Overview of laser-driven X-ray sources

- basic concept
- **open questions**
- experimental break-thru

The FEL group

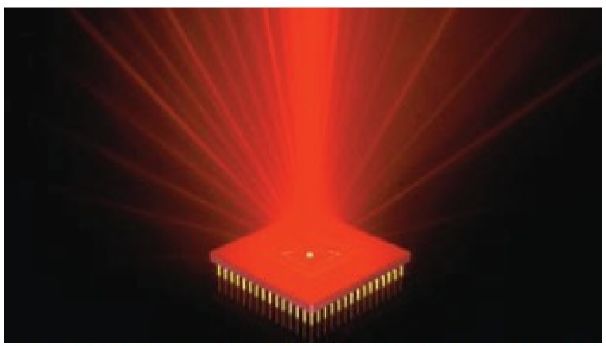
Basic Setup – as seen by *NatureNews*…

MPQ LMU www.attoworld.de

naturenews

News: Driven out of research   stop ticker | previous | next

Top story



Physicists shrink X-ray source

27 September 2009

Latest stories

Q+A: **Driven out of research** P

A virologist describes how stringent biosecurity regulations caused her to drop one line of work.

30 September 2009

Rutherford Building cancers a "coincidence"

Independent inquiry finds cancer connection to historic radiation experiments "unlikely".

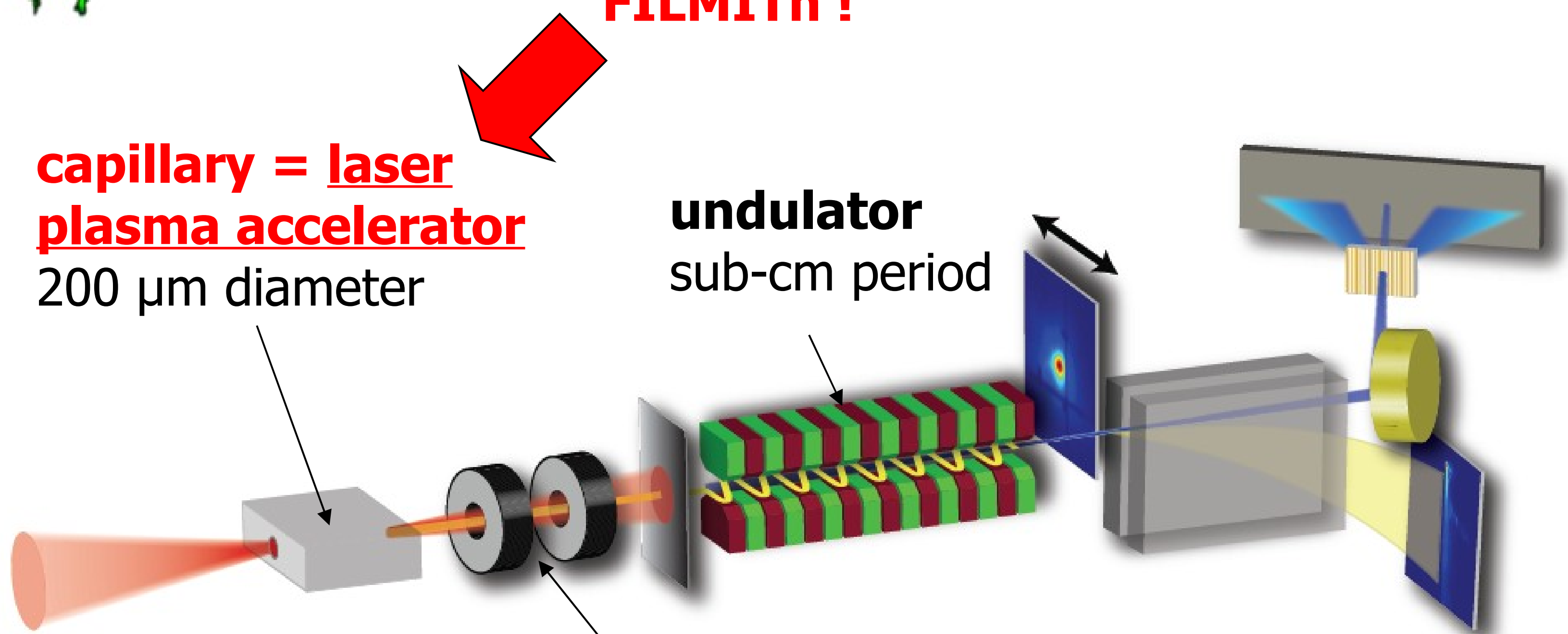
30 September 2009

Basic Concept – in reality

FILMITh !

capillary = <u>laser plasma accelerator</u>
200 µm diameter

undulator
sub-cm period



laser
energy ~ J
pulse length ~ 25 fs

magnetic lenses
500 T/m gradient

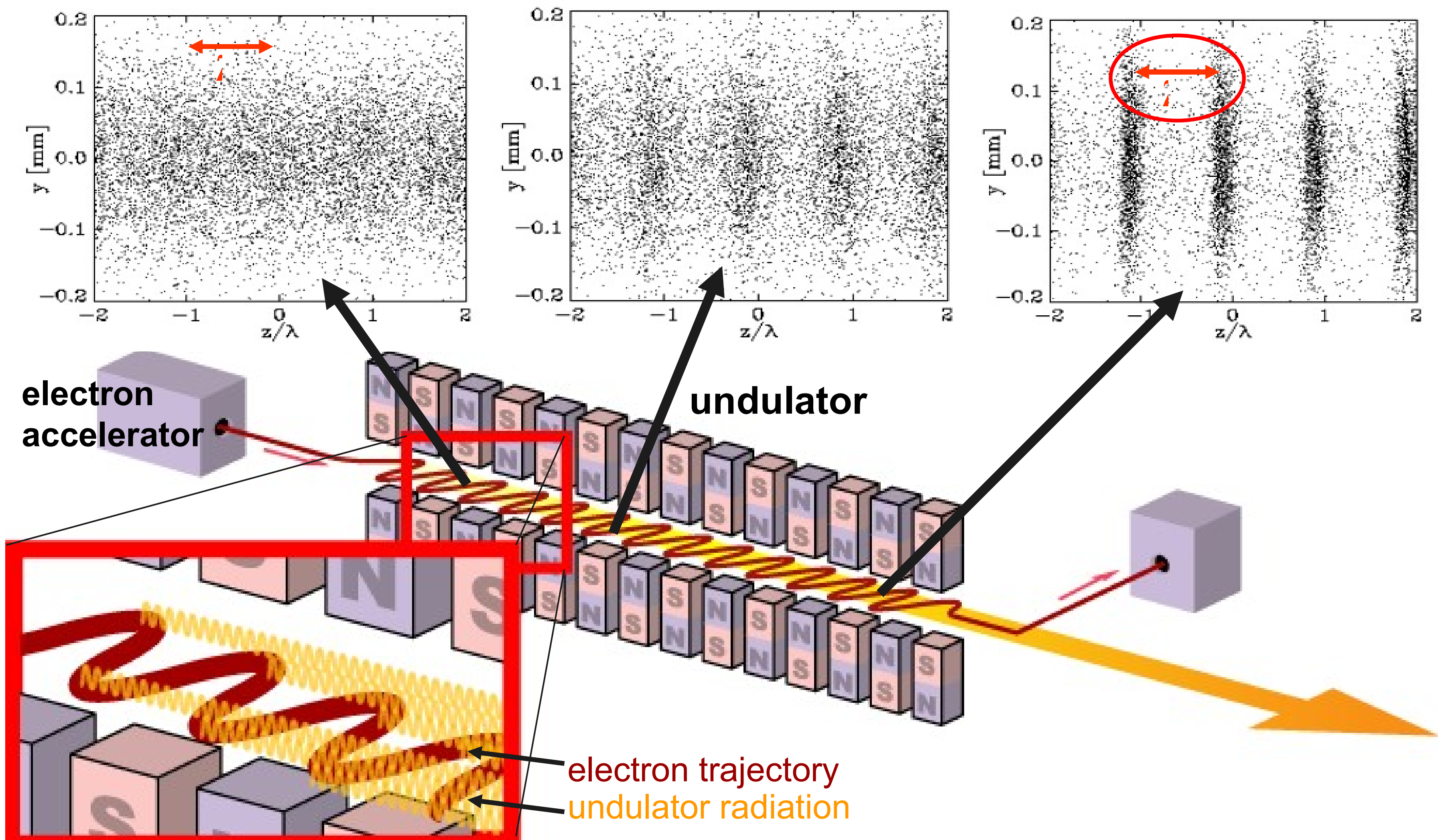
diagnostics/ applications

2 tables

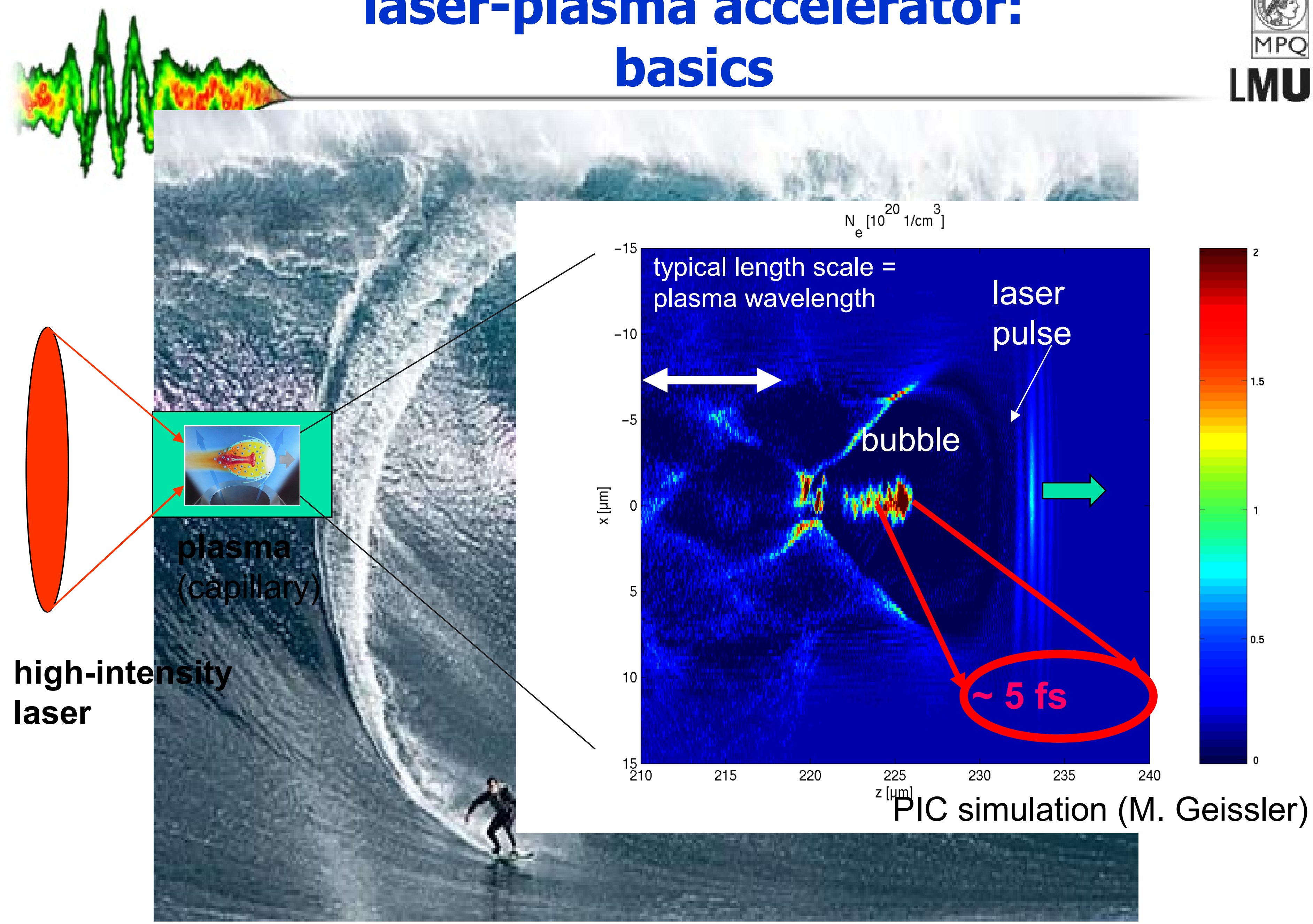
up to 2 m

up to 6 m (modular)

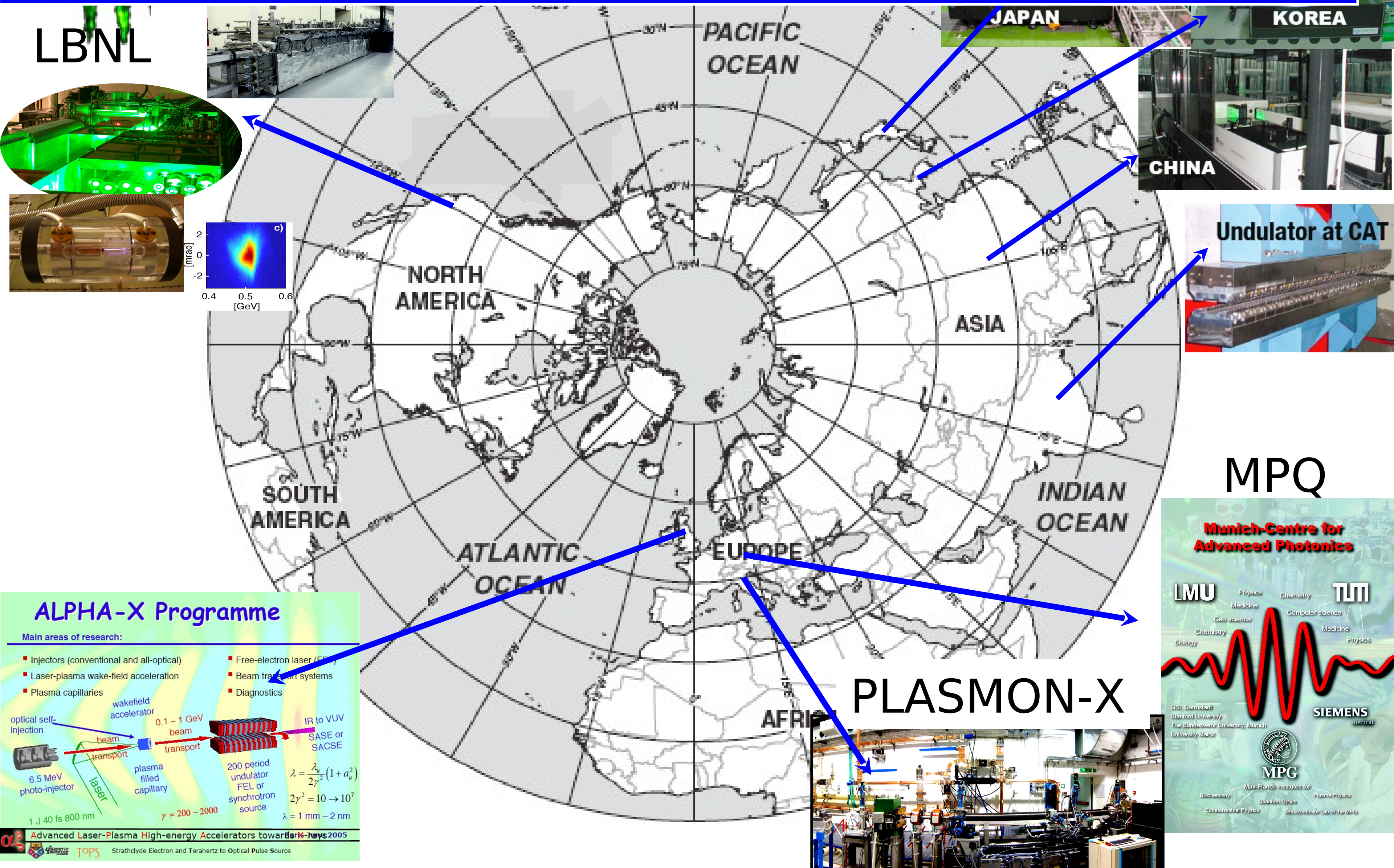
What is a free-electron-laser (FEL) ?



laser-plasma accelerator: basics



World-wide effort aimed at FEL using laser-plasma accelerators (courtesy of C. Schroeder)



let's look back:
Dream Beam Symposium 2007

Design Studies of *Table-Top* Free-Electron-Lasers

Dream Beam Symposium, Feb 26-28, MPQ 2007

F. Grüner, S. Becker, M. Fuchs, R. Weingartner, T. Eichner,
B. Marx, **D. Habs** (LMU)
U. Schramm (FZD)
S. Karsch, J. Osterhoff, A. Popp, M. Geissler, L. Veisz, J. Meyer-ter-Vehn,
Z. Major, **F. Krausz** (MPQ)
S. Reiche (UCLA)

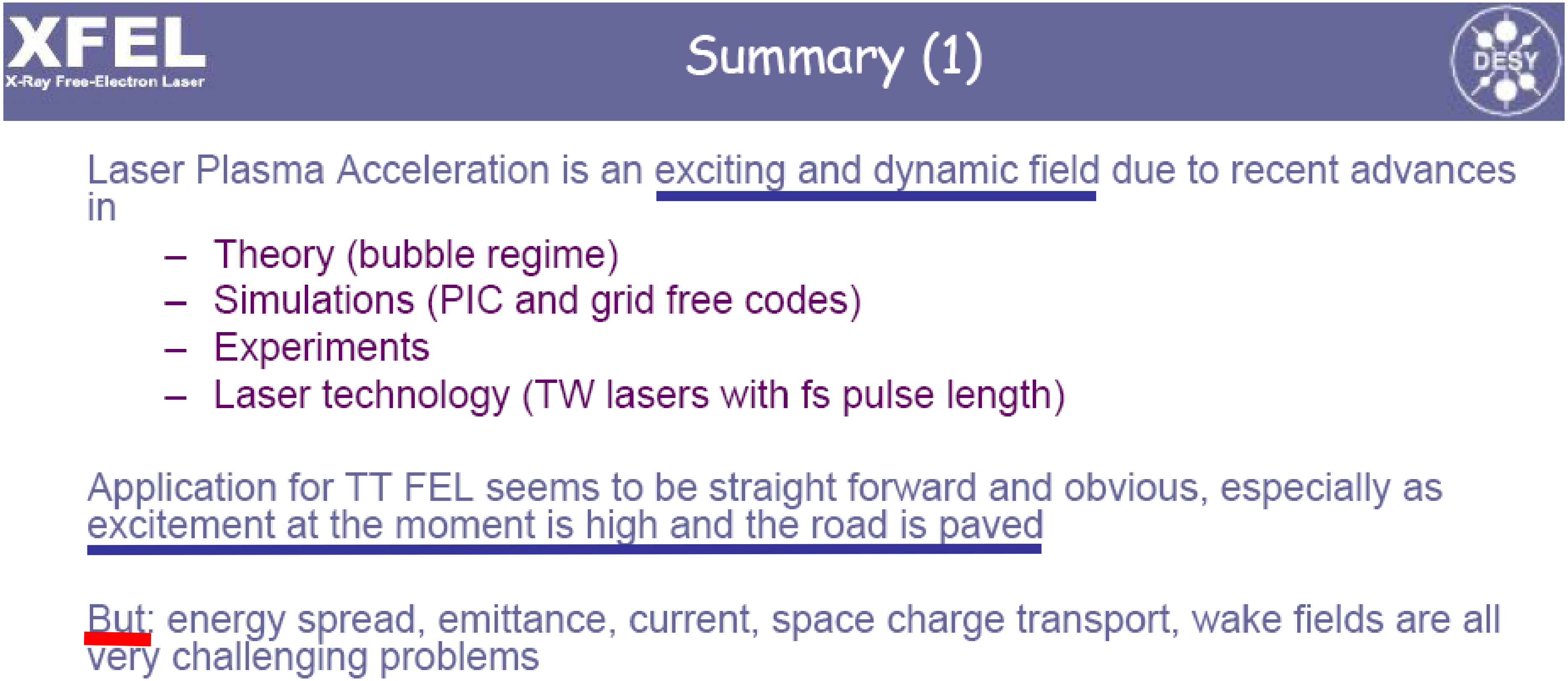
- why XFELs?
- what is an FEL?
- principal possibility of *table-top* FELs
- **demands on bubble physics**
- experimental status

let's look back: Dream Beam Symposium 2007

Demands on "Bubble Physics"

- we need new ideas for reaching the demanding parameters
  - proof-of-principle cases relaxed
  - TT-XFEL for 5 keV
  - med-XFEL for 50 keV:
    ~7 GeV electrons, 0.1% energy spread,
    ≤ 0.5 mm·mrad norm. emittance, ≥ 1 nC charge
- we need models/designs for capillary scenarios:
  - bubble to blowout transition?
  - density gradients?
  - staged capillaries?
- we need understanding of the amount of energy spread, emittance
  - make use of dephasing?
  - is absolute energy spread frozen after injection?
  - emittance reduction?

DESY's summary of Dream Beam Symposium 2007


XFEL
X-Ray Free-Electron Laser

Summary (1)

Laser Plasma Acceleration is an exciting and dynamic field due to recent advances in

- Theory (bubble regime)
- Simulations (PIC and grid free codes)
- Experiments
- Laser technology (TW lasers with fs pulse length)

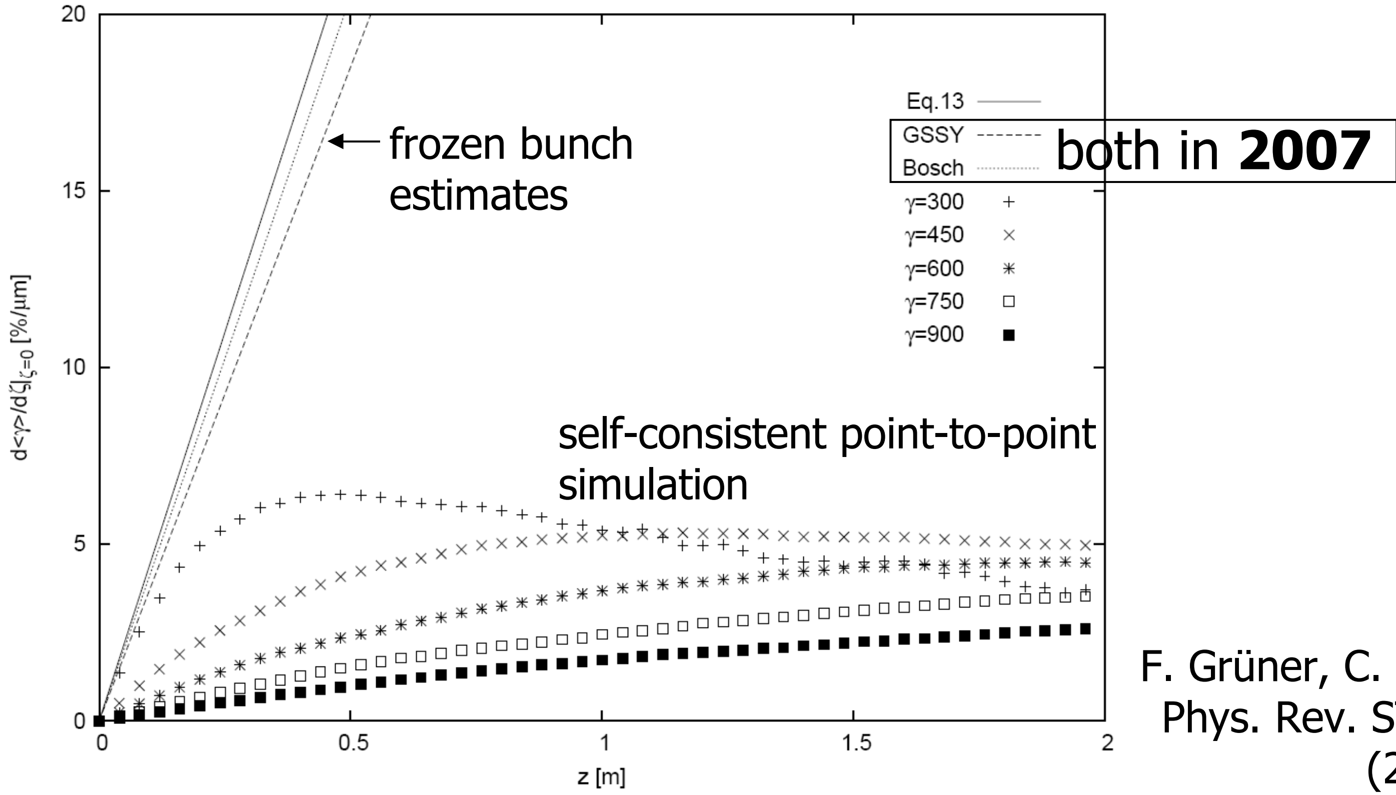
Application for TT FEL seems to be straight forward and obvious, especially as excitement at the moment is high and the road is paved

But: energy spread, emittance, current, space charge transport, wake fields are all very challenging problems

http://www.desy.de/fel-beam/data/talks/talks/decking_-_dream_beams_symp_20070305.pdf

critical issues

- **space-charge issues** (case study: 0.4 nC, σ_z = 1.0 μm, 150 MeV)



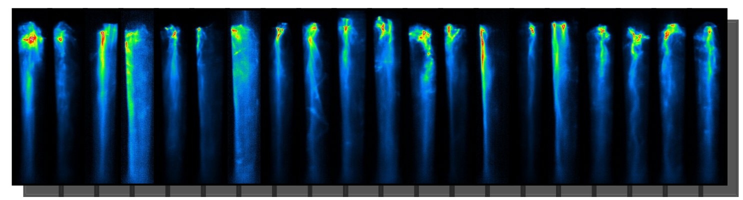
F. Grüner, C. Schroeder, et al., Phys. Rev. STAB 12, 020701 (2009)

- **wakefields**

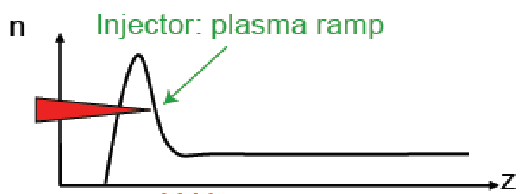
→ cryogenic undulator (cooperation with BESSY)

laser-plasma accelerator: state-of-the-art

- 2000, theory of bubble acceleration (Meyer-ter-Vehn & Pukhov)
- 2004, first experimental results (Nature cover issue)
- 2006, Berkeley lab reaches 1.0 GeV (W. Leemans et al., Nature Physics)
- 2008, stability improvement (MPQ, PRL)
- 2008/09, new schemes:



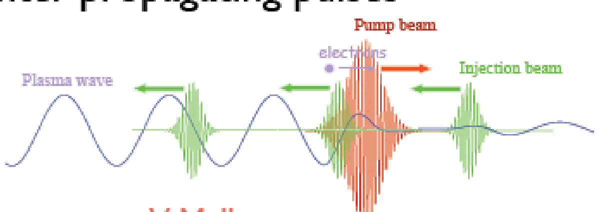
downramp injection



courtesy: W. Leemans

0.5-1 nC, low long. & trans. momentum: C.Geddes et al, PRL 100 (2008)

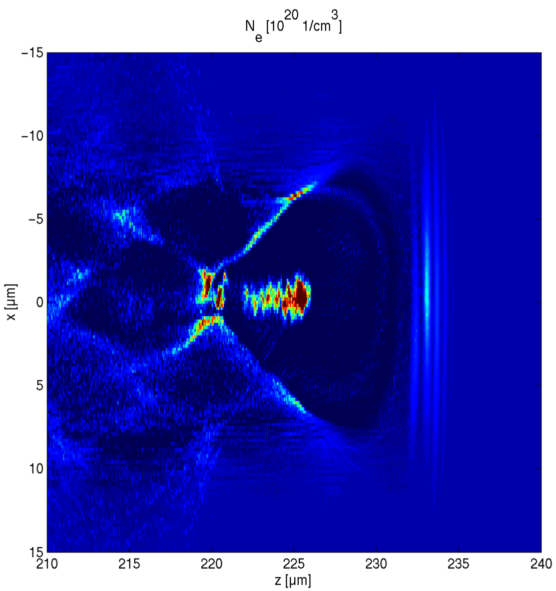
counter-propagating pulses



courtesy: V. Malka

1% RMS: C.Rechatin et al, PRL 102 (2009)

laser-plasma accelerator: open questions

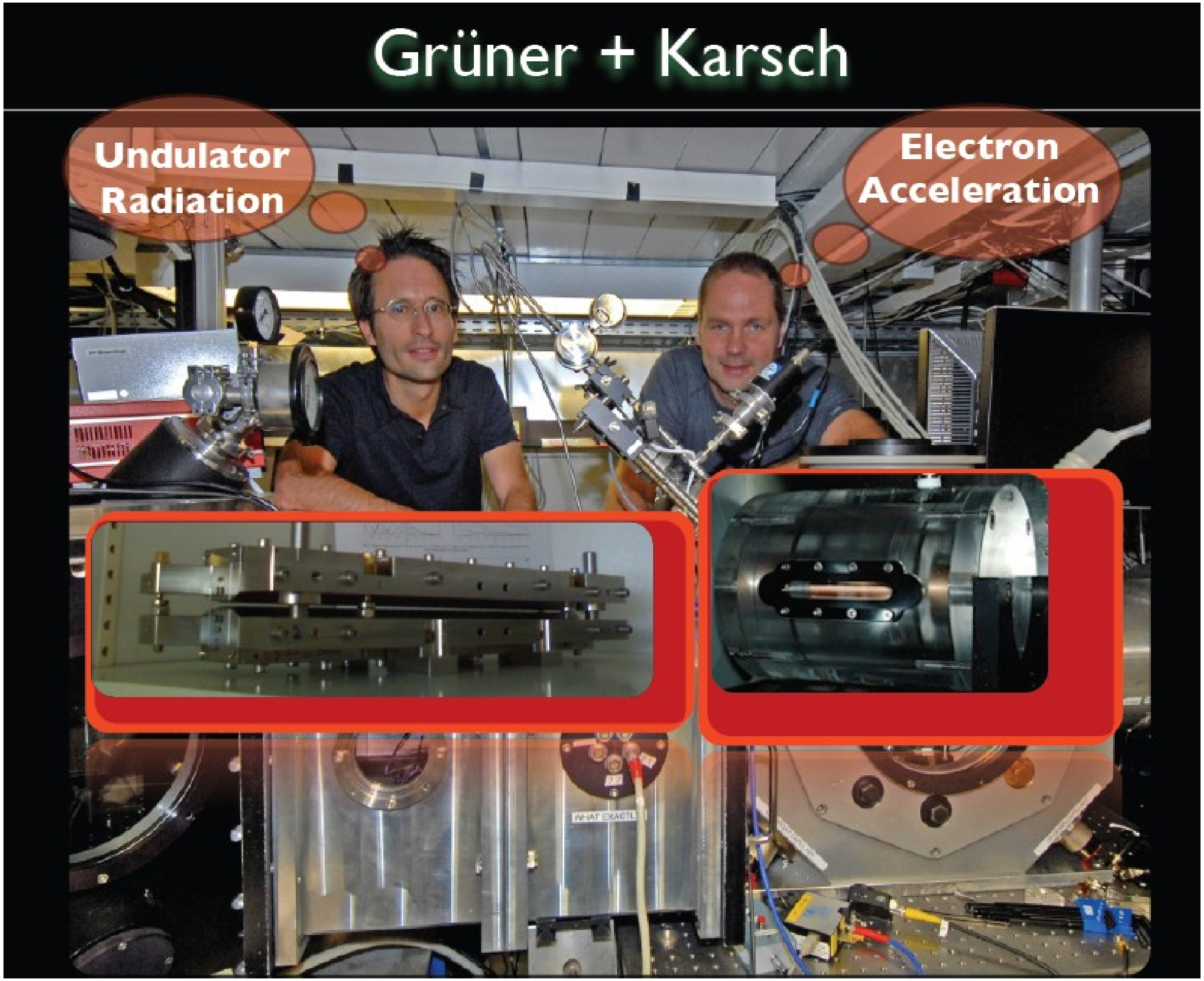


- discrepancy between simulated and measured charge (beam loading, resolution of PIC codes, laser instabilities)
- **energy spread** typically ≥ 1…5 %
  FEL requires < 0.1…0.5 %

- ? minimum energy spread ?
- ? minimum emittance ?
- ? trapped charge/bunch length ?

- ! study new trapping schemes !
- ! study new dephasing schemes !
- ! study beam loading !

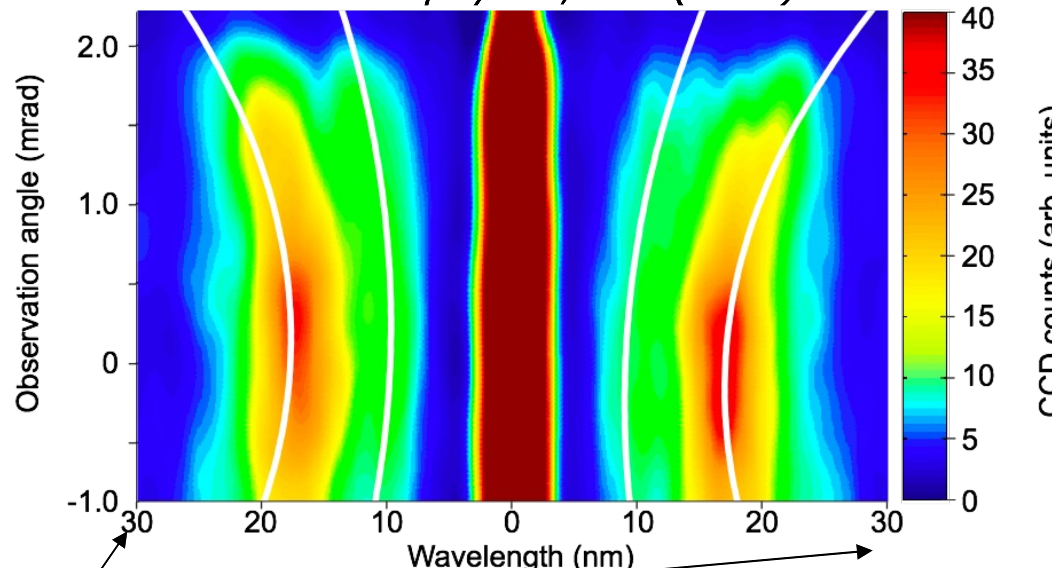
experimental break-thru



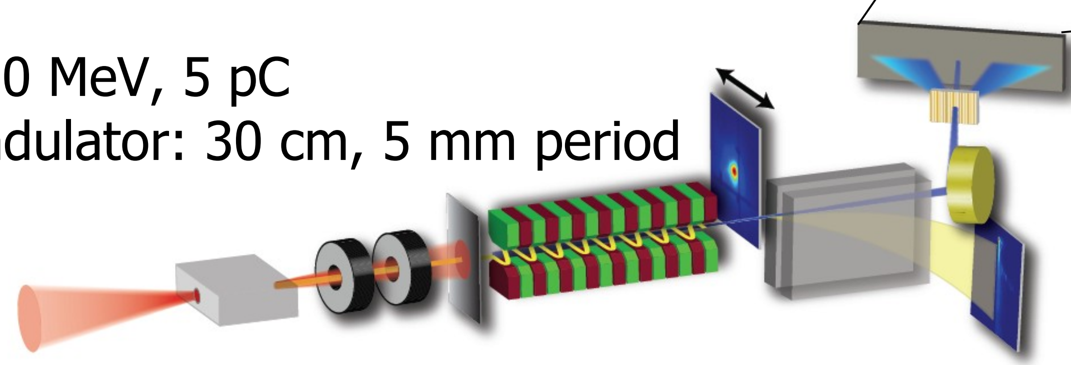
laser-driven soft x-ray undulator radiation

first time:
soft x-rays from laser-accelerated electrons

M. Fuchs,..., S. Karsch, F. Grüner,
Nature phys. 5, 826 (2009)



200 MeV, 5 pC
undulator: 30 cm, 5 mm period



spectrum in 70% of all laser shots

conclusion

- basic concept
- laser-plasma accelerators: state-of-the-art

- **open questions** – origin/control of:
  - energy spread and emittance
  - amount of trapped charge
  - bunch length

- first laser-driven x-ray undulator source