Laser Induced Energy Modulation for the Optical Replica Synthesizer Experiment at FLASH

12/02/08

Jörn Bödewadt

Overview

1. Principle of the Optical Replica Synthesizer (ORS)
2. Laser electron interaction in the modulator
3. Experimental setup at FLASH
   - laser transfer line
4. Commissioning of the ORS telescope
5. First measurements (end of October 2007)

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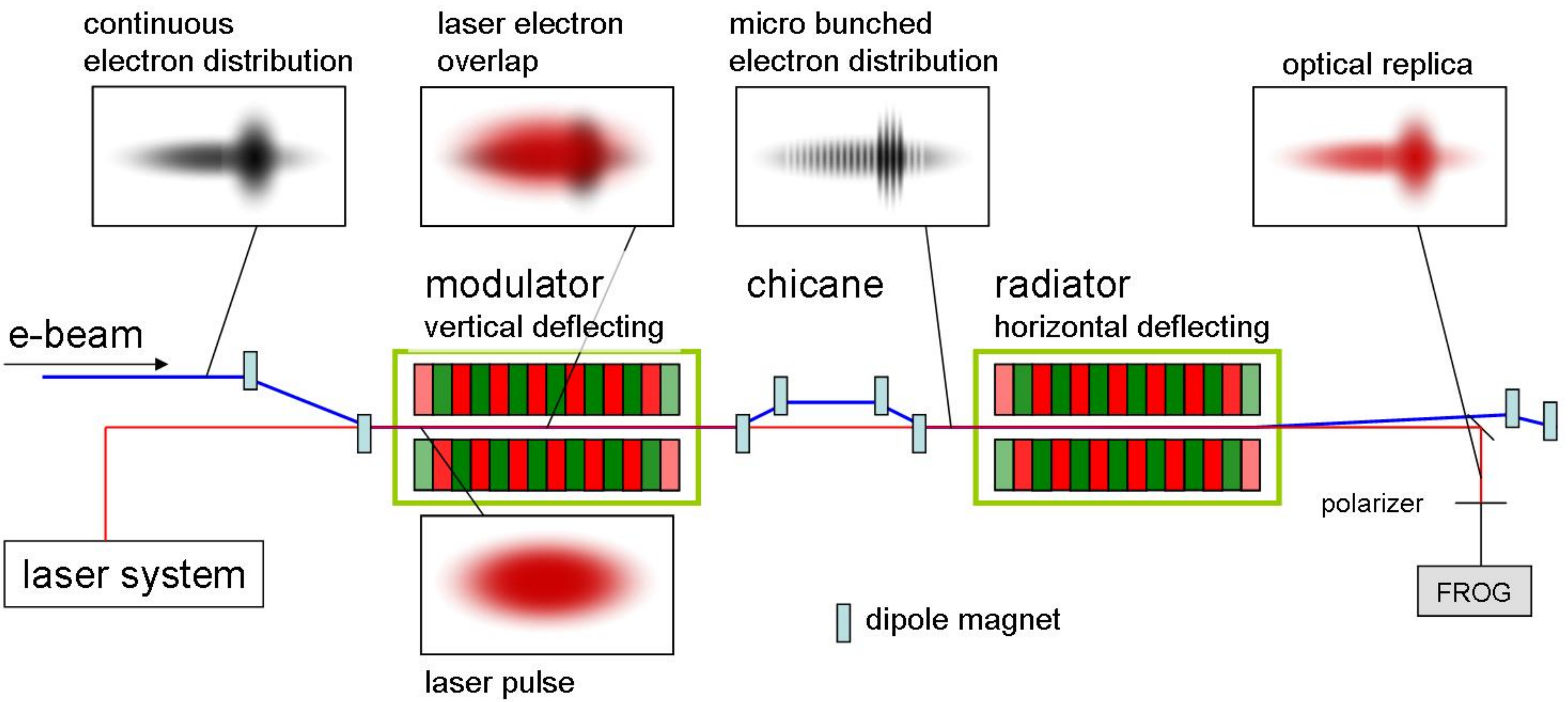
1. Principle of the ORS

(E.L. Saldin et al. Instr. Methods A 539, 499 (2005))



1. Principle of the ORS

(E.L. Saldin et al. Instr. Methods A 539, 499 (2005))

- electric field envelope of the replica pulse:

$$E(t) \propto f[I(t) \cdot \varepsilon(t) \cdot \Delta\gamma(t)]$$

peak current — $I(t)$; slice emittance — $\varepsilon(t)$; slice energy spread — $\Delta\gamma(t)$

- assuming a small electron beam and a small micro bunching spread the electric field is directly proportional to the peak current:

$$E(t) \propto const \cdot I(t)$$

- measure $E(t)$ with frequency resolved optical gate (FROG) methods

2. Laser electron interaction

- energy change for electrons:

$$\frac{d\gamma}{dt} = -\frac{e}{m_e c^2}\vec{E}(t)\cdot\vec{v}(t)$$

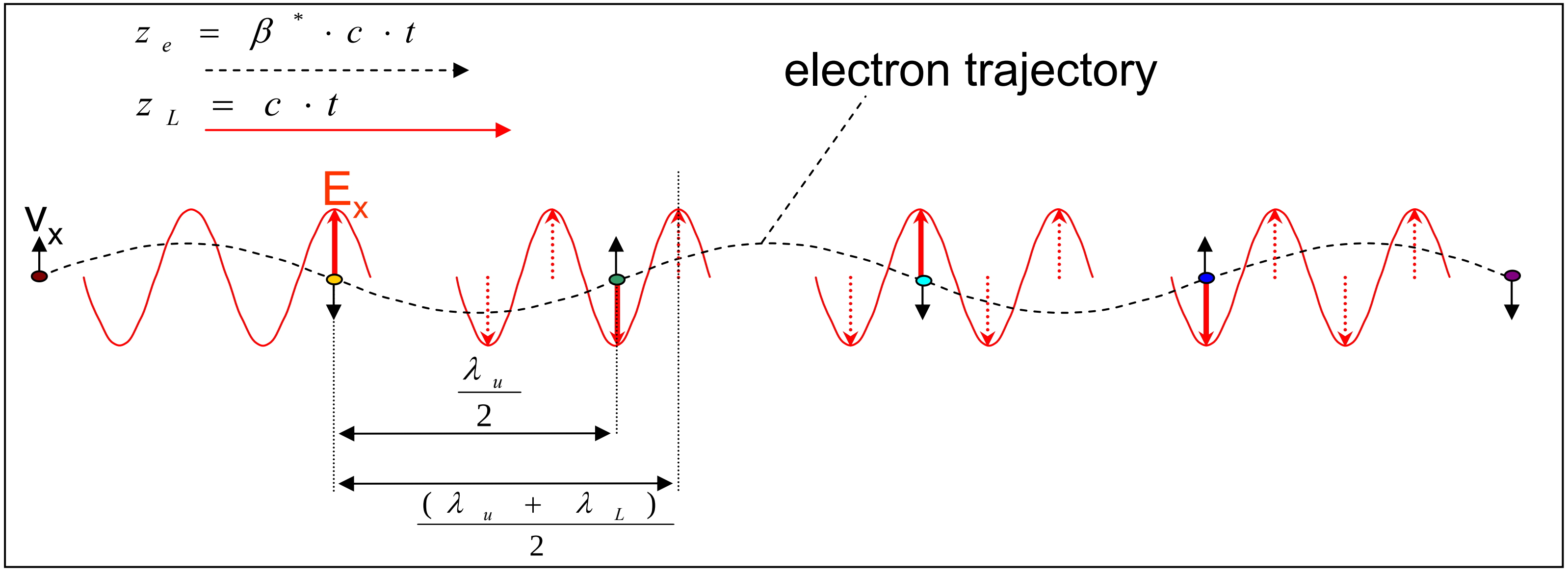
- electric field $E(t)$ given by a laser
- velocity components parallel to $E(t)$ given in an undulator

2. Laser electron interaction

• if an electron with energy γ fulfills the undulator resonance condition for given undulator and laser parameters

$$\lambda_l = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

and is in phase with the laser field, it "continuously" gains energy



2. Laser electron interaction

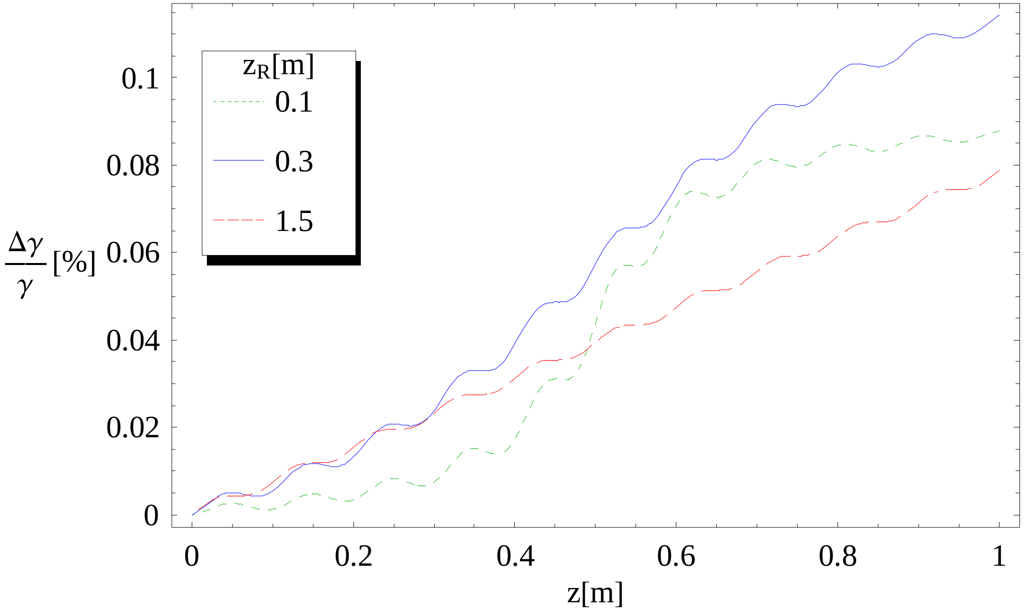
- calculate the relative energy change for a <u>single</u> electron by assuming a laser pulse with:
  - Gaussian field envelope
  - Gaussian transverse beam shape
  - beam waist in the center of the modulator

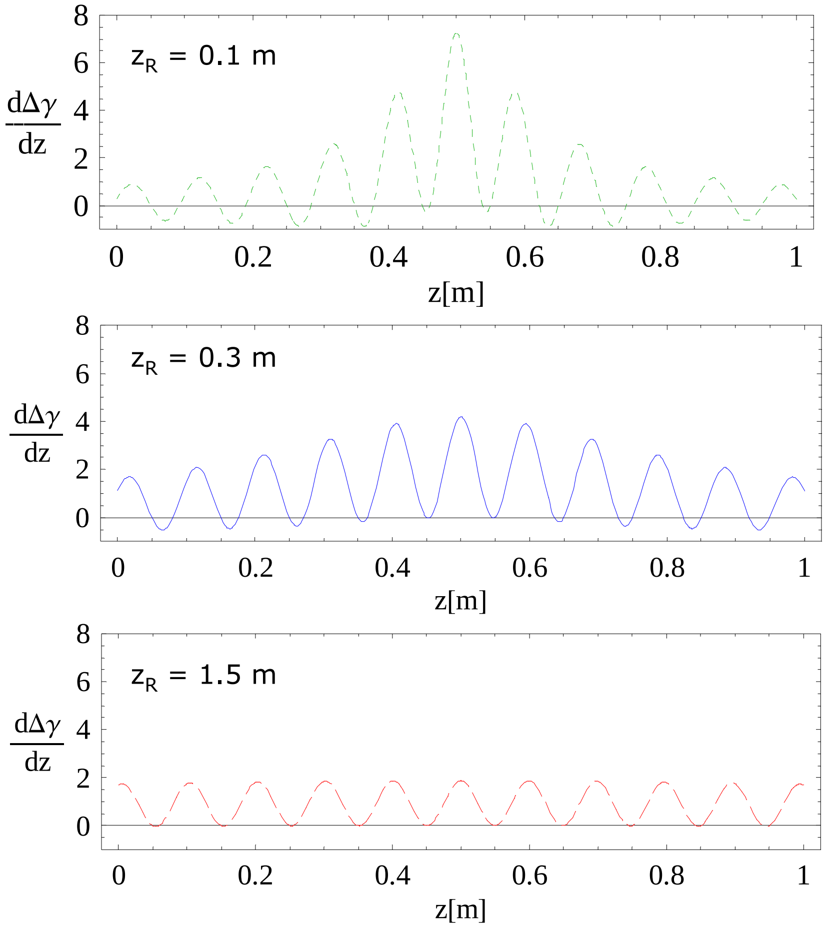
- vary the following parameters
  - Rayleigh length of the laser beam
  - pulse energy
  - K parameter of the undulator
  - electron energy

(Rayleigh length of the laser beam, pulse energy} electric field strength

2. Laser electron interaction

dependency on the Rayleigh length





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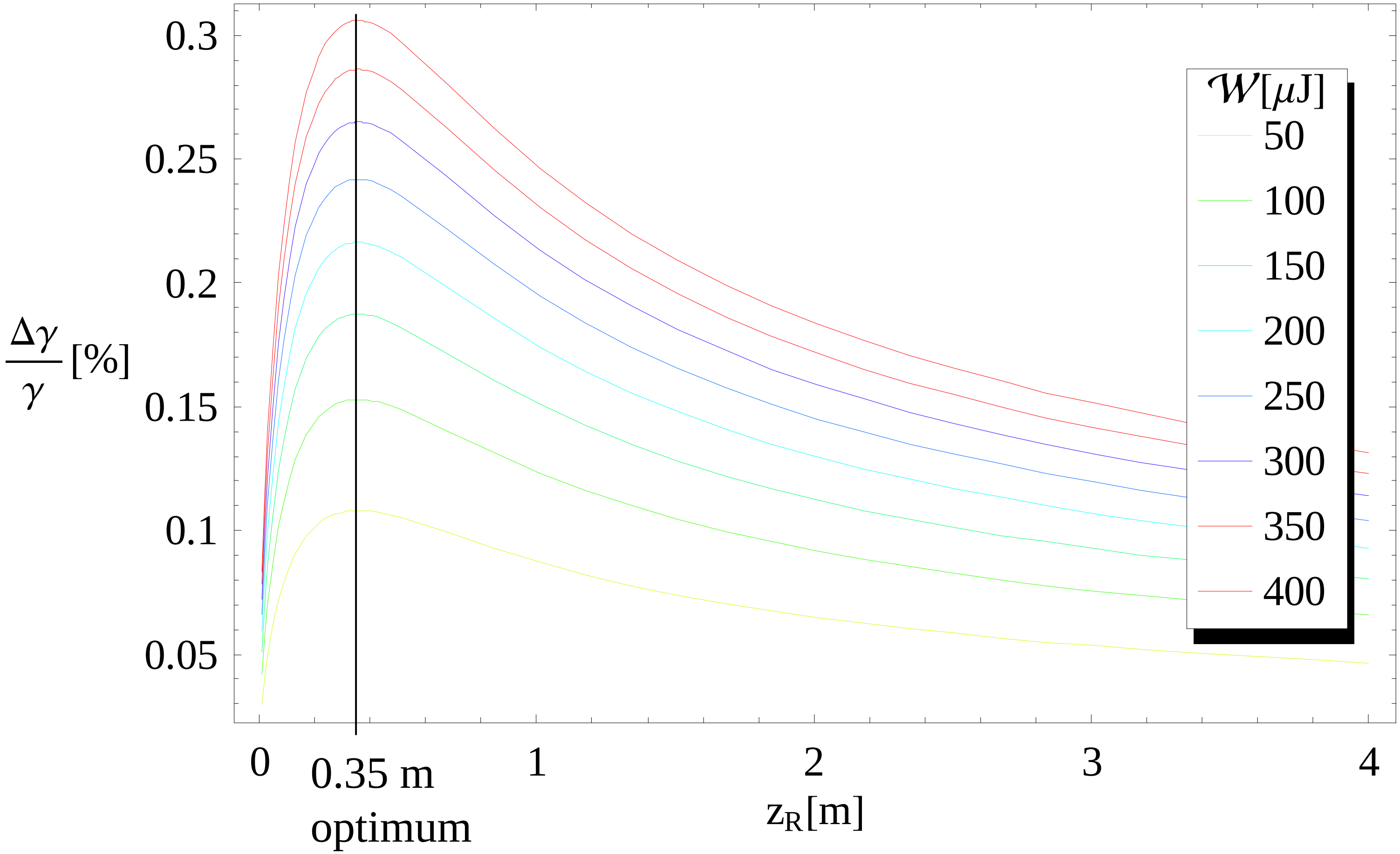
dependency on the Rayleigh length

- for different pulse energies @ 2 ps pulse length (FWHM)



2. Laser electron interaction

dependency on the Rayleigh length

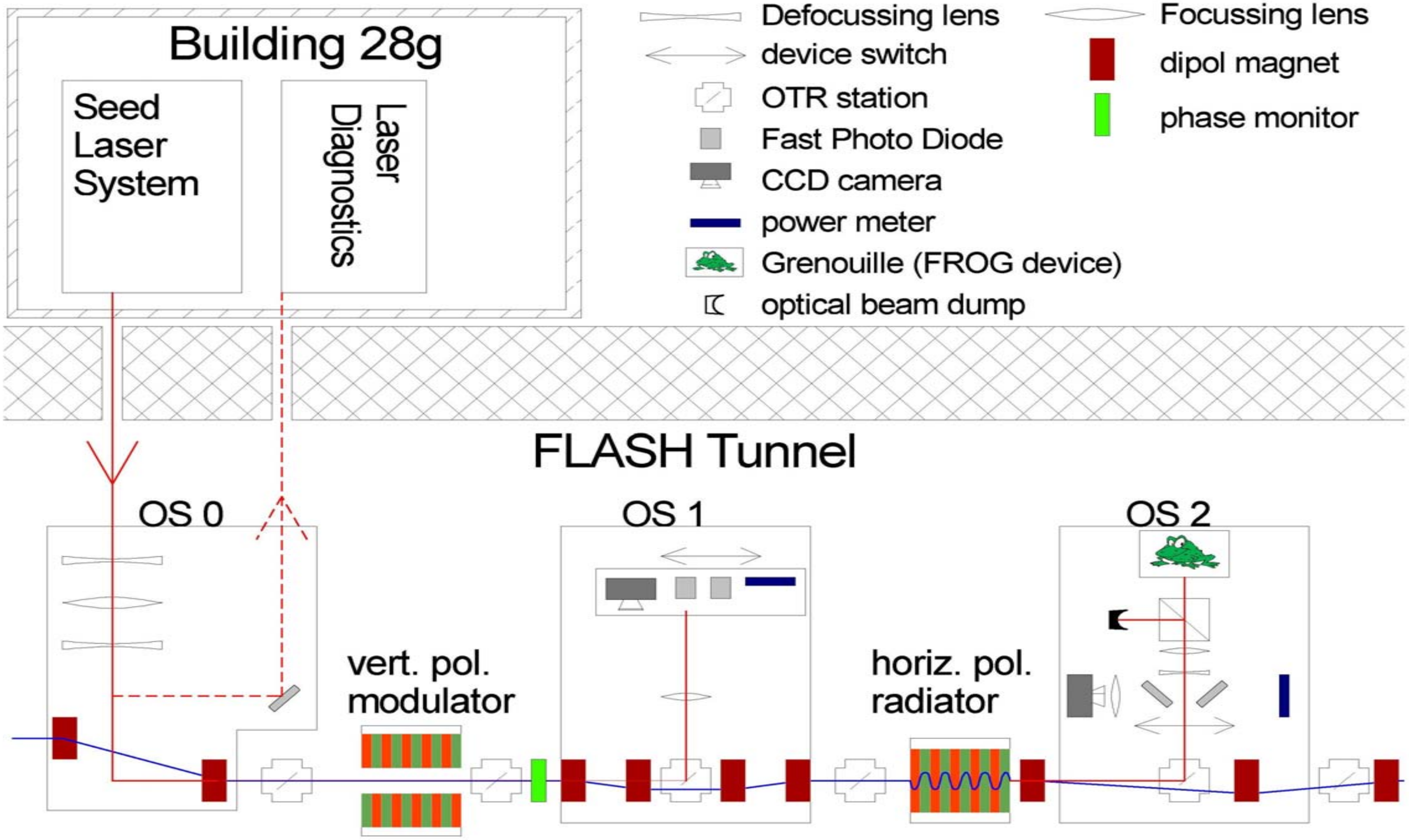
- optimum energy modulation at $z_R \sim 0.3$ m
- this corresponds to a rms laser beam size of $w_0/2 \sim$ 140 μm
- similar to the electron beam size
- for Optical Replica operation one needs a larger laser beam to cover the e-beam and to induce an evenly distributed energy modulation

3. Experimental setup at FLASH

Implementation of the ORS in FLASH

- in collaboration with
  - University of Uppsala
    - undulators
    - coordination
  - Stockholm University
    - laser system
    - diagnostics
  - Universität Hamburg
    - laser transfer
    - diagnostics
  - BESSY
    - simulations
  - DESY
    - infrastructure
    - laser timing

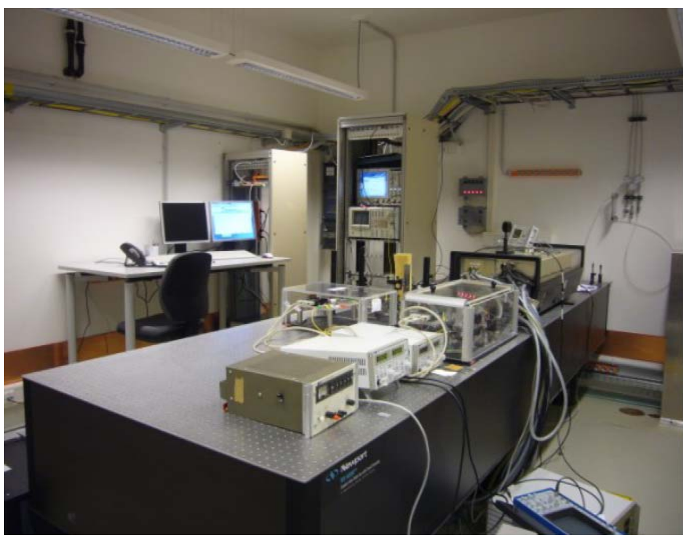
3. Experimental setup at FLASH

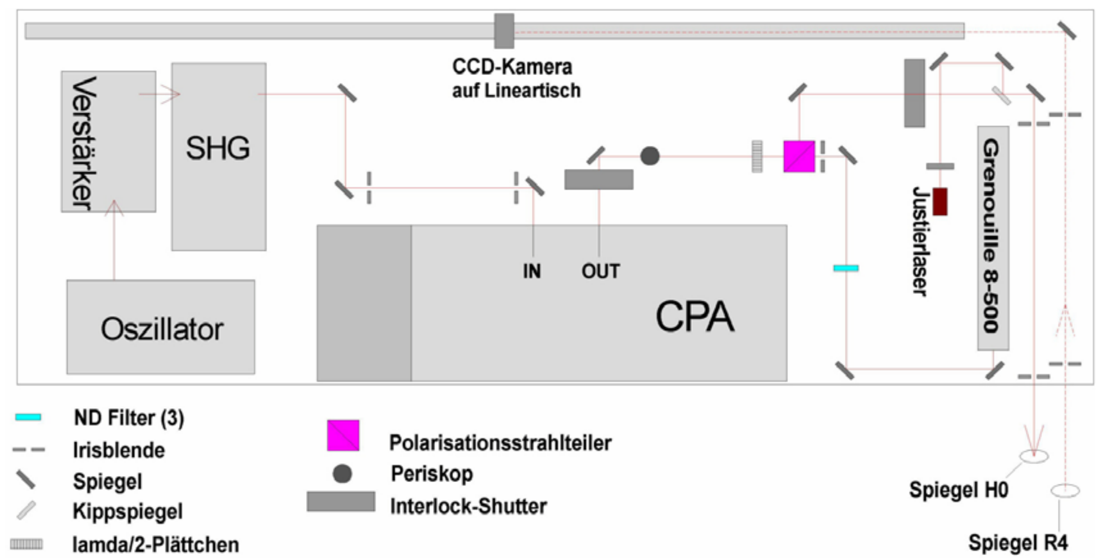


3. Experimental setup at FLASH

The laser system

- diode pumped Erbium-doped fiber oscillator
    - 1550 nm, 150 fs (FWHM) pulse length
- diode pumped amplifier
- frequency doubler (SHG) (775 nm)
- Chirped Pulse Amplifier
    - λ = 775 nm, Δλ ~ 10 nm @ 200 fs (FWHM)



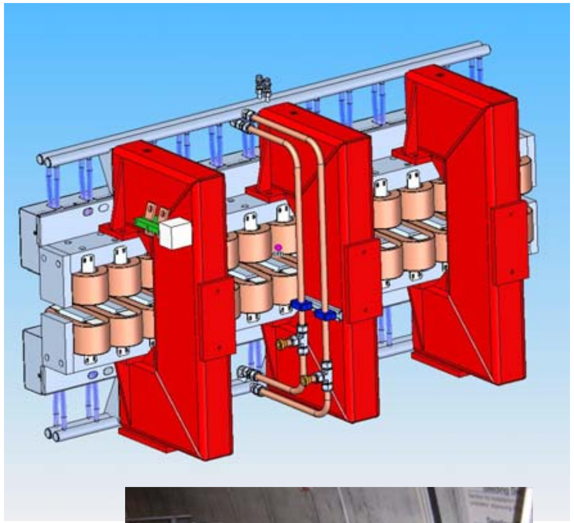


3. Experimental setup at FLASH

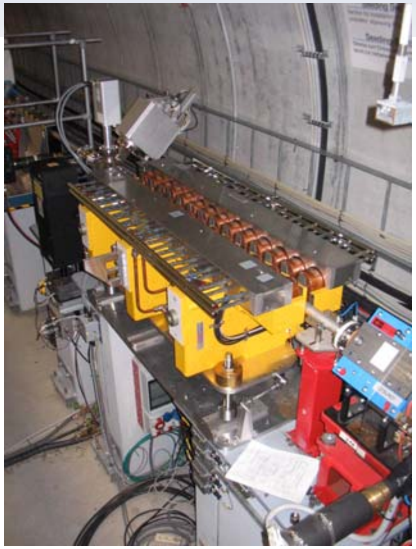
Undulators “Veronica” and “Hilda”

- two electromagnetic undulators
  - 5 periods + 2 correction periods
  - 0.2 m period length
  - on axis field strength 0 – 0.48 T
  - K-parameter 0 – 10.8

- 1. undulator (modulator) vertical deflecting
- 2. undulator (radiator) horizontal deflecting



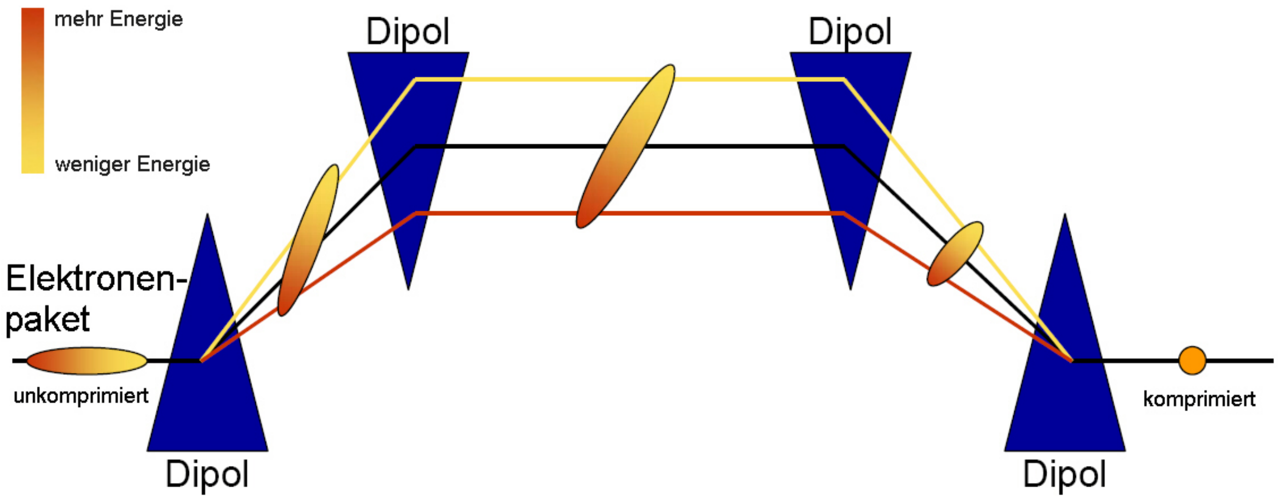
Veronica



Hilda

Magnetic chicane

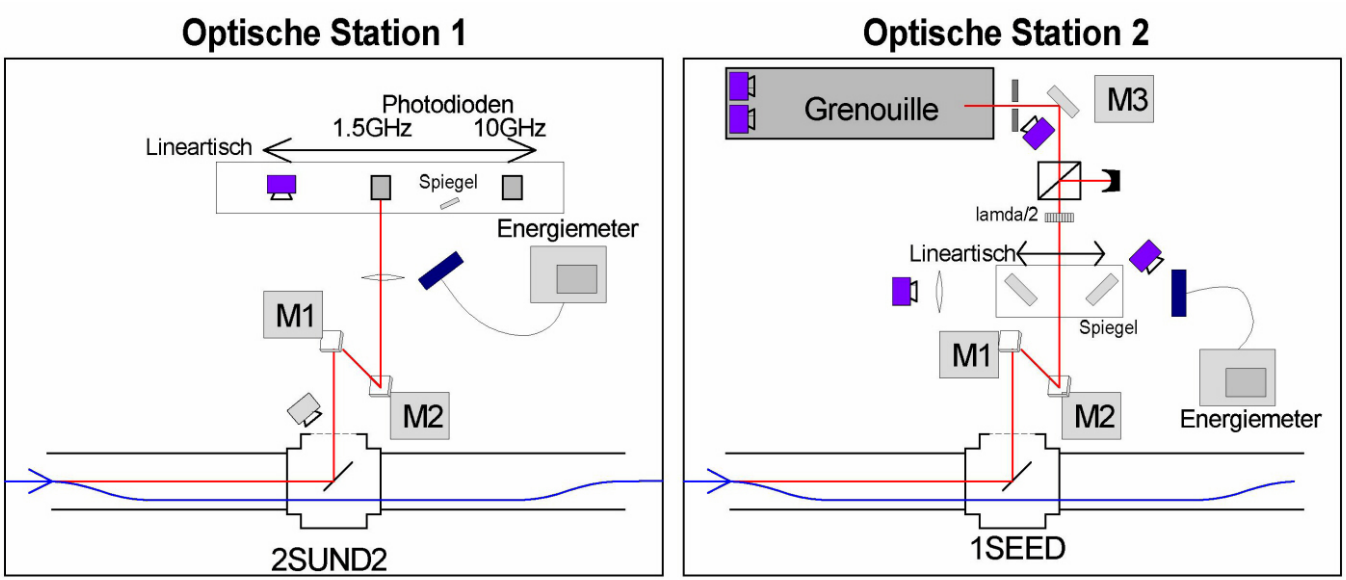
- four dipole steerer magnets form a magnetic chicane
- converts the energy modulation into a density modulation
- analogous to a bunch compressor



3. Experimental setup at FLASH

Diagnostics

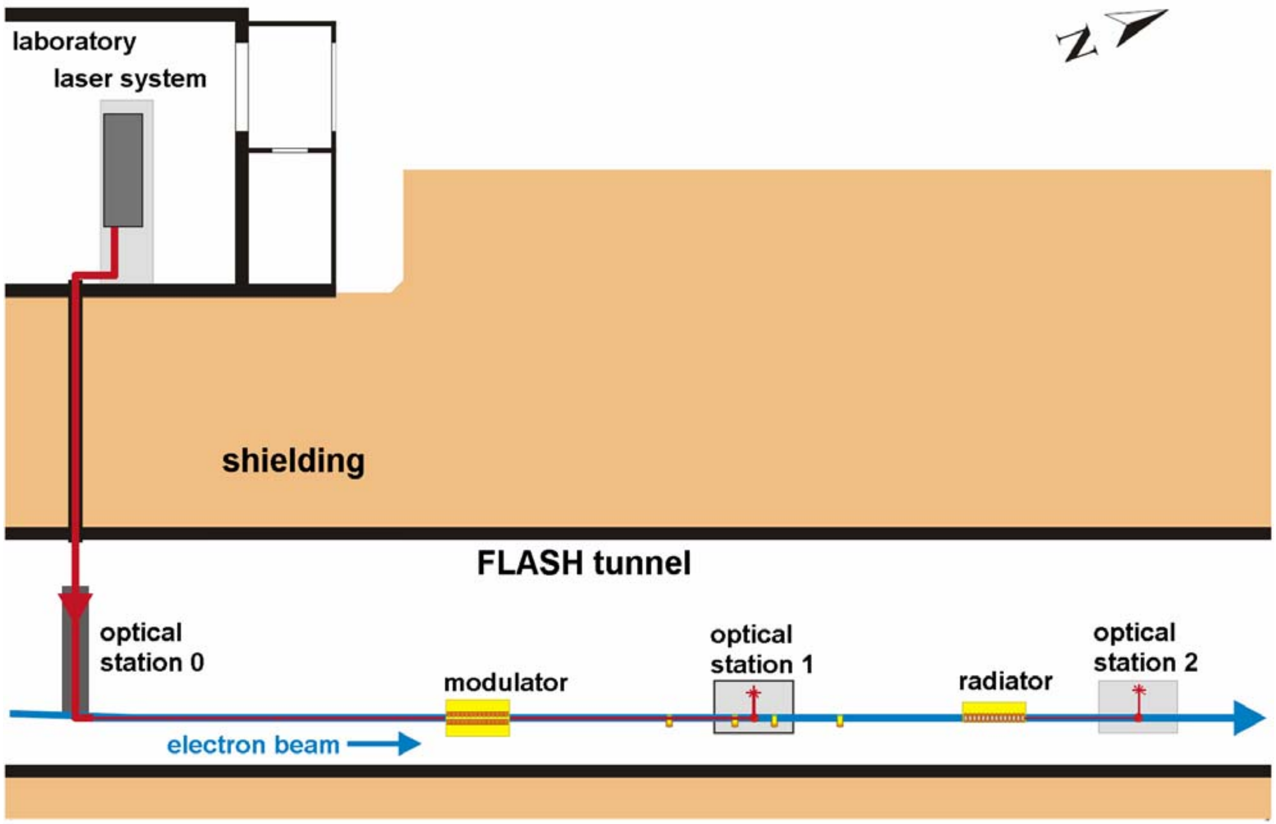
- several OTR stations in the ORS section to monitor the electron and the laser beam position
- two stations to couple out the light from the accelerator vacuum ("optical Station I and II")
- cameras, photodiodes, power meter, GRENOUILLE installed on the Optical Stations



3.1 Laser Transfer Line

design and implementation

- Deliver laser pulses from laser laboratory to electron beam pipe
- focus the laser beam within the modulator
  (telescope on optical station 0)
- remotely controlled mirrors and lenses



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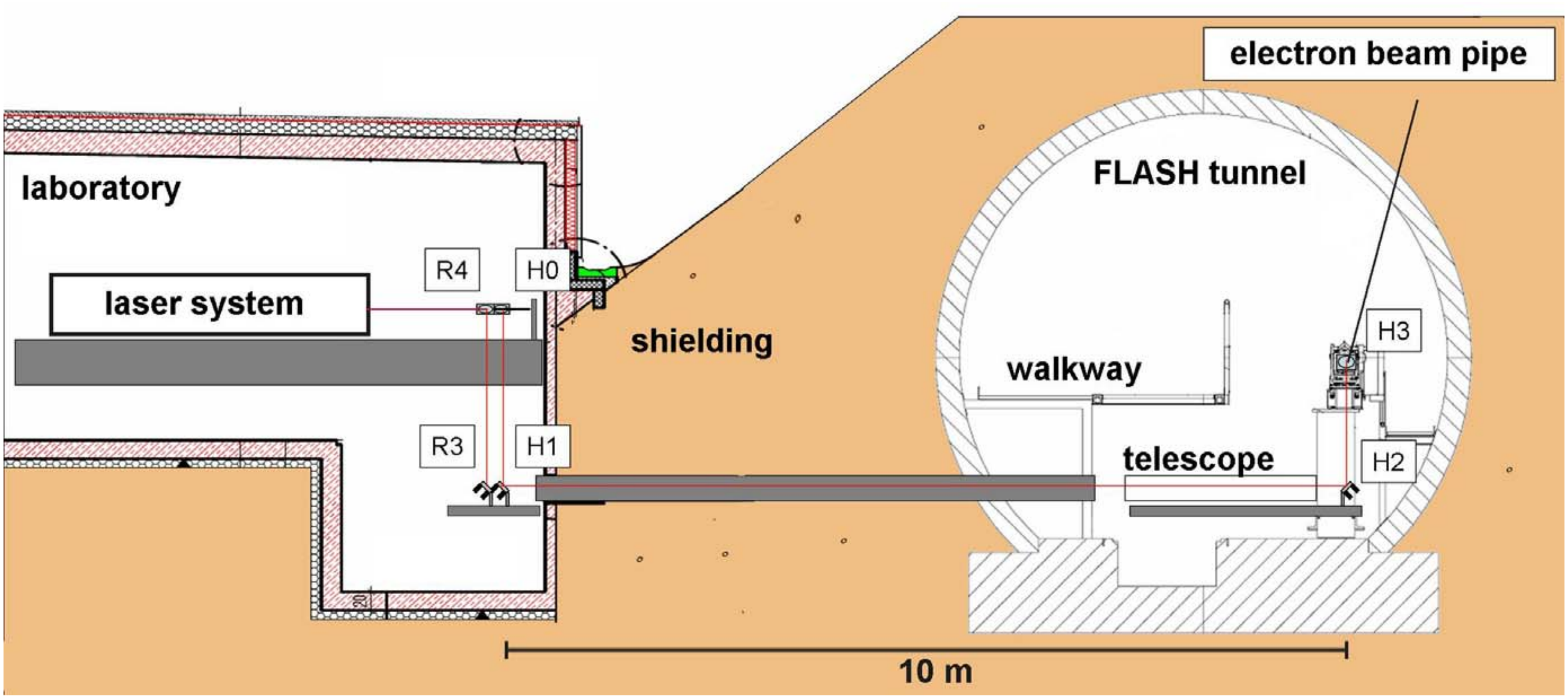
3.1 Laser Transfer Line

design and implementation



3.1 Laser Transfer Line

telescope design marginal conditions

- initial laser beam size and beam quality

	horizontally	vertically
FWHM beam size	3.5 ± 0.1 mm	3.8 ± 0.1 mm
beam divergence	0.296 ± 0.005 mrad	0.208 ± 0.002 mrad
M^2-value	1.63 ± 0.03	1.06 ± 0.03

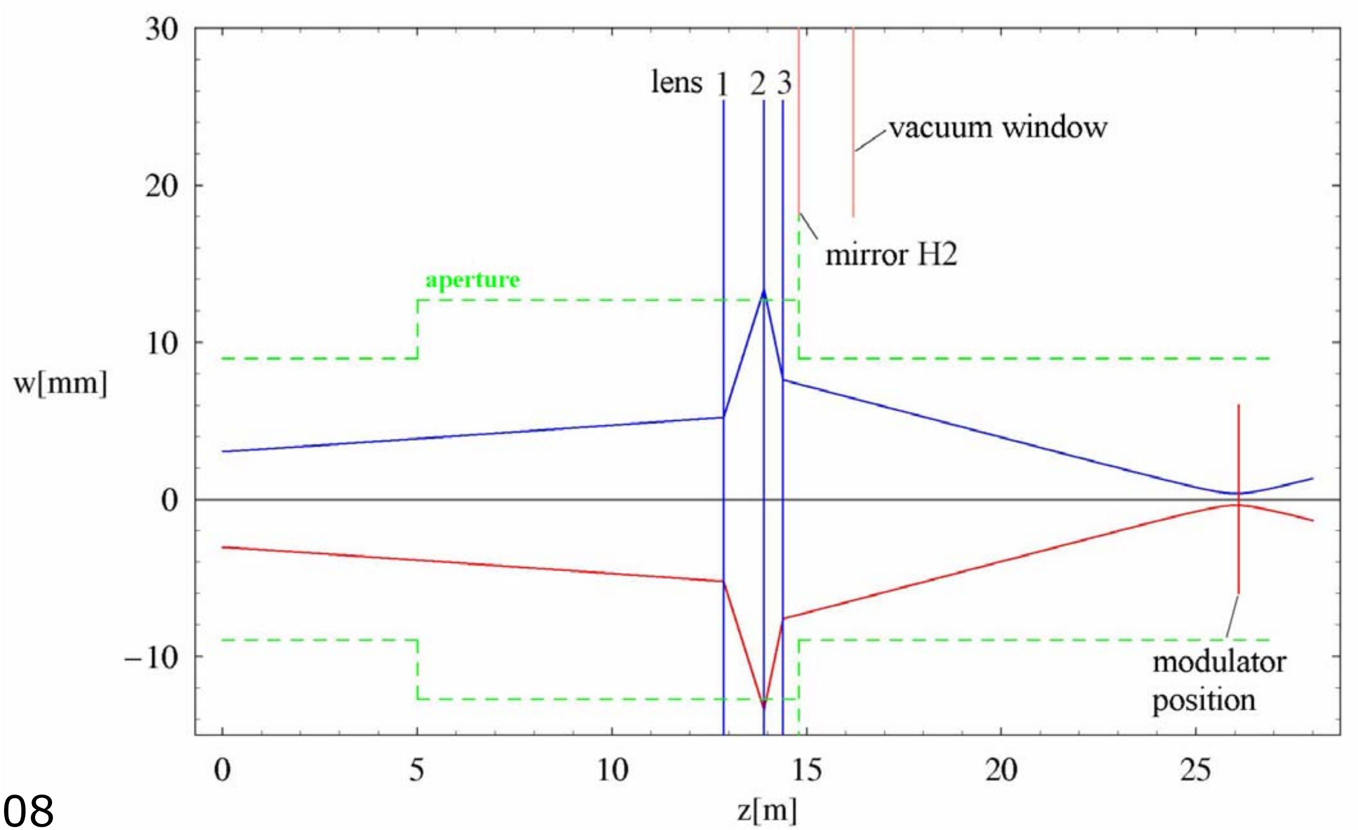
- maximum laser beam size at the vacuum window
  - $w_{max} \sim 10$ mm

- locations of laser, modulator, possible telescope positions

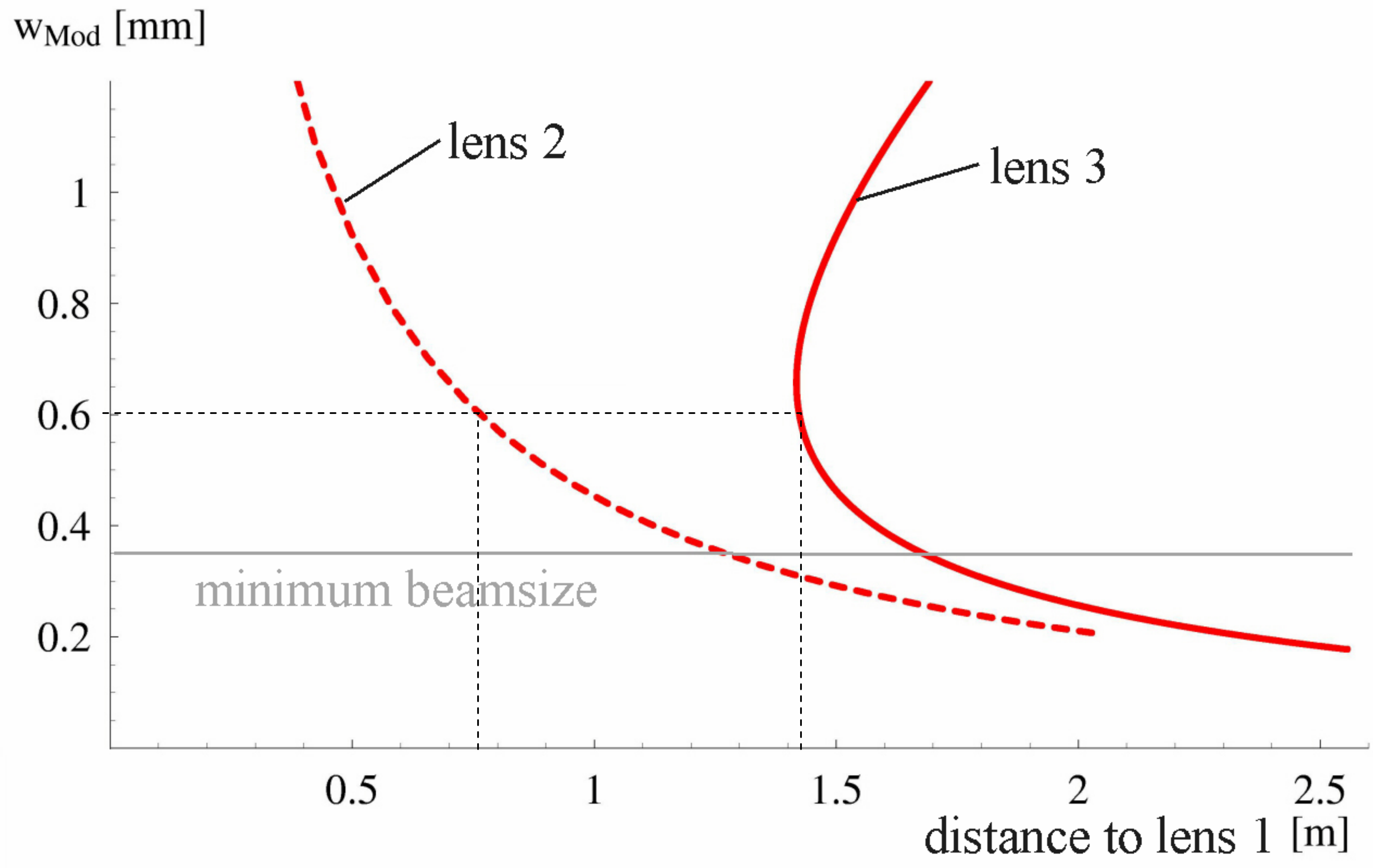
3.1 Laser Transfer Line

telescope

- Galilean type three lens telescope
  defocusing – focusing – defocusing
- first lens L1 fixed; z-position of lens L2 and L3 variable

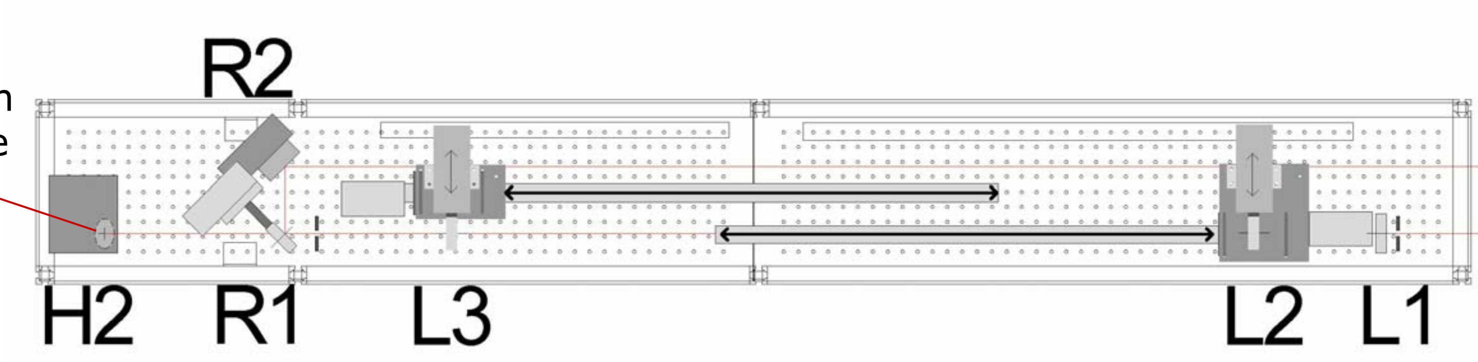


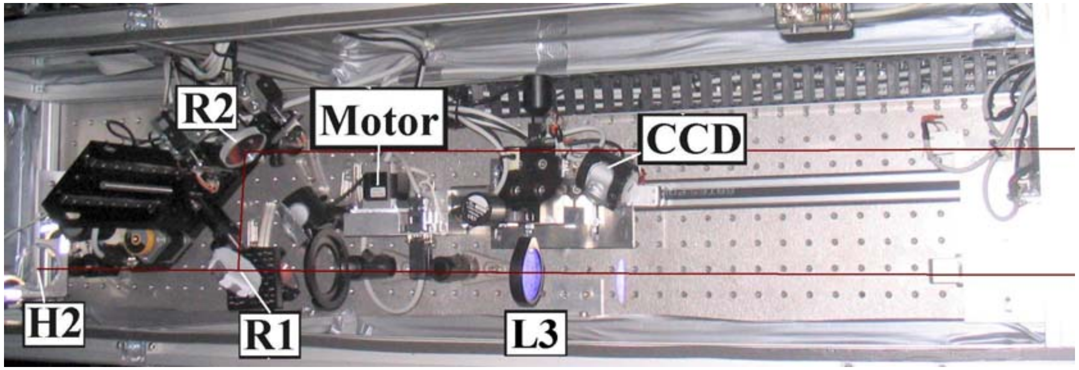
telescope characteristic



optical station 0 (telescope) setup

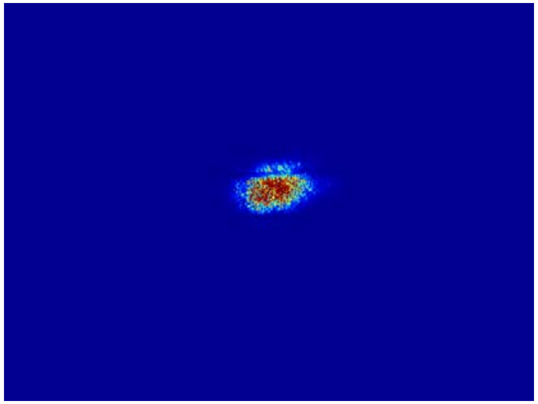
- first lens L1 fixed; lenses L2 and L3 each on a one meter translation stage for the z-position.
- for diagnostic the beam can be reflected back to the laser hutch

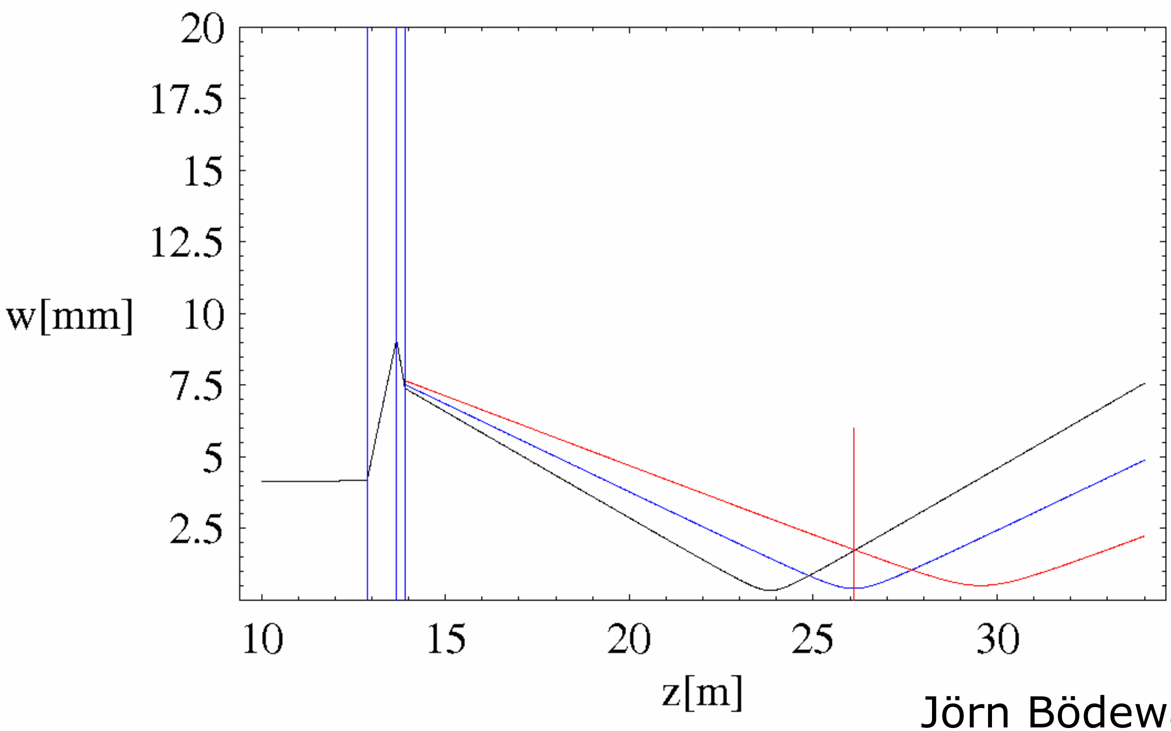




laser beam waist

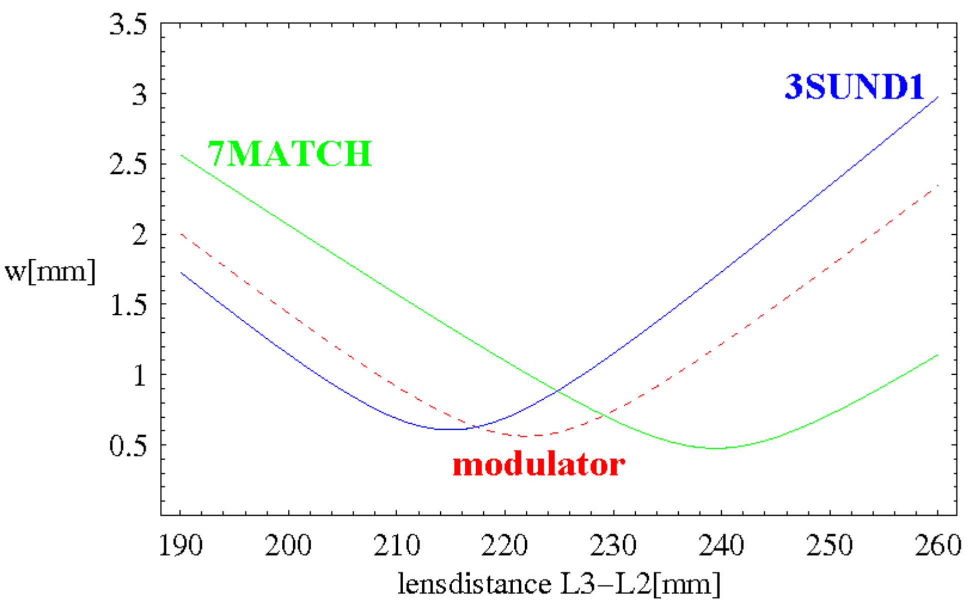
- use OTR screens “7MATCH” and “3SUND1” before and after the modulator to measure the laser beam size
- use diffuse reflection on the calibration screens (picture below)
- determine rms beam size horizontally and vertically
- move lens L3 to change the beam waist position

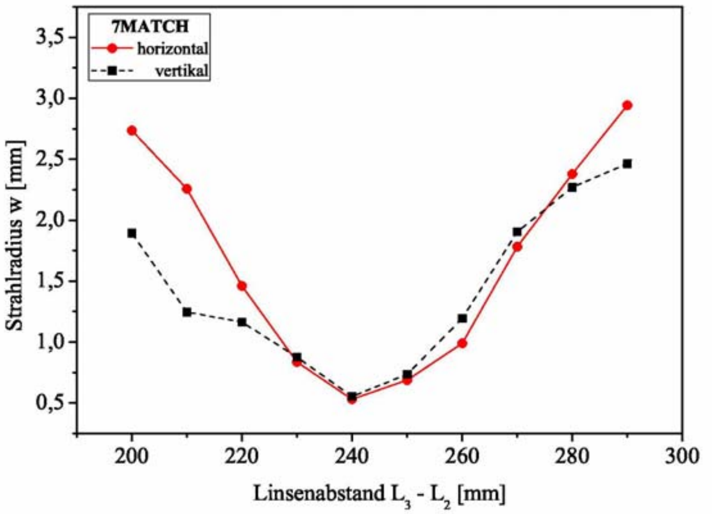


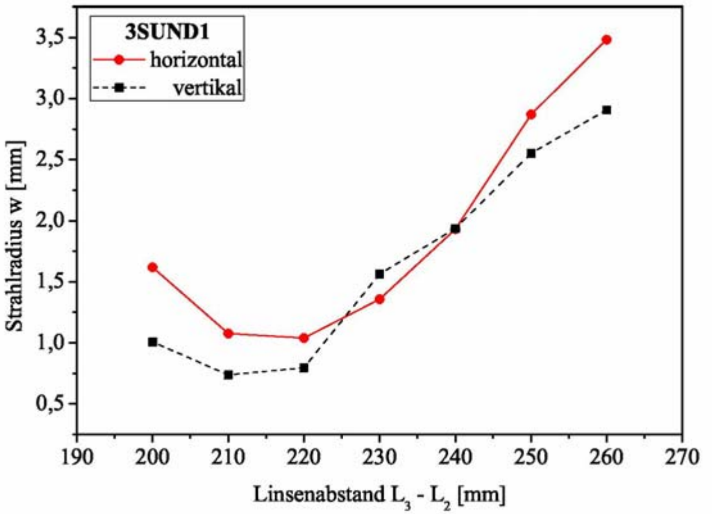


laser beam waist

- data fit to expected values







5 First Measurements

shift block in October 2007

- to find the laser electron overlap in the modulator

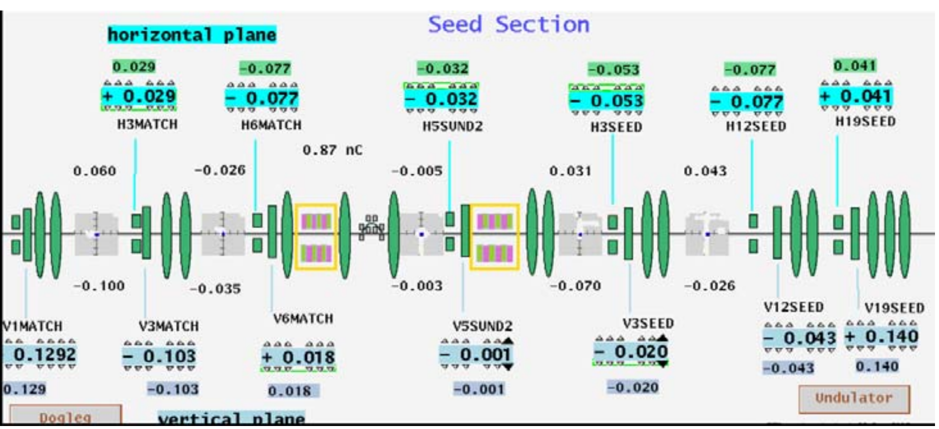
  1. the magnetic chicane and the modulator were turned on
  2. use a CCD camera to detect OTR on optical station 2
  3. the idea to prove the laser electron interaction is a saturation of the camera due to a coherent OTR signal for a modulated and microbunched electron beam

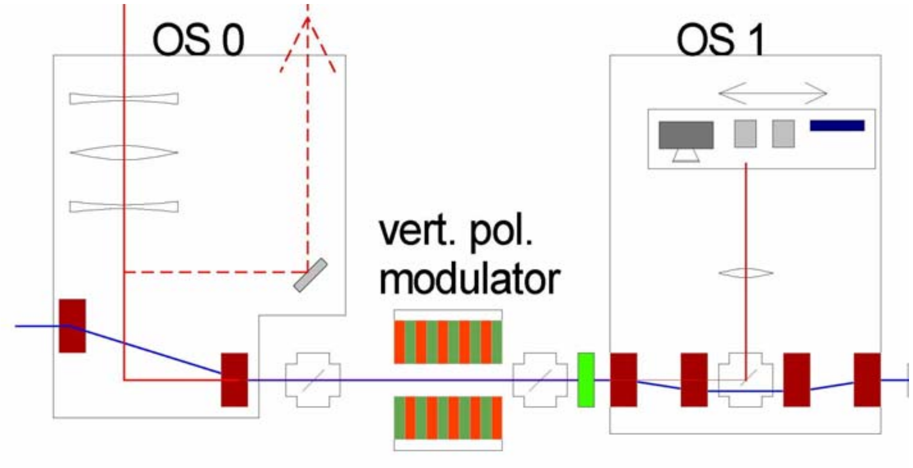
5 First Measurements

shift block in October 2007

- To achieve a transverse laser electron overlap in the modulator:

  1. flatten the electron orbit by using steerer magnets and BPM readings in the SEED section
  2. determine the electron position on the OTR stations 7MATCH and 3SUND1
  3. use the last two mirrors in the laser transfer line (H2 and H3) to steer the laser to the same position (use calibration screen on the OTR stations)





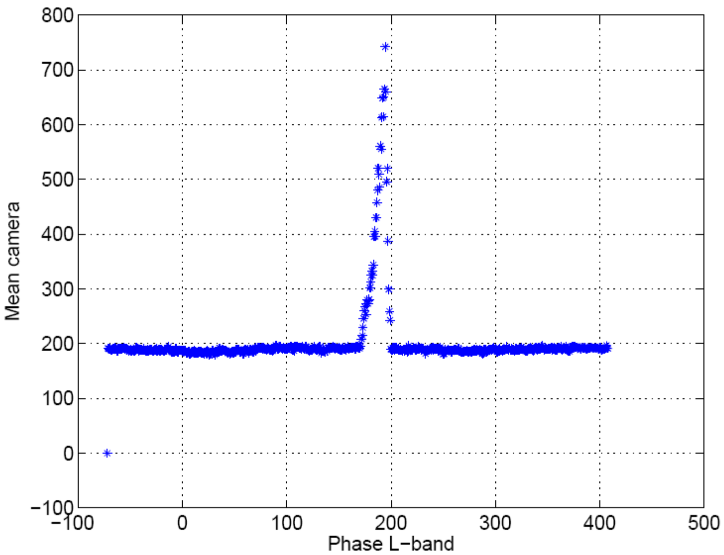
7MATCH 3SUND1

5 First Measurements

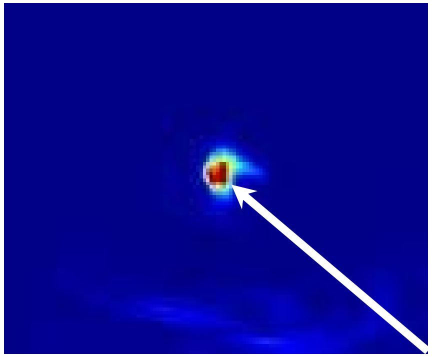
shift block in October 2007

- To achieve a longitudinal laser electron overlap in the modulator

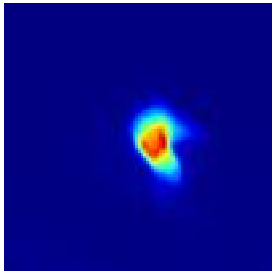
  1. use long electron pulses (no bunch compression) ~11 ps (FWHM) and short laser pulses ~ 200 fs (FWHM)
  2. change the relative timing between laser and electron beam by shifting the phase of the trigger signal for the laser system using a vector modulator
  3. the minimum step size of the phase scans was about 100 fs



with interaction



without

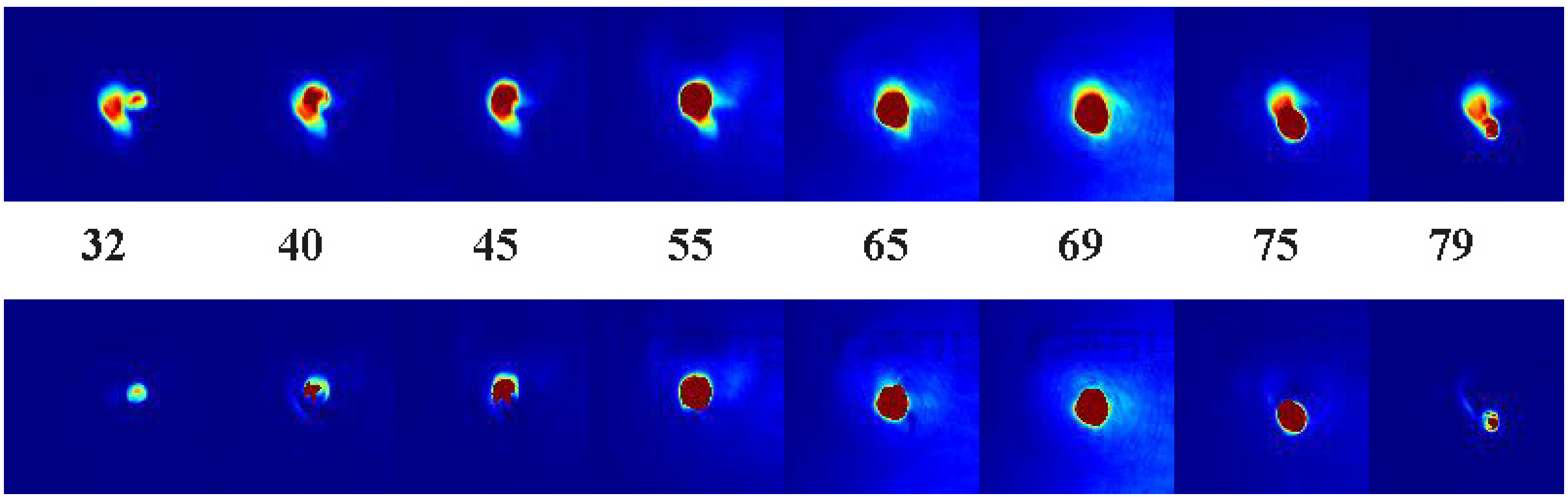


5 First Measurements

bunch shape

• one of the vector modulator scans could be used to determine an upper limit for the transversal width and
• determine the position of the beam centroid

before

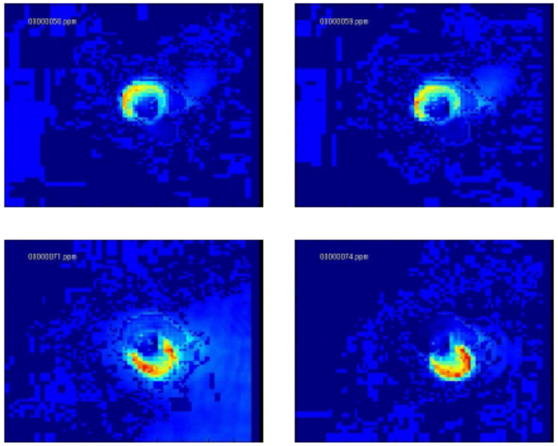


and after background “subtraction”

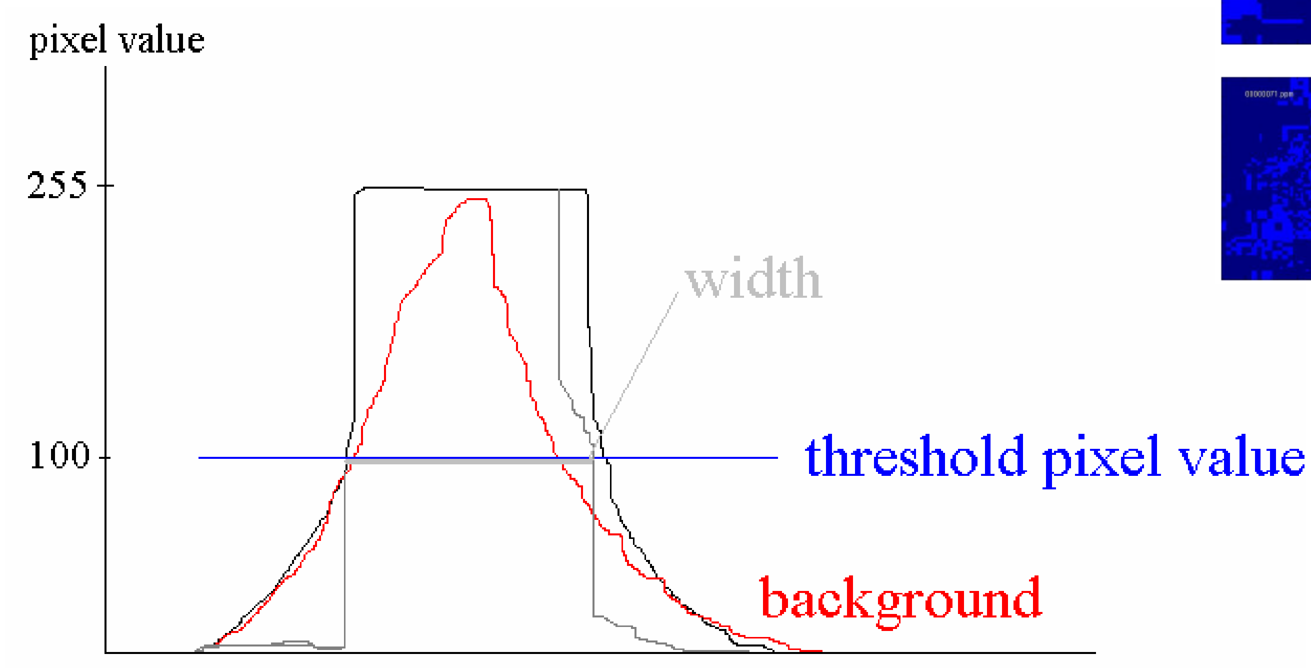
5 First Measurements

bunch shape

- background subtraction:
  - only the not saturated parts were subtracted otherwise you get a “hole” in the beam profile



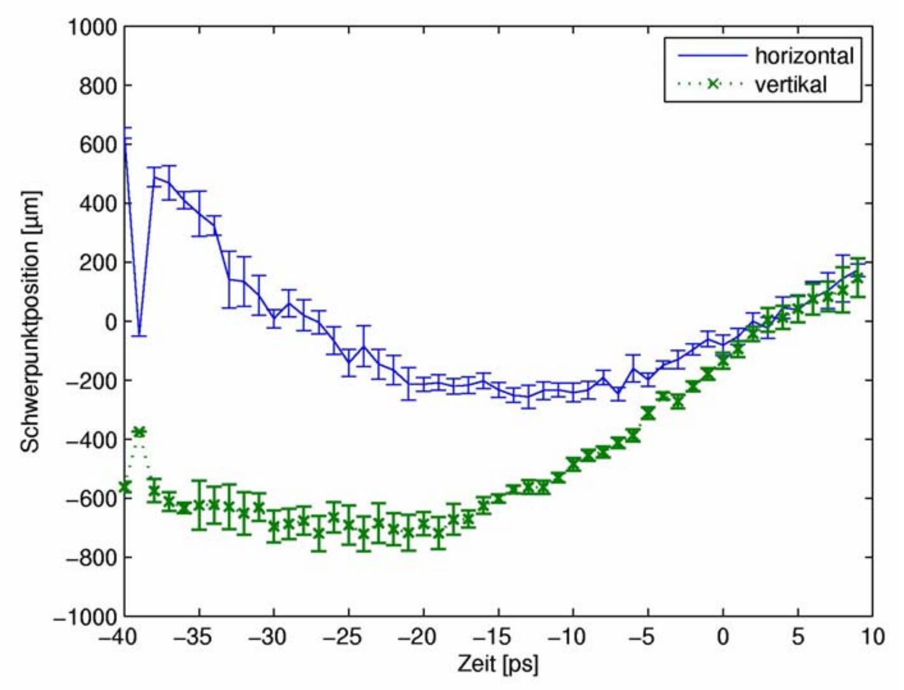
V. Ziemann



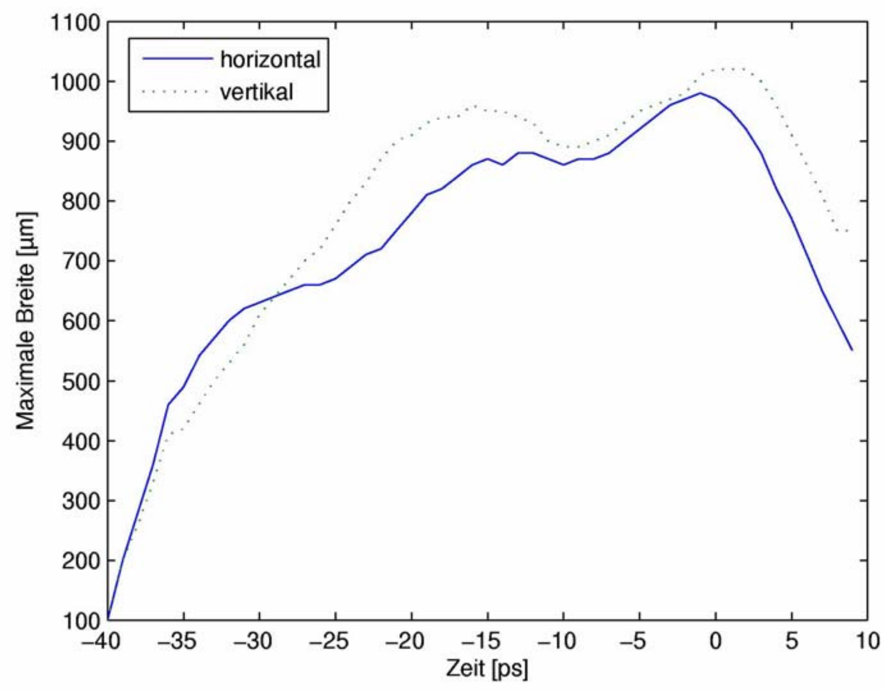
bunch shape

- electron bunch forms a kind of helix

controid position



width



5 First Measurements

Summery and outlook

- the laser transfer line for the ORS-experiment is in operation
- first laser-electron-interaction could be reached in the modulator
- measured data could be used for bunch shape reconstruction

- but

- no optical replica has been measured in the frog yet
- time to get the laser electron overlap still takes more than two hours

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- development of a fast(er) procedure to get overlap
- getting optical replica pulses into the GRENOUILLE

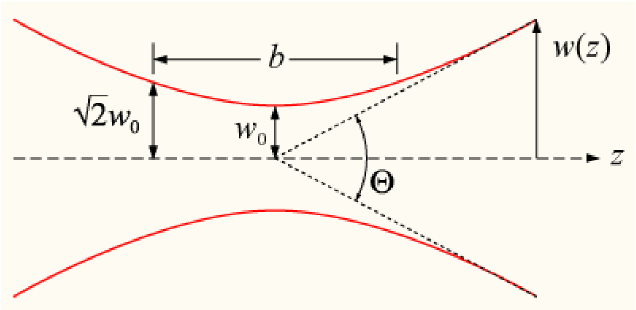
Thank you for your attention

Rayleigh length z_R

• defined as the distance between the waist position of a Gaussian beam and the position where the beam size gets:

$$w(z_R) = \sqrt{2} \cdot w_0$$

• w_0 is the beam waist spot size



• one can calculate the Rayleigh length from:

$$z_R = \frac{\pi \cdot w_0^2}{\lambda}$$

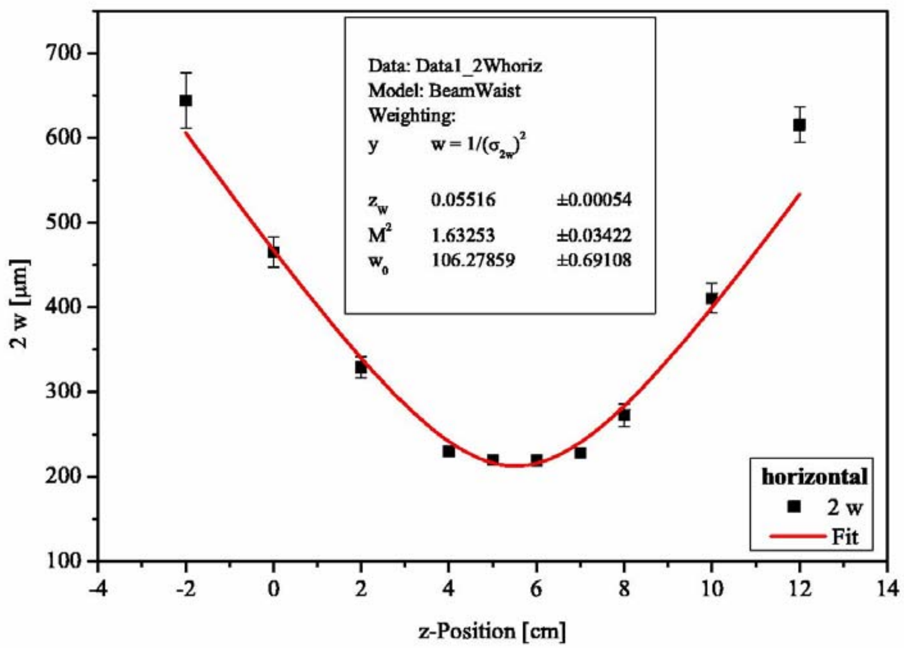
back

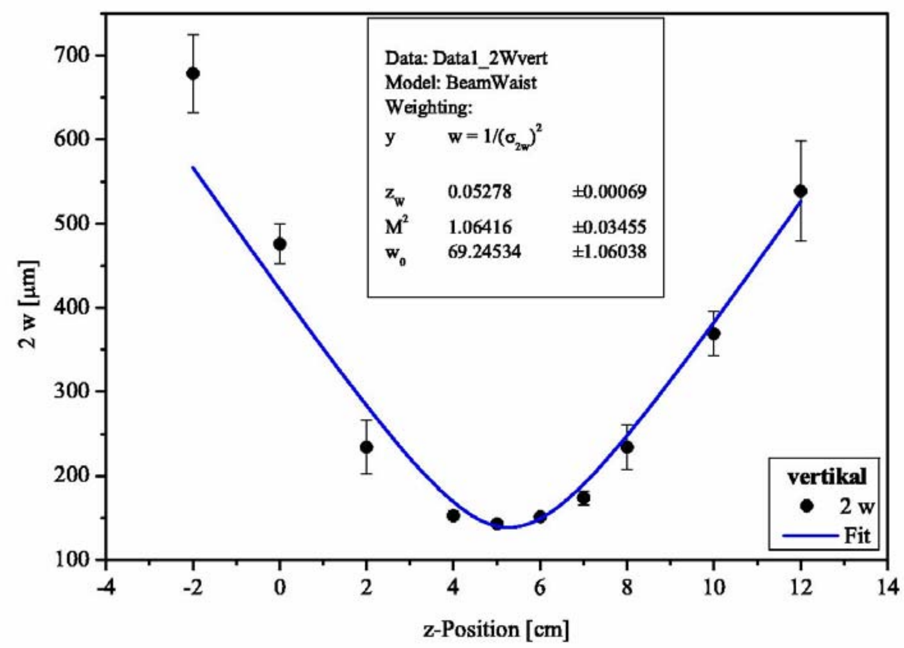
beam parameter product

- product of minimum beam radius and far field divergence

$$w_0 \cdot \theta = M^2$$

- M²-measurements:





back

dependency on the Rayleigh length

- shift of the resonance K value