Electro-Optical Measurements at the Swiss Light Source (SLS) Linac at the PSI

First Results

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Overview

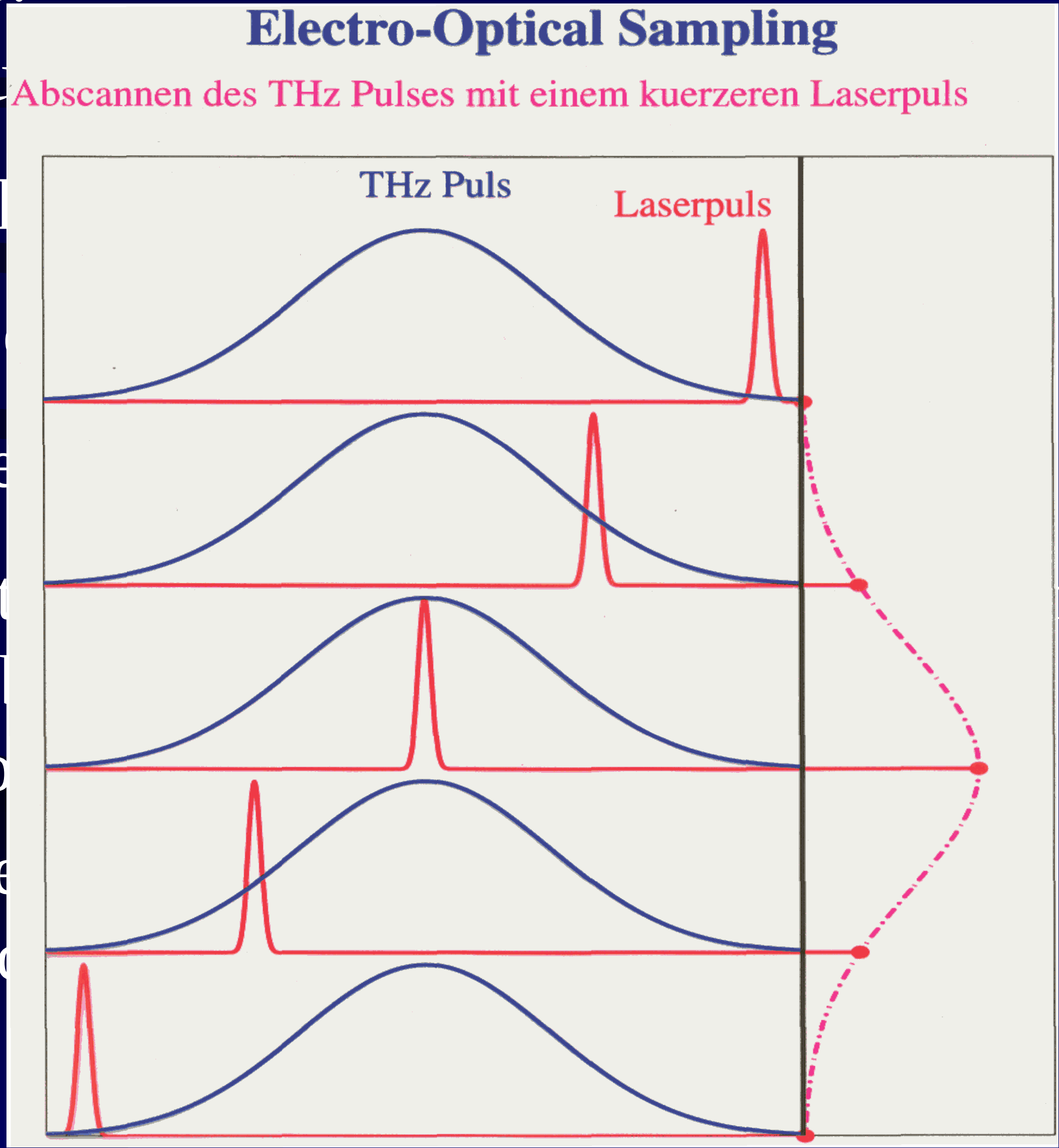
- motivation
- electro-optical sampling
  - general remarks
  - experimental setup
  - synchronisation between TiSa-laser and linac RF
- results of February 2004
- outlook

Motivation

- knowledge of the electron bunch structure is extremely important for both linear collider and free electron laser.
- electro-optical sampling (EOS) offers the possibility to obtain precise results on a realtime scale.
- challenge: synchronisation between TiSa-laser and RF

Electro-optic Sampling

- requirements:
  - •resolu
  - •few sh
  - •indepe
  - •nonde
- feasible solut   n of a short laser pulse due to l   the electric field of the electro
- this experime   (CTR) reflected out of the vac



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electro-optical effects in anisotropic crystals

- for a homogeneous medium:

$$\boldsymbol{D} = \epsilon_0 \epsilon \boldsymbol{E}$$

- surfaces of constant energy are ellipsoids in D-space

$$\epsilon_0 w_e = \boldsymbol{D} \cdot \hat{\epsilon}^{-1} \cdot \boldsymbol{D} = \frac{D_1^2}{\epsilon_1} + \frac{D_2^2}{\epsilon_2} + \frac{D_3^2}{\epsilon_3}$$

with $\boldsymbol{u} = \boldsymbol{D}/\sqrt{2\epsilon_0 w_e}$ leads to $\frac{u_1^2}{n_1^2} + \frac{u_2^2}{n_2^2} + \frac{u_3^2}{n_3^2} = 1$

with $\hat{\eta} = \hat{\epsilon}^{-1}$ the index ellipsoid can be rewritten

$$\boldsymbol{u} \cdot \hat{\eta} \cdot \boldsymbol{u} = 1$$

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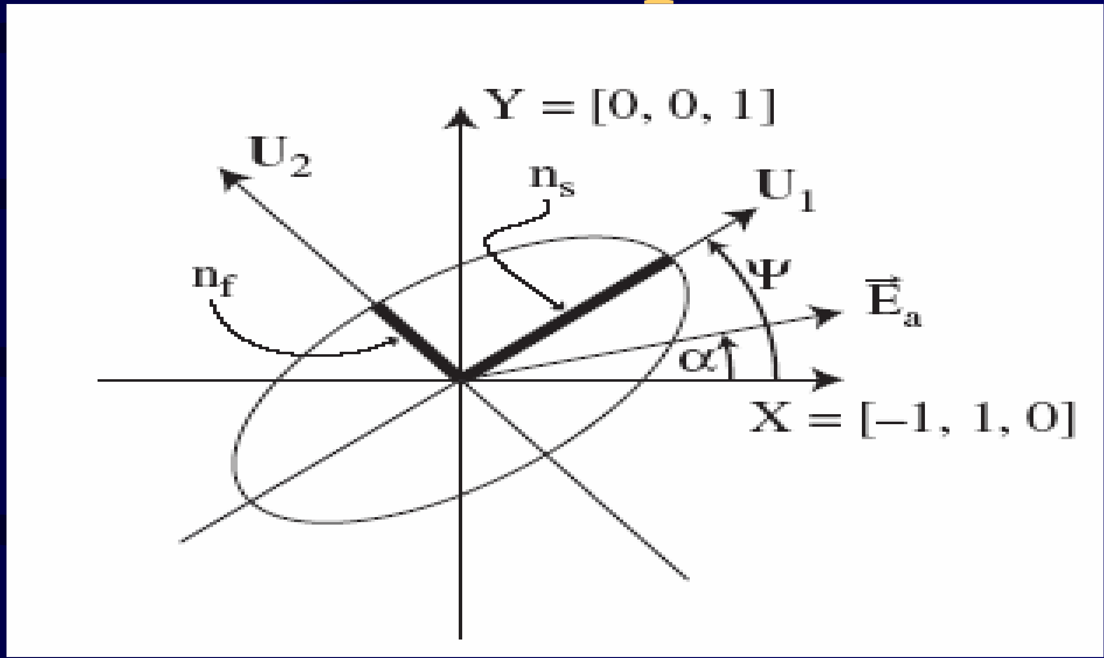
index ellipsoid



•find plane through the origin of the index ellipsoid perpendicular to the direction of the propagating light ray

•The two axis of this intersecting ellipse are equal in length to n_s and n_f.

• These axes are parallel to the directions of the displacement vector of the two independent plane waves that can propagate along a direction s in the crystal.

Pockels effect in Zink-Telluride

- for strong electric fields, susceptibility becomes nonlinear

$$\boldsymbol{P} = \epsilon_0(\chi_e^{(0)}\boldsymbol{E} + \chi_e^{(1)}\boldsymbol{E}^2 + \chi_e^{(2)}\boldsymbol{E}^3 \ldots)$$

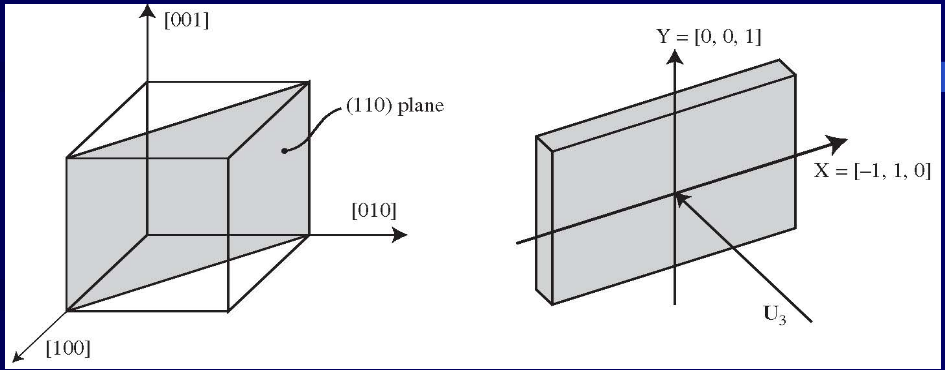
- this means for the impermeability tensor:

$$\hat{\eta}(\boldsymbol{E}) = \epsilon^{-1}\boldsymbol{I} + \boldsymbol{r} \cdot \boldsymbol{E}$$

- For ZnTe (zincblende structure), only one independant component of r remains, so the equation for the index ellipsoid becomes:

$$\frac{1}{n_0^2}(u_1^2 + u_2^2 + u_3^2) + 2r_{41}(E_1 u_2 u_3 + E_2 u_3 u_1 + E_3 u_1 u_2) = 1$$

determination of the main refractive indices



- Crystal cut parallel to (110)-plane
- coordinate system: $X = \begin{bmatrix} -1 \\ 1 \\ 0 \end{bmatrix}$ and $Y = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$
- incident vector: $\boldsymbol{E}_a = E_a \begin{pmatrix} -\cos\alpha/2 \\ \cos\alpha/2 \\ \sin\alpha \end{pmatrix}$
- this means for the index ellipsoid:

$$\boldsymbol{u} \cdot \hat{\eta}(\boldsymbol{E}_a) \cdot \boldsymbol{u} = 1$$

with

$$\hat{\eta}(\boldsymbol{E}_a) = \frac{1}{n_0^2}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + r_{41} E_\alpha \begin{pmatrix} 0 & \sin\alpha & \cos\alpha/\sqrt{2} \\ \sin\alpha & 0 & -\cos\alpha/\sqrt{2} \\ \cos\alpha/\sqrt{2} & -\cos\alpha/\sqrt{2} & 0 \end{pmatrix}$$

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determination of the main refractive indices II

- calculate eigenvalues of $\hat{\eta}(E)$:

$$\lambda_{1,2} = \frac{1}{n_0^2} - \frac{r_{41}E_\alpha}{2}\left(\sin\alpha \pm \sqrt{1+3\cos^2\alpha}\right) \quad , \quad \lambda_3 = \frac{1}{n_0^2} + r_{41}E_\alpha \sin\alpha$$

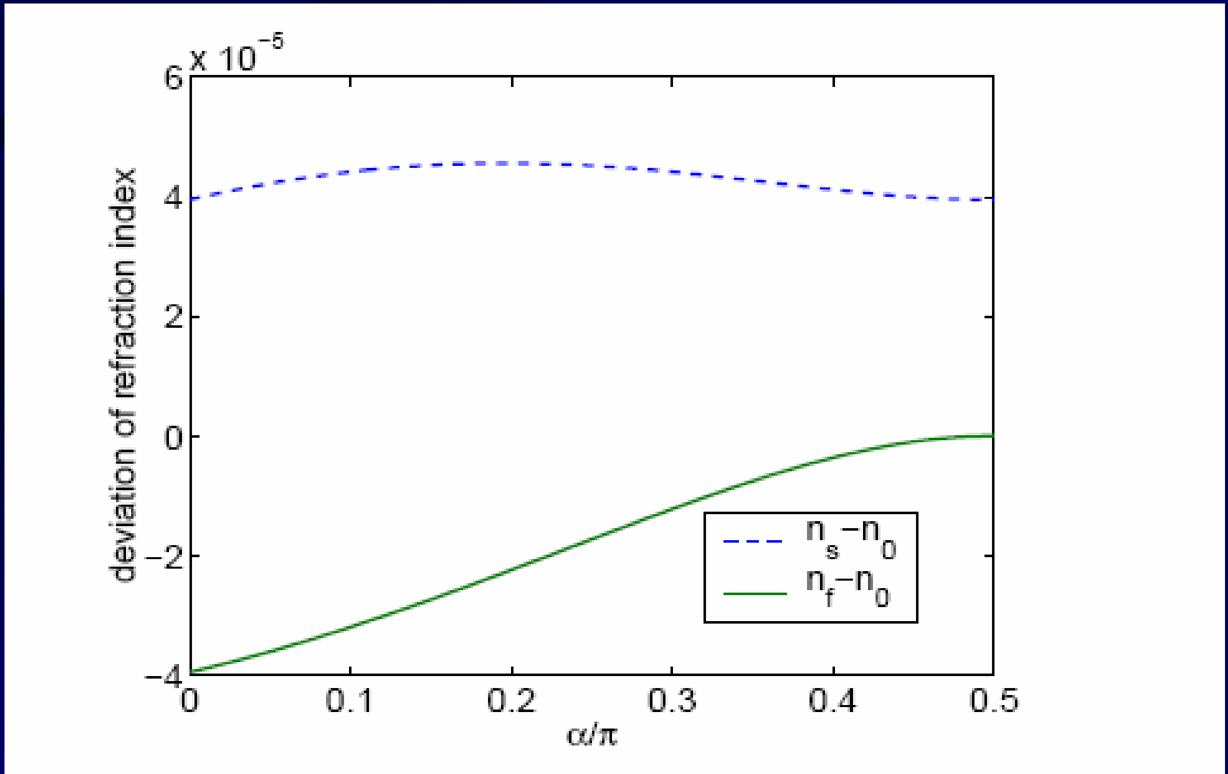
- the main refractive indices are given by $n_i = \frac{1}{\sqrt{\lambda_i}}$
- considering $r_{41}E_\alpha \ll 1/n^2$ and expanding the root:

$$\begin{aligned} n_1 &= n_0 + \frac{n_0^3 r_{41} E_\alpha}{4}\left(\sin\alpha + \sqrt{1+3\cos^2\alpha}\right) \\ n_2 &= n_0 + \frac{n_0^3 r_{41} E_\alpha}{4}\left(\sin\alpha - \sqrt{1+3\cos^2\alpha}\right) \\ n_3 &= n_0 - \frac{n_0^3 r_{41} E_\alpha}{2}\sin\alpha \end{aligned}$$

determination of the main refractive indices III

- TiSa laser beam is incident along the $[-1,-1,0]/\sqrt{2}$ direction (one of the eigenvectors of the system), so $\mathbf{E_b}$ lies in (110)-plane.

$$\Gamma(\alpha) = \frac{\omega d}{c}(n_1 - n_2) = \frac{\omega d}{2c} n_0^3 r_{41} E_a \sqrt{1 + 3\cos^2\alpha}$$



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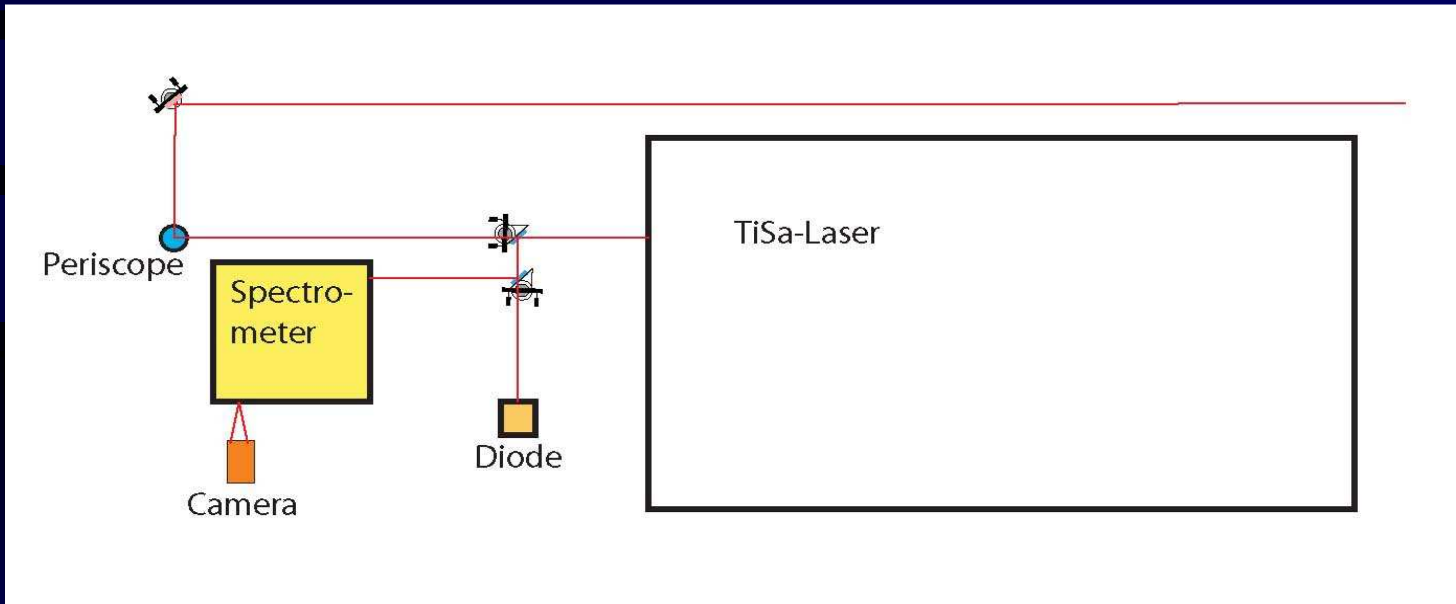
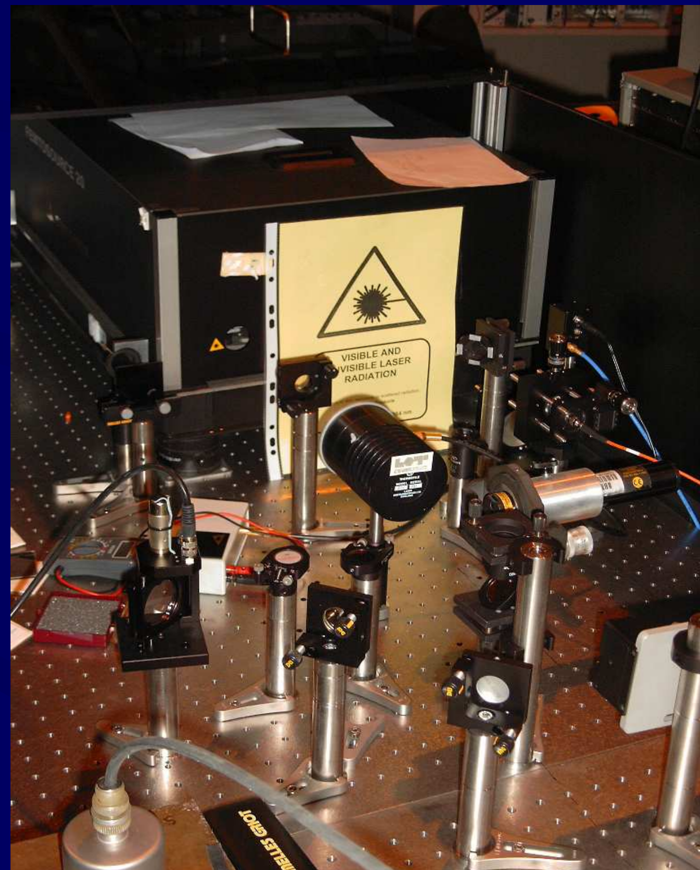
Outside Schematic

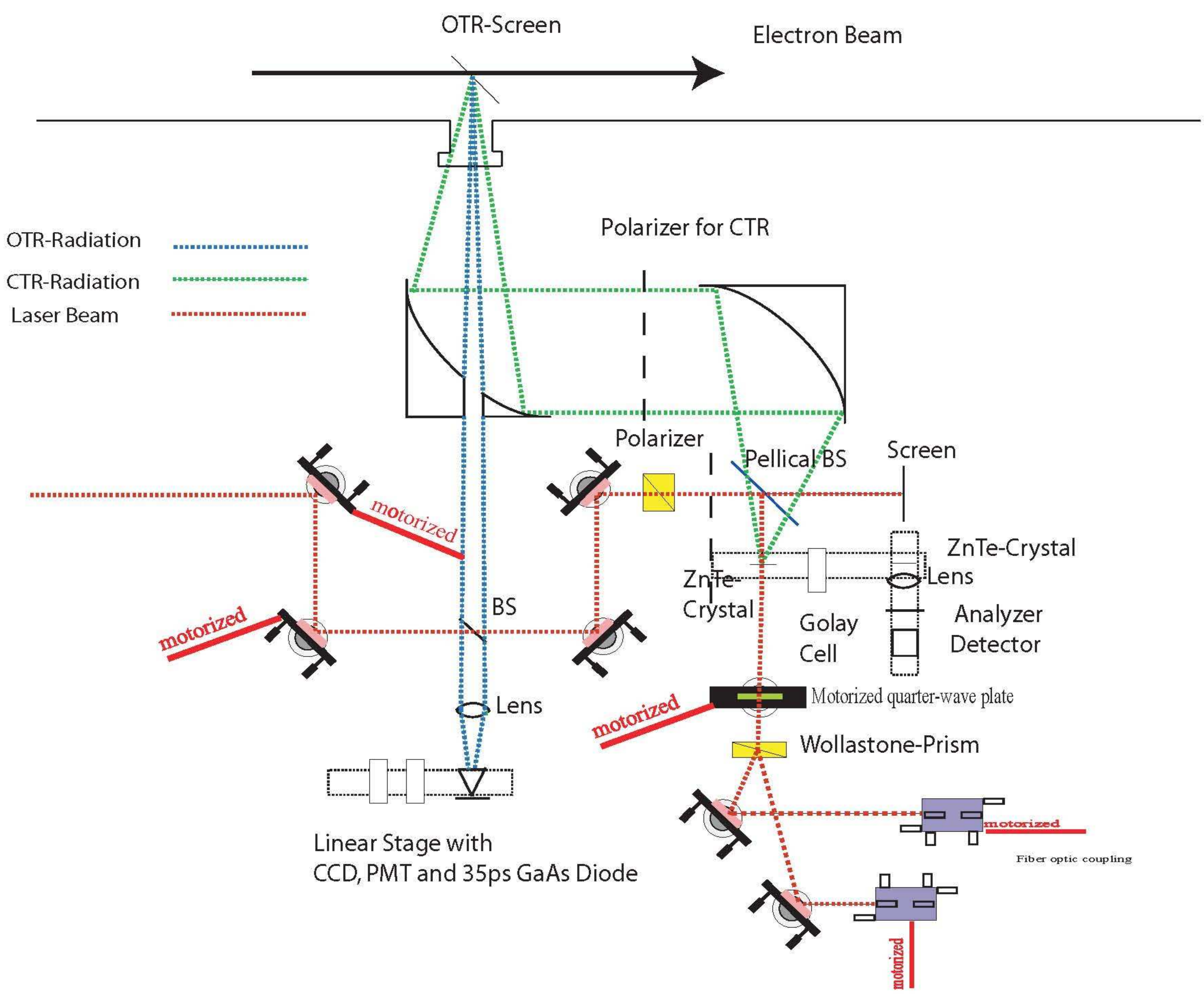
•optical table ouside linac bunker with the fs-Laser
•area is temperature stabilized to 24°

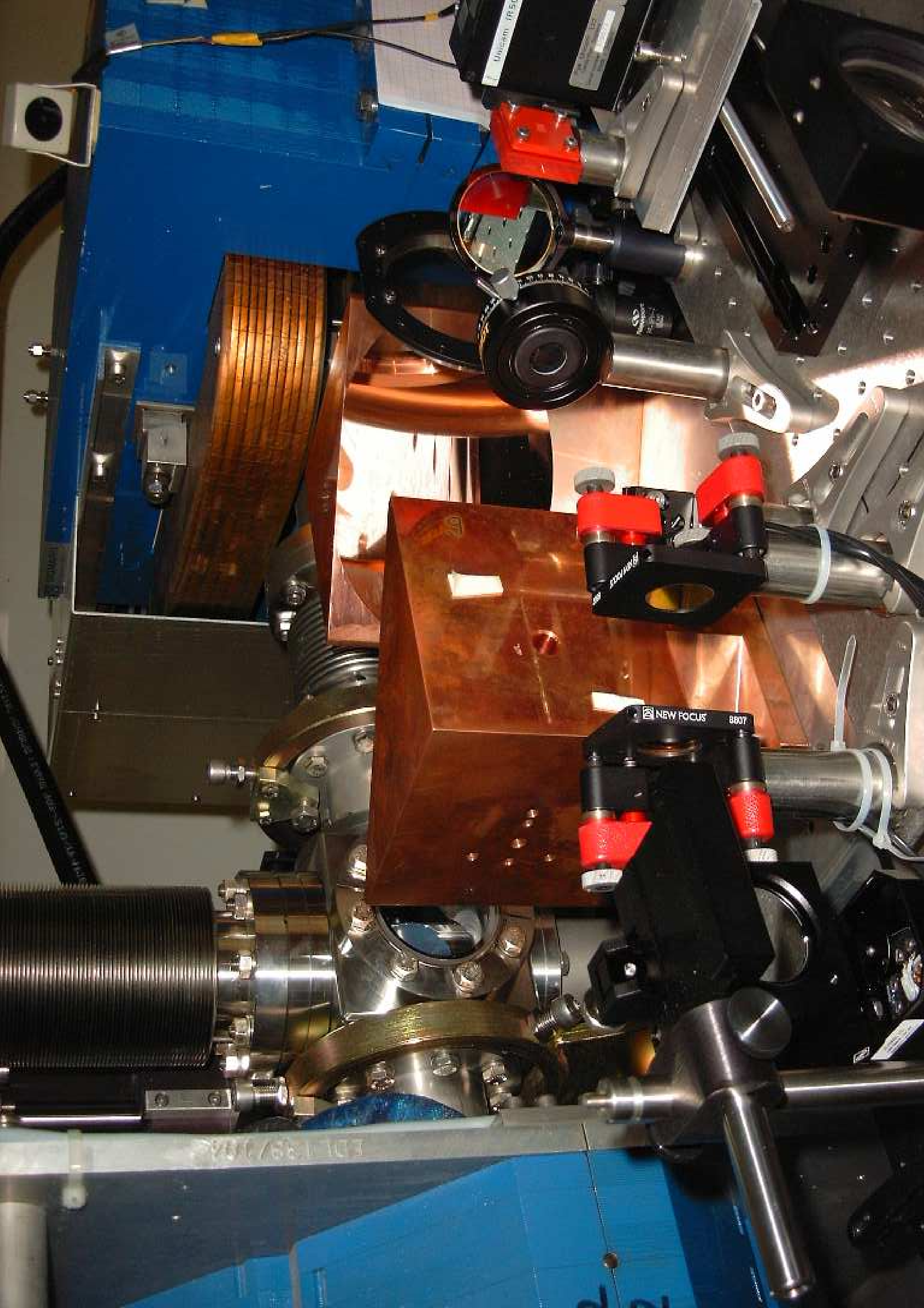


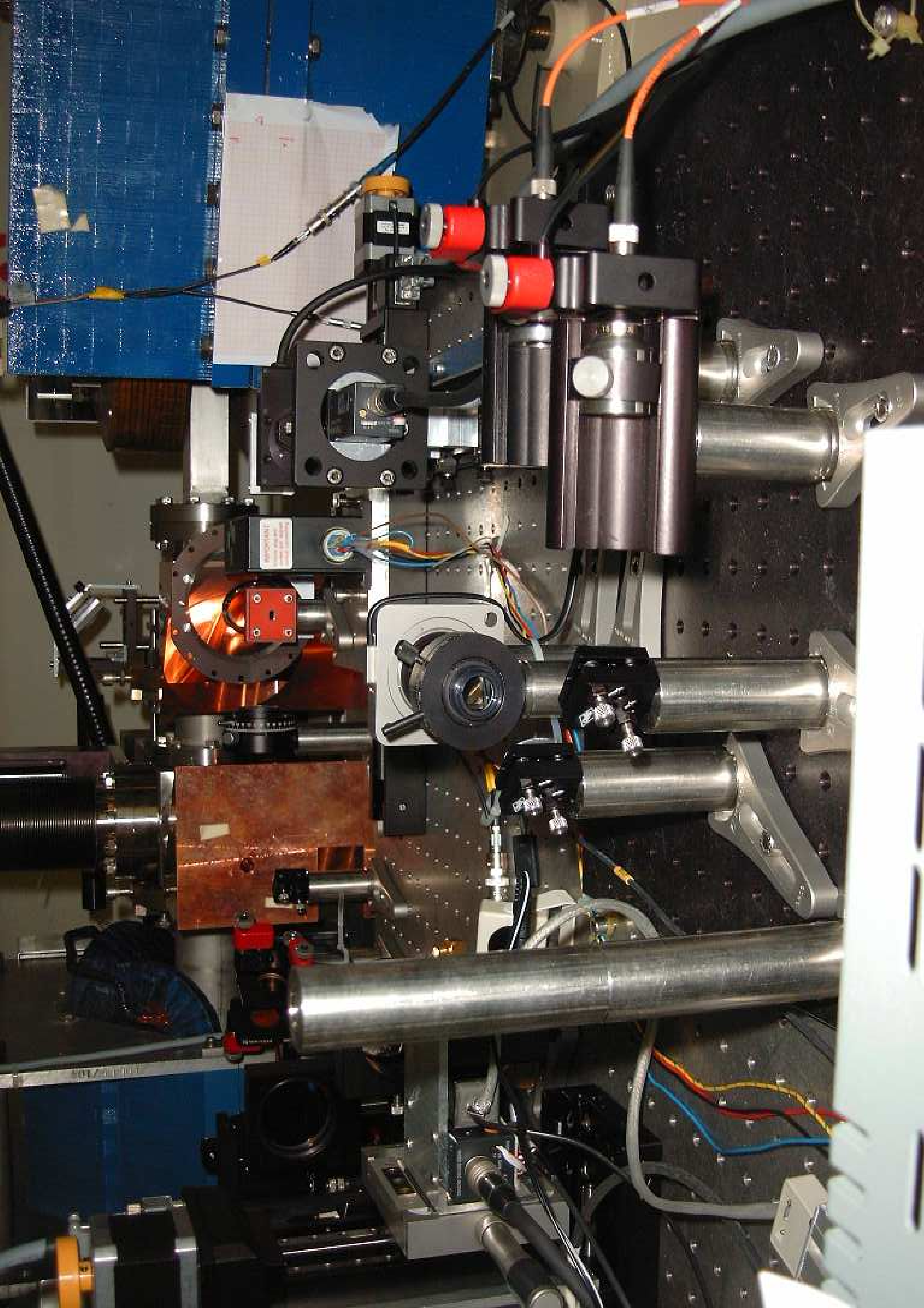


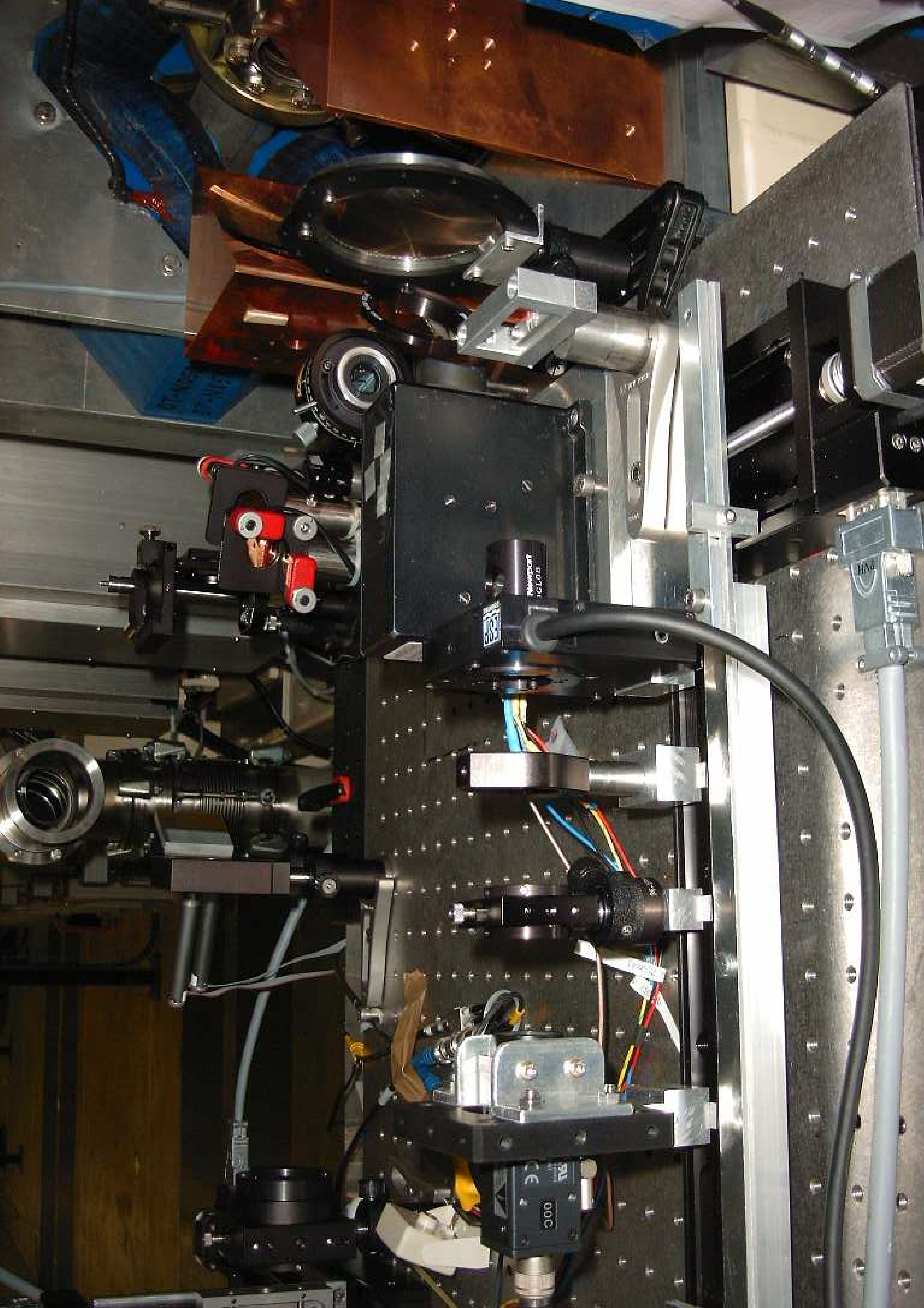
Beam Transfer

- 15m beam transfer line into bunker with 2 lenses to image beam profile at exit of laser on to crystal
- due to dispersion in lenses: pulse length of 130fs
- due to good temperature stabilisation neglegible short and long term drifts of laser spot inside tunnel

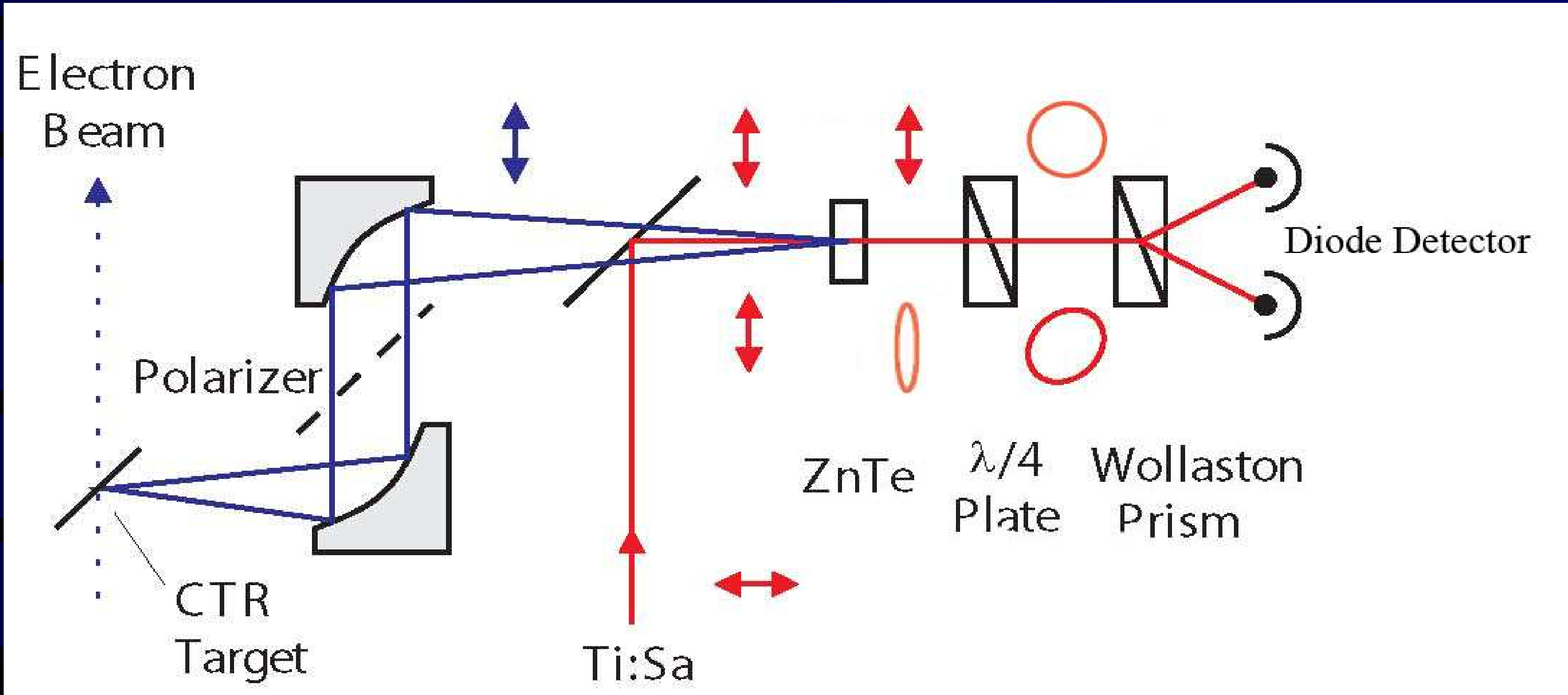

OTR-Screen
Electron Beam
Polarizer for CTR
OTR-Radiation
CTR-Radiation
Laser Beam
Polarizer
Pellical BS
Screen
motorized
ZnTe-Crystal
Lens
ZnTe-
Crystal
BS
Golay
Cell
Analyzer
Detector
motorized
Lens
Motorized quarter-wave plate
motorized
Wollastone-Prism
Linear Stage with
CCD, PMT and 35ps GaAs Diode
motorized
Fiber optic coupling
motorized


NEW FOCUS





Polarization of Laser and CTR



•Laser and CTR are horizontally polarized

•laser polarisation is slightly elliptical after crystal

•elliptical part of laser polarisation is converted to an elliptical polarisation by quarter wave plate

experimental procedure

- scan interval of 12.5 ns with 1ps stepwidth @3.125 Hz: measurement time of 1 hour!
- solution: find coarse overlap between OTR and bunch (accuracy of about 100ps) and scan with high accuracy around that spot.

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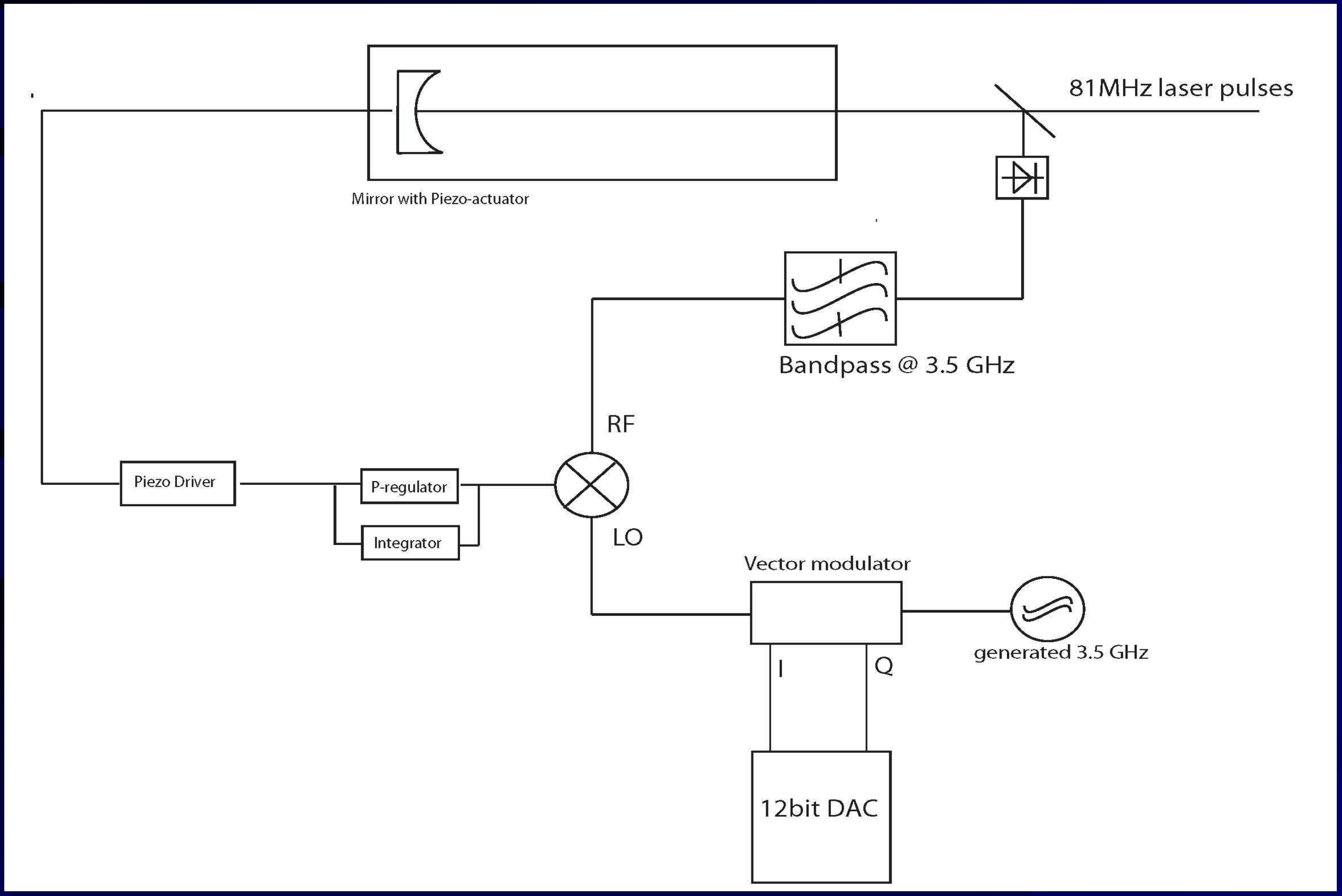
Synchronisation Scheme



phase-locked loop (PLL)

f_{laser}= 81 MHz

f_{RF} = 500 MHz

f_{dm} = 3.5 GHz

scanning done by phase shift of the 3.5GHz local oscillator (LO) with a vector modulator

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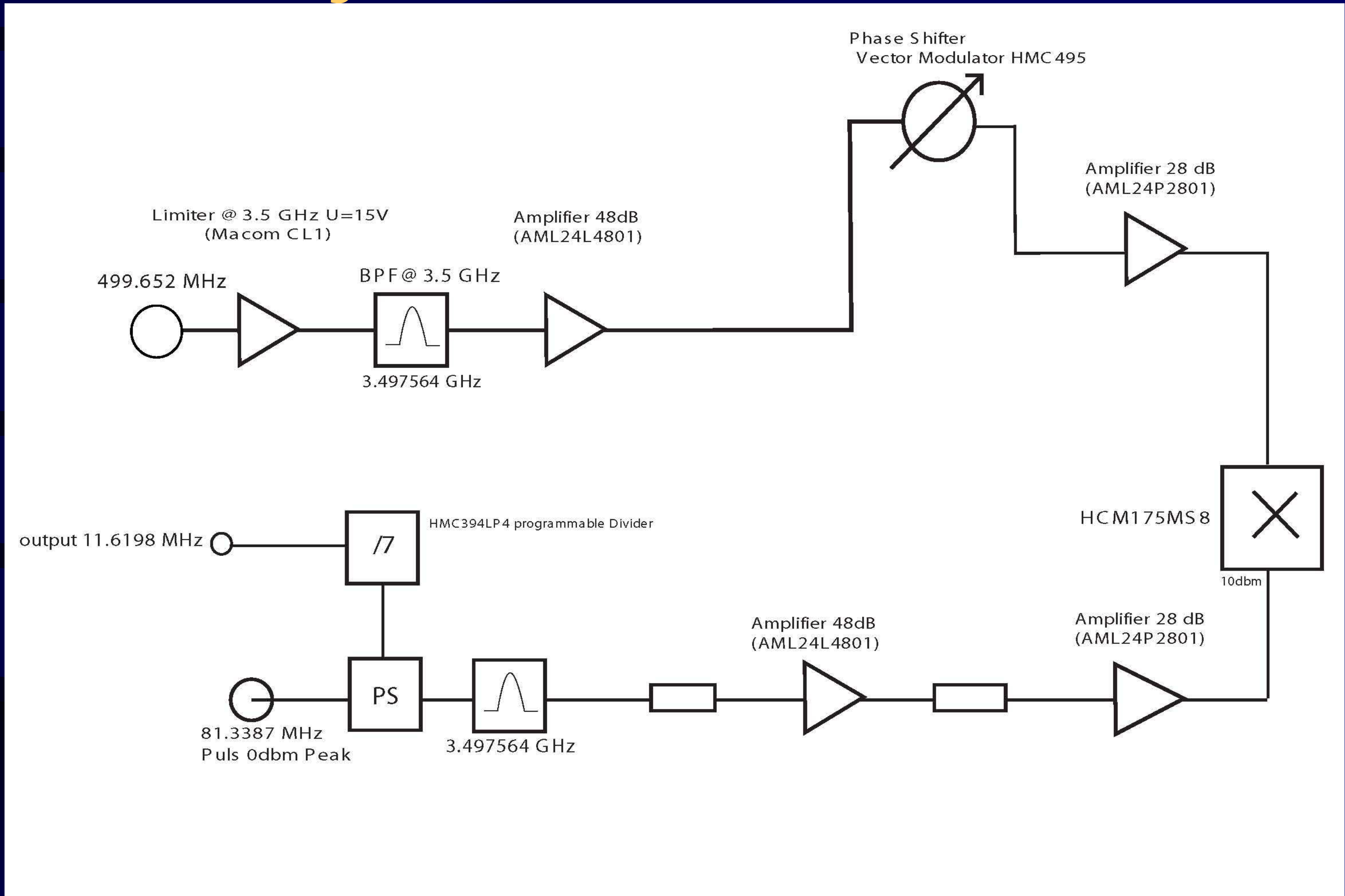
Synchronisation II



- 7th harmonic from linac RF generated through limiter amplifier
- phase shift through vector modulator
- downmixed with 43rd harmonic of laser

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Timing

- only every 7th laser pulse is at the same spot relative to the linac RF (every 43rd RF cycle)
- problem: linac trigger must be synchronized to laser
- solution: downconverting of 81MHz to 11.65MHz (=81MHz/7) synchronising that to the 3.125 Hz Linac trigger

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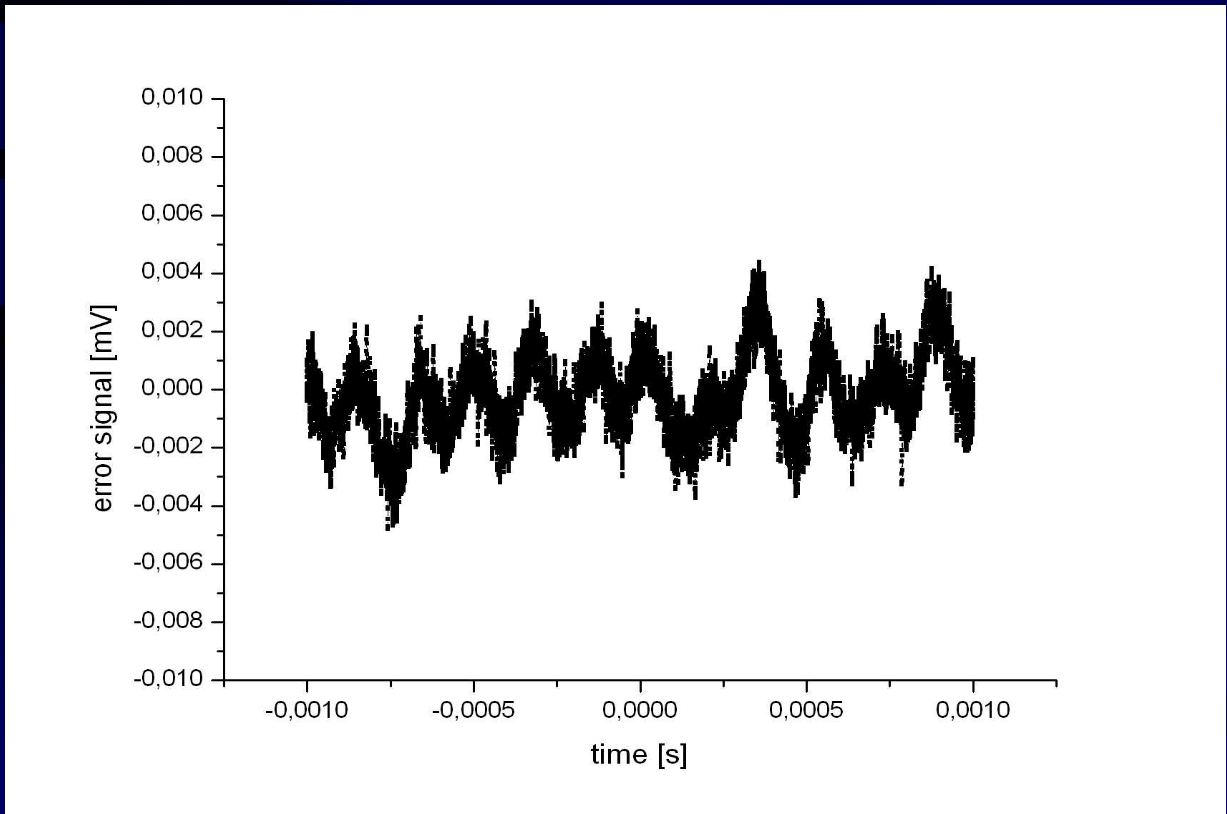
Synchronisation Accuracy

- open loop: 230mV rms for 45° phase shift
  that is 5.1mV per degree phase shift

at 3.5 GHz 1°=793fs, so 1mV per 155fs jitter



measured rms value: 420µV

accuracy of 65fs reached

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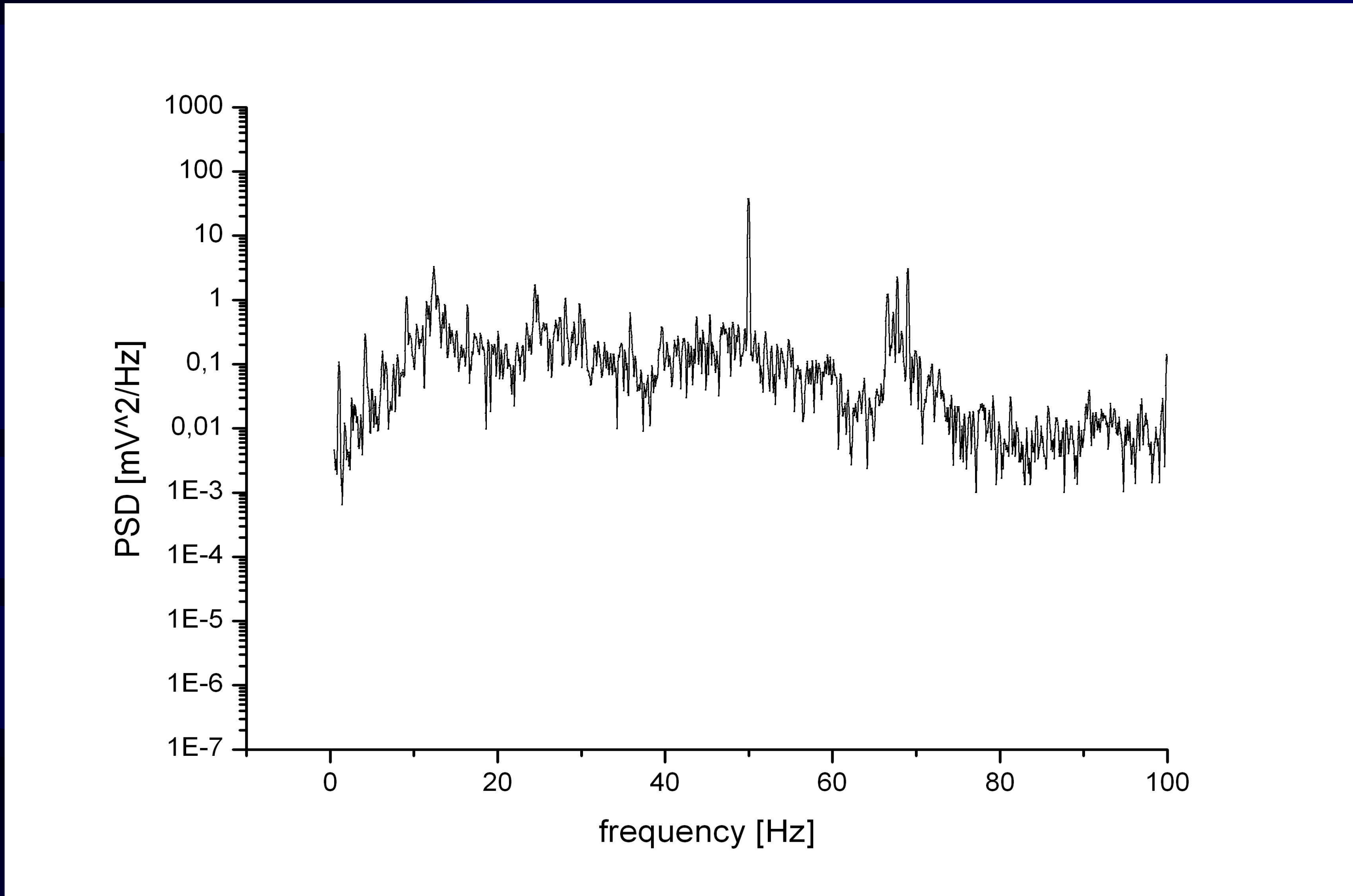
Measurement of Synchronisation



spectrum shows dominant peaks at 50Hz (1.87fs); 375Hz (1.7 fs) and 19 kHz (1.4fs)

Integration yields jitter of 65 fs

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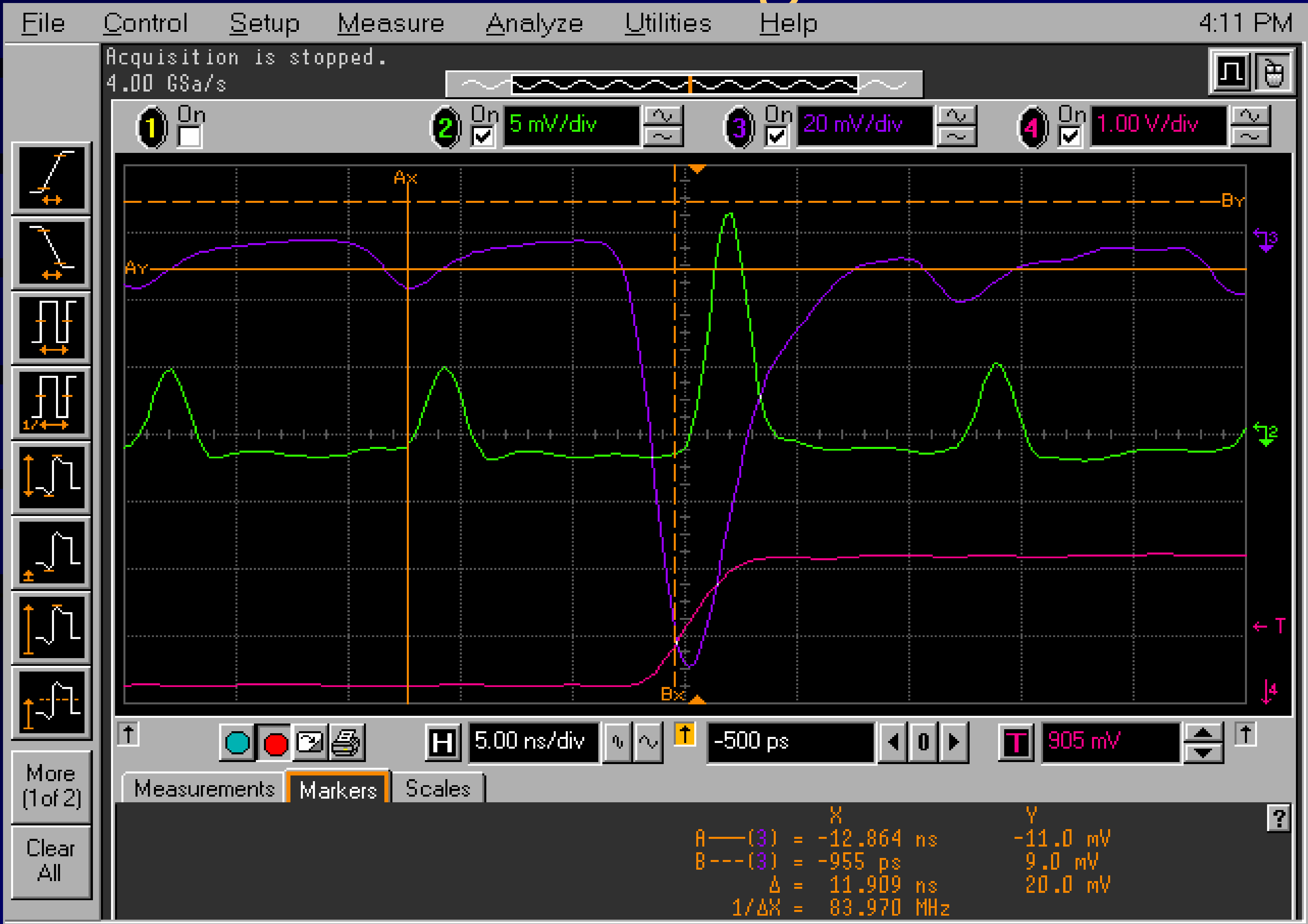
First Signal



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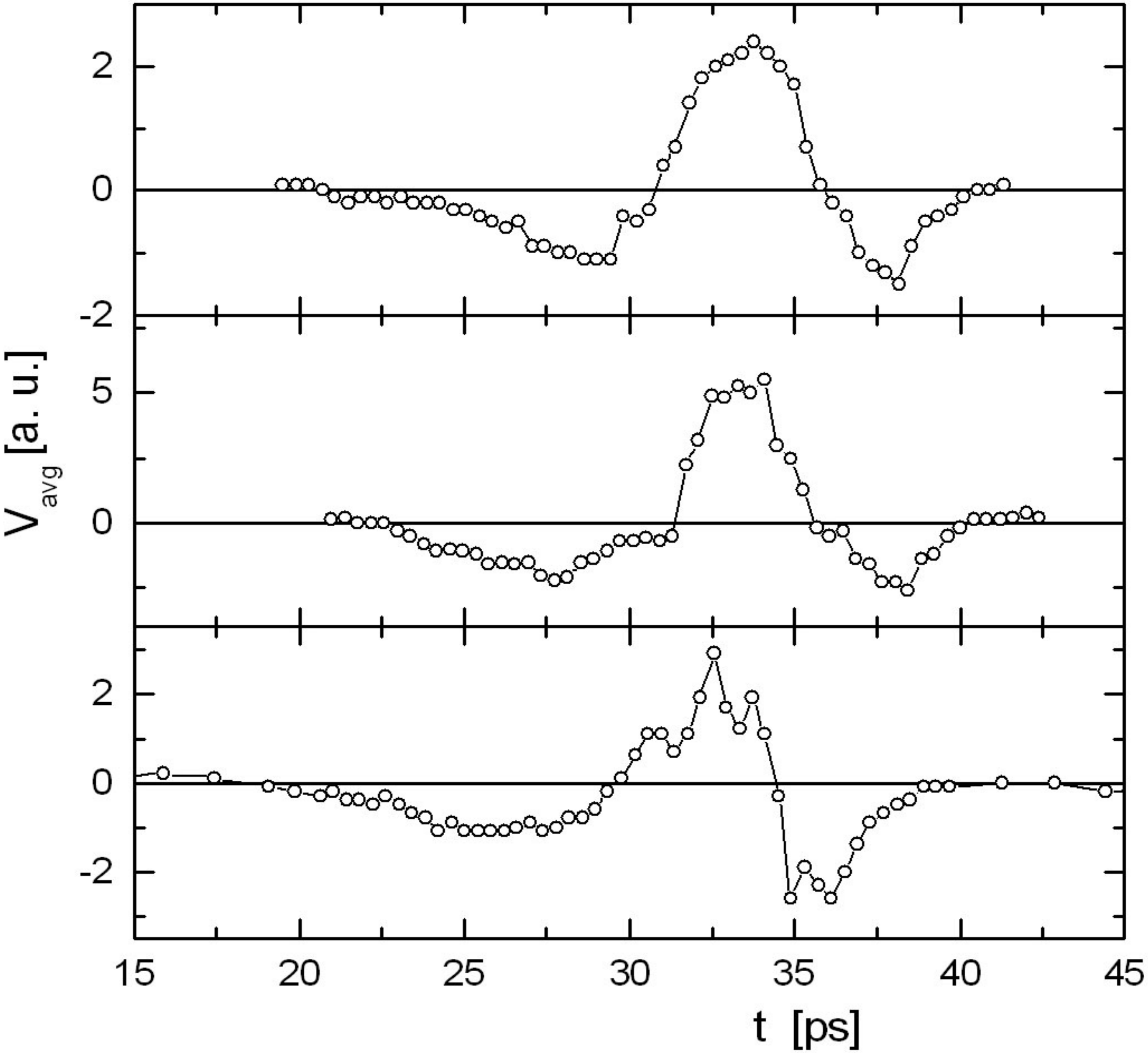
EOS scans for different linac settings



- preliminary data !
- scanning resolution: 396fs
- jitter through gun: 1ps
- improvements will be made during next shutdown
- measurements in good agreement with expected bunch length of ~6ps FWHM

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summary and outlook

- synchronisation between laser and RF with resolution of 200fs accomplished
- first EOS-signal seen in February 2004 in good accordance with expected SLS bunch length
- further measurements with reduced jitter will be conducted soon

contributions and thanks

thanks to the EOS Team

- S. Casalbuoni, N. Ignashine, T. Korhonen, T. Schilcher, V. Schlott, B. Schmidt, P. Schmüser, S. Simrock, B. Steffen, D. Sütterlin, S. Sytov, M. Tonutti,

References:

• M. Brunken et. al.: Electro-optic Sampling at the Tesla Test Accelerator Tesla Report 2003-11

Thank you for your attention !!