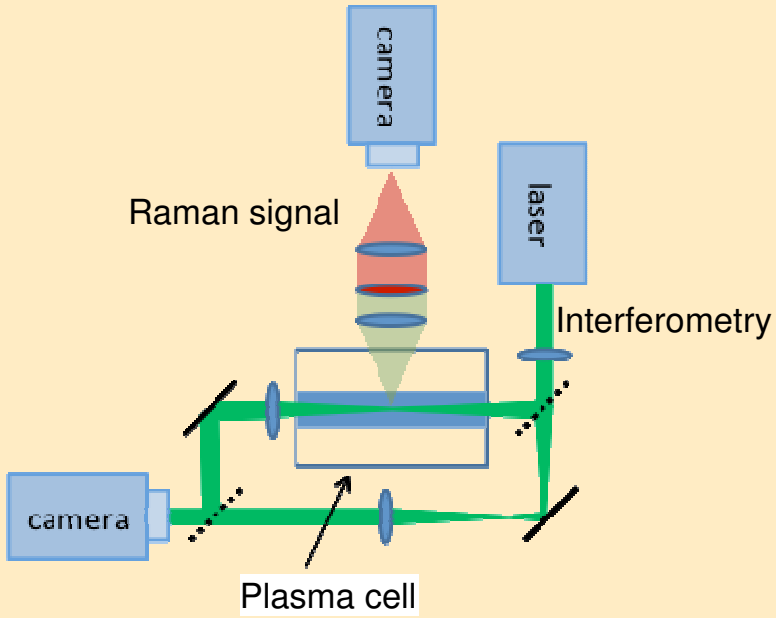
tailored plasma targets – joint project between DESY, HZDR, and HI Jena

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



- Required plasma densities for LAOLA experiments ~10^{17} cm^{-3}, difficult to diagnose

Sensitive diagnostics being developed:



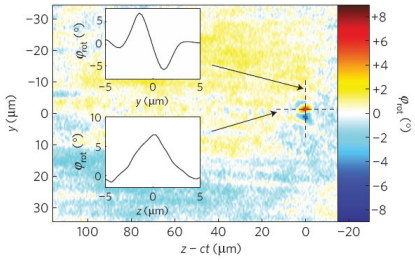
- Density regime important for many other upcoming PWA projects (e.g. BELLA @ LBNL)

summary

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

  combining various expertise at different Helmholtz labs
  and
  merging modern accelerators with plasma-wakefield accelerators

- **key experiments**:



agnostics

al injection
beam-driven studies