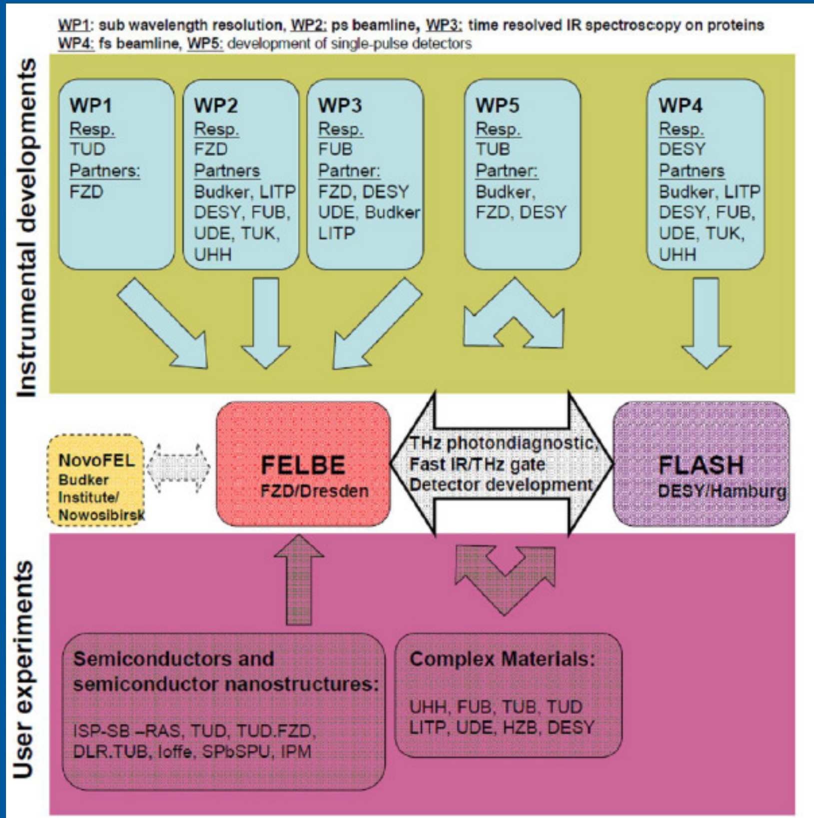
FELBE



M. Gensch
AG Coherent THz Radiation
Institute for Radiationphysics /
Institute for Ion-Beam Physics and Mat. Research
Helmholtz-Zentrum Dresden-Rossendorf

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

- ELBE
- FELBE

Accelerator-based Coherent THz sources

in Germany

- *low alpha sources*
- *low gain FEL*
- *coherent THz linac sources*

BESSY 2002
Berlin

FELBE 2004
Dresden

ANKA 2005
Karlsruhe

FLASH 2007
Hamburg

MLS 2008
Berlin

DELTA 2010
Dortmund

TELBE 2012
Dresden

+ FLASHII, FLUTE, …..

nice global overview (also comparison table top <-> accelerator based)
J.H. Booske, R.J. Dobbs, C.D. Joye, C.L. Kory, G.R. Neil, G.S. Park, J. Park, R.J. Tempkin,
Vacuum Electronic High Power Terahertz Sources,
IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY, VOL. 1, NO. 1, SEPTEMBER 2011, 54.

Accelerator-based Coherent THz sources

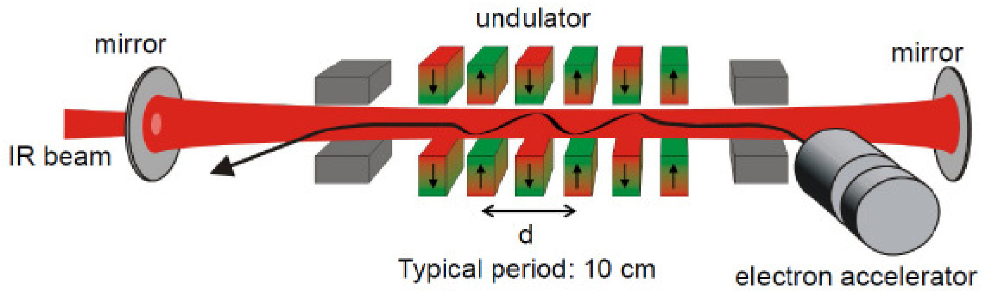
in PIDID

only peak power sources participate!

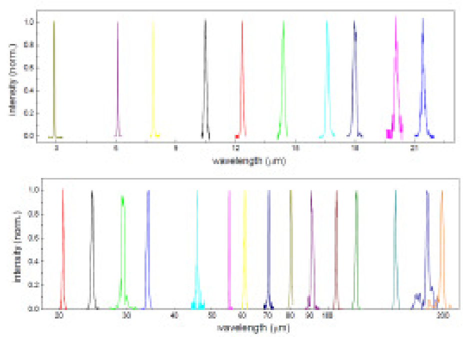
nice global overview (also comparison table top <-> accelerator based)
J.H. Booske, R.J. Dobbs, C.D. Joye, C.L. Kory, G.R. Neil, G.S. Park, J. Park, R.J. Tempkin, Vacuum Electronic High Power Terahertz Sources, IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY, VOL. 1, NO. 1, SEPTEMBER 2011, 54.

FELBE: low gain free electron laser

Low gain free electron laser



FELBE – FEL / HZDR
- Spectral range: 100 – 1 THz
- Spectral bandwidth: 0.1 – 2%
- Reprate: 13 MHz or 1 KHz (cw)
- Pulse energy: several µJ
- Average power: up to sev. 10 W
- Linear polarization
- Pulse duration: picoseconds



e.g. C.A. Brau, Science (1988)

FELBE 2004
Dresden

FLASH 2007
Hamburg

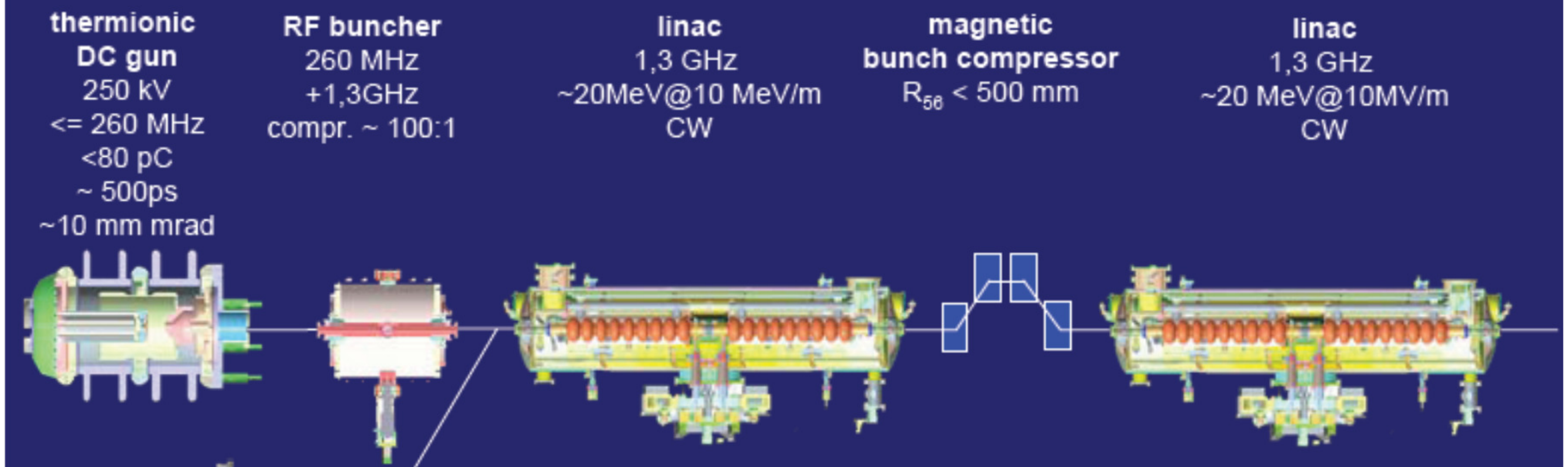
TELBE 2012
Dresden

+ FLASHII, FLUTE, …..

extreme average power+high pulse energy, narrow spectr. Bandw.:
-> nonlinear and/or timeresolv. THz exp., cluster/gasphase exp.

- **ELBE**
  - **FELBE**

ELBE: superconducting cw linac



	Thermionic gun + bunch compressor
maximum energy	36 MeV (CW) ~50 MeV pulsed RF
maximum bunch charge	77 pC
maximum beam current	1 mA
bunch length rms	1-10 ps

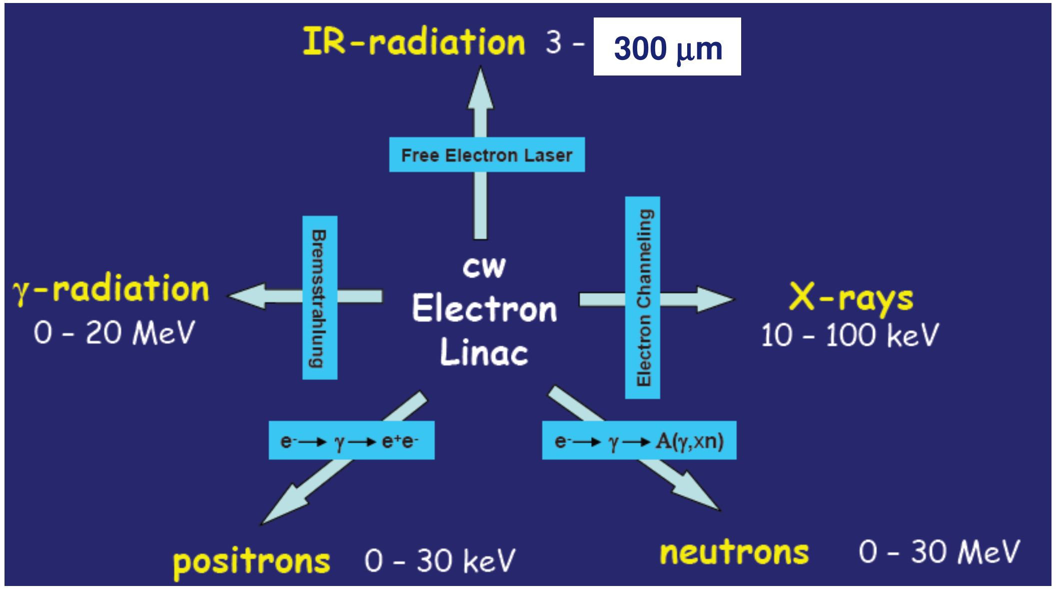
	low emittance mode (channeling)	high average current mode (FEL& all others)
transverse emittance rms	2 mm mrad	10 mm mrad
repetition rate	260 MHz (0,77 pC)	13 MHz (77 pC)
energy spread fwhm	35 keV	55 keV

liquifier LINDE
) W @ 1,8 K

DRESDEN concept

ELBE: superconducting cw linac

(present status)

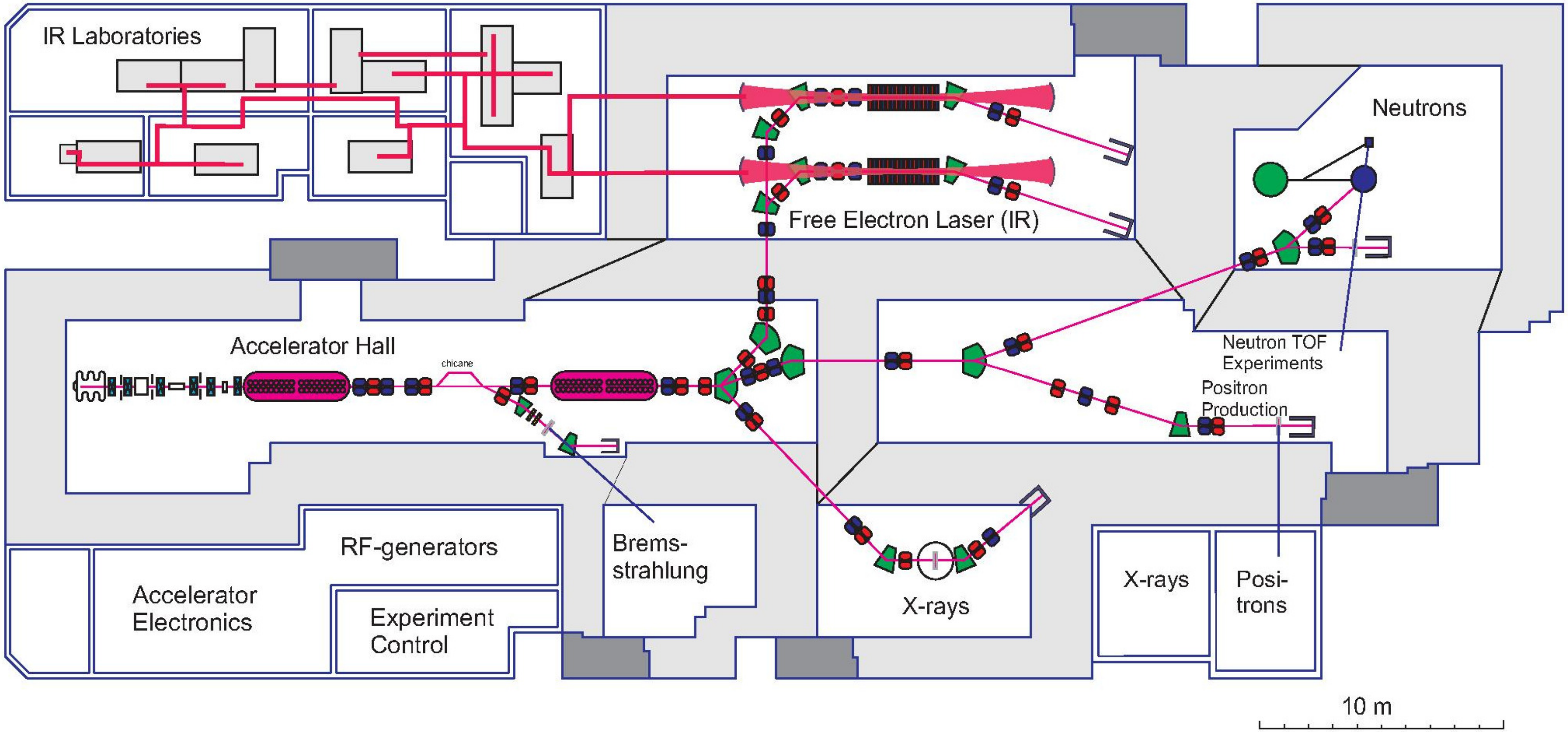


+

TW laser-electron interaction pilot experiment

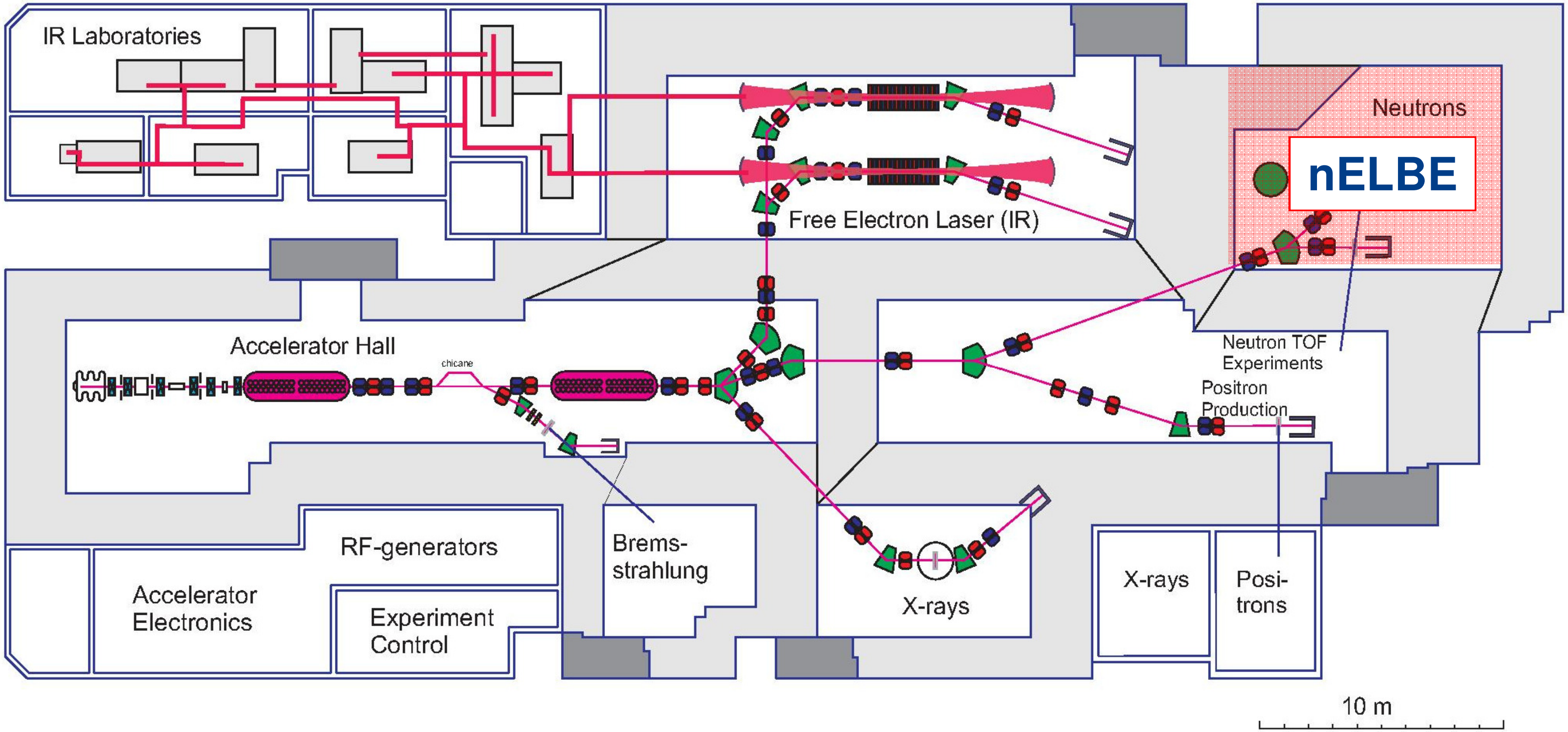
Proof of Principle 09/2011: 10-20 KeV Photons generated

ELBE (as it is)



- **Repetition rate: 13 MHz (cw)**
- **Electron bunches: few ps**
- **Thermionic gun + SRF accelerator!**

ELBE (as it is)



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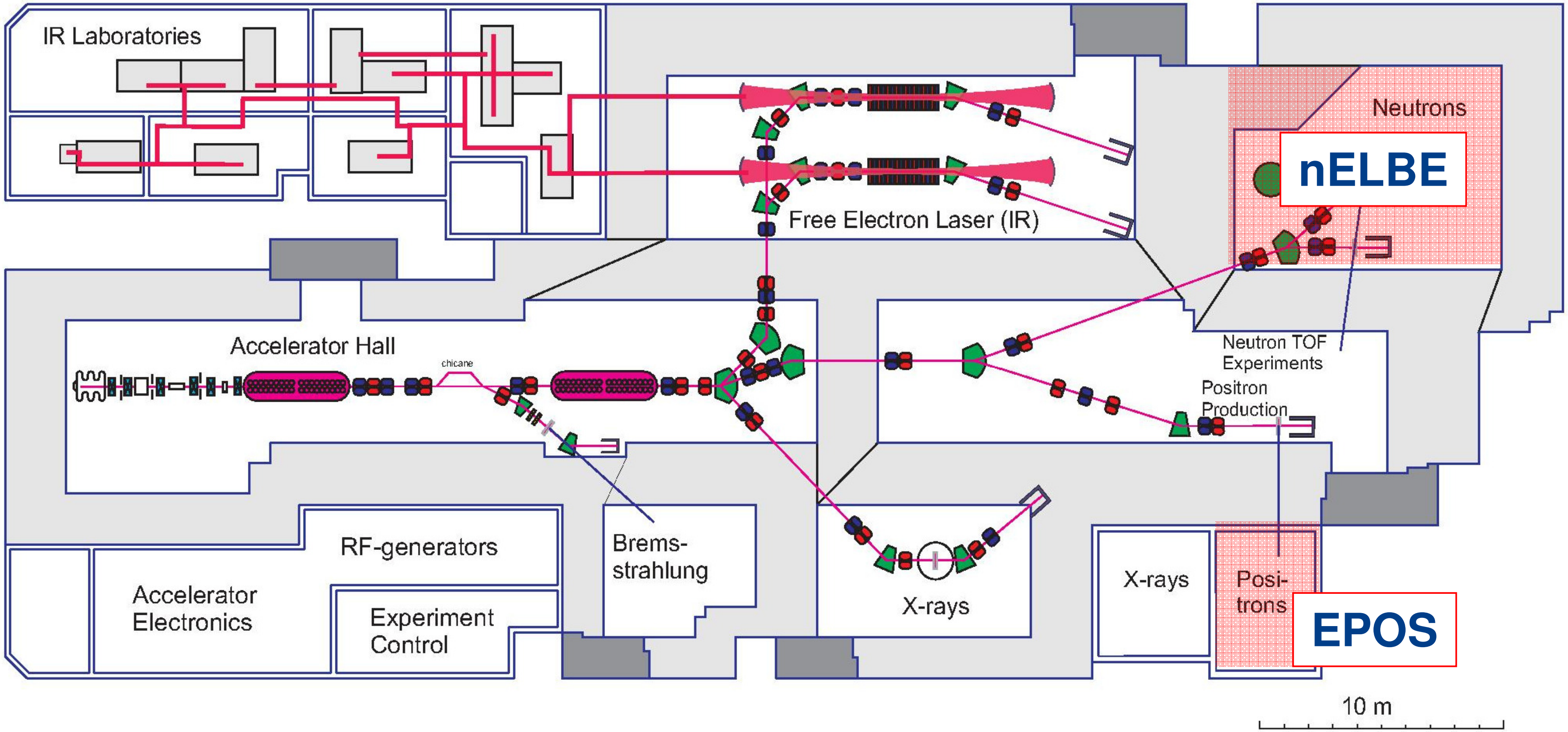

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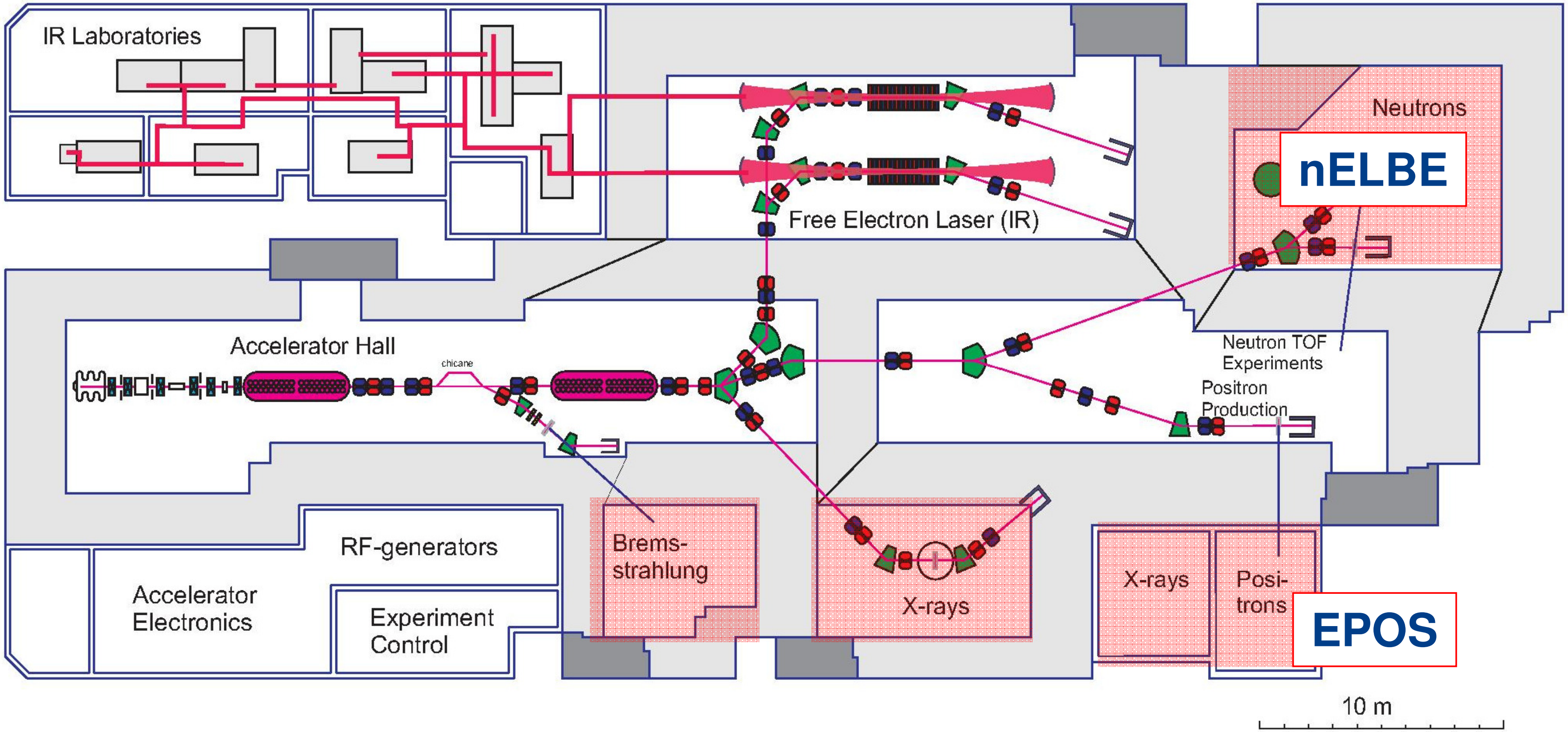

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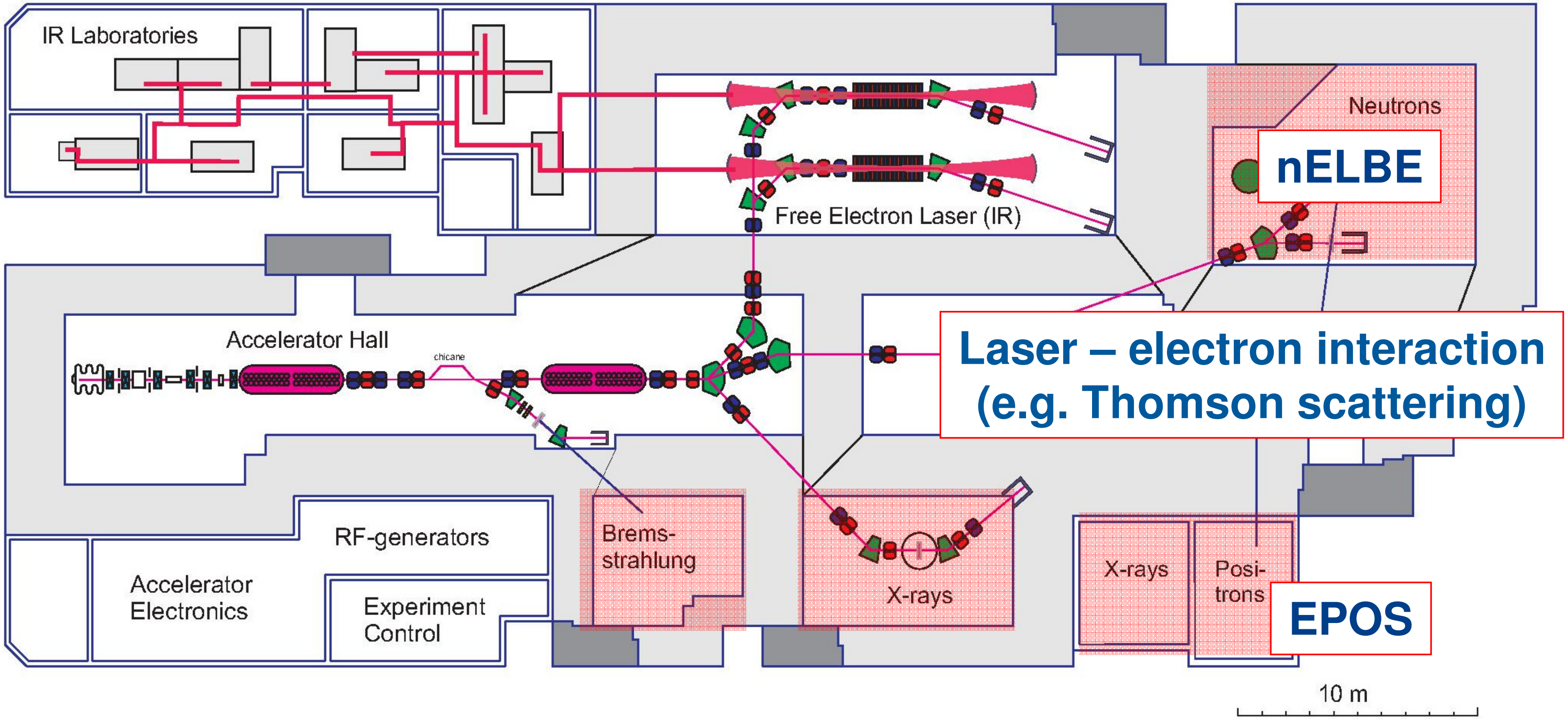

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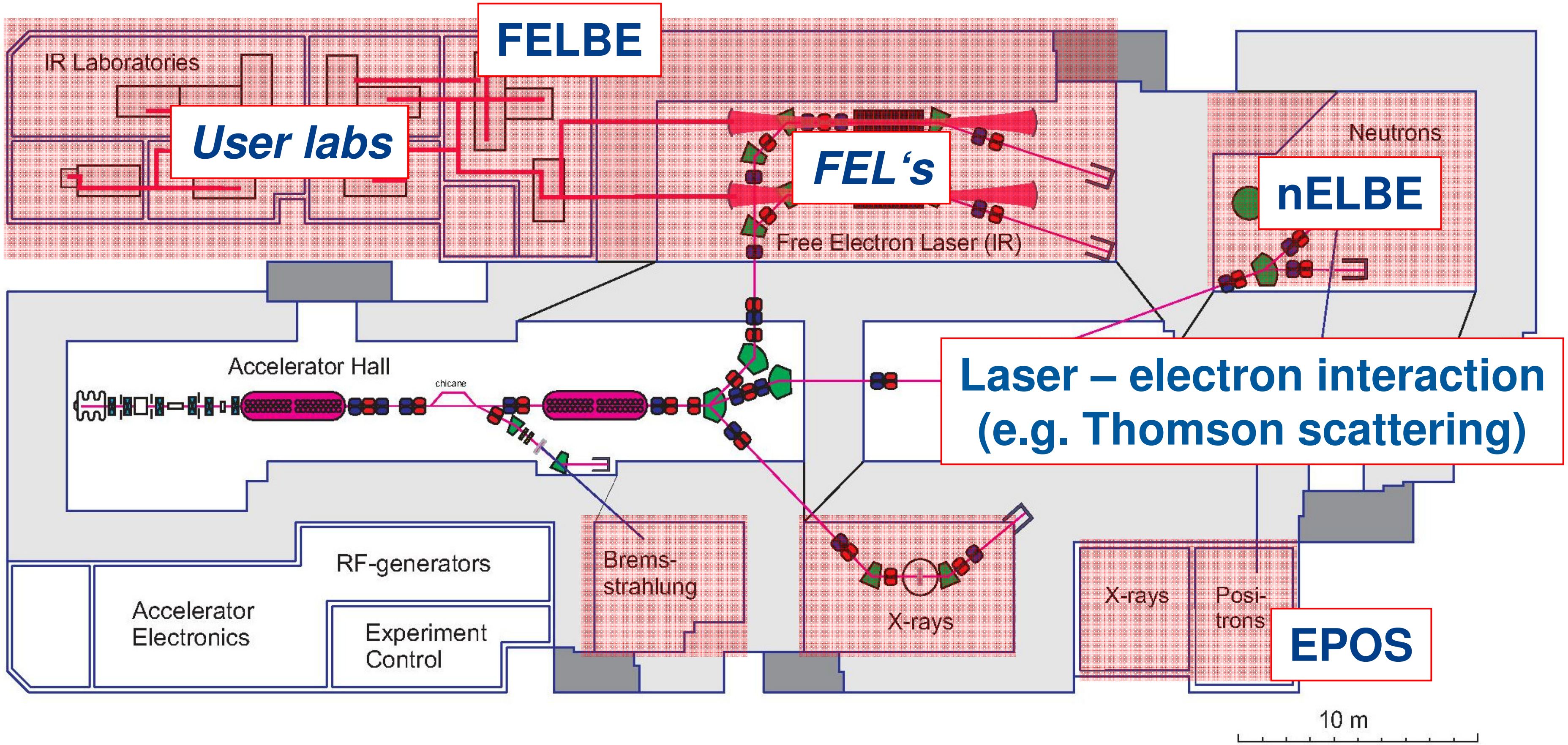
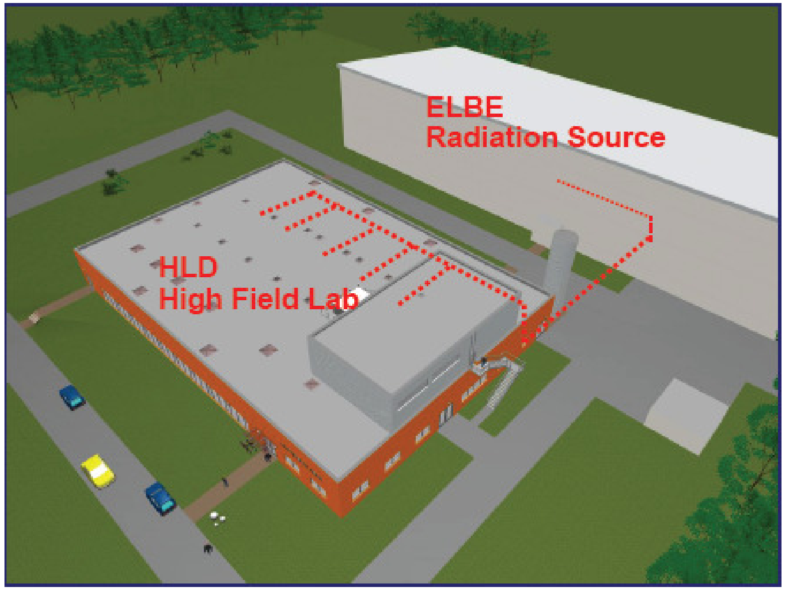
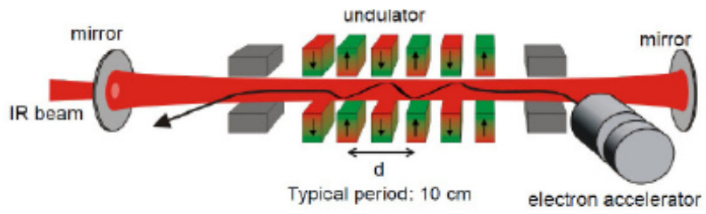


- **Repetition rate: 13 MHz (cw)**
- **Electron bunches: few ps**
- **Thermionic gun + SRF accelerator!**

FELBE: THz FEL @ ELBE



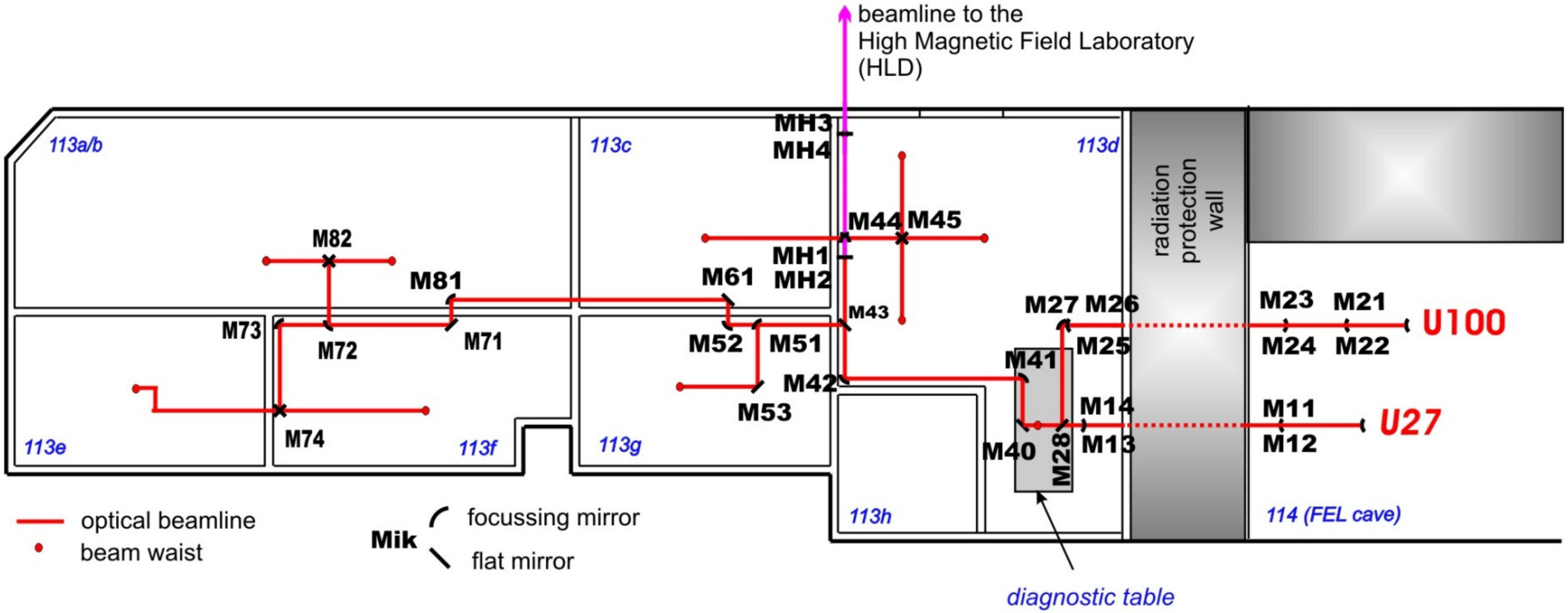


Infrastructure:
- ***various femtosecond/picosecond lasersysstems***
- ***magnets: 10T (every lab), 20 – 90T (HLD)***
- ***tabletop THz (Austin switch, BWO)***
- ***various kryostates***
- ***FTIR (Bruker 80V)***

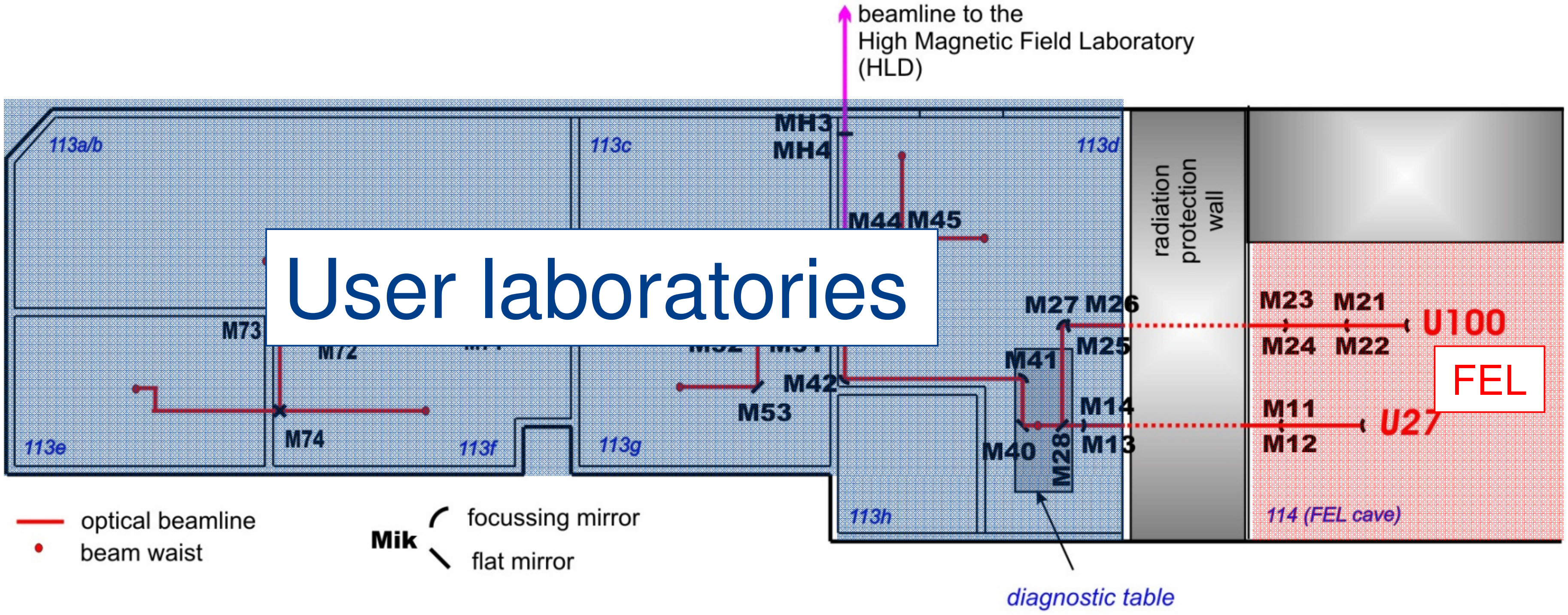
FELBE – FEL / HZDR
- **Spectral range: 66 – 1 THz**
- **Spectral bandwidth: 0.1 – 2%**
- **Reprate: 13 MHz or 1 KHz (cw)**
- **Pulse energy: several μJ**
- **Average power: up to sev. 10 W**
- **Linear polarization**
- **Pulse duration: picoseconds**

- ELBE
- **FELBE**

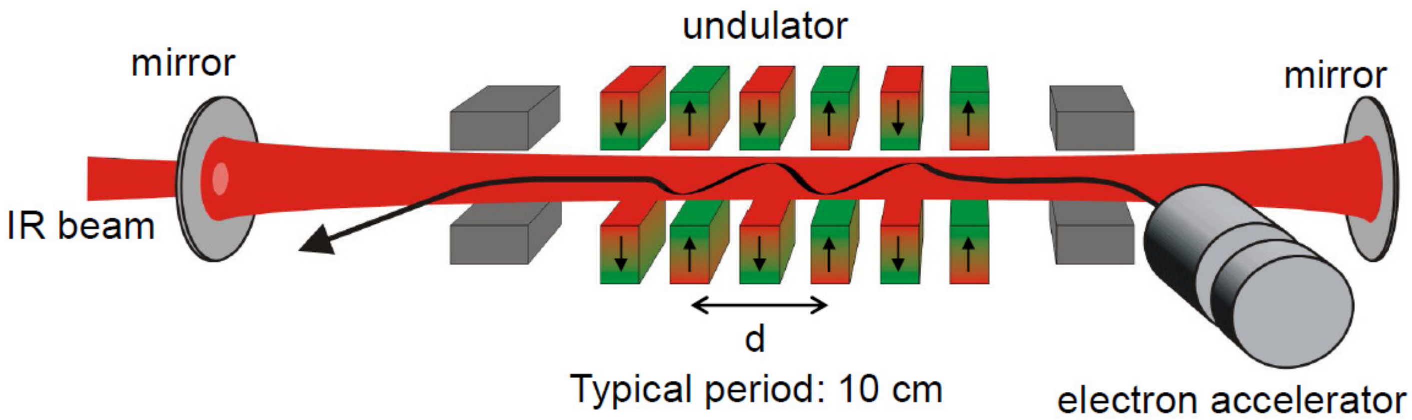
FELBE: the user facility



FELBE: the user facility



FELBE: - THz FEL



FELBE – FEL / HZDR

- Spectral range: 100 – 1 THz
- Spectral bandwidth: 0.1 – 2%
- tunable
- Reprate: 13 MHz or 1 KHz (cw)
- Pulse energy: several µJ
- Average power: up to sev. 10 W
- Linear polarization
- Pulse duration: picoseconds

- **Pump probe**
- **Microspectroscopy**

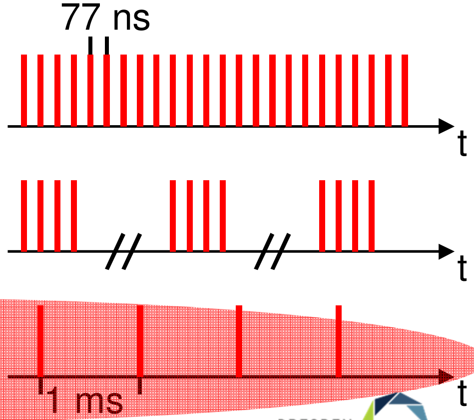
FELBE: Pump probe – relev. parameters

Wavelength **FEL I** (since 2004): λ = 4 – 24 µm
FEL II (since 2006): λ = 20 – 280 µm ⇒ **1 – 100 THz**

pulse energy: 0.1 - 1 µJ (depends on λ)
pulse width: 0.5 - 20 ps (depends on λ)
repetition rate: 13 MHz continuous pulse train (only FEL in Europe)

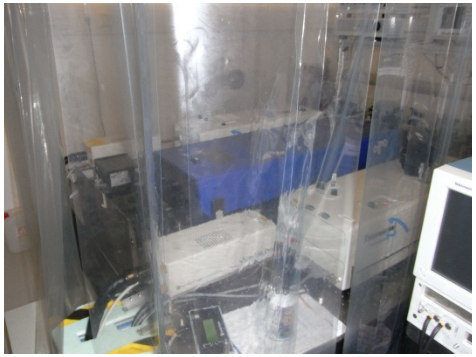
peak power: 100 kW – 1 MW
average power: 1- 10 W
bandwidth: Δλ/λ = 0.4 – 1.6 %

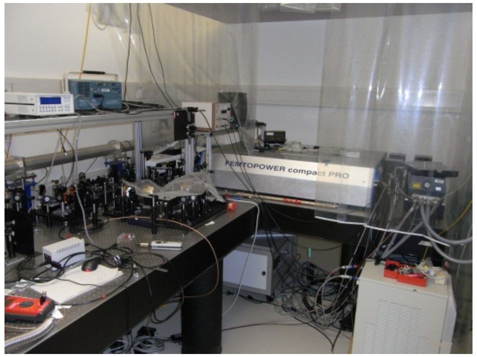
Pulse structure: micro pulse („cw“) 13 MHz
macro pulse 100 µs – cw (1Hz – 25 Hz)
PIDID / WP2: 1 KHz

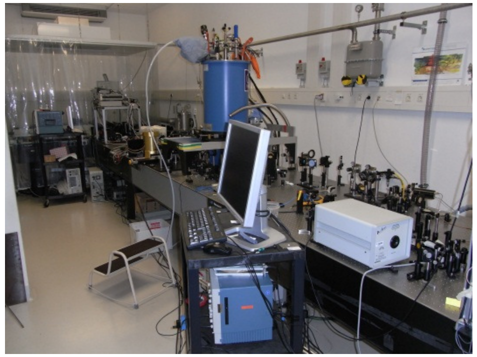


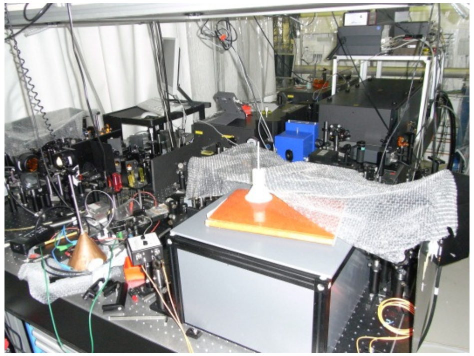
DRESDEN concept
HZDR

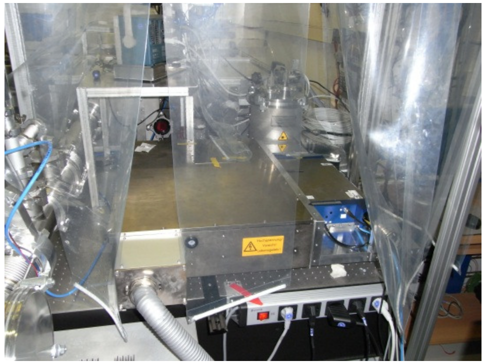
FELBE: Pump probe – relev. parameters



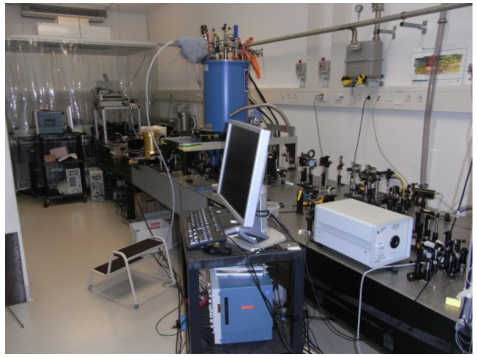


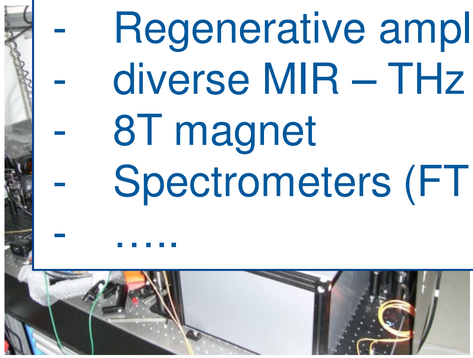






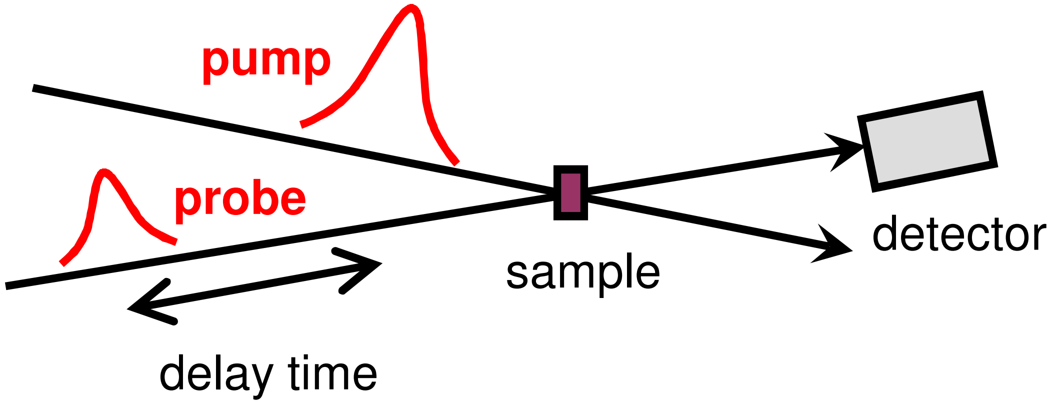
FELBE: Pump probe – relev. parameters

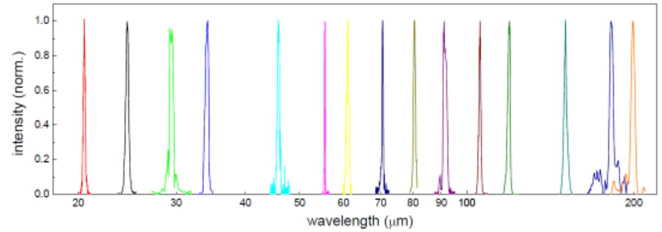




- mJ, 2 KHz , YAG laser
- fs/ps table-top Ti:sapphire laser (MHz)
- state-of-the-art fs laser amplifier system (1 mJ, 1 kHz)
- Regenerative amplifier (μJ, 200 KHz)
- diverse MIR – THz detectors
- 8T magnet
- Spectrometers (FTIR – grating)
- …..

FELBE: Pump-Probe Experiments





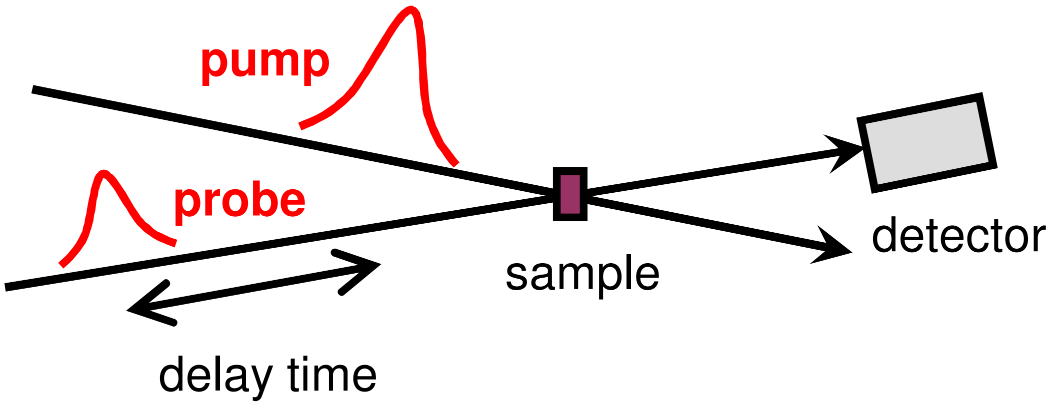
- pump pulse
  - Stimulates a process, reaction, phase transition, ….

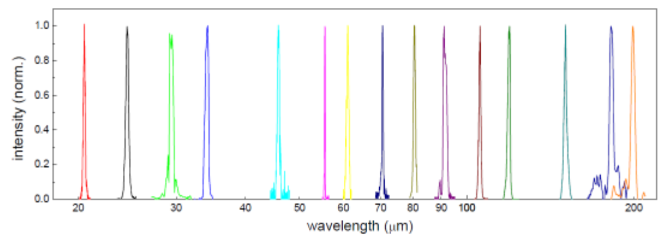
  -> preferably by photons!

- probe pulse
  - measures change of materials properties

    @ different diff. times

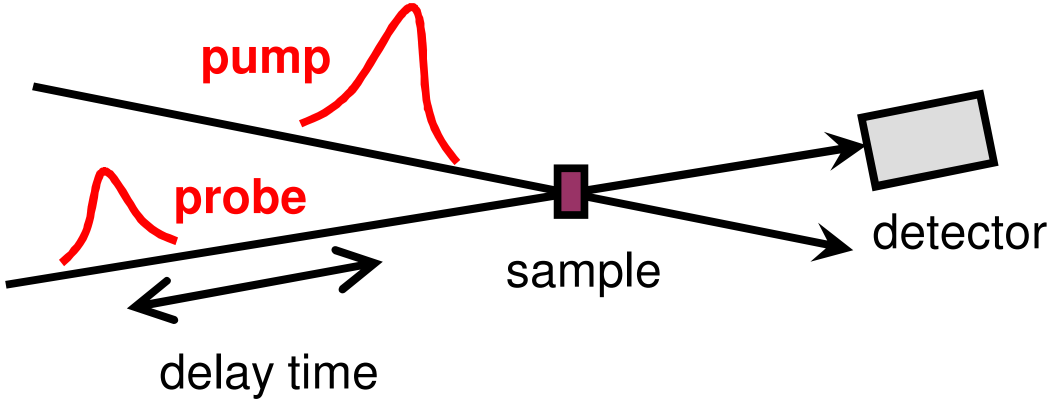
FELBE: Pump-Probe Experiments

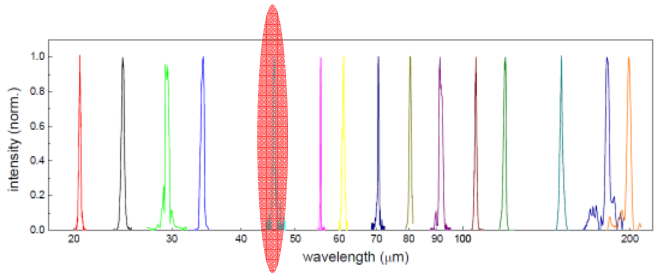


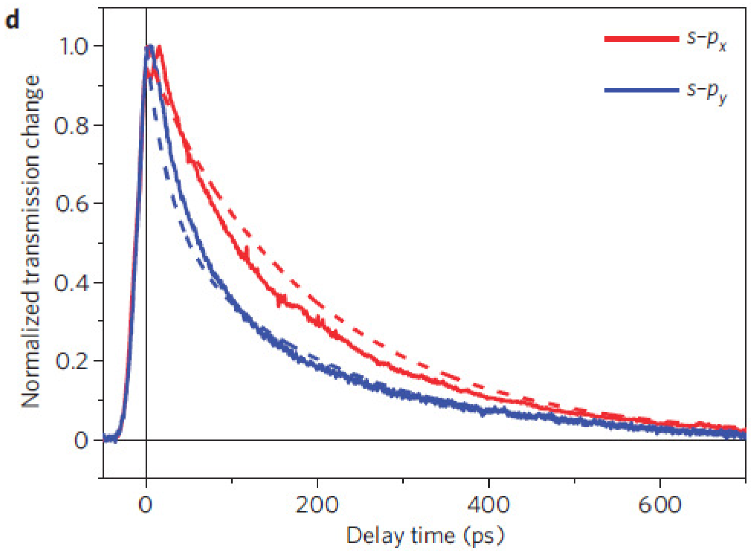


- **FEL pump FEL probe**
- **2 color pump probe**
- **FEL/Laser pump FT-IR step scan probe -> WP3!**

FELBE: FEL pump FEL probe

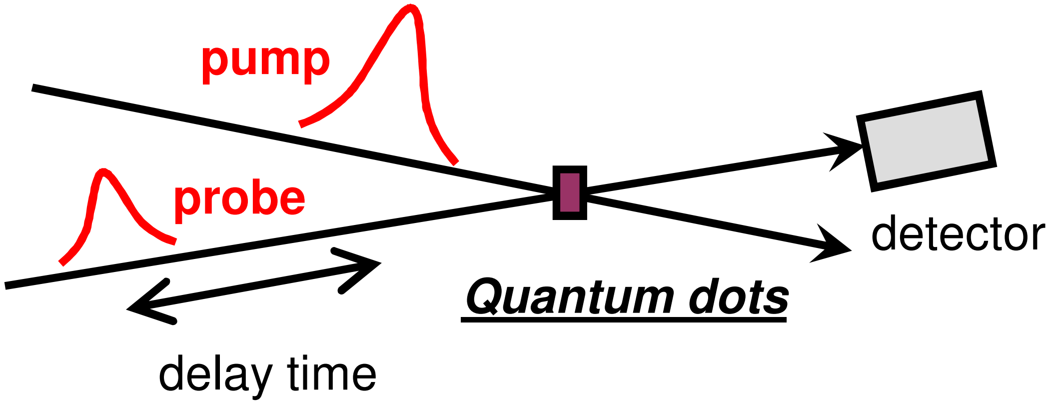


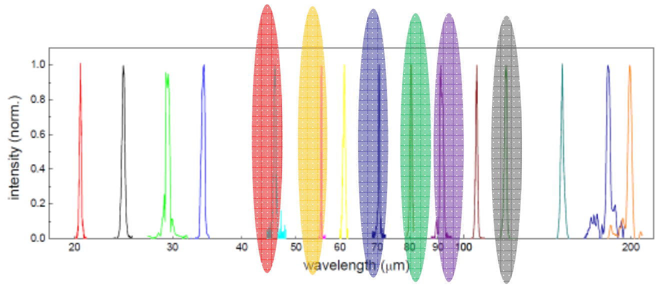


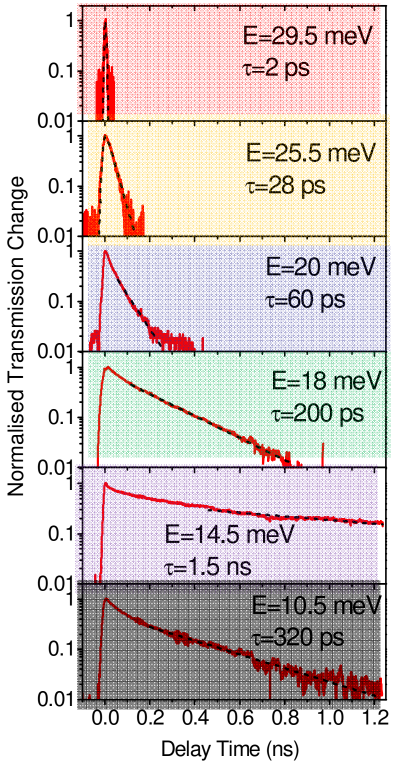


„Photobleaching“

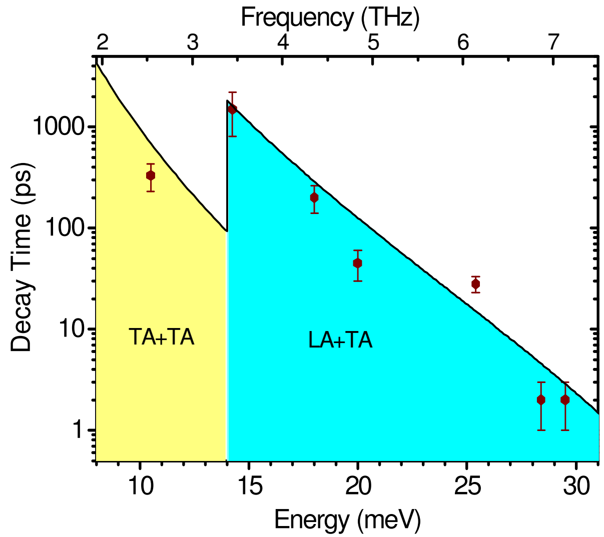
FELBE: FEL pump FEL probe







Experimental and theory



E.A. Zibik et al, Nature Materials 8, 803 (2009)

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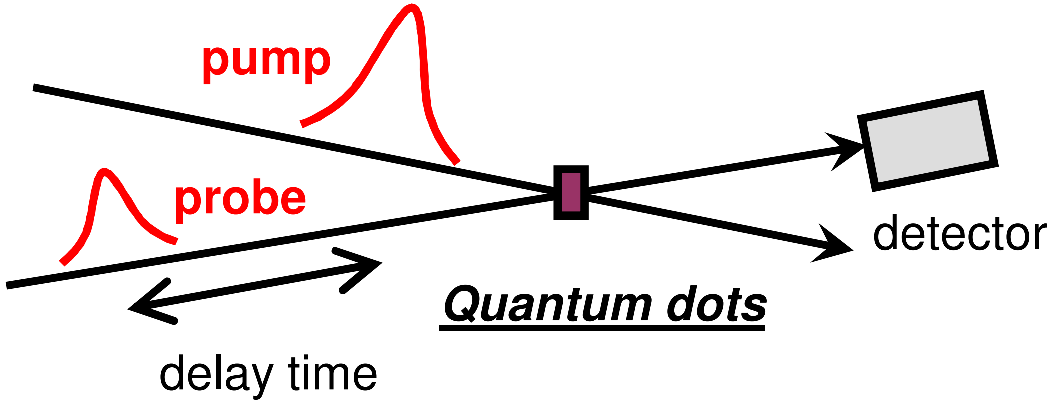

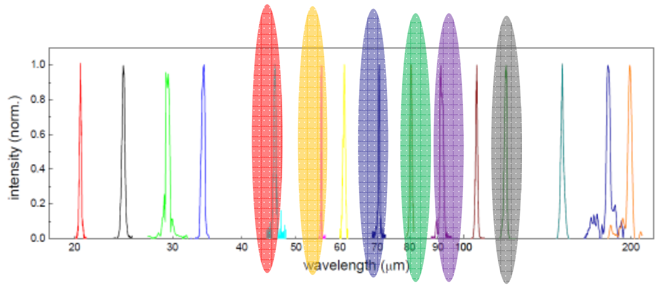

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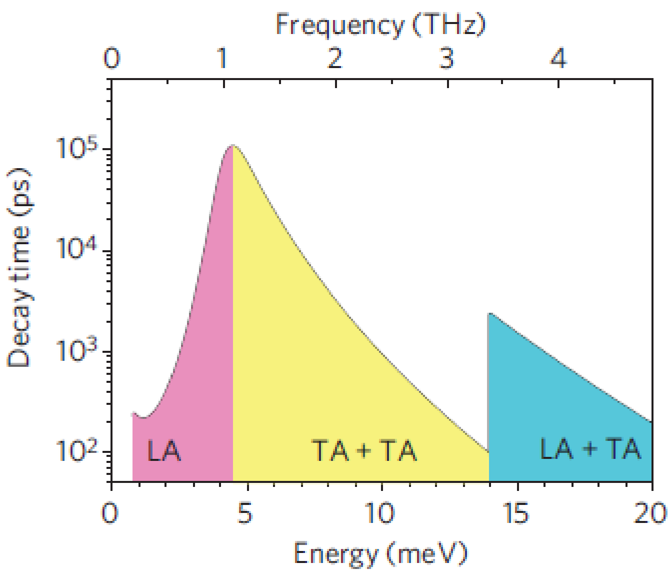
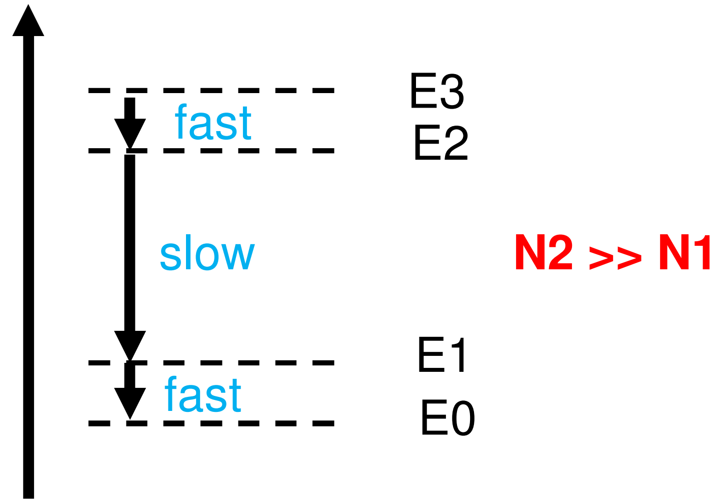


Laser principle (4 level)



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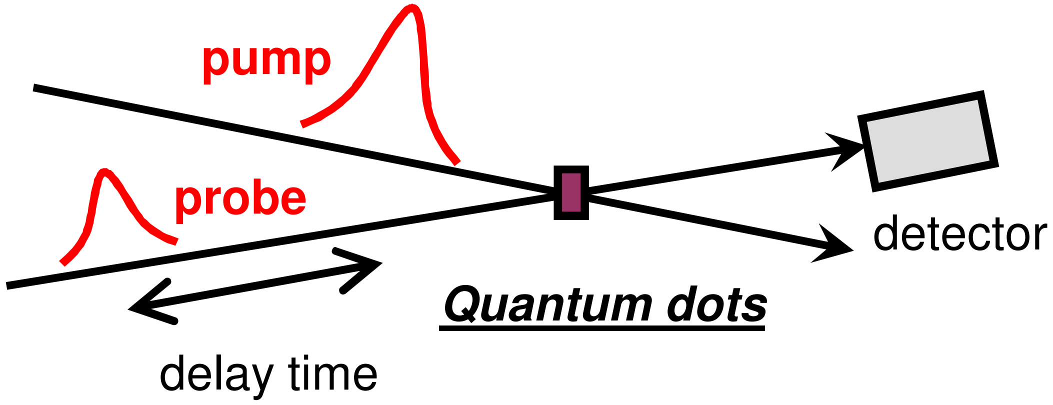

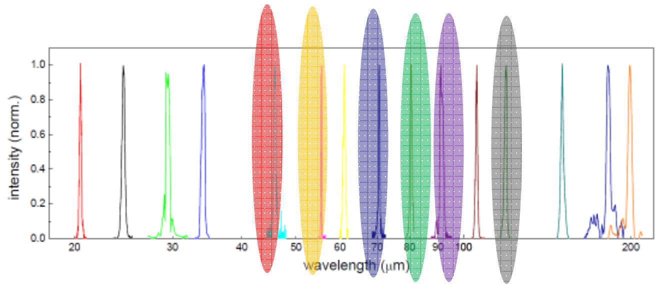

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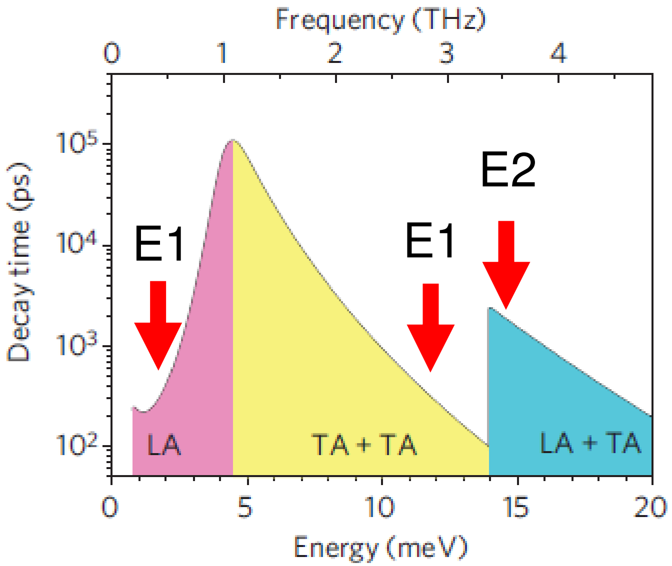
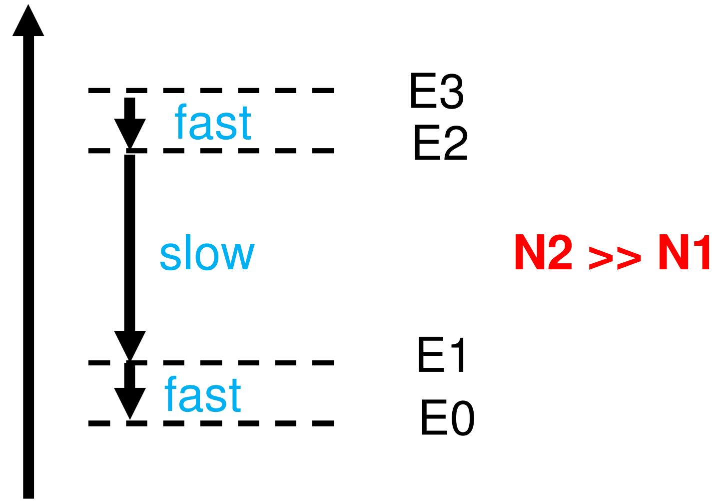


Optimization of THz Quantumdotlasers



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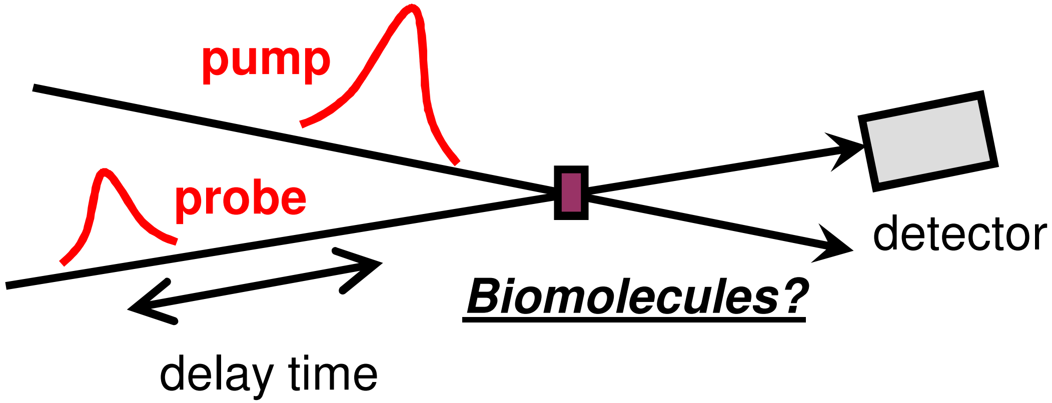

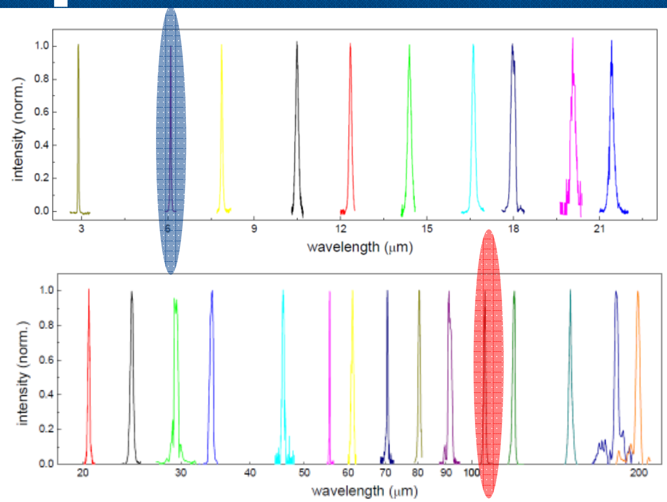

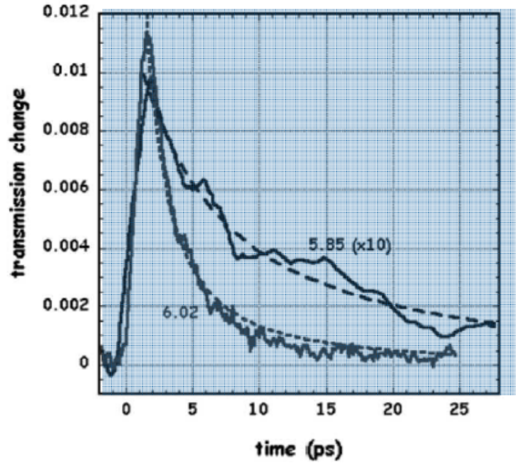

FIG. 3. (a) The pump/probe decay of Mb at 6.02 μm and 5.85 μm. The 5.85 μm decay amplitude has been multiplied by 10. The power law curve fits to the decay of the pump/probe signal are shown as dashed lines for the two wavelengths. The pulse width of FELIX was set to be as long as possible for these experiments, 1.5 ps or 10 cm^{-1} in linewidth. (b) Log amplitude

A.H. Xie et al, Phys. Rev. Lett. 82, 5438 (2000)

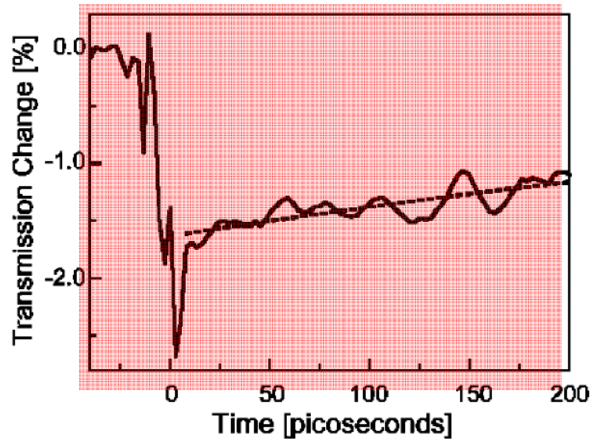

FIG. 4. Pump-probe response of bR at 87 μm. The data are shown as the percentage transmission change. The spot size of the pump beam was 1000 μm and the pump energy per micropulse was 1 μJ. The dotted line is a single exponential fit to the data, with a time constant of 500 $\pm$ 100 ps.

A.H. Xie et al, Phys. Rev. Lett. 88, 018102 (2002)

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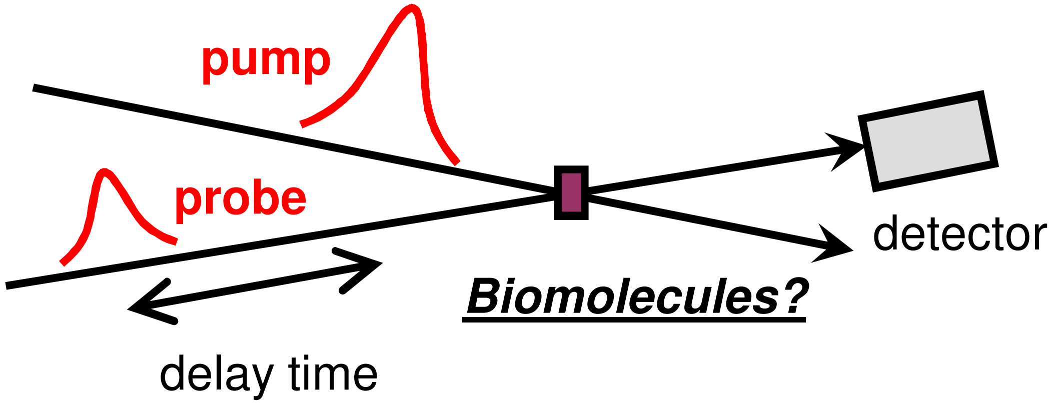

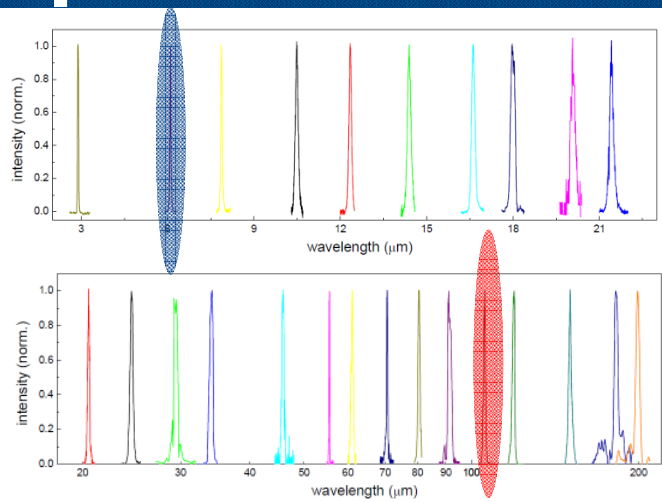

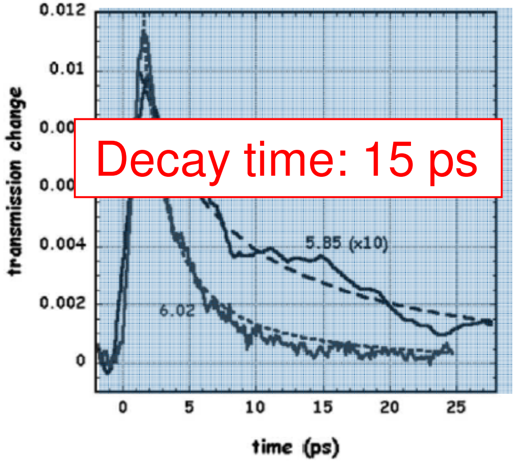

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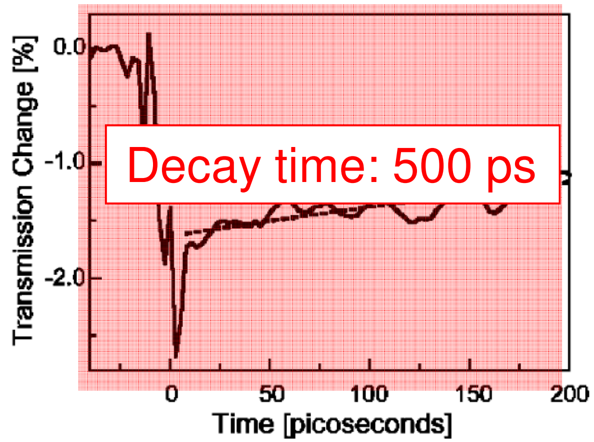

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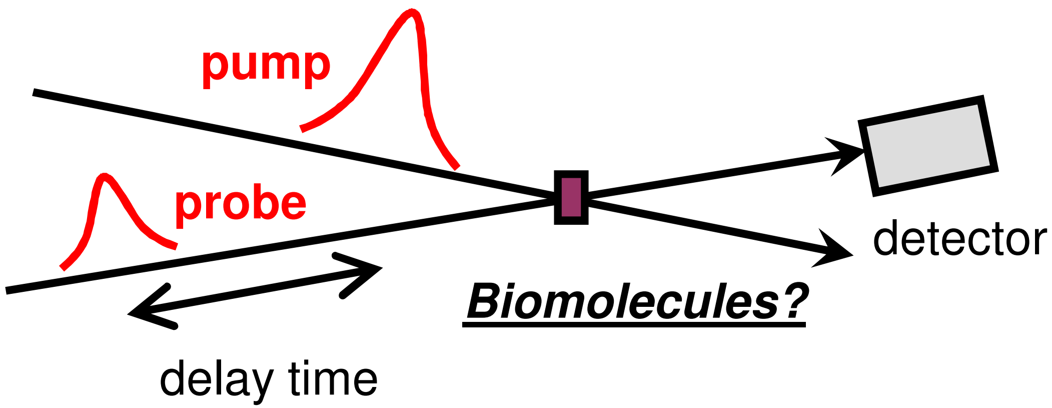
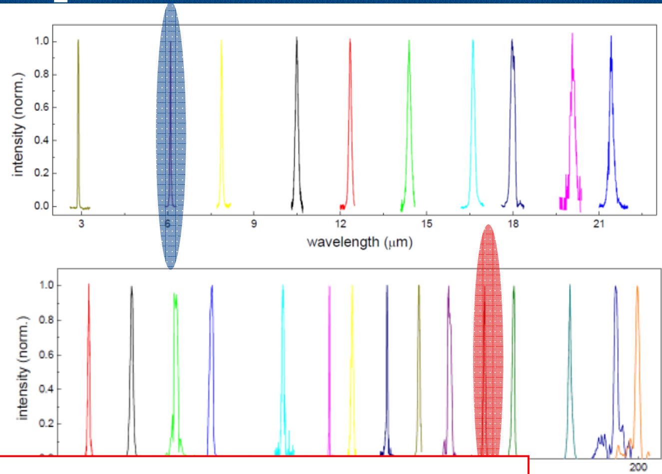




-> important insights ínto the complex solvent-protein interaction („energy flow“)

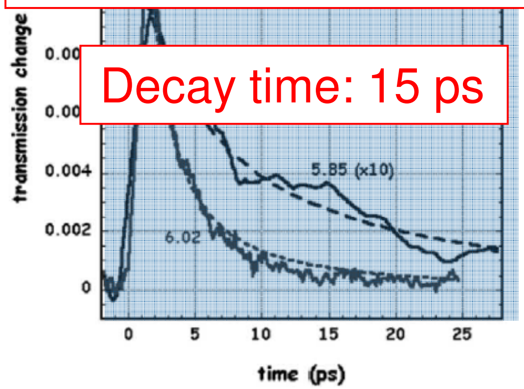


FIG. 3. (a) The pump/probe decay of Mb at 6.02 μm and 5.85 μm. The 5.85 μm decay amplitude has been multiplied by 10. The power law curve fits to the decay of the pump/probe signal are shown as dashed lines for the two wavelengths. The pulse width of FELIX was set to be as long as possible for these experiments, 1.5 ps or 10 cm^{-1} in linewidth. (b) Log amplitude

A.H. Xie et al, Phys. Rev. Lett. 82, 5438 (2000)

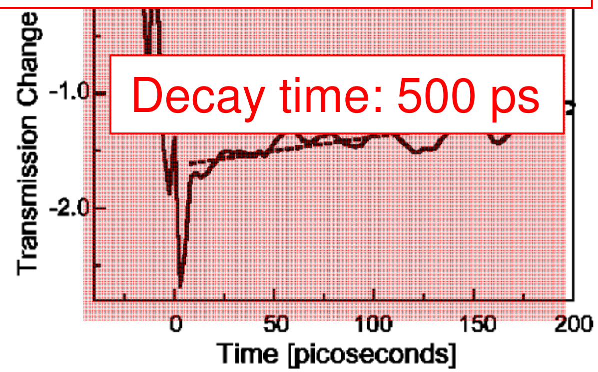
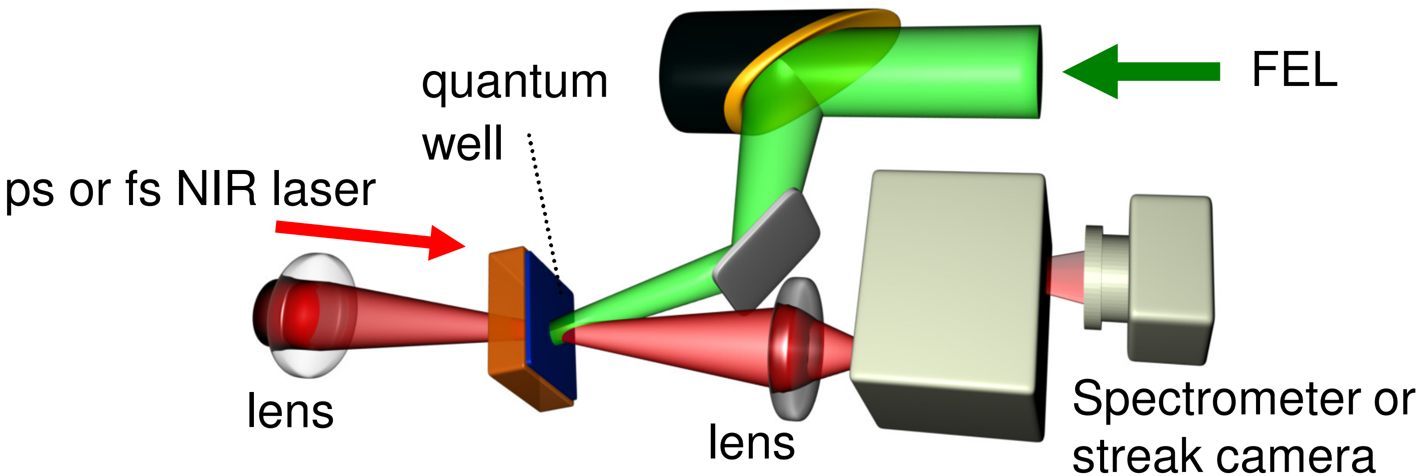


FIG. 4. Pump-probe response of bR at 87 μm. The data are shown as the percentage transmission change. The spot size of the pump beam was 1000 μm and the pump energy per micropulse was 1 μJ. The dotted line is a single exponential fit to the data, with a time constant of 500 $\pm$ 100 ps.

A.H. Xie et al, Phys. Rev. Lett. 88, 018102 (2002)

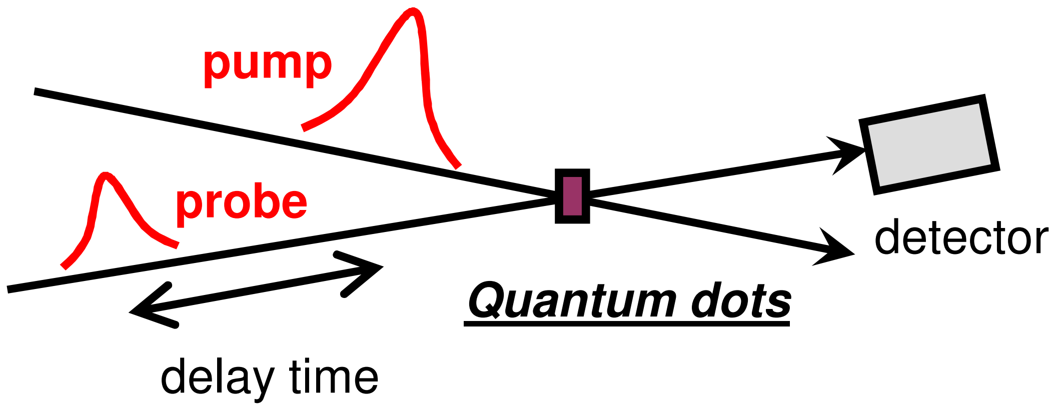
FELBE: 2 color pump probe Experiments

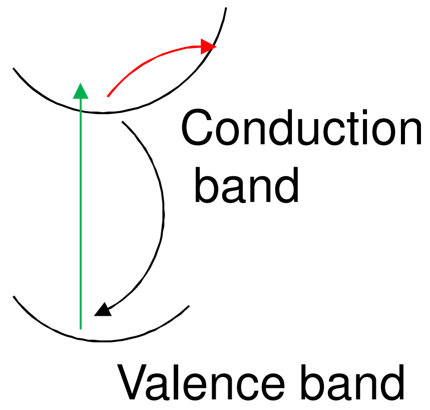


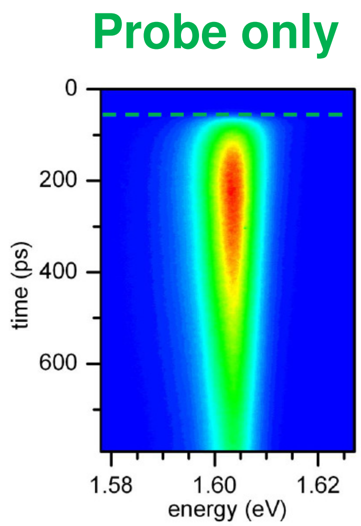
e.g. THz pump Fluorescence/Photoluminescence probe

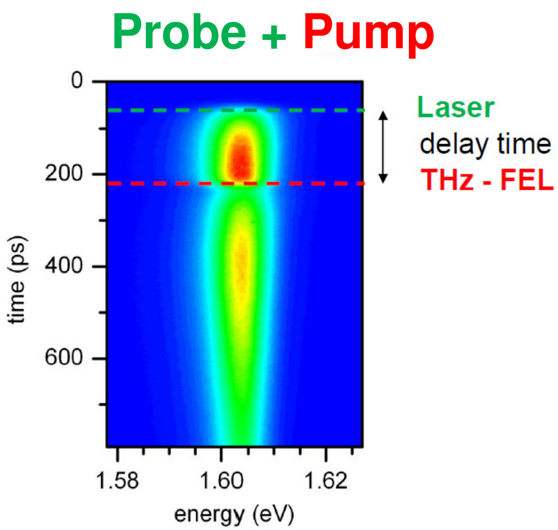
Courtesy M. Helm

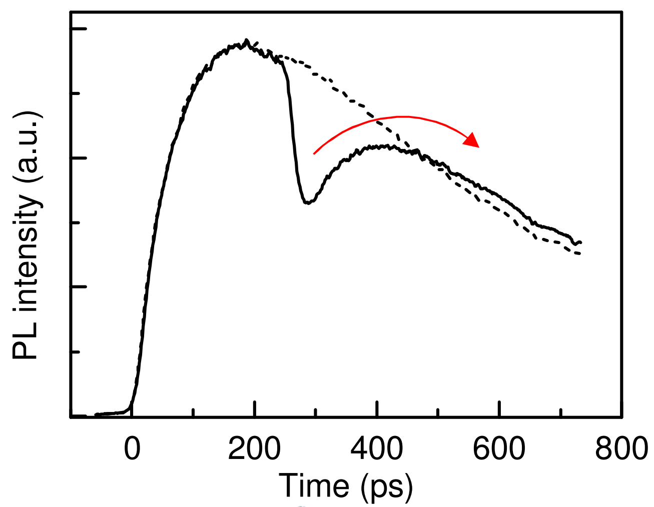
FELBE: 2 color pump probe Experiments





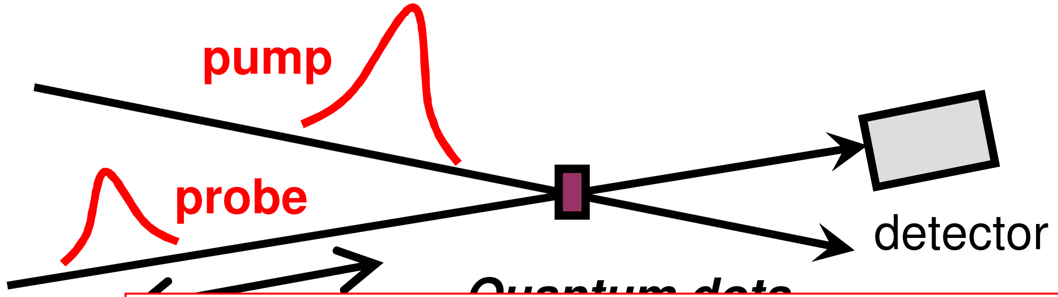


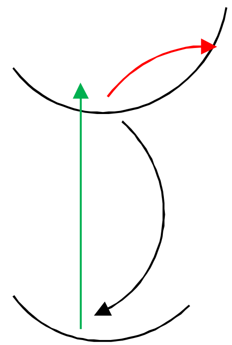




Courtesy S. Zybell

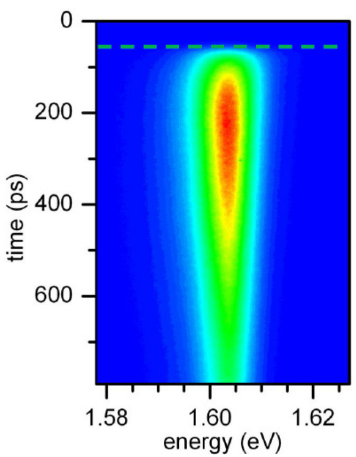
FELBE: 2 color pump probe Experiments



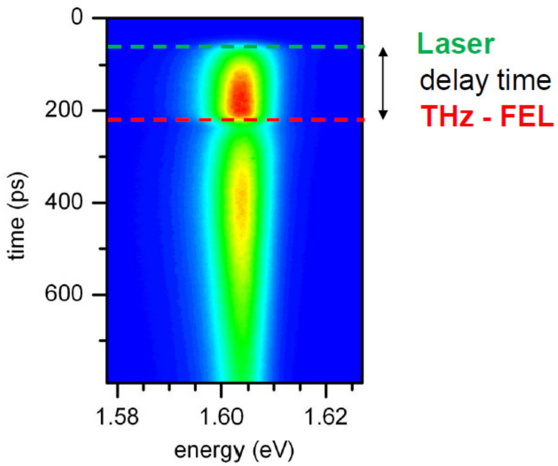


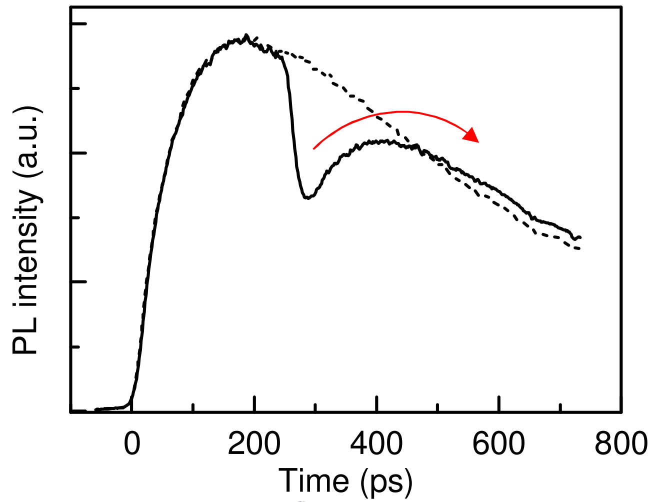
-> near infrared spectra can be taken of materials before and after THz pump! works at 13 MHz reprate

Probe only



Probe + Pump

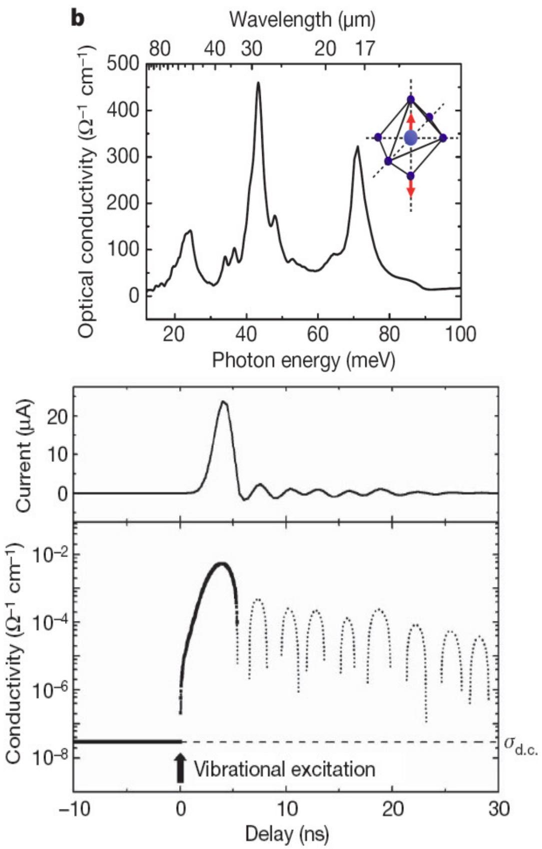




Courtesy S. Zybell

FELBE: 2 color pump probe Experiments

New: -> vibrational control of complex materials



Rini et al., Nature 449, 72 (2007)

Light-Induced Superconductivity in a Stripe-Ordered Cuprate

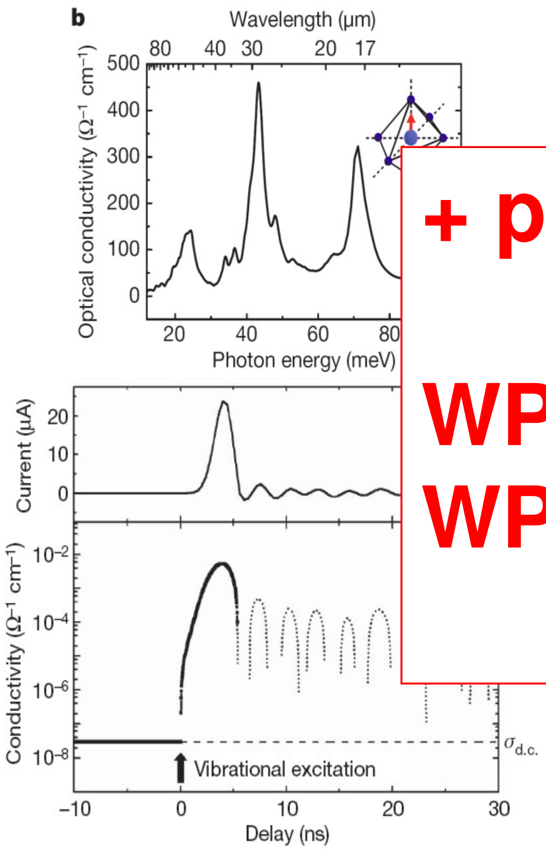
D. Fausti,[1,2]*†‡ R. I. Tobey,[2]†§ N. Dean,[1,2] S. Kaiser,[1] A. Dienst,[2] M. C. Hoffmann,[1] S. Pyon,[3] T. Takayama,[3] H. Takagi,[3,4] A. Cavalleri[1,2]*

Science, 2011!

- -> control macroscopic properties by mode selective vibrational excitation
- -> long lived transient phase (relaxation into normal state within several ns - μs)

FELBE: 2 color pump probe Experiments

New: -> vibrational control of complex materials



Rini et al., Nature 449, 72 (2007)

Light-Induced Superconductivity in a

Pyon,[3]

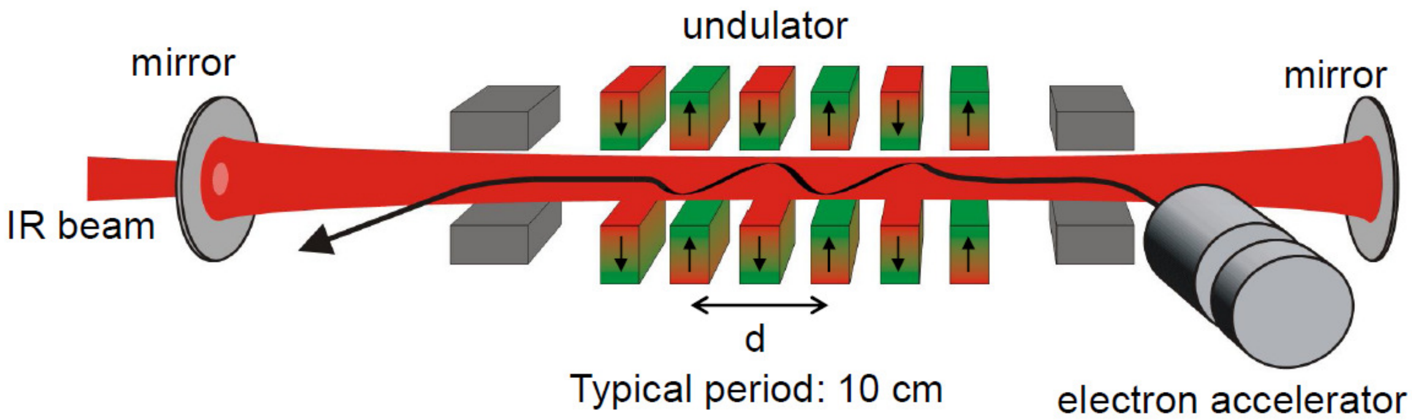
+ proteins…. ***slow fast processes***

WP2: ps beamline, KHz reprate

WP3: time resolved spectrosc. on proteins

(relaxation into normal state within several ns - μs)

FELBE: Microspectroscopy

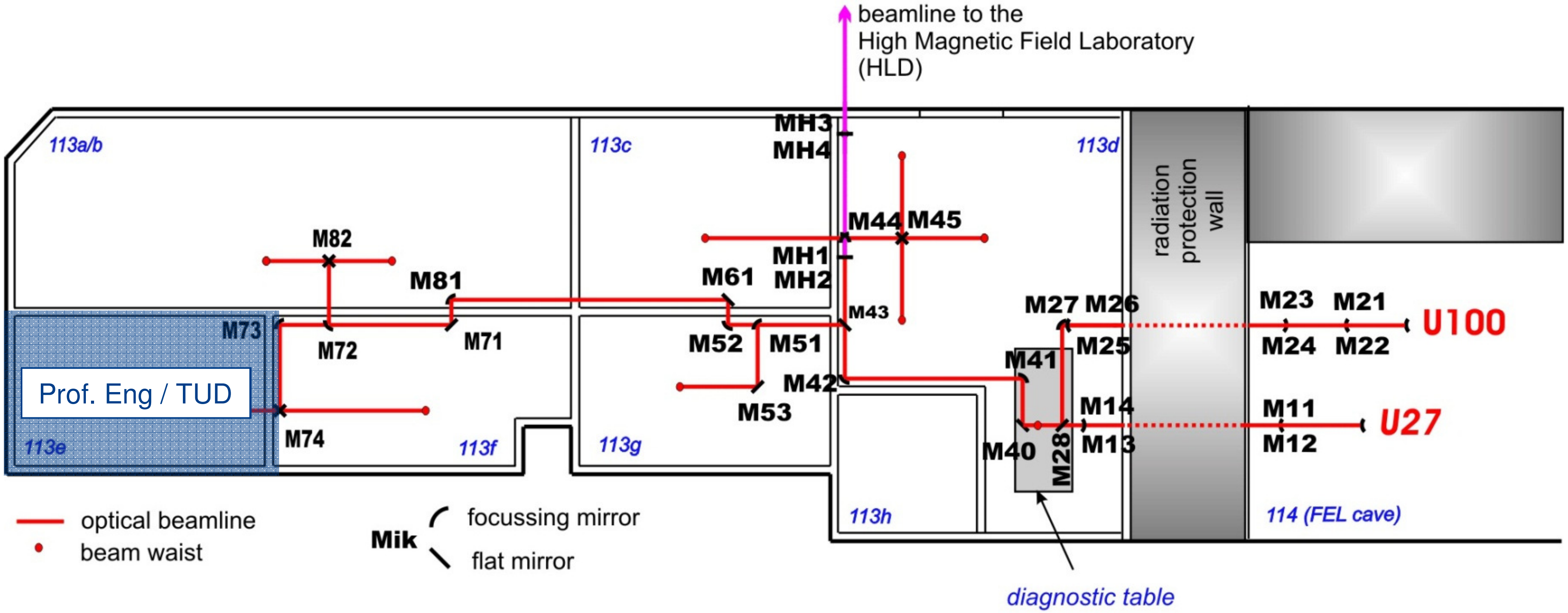


FELBE – FEL / HZDR

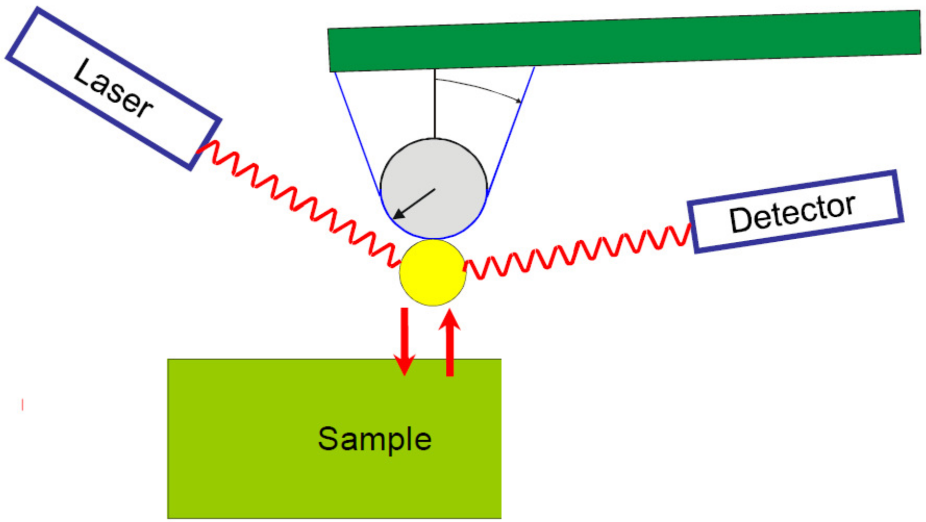
- Spectral range: 100 – 1 THz
- Spectral bandwidth: 0.1 – 2%
- tunable
- Reprate: 13 MHz or 1 KHz (cw)
- Pulse energy: several μJ
- Average power: up to sev. 10 W
- Linear polarization
- Pulse duration: picoseconds

- **Pump probe**
- **Microspectroscopy**

FELBE: SNIM (scanning nearfield microscopy)



FELBE: SNIM (scanning nearfield microscopy)

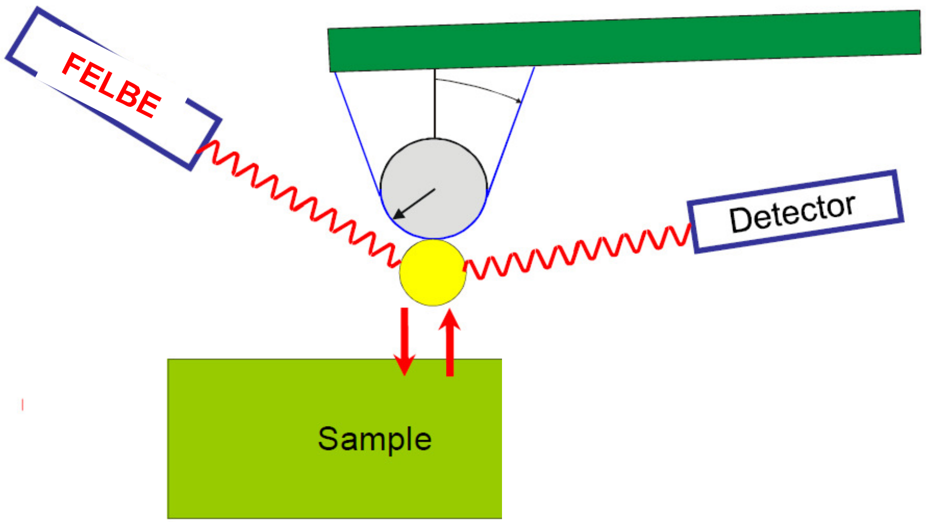


Only nearfield of the tip is probed -> „sub-Abbe" limit microspectroscopy

Courtesy L.M. Eng / TUD

FELBE: SNIM (scanning nearfield microscopy)

Spectral range: 100 – 1 THz
Spectral bandwidth: 0.1 – 2%



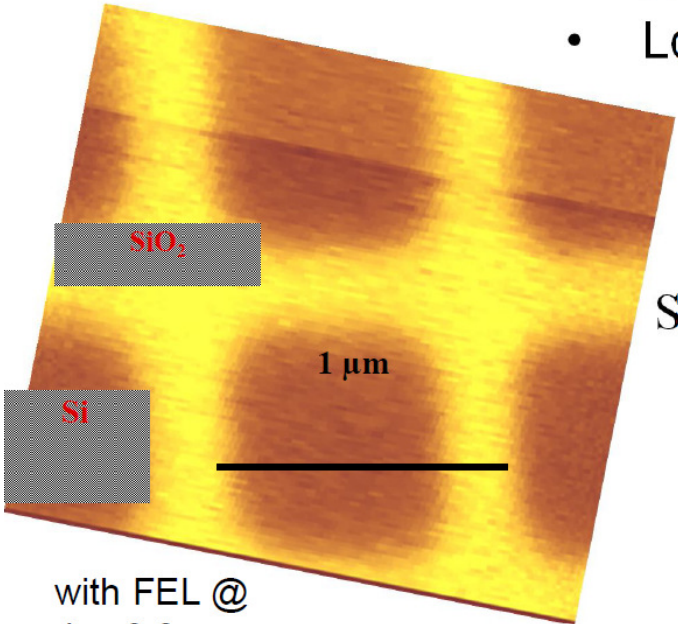
Only nearfield of the tip is probed -> „sub-Abbe“ limit THz microspectroscopy

Courtesy L.M. Eng / TUD

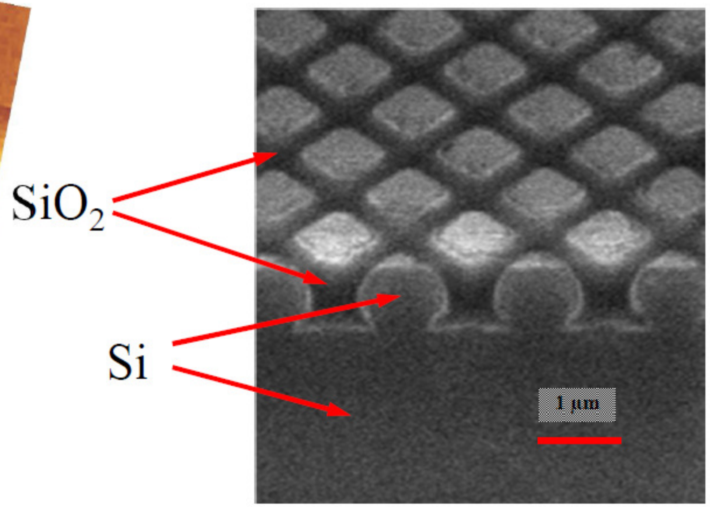
FELBE: SNIM (scanning nearfield microscopy)

Si/SiO2

- High practical interest (DRAM)
- Non-destructive technique
- Local dopant concentration



with FEL @
λ = 9.3 µm

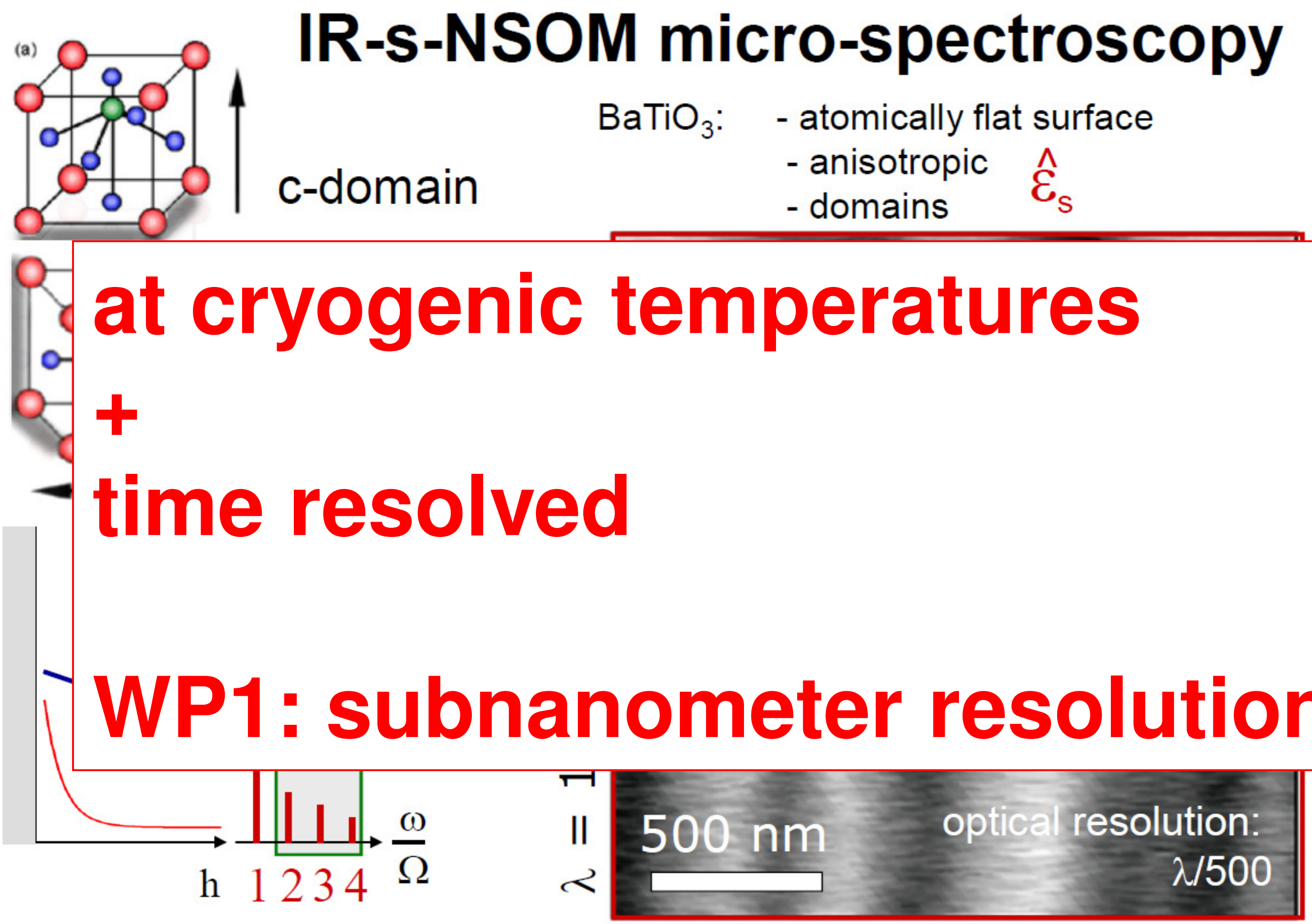


SiO_2 filled trenches,
thickness 400 nm,
width 300 nm

➢ **Resolution of λ/500 @ 10.6 µm**

Courtesy L.M. Eng / TUD

FELBE: SNIM (scanning nearfield microscopy)



at cryogenic temperatures

+

time resolved

WP1: subnanometer resolution

Courtesy L.M. Eng / TUD

Acknowledgement:

S. Winnerl, D. Stehr, S. Zvyagin,
H. Schneider, M. Helm (FWI)

W. Seidel, M. Kuntzsch, U. Lehnert,
C. Ilgner M. Freitag, V. Asgekar,
R. Wünsch, P. Michel (FWK)

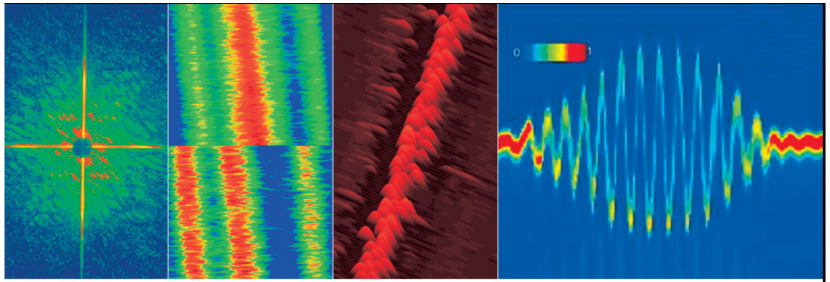
N. Stojanovic, F. Tavella, B. Faatz,
M. Yurkov, H. Schlarb, E. Schneidmiller,
V. Kocharyan, E. Saldin (DESY)

G. Geloni (X-FEL)

L.M. Eng (TUD)

THANK YOU

WE ARE LOOKING FOR A POSTDOC!
(could start immediately)



503. WILHELM AND ELSE HERAEUS SEMINAR
FREE-ELECTRON LASERS: FROM FUNDAMENTALS TO APPLICATIONS

Free-electron lasers (FEL) have recently received a lot of attention, mainly due to the development of short-wavelength free-electron lasers such as FLASH in Hamburg operating in the deep UV, and the worldwide first X-ray free-electron laser LCLS in Stanford, USA. Yet free-electron lasers in the longer-wavelength infrared and terahertz regions have been operating already for two decades and contributed a wealth of results in various scientific fields.

The goal of the seminar is to
- Familiarize students and young postdocs with the basic physical concepts and mechanism of FELs.
- Discuss the spectacular possibilities recently developed short-wavelength FELs offer for research in fields like biology, atomic and solid state physics.
- Present highlights of research long-wavelength FELs have contributed to in the past decade in the fields of solid state and molecular physics.

Contact: Susann Gebel, s.gebel@hzdr.de, www.hzdr.de

Confirmed Speakers:
- Andrea Cavalleri (MPSD, Hamburg)
- Henry Chapman (CFEL, Hamburg)
- Thomas Cowan (HZDR, Dresden)
- Lukas M. Eng (TU Dresden)
- A.F.G. van der Meer (FELIX, Nieuwegein, NL)
- Gerard Meijer (FHI, Berlin)
- Thomas Möller (TU Berlin)
- Ben N. Murdin (Univ. Surrey, U.K.)
- Wolfgang Schleich (Univ. Ulm)
- Theo Rasing (Univ. Nijmegen)
- Peter Schmüser (DESY, Hamburg)
- Jochen Schneider (DESY, Hamburg)
- Simone Techert (MPIBPC, Göttingen)
- Sven Toleikis (DESY, Hamburg)
- Luke Wilson (Univ. Sheffield, U.K.)
- Stephan Winnerl (HZDR, Dresden)
- Marc Vrakking (MBI, Berlin)

Organizers:
- J. Feldhaus (DESY, Hamburg)
- M. Gensch (HZDR, Dresden)
- M. Helm (HZDR, Dresden)

PHYSIKZENTRUM BAD HONNEF
APRIL 10 – 13, 2012

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HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF