The Rossendorf IR FEL ELBE

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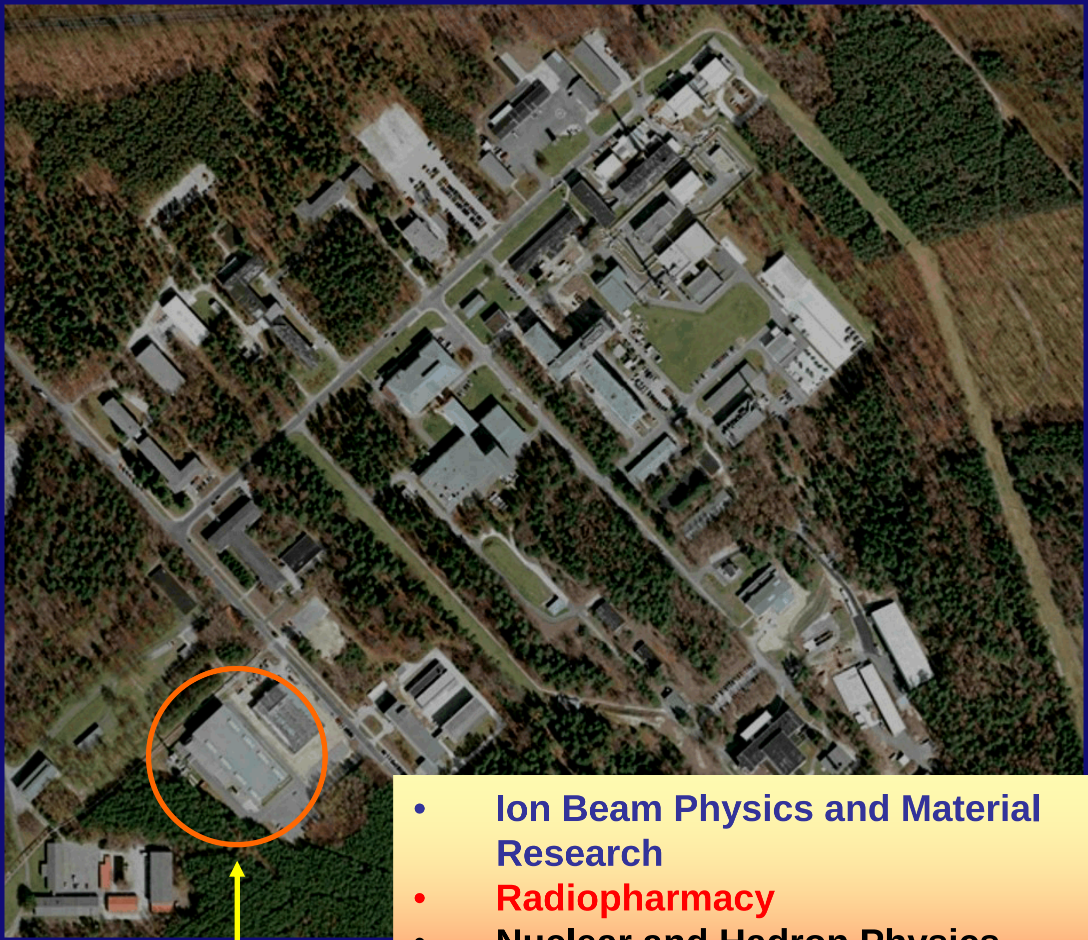
- Introduction
- ELBE concept
- Electron machine
- FELs & optical user labs
- User operation @ELBE

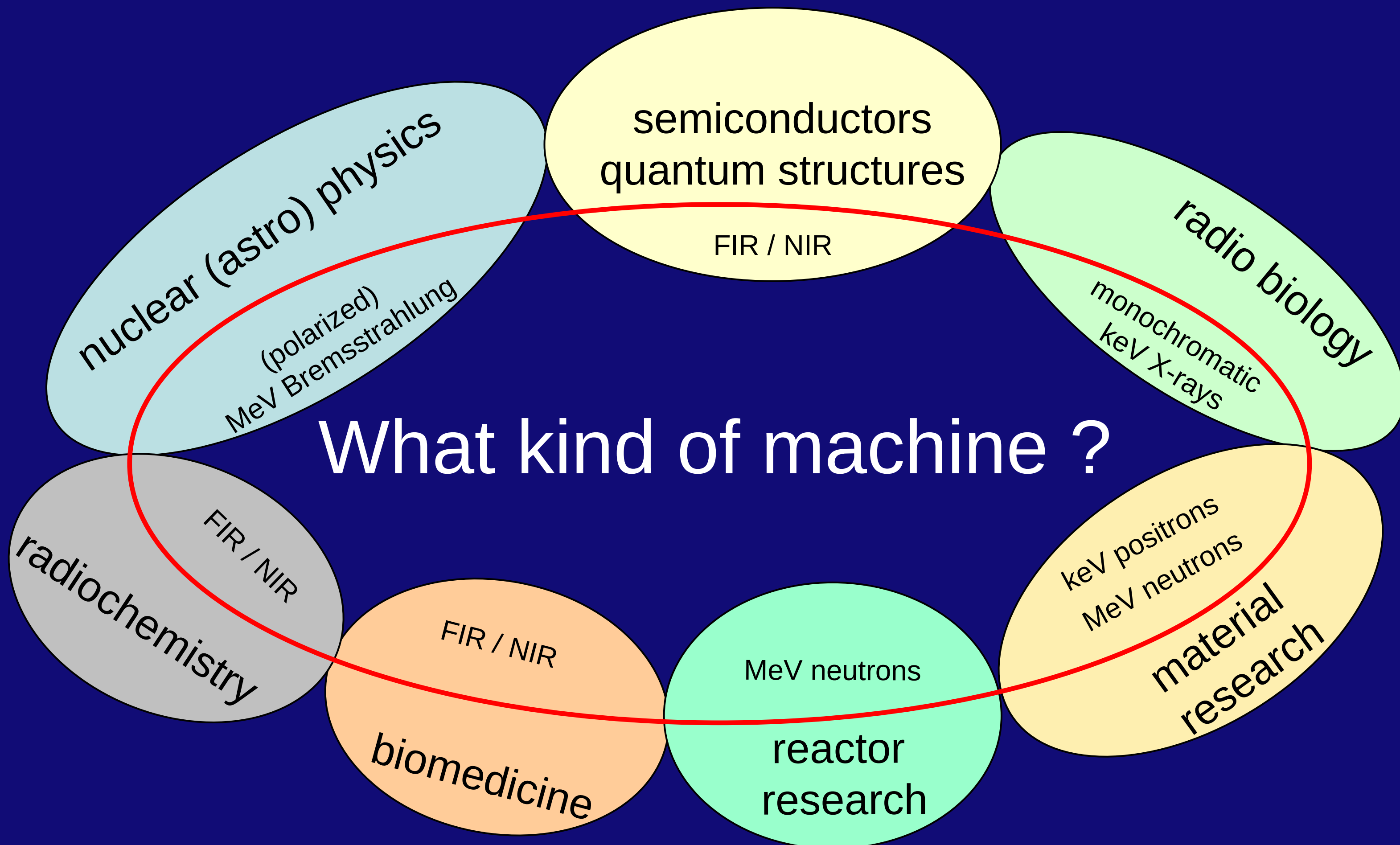
The Radiation Source ELBE at Forschungszentrum Rossendorf (FZR)

- Structure of Matter
- Life Sciences
- Environment and Safety



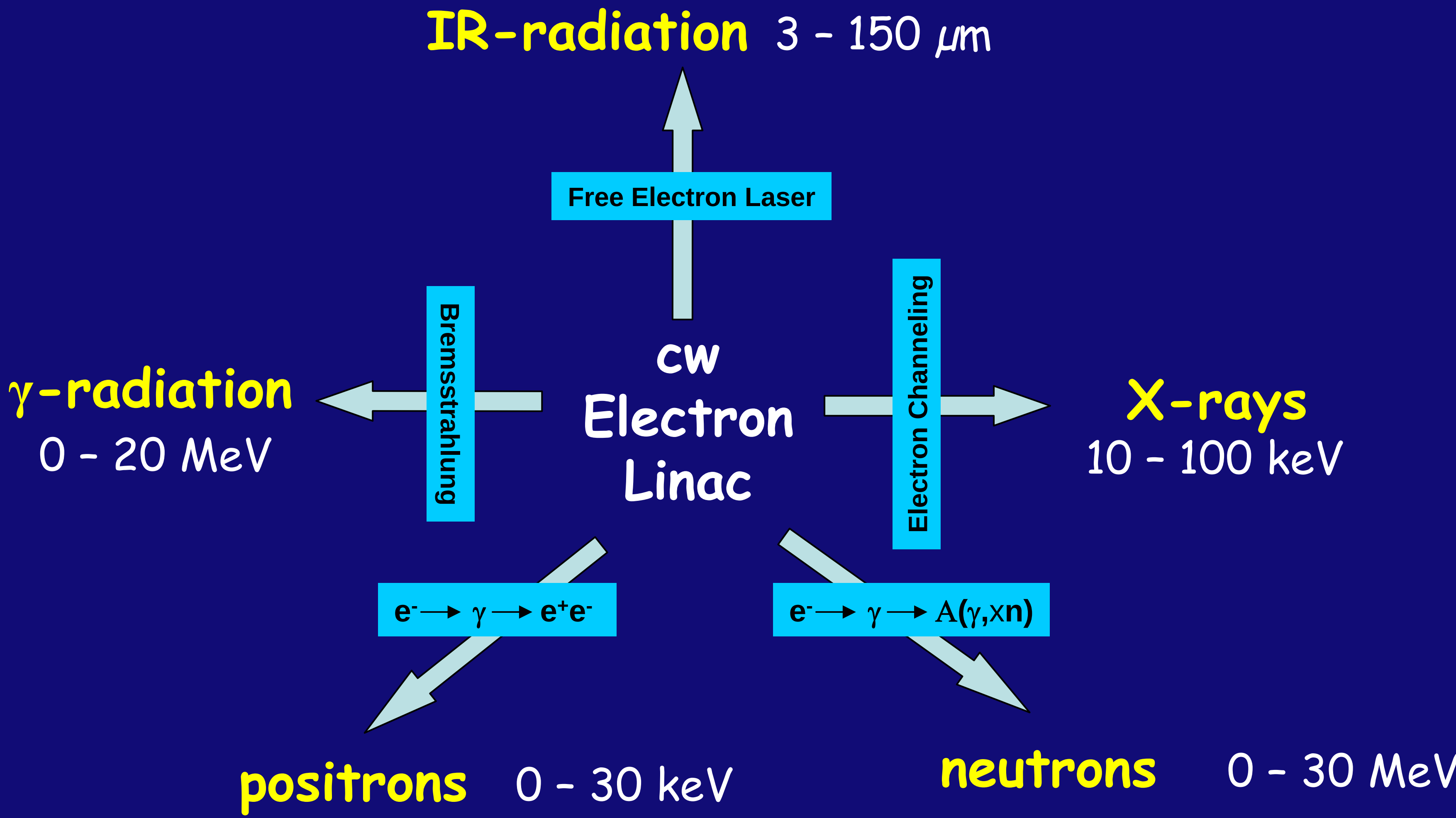
ELBE

- Ion Beam Physics and Material Research
- Radiopharmacy
- Nuclear and Hadron Physics
- Safety Research
- Radiochemistry
- High Magnetic Field Lab

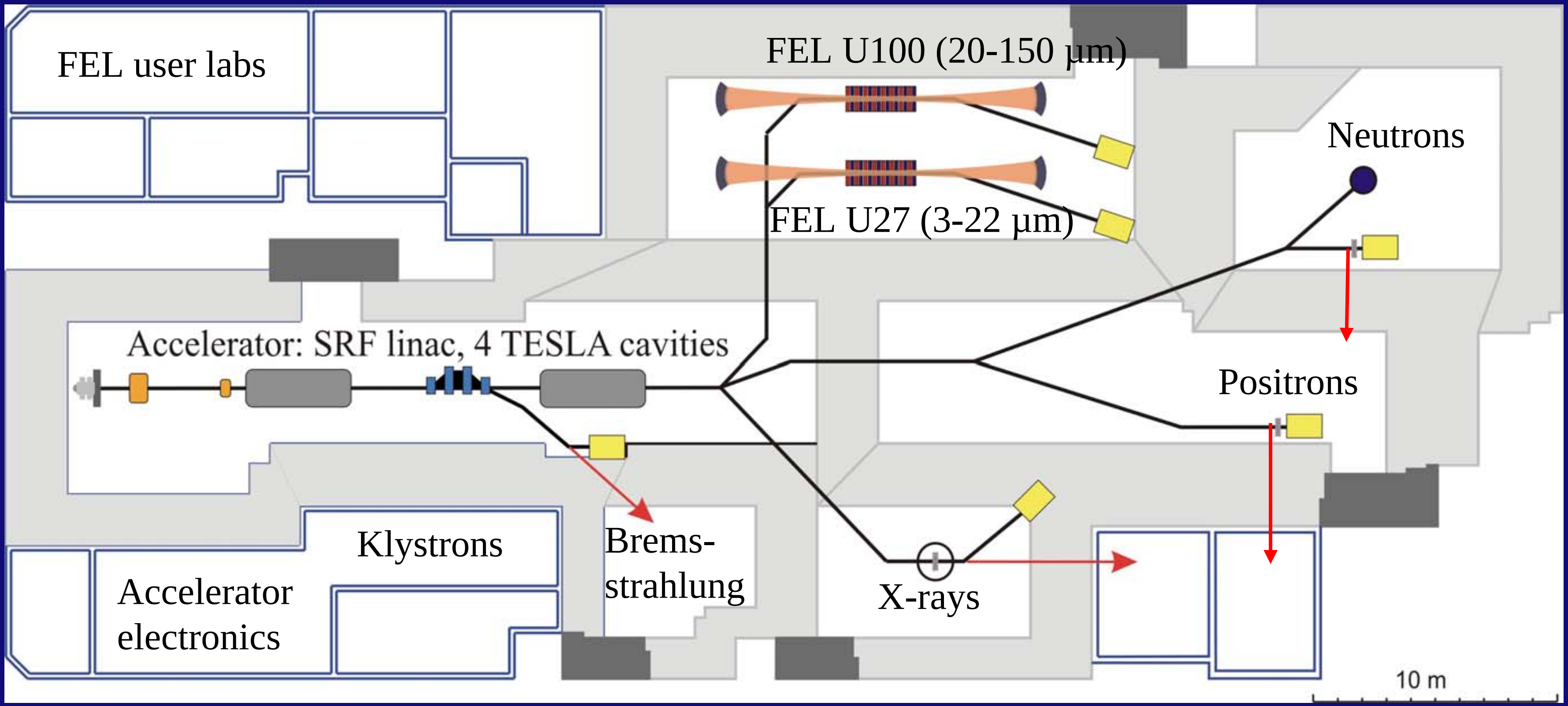

What kind of machine ?
semiconductors
quantum structures
FIR / NIR
nuclear (astro) physics
(polarized)
MeV Bremsstrahlung
radio biology
monochromatic
keV X-rays
radiochemistry
FIR / NIR
biomedicine
FIR / NIR
reactor
research
MeV neutrons
material
research
keV positrons
MeV neutrons

Radiation Source ELBE

superconducting **E**lectron **L**inac of high **B**rilliance and low **E**mittance



ELBE Layout



- Start Bremsstrahlung experiments : 2002
- Channeling radiation (X-ray's) : 2003
- IR-Radiation : FEL 1 first lasing 7.05.2004
- FEL 2 first lasing 21.08.2006
- Neutron and Positrons planned for 2007

Electron Accelerator

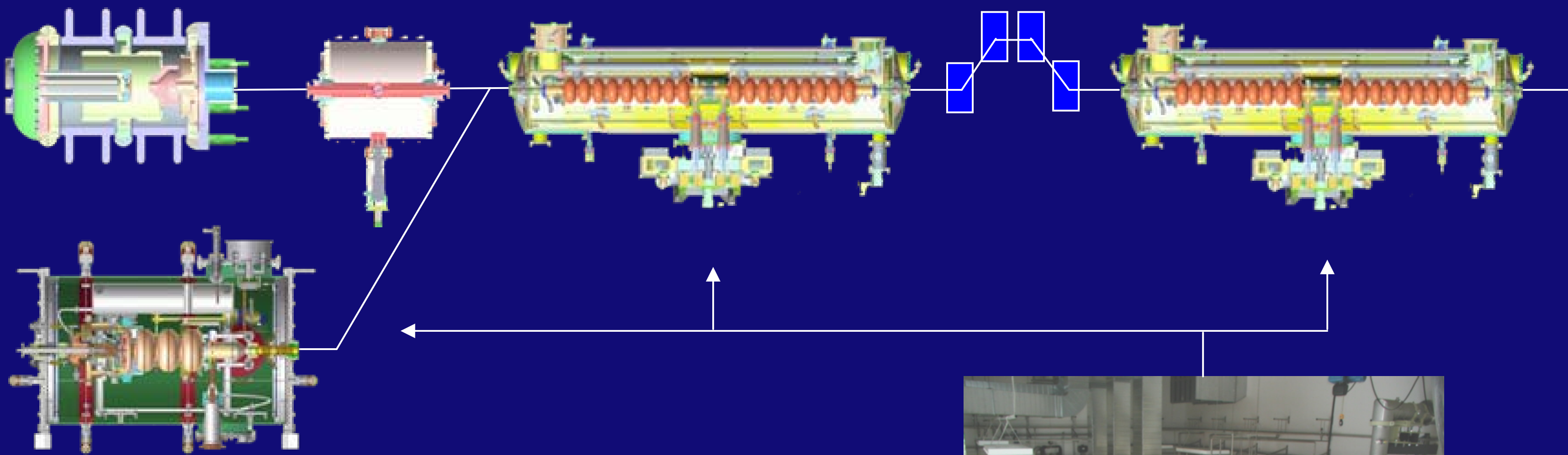
thermionic DC gun
250 kV
<= 260 MHz
<80 pC
~ 500ps
~10 mm mrad

RF buncher
260 MHz
+1,3GHz
compr. ~ 100:1

linac
1,3 GHz
~20MeV@10 MeV/m
CW

magnetic bunch compressor
R_{56} < 500 mm

linac
1,3 GHz
~20 MeV@10MV/m
CW



SRF photo gun
9.5 MeV
<= 13 MHz
80pC / 1nC / 2.5 nC
~ 5-20 ps
~ 1.5-3 mm mrad

Poster !!!!
THPPH006
THPPH007
THPPH008
THPPH009

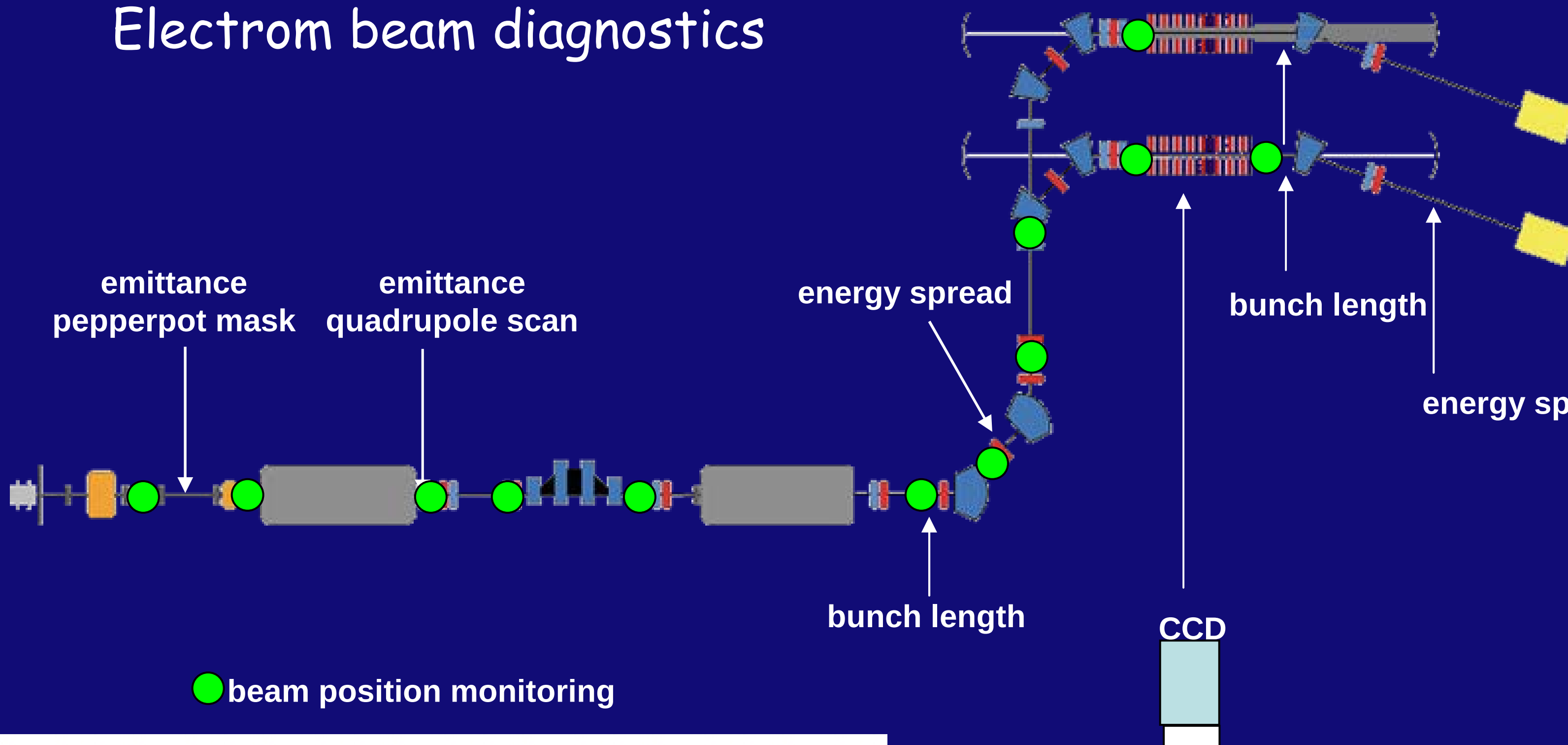
helium liquifier LINDE
200 W @ 1,8 K

ELBE Accelerator Beam Paramters

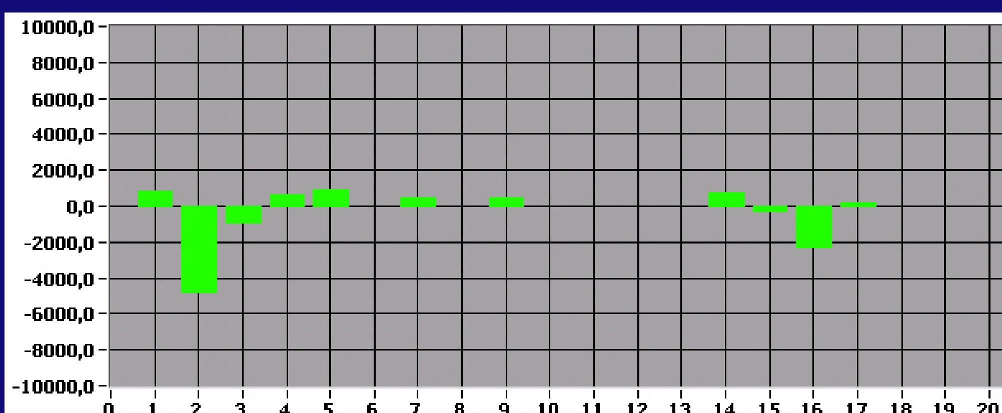
	Thermionic gun + bunch compressor		SRF photo gun
maximum energy	36 MeV (CW)	~50 MeV pulsed RF	~ 44 MeV (CW)
maximum bunch charge	77 pC		2,5 nC
maximum beam current	1 mA		1 mA
bunch length rms	1-10 ps		

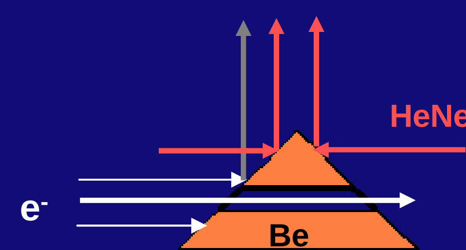
	low emittance mode (channeling)	high average current mode (FEL& all others)	
transverse emittance rms	2 mm mrad	10 mm mrad	0,5-2,5 mm mrad
repetition rate	260 MHz (0,77 pC)	13 MHz (77 pC)	1-13 MHz
energy spread fwhm	35 keV	55 keV	

Electrom beam diagnostics

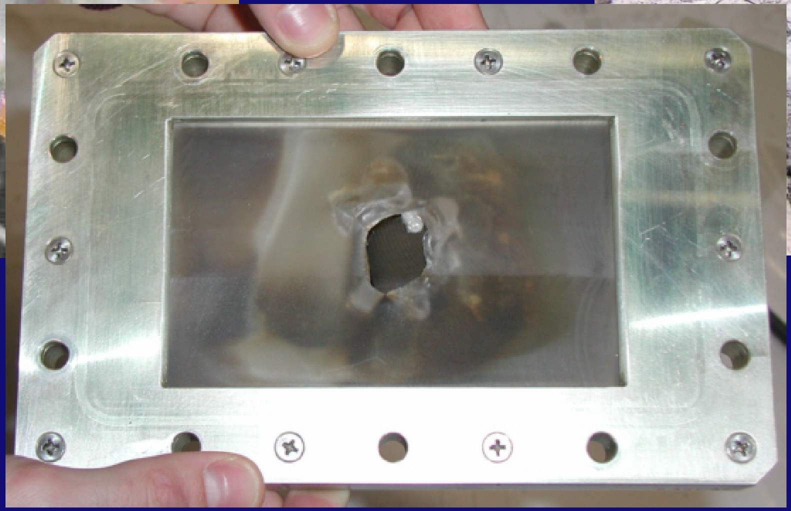


beam position monitoring





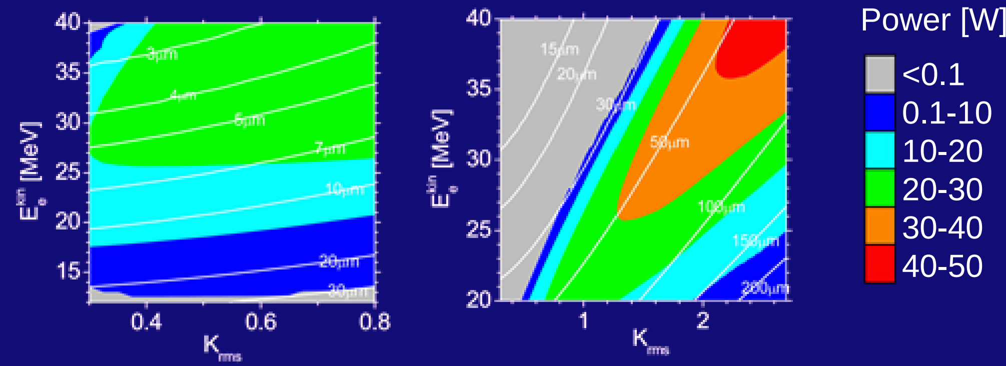
Machine protection system

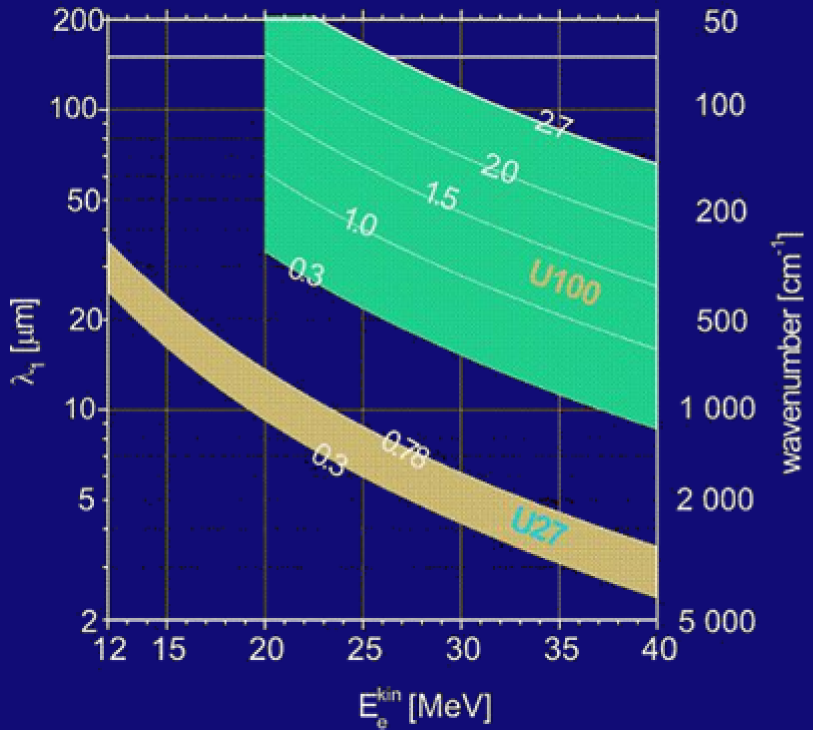


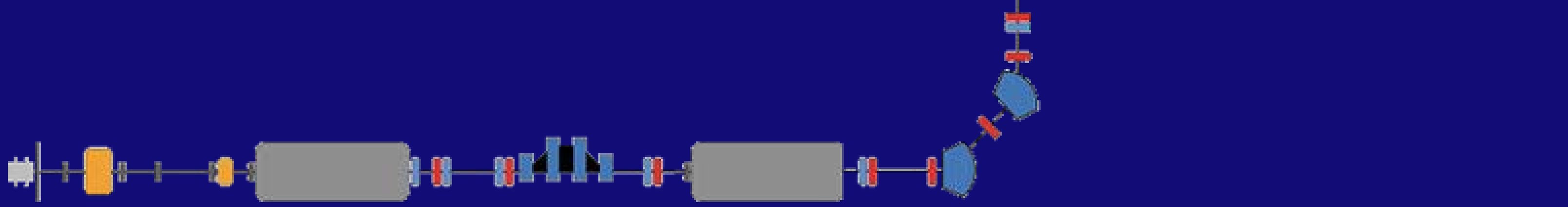
•Long ionization chambers to detect beamloss (fast interlock @ beamloss > 10 µA)
•Transmission monitoring (fast interlock @ current difference > 20 µA)
•Detection of discharge, pressure and temperature rise on RF windows
•Fast vacuum valves close to Linac modules
•....

ELBE IR Concept

Outcoupled power: U27 (2mm hole τ=0,7ps) U100 (4,5mm hole τ=2ps)

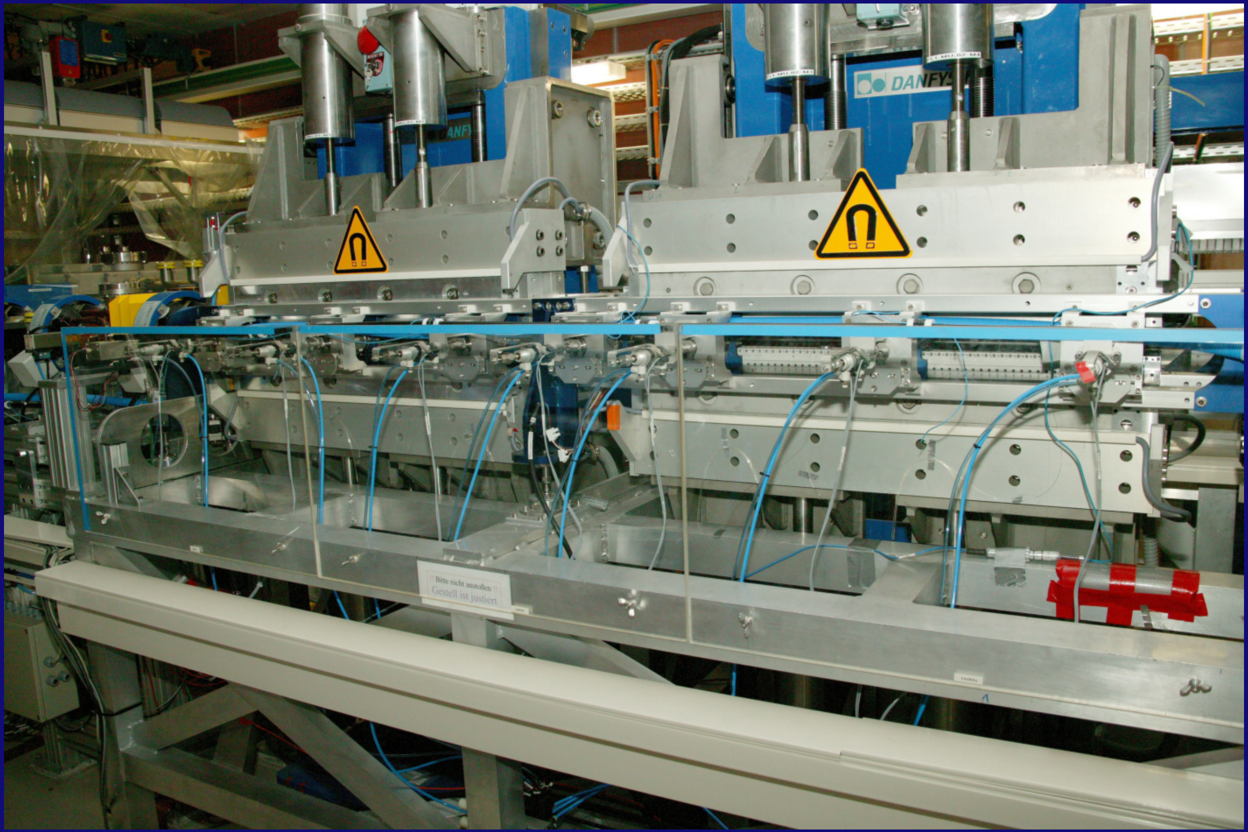






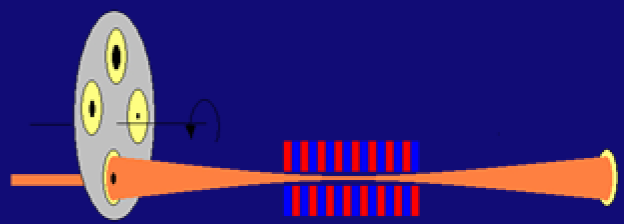
U27 FEL

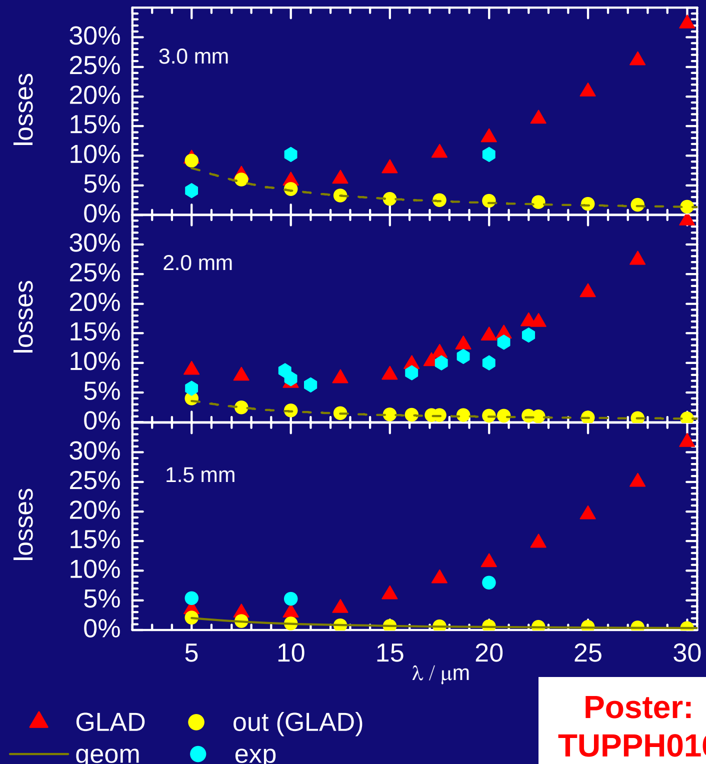
Undulator period	27.3 mm
Number of periods	2 * 34
Undulator K	0,3 – 0,7
Undulator type	hybrid NdFeB
Resonator length	11.53 m
Rayleigh length	1 m
Outcoupling holes	1,5 / 2/ 3 / 4mm
Mirror R(curvature)	5940 mm (h+v)
Mirror diameter	70 mm
Mirror material	Au / Cu
Waveguide	no
Wavelength	3-22 µm
Max. power (out)	~ 25 W
Max. pulse energy	~ 1µJ



Optimizing outcoupled Power

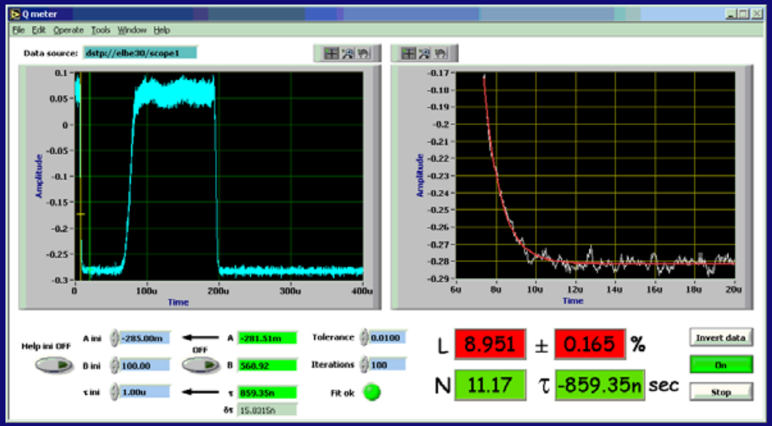
interchangeable mirrors (different hole diameter)





Poster: TUPPH016

Measurement of round-trip loss



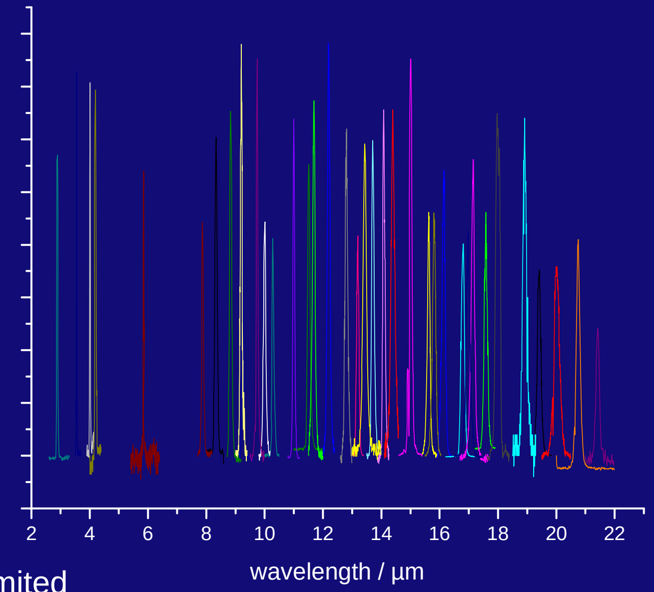
$$\sim e^{-t/\tau}$$

$$L = \frac{t_{roundtrip}}{\tau}$$

out-coupling hole size	1.5 mm	2.0 mm	3.0 mm
measured average power	16.8 W	24.8 W	13.9 W
measured round-trip losses	5.25 %	7.25 %	10 %
outcoupled fraction (computed)	1.1 %	2.0 %	4.4 %
average intra-cavity power	1600 W	1300 W	330 W
intra-cavity saturated power	62 MW	50 MW	13 MW

U27-FEL parameter in practice

Wavelength: 3,4 -22 µm



Outcoupled Power:

- \> 3W @ 4-5 µm
- \> 10W @ 5-10 µm
- \> 5W @ 10-13 µm
- \> 3W @ 13-20µm
- \> 1W @ 20-22 µm

Pulse energy: ~ 1µJ (1,3W @ cw = 100nJ)

Puls length: ~ 0,9 – 3,4 ps @11 µm

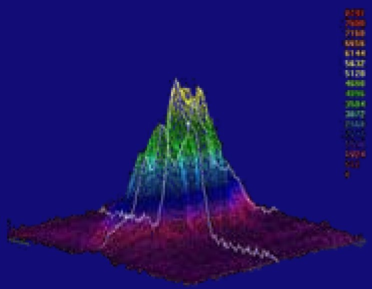
Spectral width: ~ 0,4 – 1,6 % @ 11µm

bandwith limited

Pulse structure:

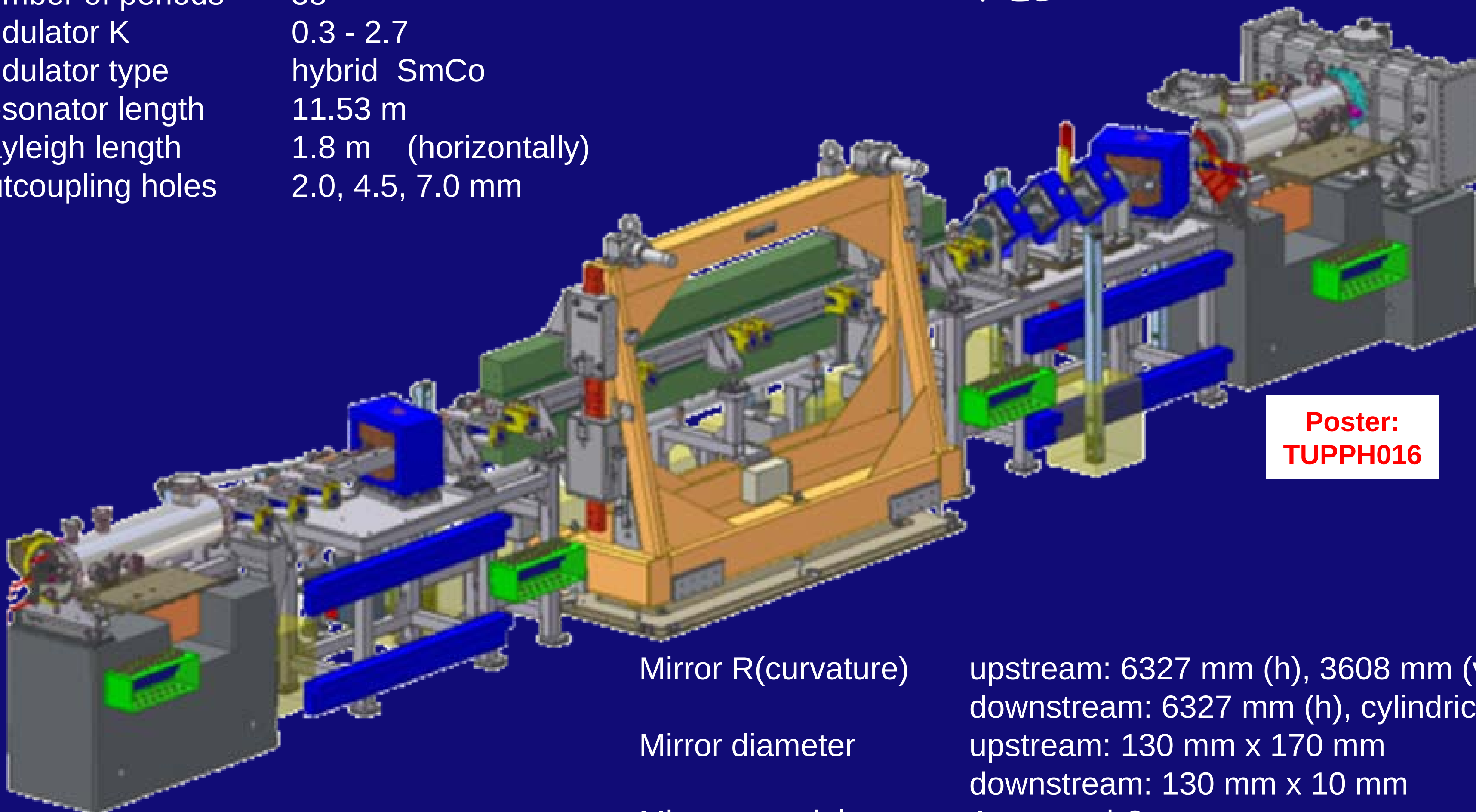
micro pulse 13 MHz
in preparation: switch 13 MHz-1kHz
macro pulse 100µs – cw (1Hz-25Hz)

Beam size: ~ 0,5 mm



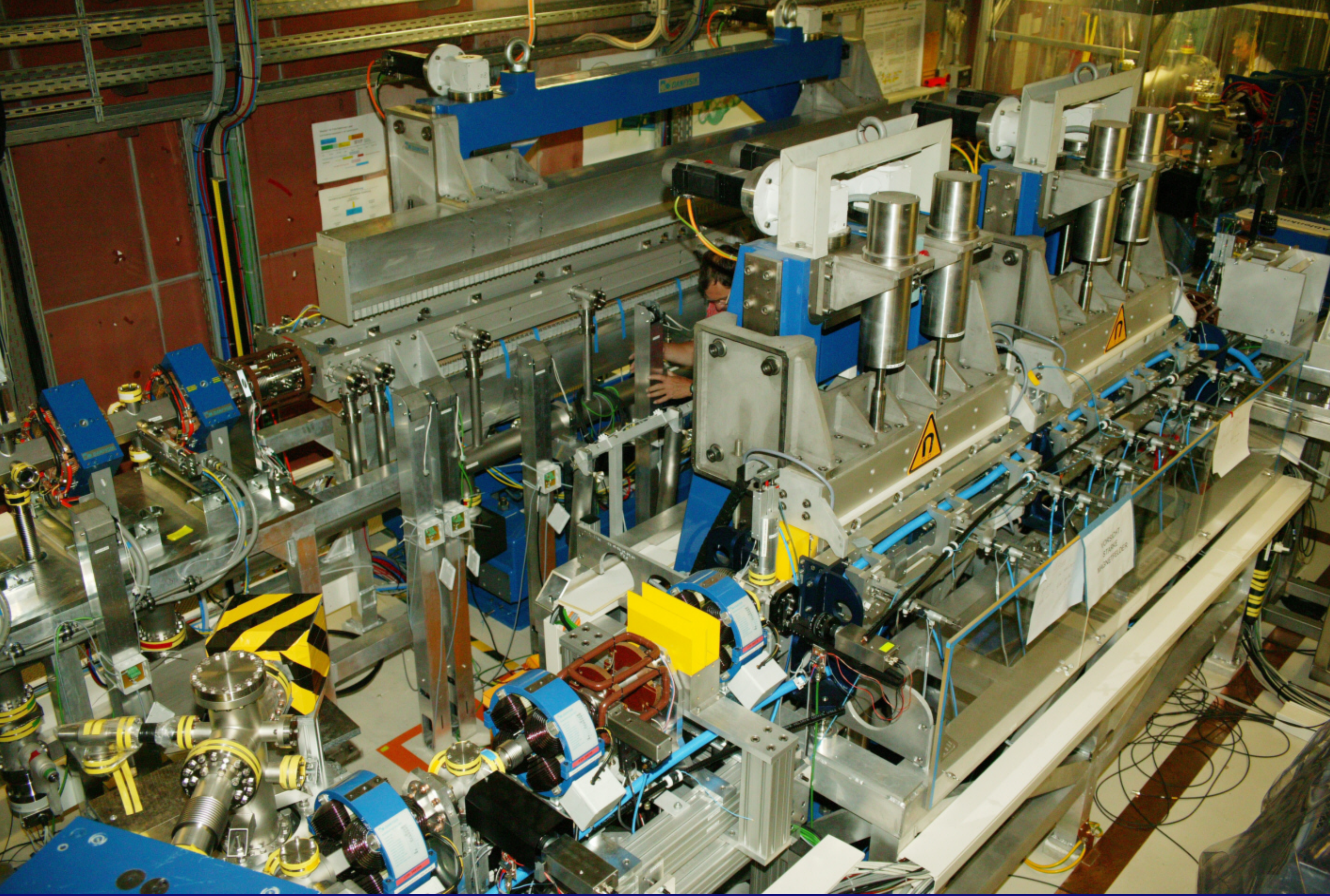
Undulator period	100 mm
Number of periods	38
Undulator K	0.3 - 2.7
Undulator type	hybrid SmCo
Resonator length	11.53 m
Rayleigh length	1.8 m (horizontally)
Outcoupling holes	2.0, 4.5, 7.0 mm

U100 FEL



Poster: TUPPH016

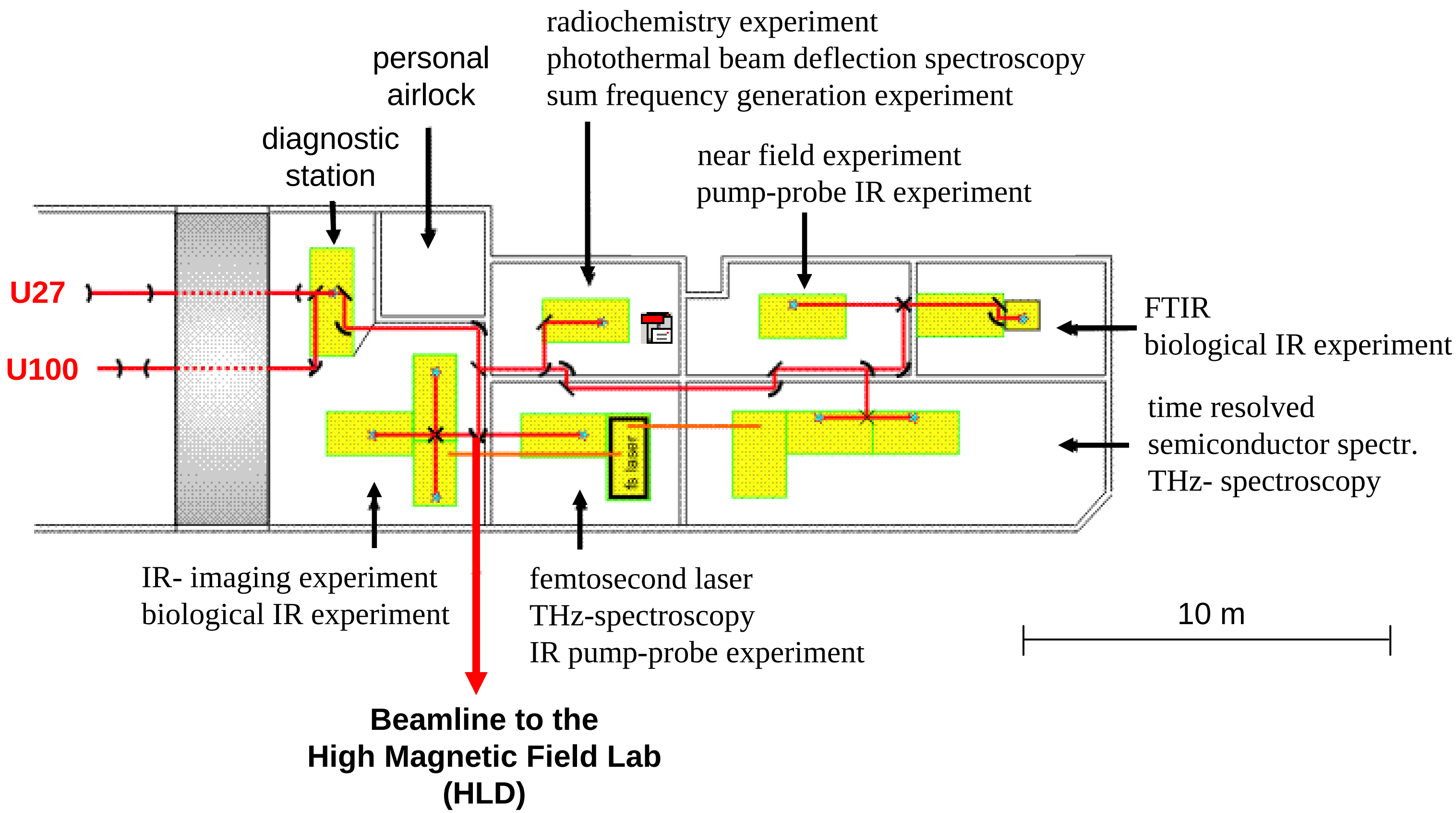
Mirror R(curvature)	upstream: 6327 mm (h), 3608 mm (v), downstream: 6327 mm (h), cylindrical
Mirror diameter	upstream: 130 mm x 170 mm downstream: 130 mm x 10 mm
Mirror material	Au coated Cu
Waveguide	partial waveguide to the downstream mirror
Wavelength	20 - 150 (200) µm
Max. power (out)	>10 W
Max. pulse energy	>1 µJ



ELBE optical user labs

„Integrating activity on synchrotron and free electron laser science“

FEL @ ELBE → FELBE



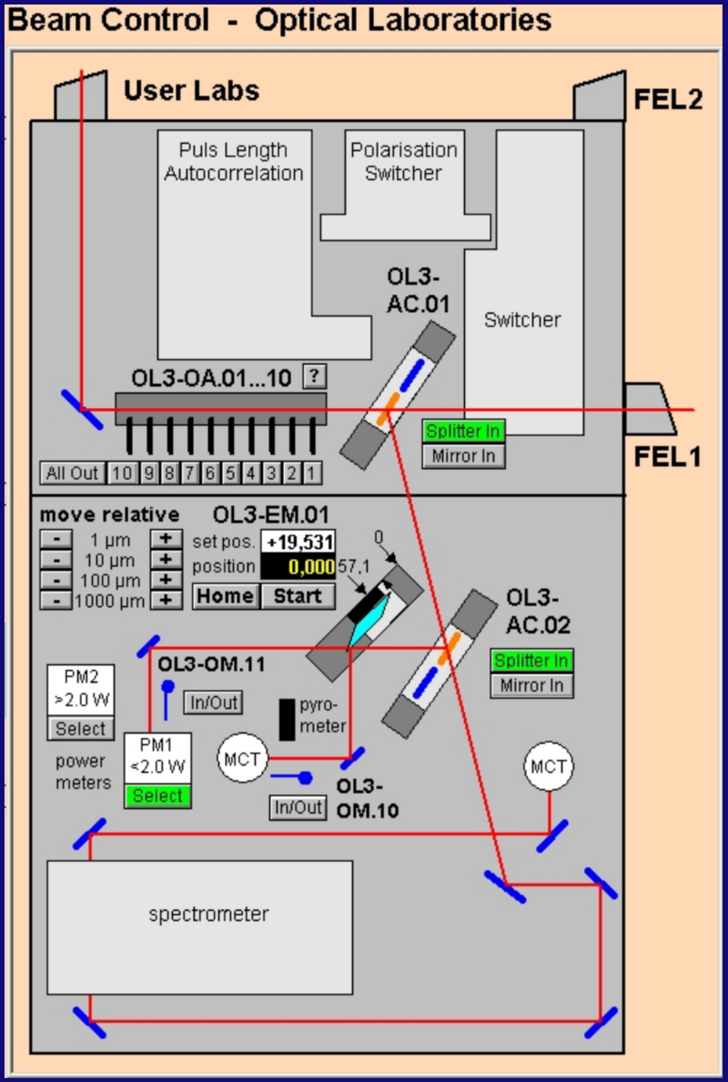
IR Beam Diagnostics

Poster: TUPPH015

Remote controlled diagnostic station (ELBE control room)
-MCT (4-26 µm ,BW ~ 10MHz) - pulse temporal structure
-IR-spectrometer
-IR-power meter
-attenuation of the user beam 5 x 3 or 10 db

Additional , not (yet) automated
-autocorrelator (micropulse duration)
-movable IR detector for imaging

In preparation
-logging of the MCT output (stability & „laser on“ statistics)
-synchronized chopper for MCT data in cw-mode



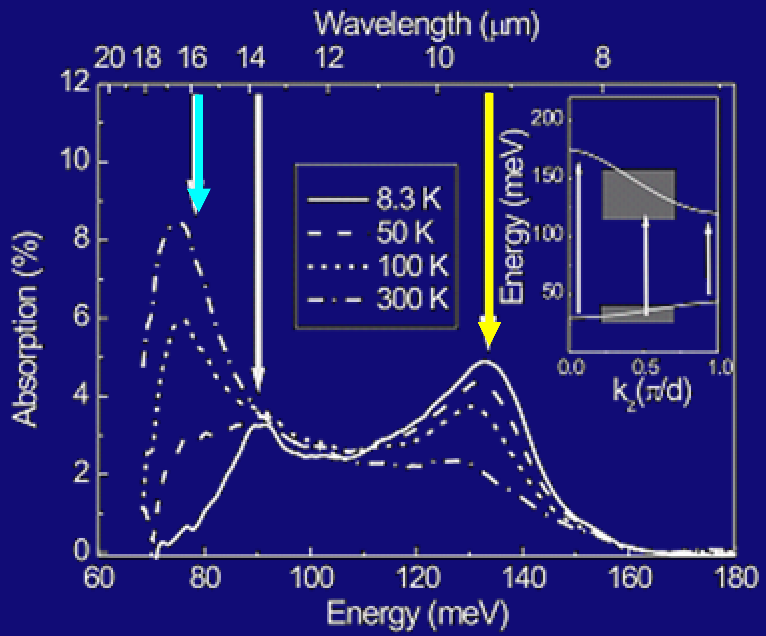
experiments running at present

- Electron dynamics of semiconductor super lattices (FZR)
- Photothermal spectroscopy of radioactice environmental samples (FZR)
- Quantitative scattering near-field IR optical microscopy of optical anisotropic samples (TU Dresden)
- High resolved polarization modulation-IR reflection absorption spectroscopy (PM-IRRAS) (University of Vilnius)
- Chemical mapping of monolayers on microstructure arrays as model systems for protein coatings on implants (TU Dresden)
- Ellipsometry (ISAS, Bessy)
- Sum frequency spectroscopy at Sapphire/Water Interfaces (FZ Karlsuhe)
- Two-colour pump-probe measurements of polaron dynamics in InAs-GaAs self-assembled quantum dots (Univ. of Sheffield,UK)
- Photoconductivity study of shallow impurities in ZnO (TU Dresden)
- Two-photon quantum well infrared photo detector (FZR)
- Absorption induced orientation polarization (University of Leipzig)
- IR-pulsed-induced structural changes in DNA (FZR)
- ...

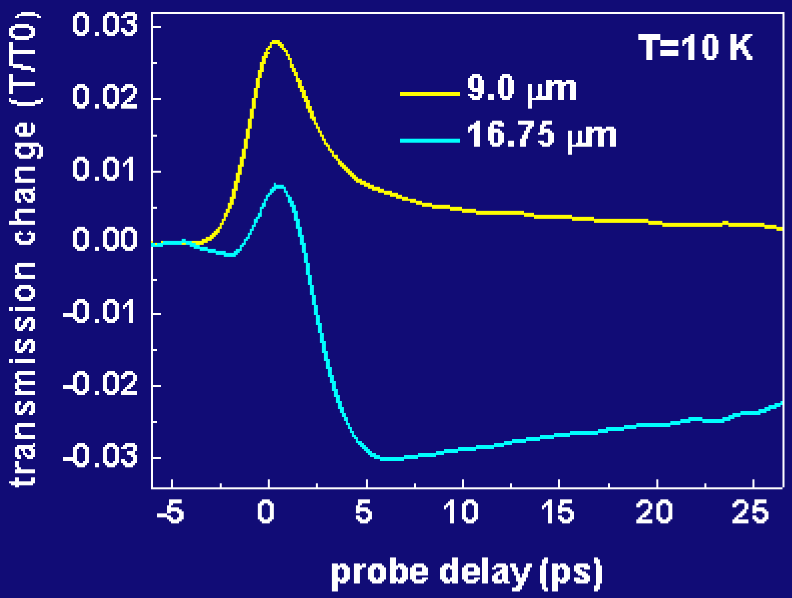
Example:

Electron dynamics in semiconductor super lattices

Absorption spectrum



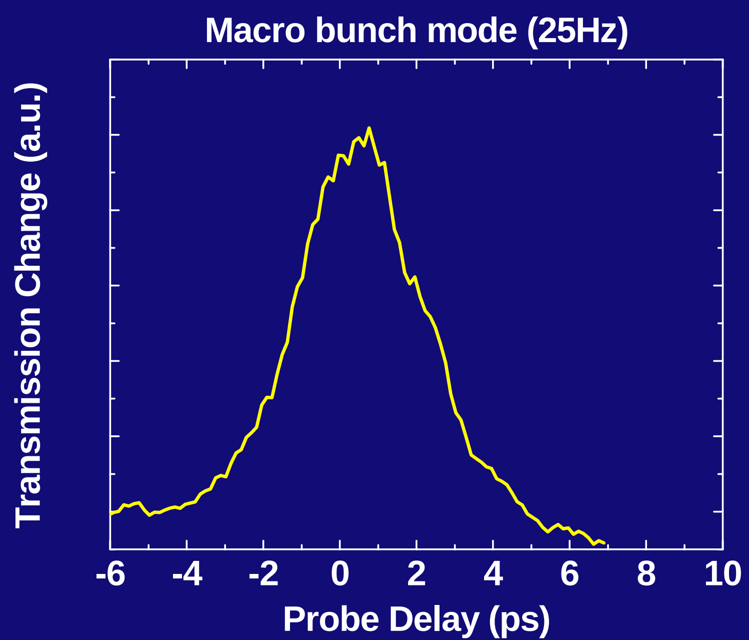
Bleaching followed by Relaxation
Thermalization at T_e, and cooling

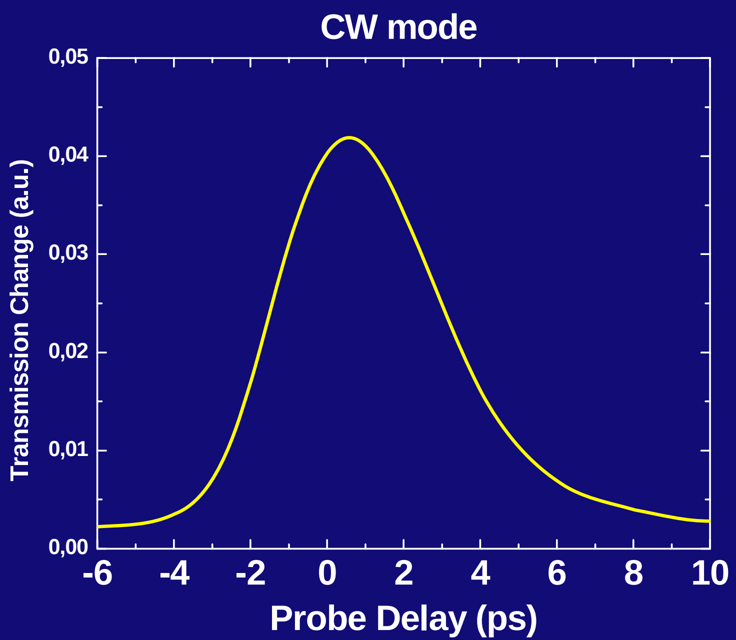


D. Stehr et al., Appl. Phys. Lett. **88**, April 2006

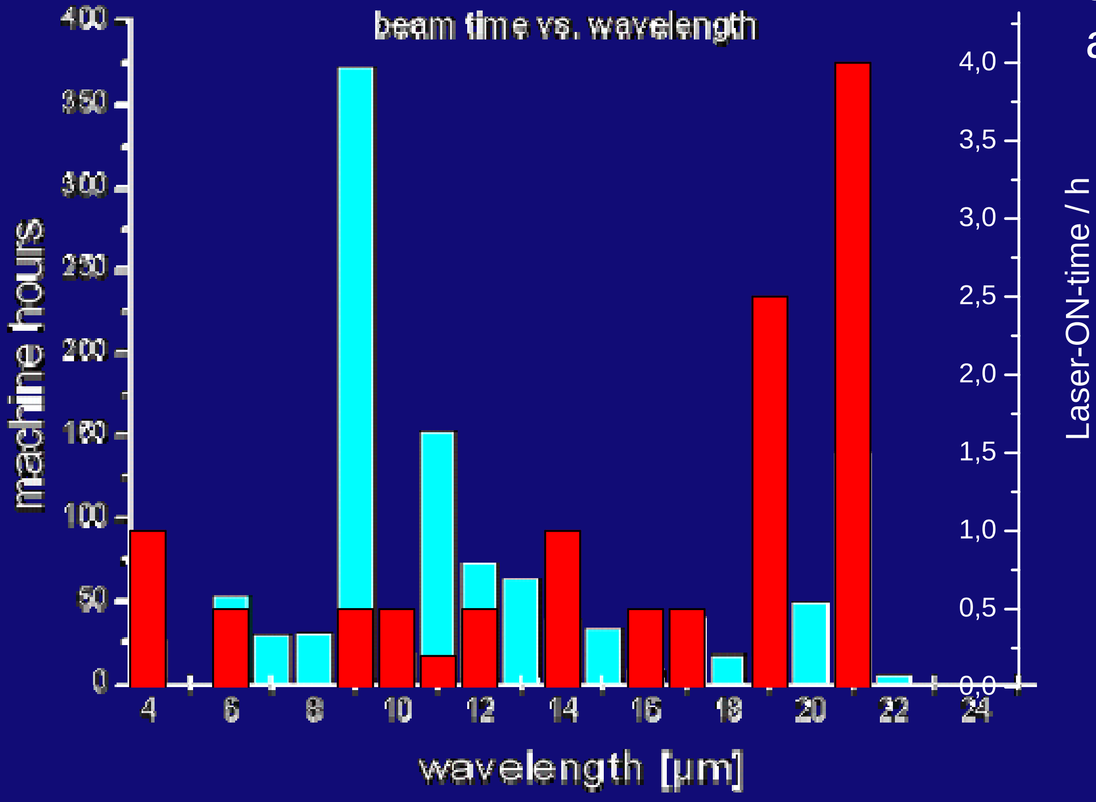
Courtesy of D.Stehr

Advantages of cw mode experiments





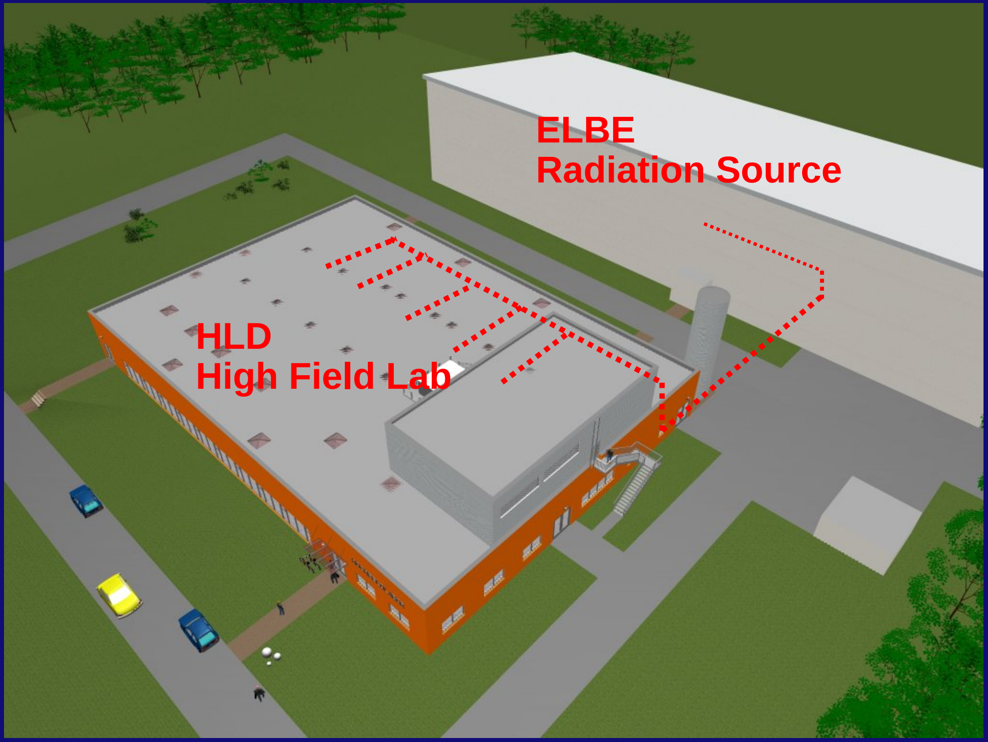
FEL operational experiences



total user hours @ FEL ~ 1300
at present: 22 proposals
availability (2006) ~ 90 %

time for chanching gap	~ 30 s
time for changing energy	~ 10-20 min

High Magnetic Field Lab & ELBE



High Field Lab Dresden

40 T static

60 T @ 1000 ms

70 T @ 100 ms

100 T @ 10 ms

Combination of ELBE FEL (3 … 150 μm) and High Magnetic Field Lab
IR spectrosocopy at high magnetic fields

$$\mu_B \cdot 100\ \mathrm{T} \sim h \cdot c / 100\ \mu\mathrm{m}$$

Experiments with ELBE IR & High magnetic fields

- investigation of low-energy excitations in solids in high magnetic fields
  cyclotron resonance in semiconductors

- materials with high effective mass and /or low mobility
  examples of present interest are ZnO or nitrides

- electron spin resonance (ESR)
  pump-probe experiments
  complete time-delay scan during the time of one magnetic field pulse
  no synchronization of the FEL with the magnetic field pulses is needed, since the FEL runs continuously at 13 MHz
  > 10^5 FEL pulses during one magnetic-field pulse of 10ms length provide excellent measurement conditions

Summary

- *ELBE FEL's are in successful (user) operation with access for external users (FELBE)*
- *Optical properties of the oscillator are as expected & meet the user requirements*
- *First Lasing @ U100 FEL (20 – 150 µm) was recently demonstrated*
- *First experiments using ELBE IR beams in the high magnetic field lab are planned for 2007*

Thank you for YOUR attention

The ELBE crew
(in the Radebeul vineyards, near Dresden)

Multi-colour pump-probe experiments

- Synchronization of other pulsed lasers to the FEL
- Available lasers:
  - ◆ Ti:sapphire laser (40 fs & 3 ps, 10 nJ/pulse, 78 MHz, 730 nm - 870 nm)
  - ◆ Ti:sapphire laser (12 fs, 5 nJ/pulse, 78 MHz, 800 nm) &

    Ti:sapphire amplifier (25 fs, 1 mJ/pulse, 1 kHz, 800 nm) &

    OPG/OPA (<100 fs, 100 µJ/pulse, 1 kHz, 1150 nm - 2600 nm) &

    Difference frequency mixer (< 100 fs, 0.3 µJ/pulse - 3 µJ/pulse, 1 kHz, crystal 1: 2.4 µm - 11 µm, crystal 2: 5 µm - 18 µm)
  - ◆ Nd:Vanadate oscillator (~ 7 ps, >2 W, 78 MHz, 1064 nm) &

    Nd: YAG amplifier (~16 ps, 1 mJ@1kHz, 1064 nm, 1 Hz - 2 kHz)
- Generation of broad-band THz-radiation with both Ti:sapphire laser systems