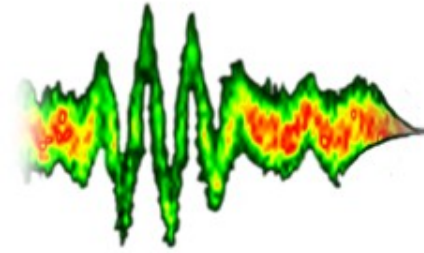


# Overview of laser-driven X-ray sources



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



# The FEL group



# Basic Setup – as seen by *NatureNews*...



www.attoworld.de  
LMU

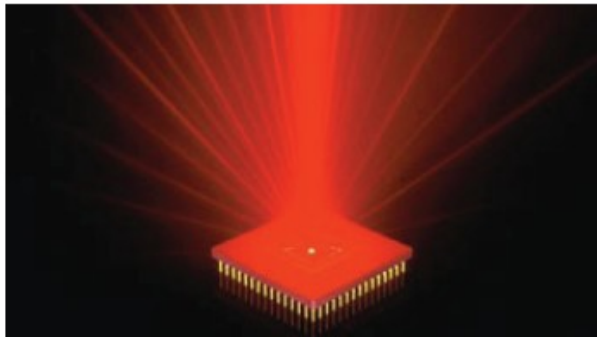


## naturenews

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

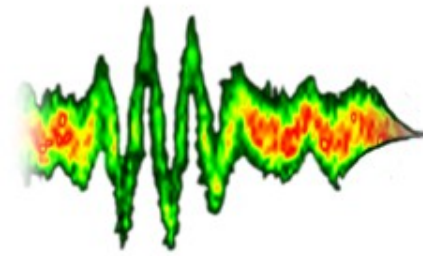


#### [Rutherford Building cancers a "coincidence"](#)

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

30 September 2009

# Basic Concept – in reality



**FILMITH !**

**capillary = laser  
plasma accelerator**  
200  $\mu\text{m}$  diameter

**undulator**  
sub-cm period

**magnetic lenses**  
500 T/m gradient

**diagnostics/  
applications**

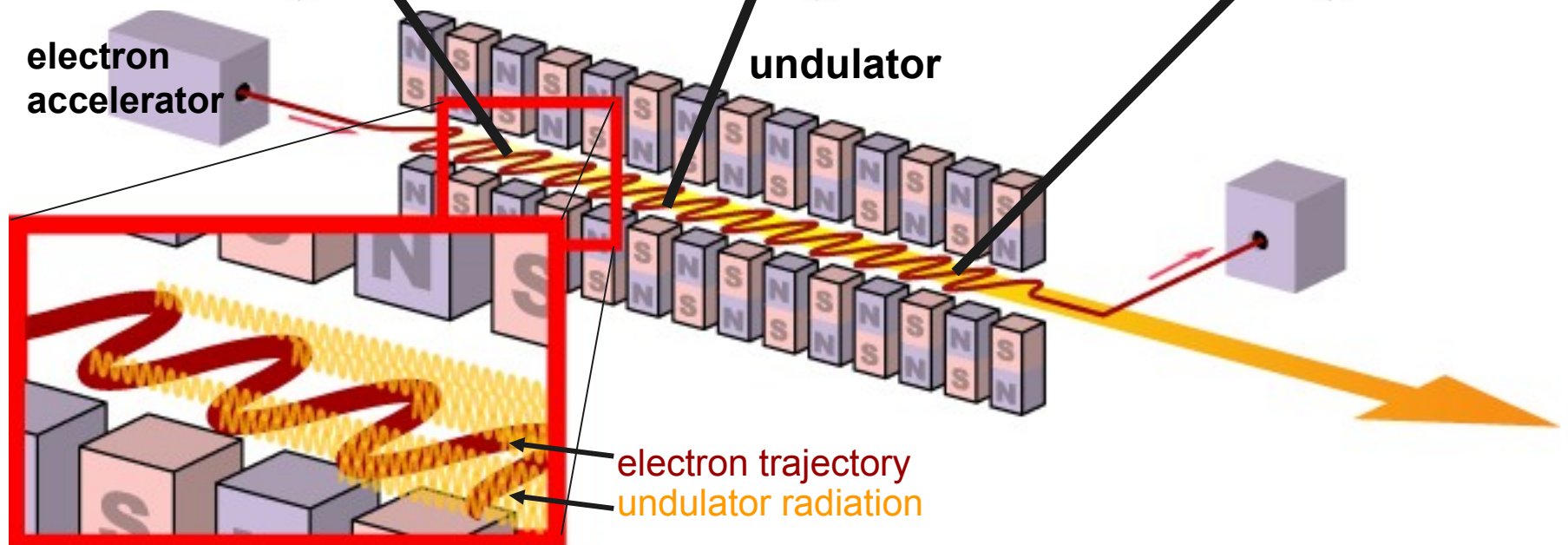
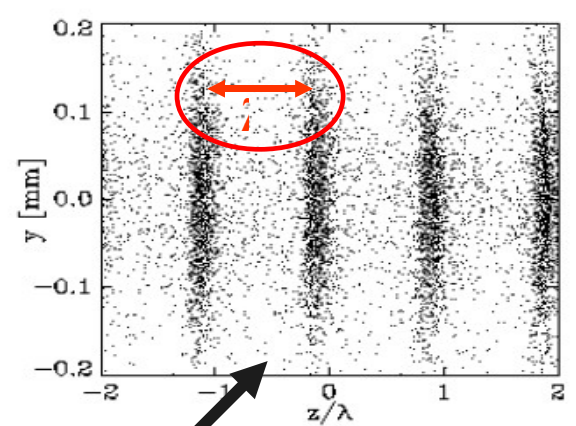
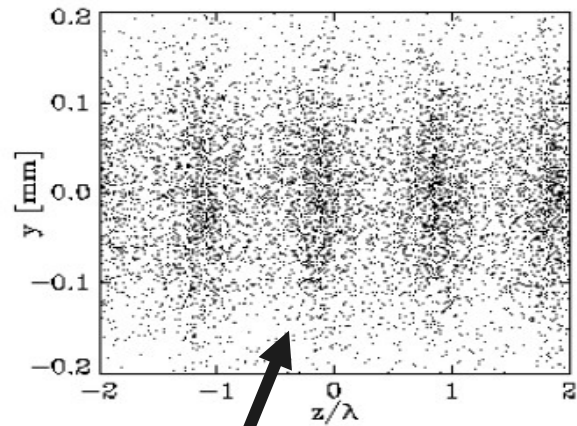
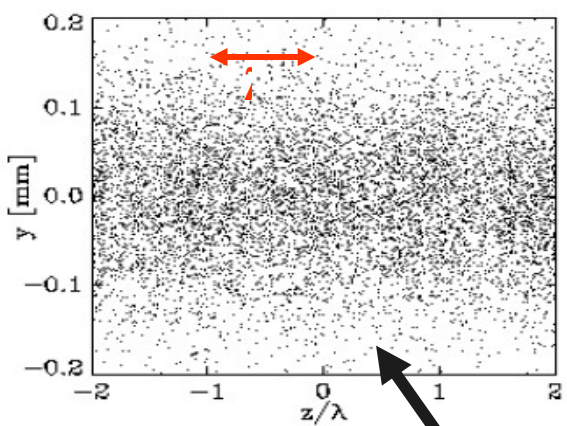
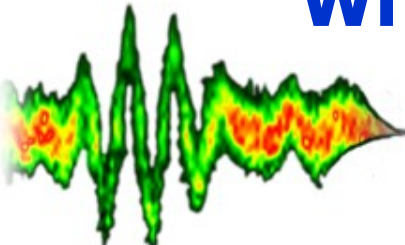
**laser**  
energy  $\sim \text{J}$   
pulse length  $\sim 25 \text{ fs}$

2 tables

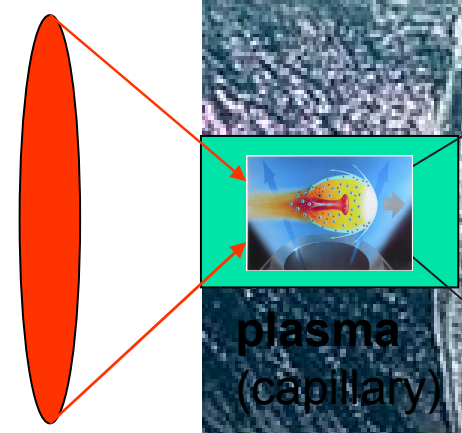
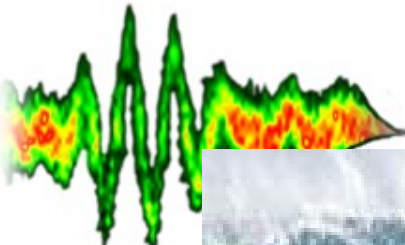
up to 2 m

up to 6 m  
(modular)

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

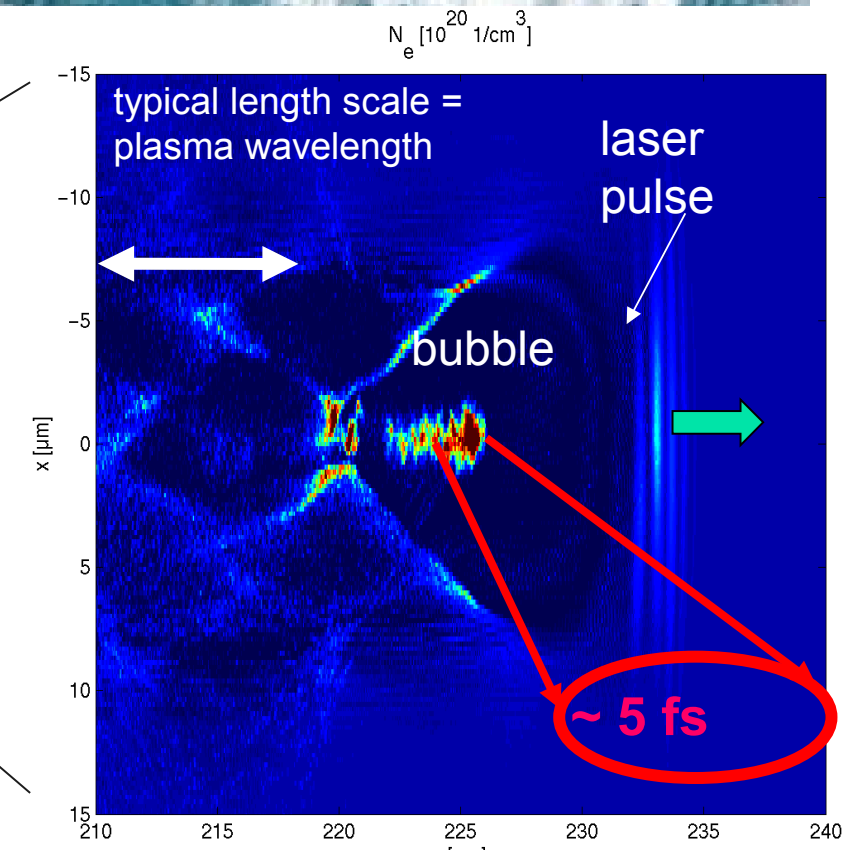
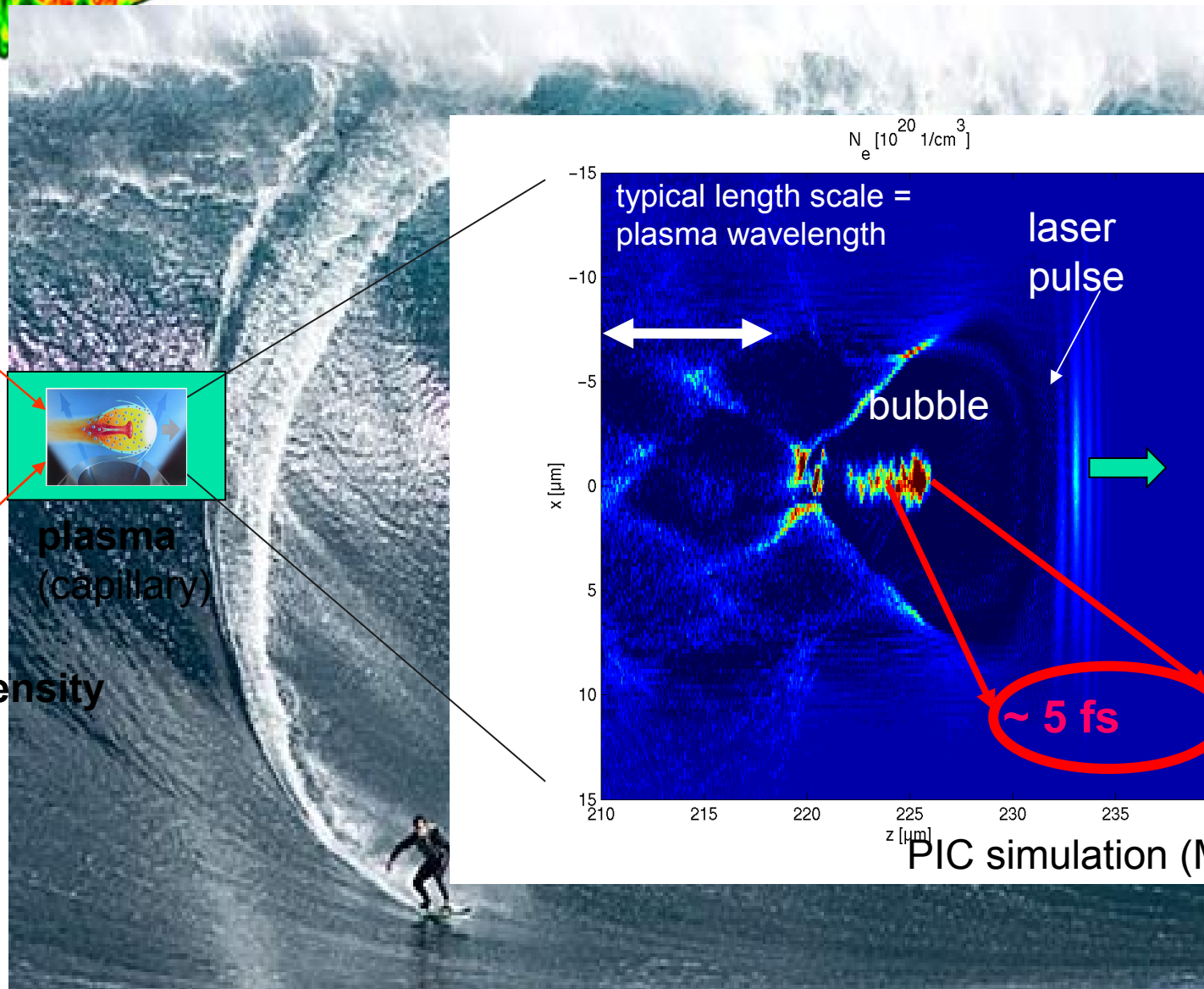


# laser-plasma accelerator: basics



high-intensity  
laser

plasma  
(capillary)



PIC simulation (M. Geissler)

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

**LBNL**

**JAPAN**

**KOREA**

**CHINA**

**Undulator at CAT**

**NORTH AMERICA**

**ASIA**

**SOUTH AMERICA**

**INDIAN OCEAN**

**ATLANTIC OCEAN**

**EUROPE**

**AFRICA**

**PLASMON-X**

**MPQ**

**Munich-Centre for Advanced Photonics**

LMU Physics Chemistry TUM

Medicine Computer science

Geo science Biology Medicine Physics

SIEMENS medical

MPG

Max-Planck-Institute for Plasma Physics

Experimental Physics Quantum Optics Semiconductor Lab of the Max-Planck-Institute

## ALPHA-X Programme

**Main areas of research:**

- Injectors (conventional and all-optical)
- Laser-plasma wake-field acceleration
- Plasma capillaries
- Free-electron laser (FEL)
- Beam transport systems
- Diagnostics

optical self-injection  
6.5 MeV photo-injector  
1 J 40 fs 800 nm  
laser  
plasma filled capillary  
wakefield accelerator  
beam transport  
0.1 - 1 GeV  
beam transport  
200 period undulator FEL or synchrotron source  
IR to VUV SASE or SACSE  
Diagnostics

$$\lambda = \frac{\lambda_0}{2\gamma^2} (1 + a_w^2)$$

$$2\gamma^2 = 10 \rightarrow 10^7$$

$$\lambda = 1 \text{ mm} - 2 \text{ nm}$$

Advanced Laser-Plasma High-energy Accelerators towards 10-100s 2005  
Strathclyde Electron and Terahertz to Optical Pulse Source

# 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,
    - $\leq 0.5 \text{ mm} \cdot \text{mrad}$  norm. emittance,  $\geq 1 \text{ nC}$  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

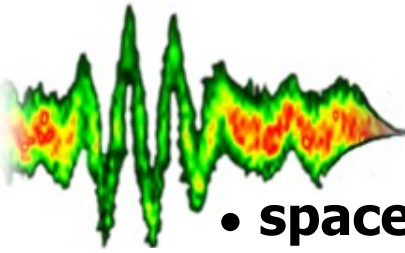
Laser Plasma Acceleration is an exciting and dynamic field due to recent advances in

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

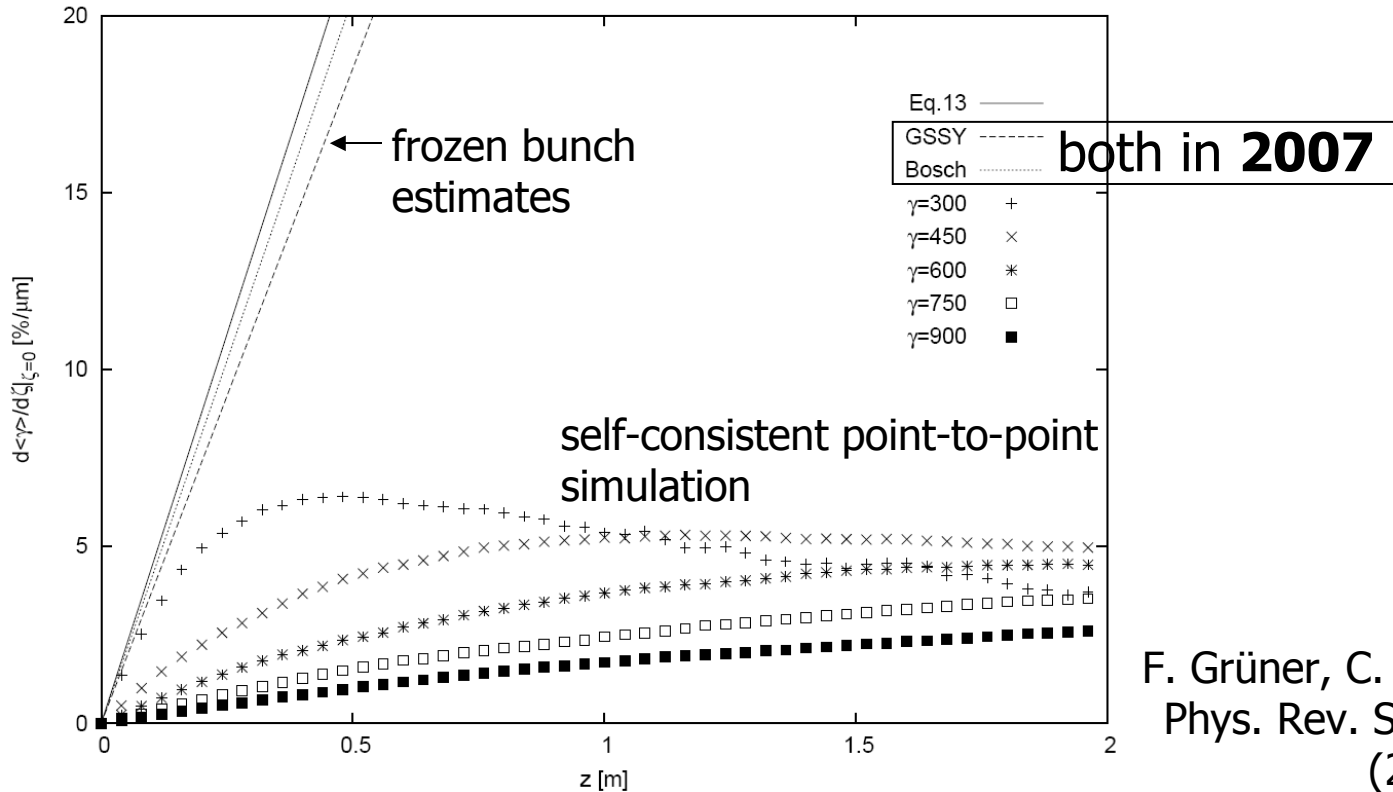
Application for TT FEL seems to be straight forward and obvious, especially as excitement at the moment is high and the road is paved

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



- **space-charge issues** (case study: 0.4 nC,  $\sigma_z = 1.0 \mu\text{m}$ , 150 MeV)



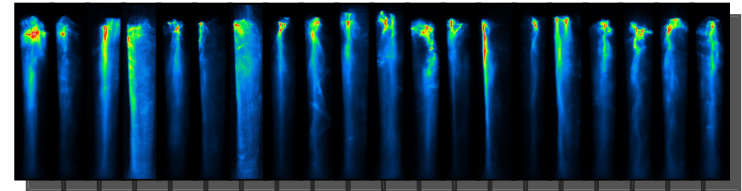
F. Grüner, C. Schroeder, et al.,  
 Phys. Rev. STAB 12, 020701  
 (2009)

- **wakefields**

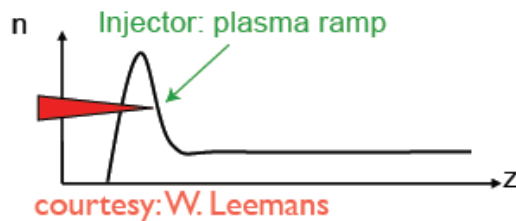
→ cryogenic undulator (cooperation with BESSY)

# 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:

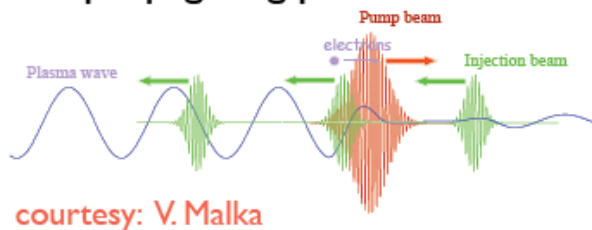


## downramp injection



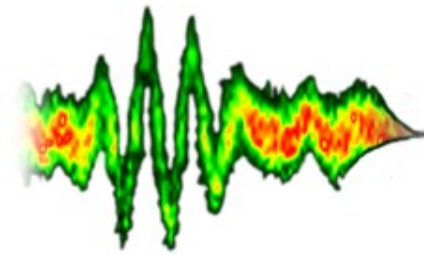
**0.5-1 nC, low long. & trans. momentum:**  
C.Geddes et al, PRL 100 (2008)

## counter-propagating pulses



**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)

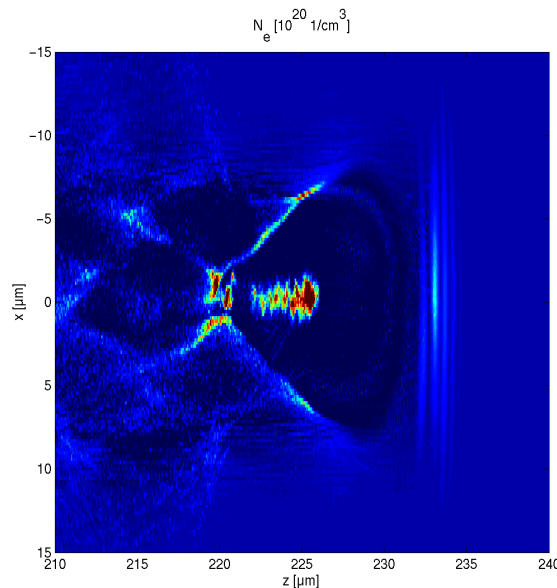
- **energy spread** typically  $\geq 1...5\%$   
FEL requires  $< 0.1...0.5\%$



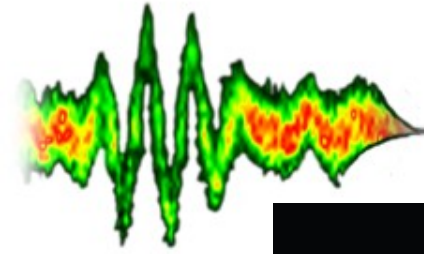
- ? minimum energy spread ?
- ? minimum emittance ?
- ? trapped charge/bunch length ?



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



# experimental break-thru



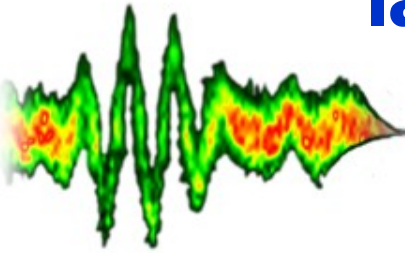
## Grüner + Karsch

Undulator  
Radiation

Electron  
Acceleration

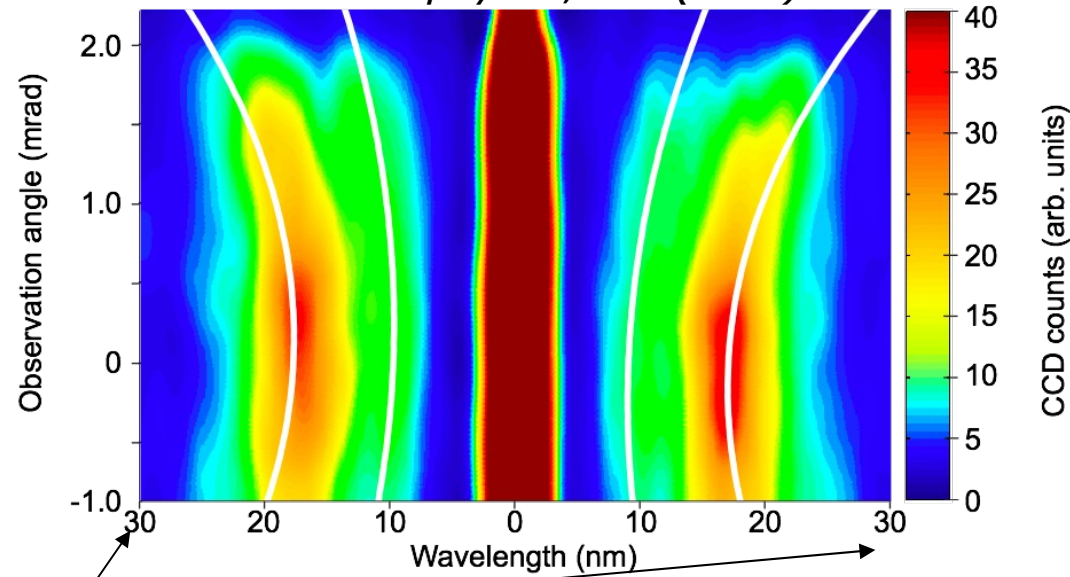


# laser-driven soft x-ray undulator radiation



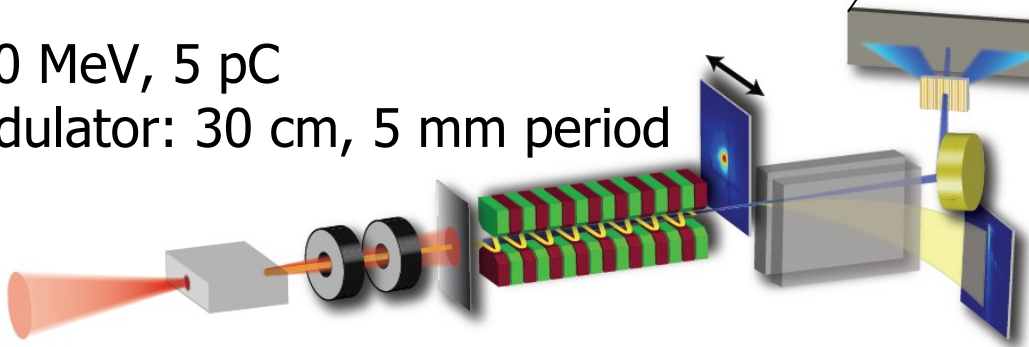
first time:  
soft x-rays from laser-  
accelerated electrons


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



spectrum in 70%  
of all laser shots

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



- 
- 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