P. Schmüser

Ultrafast time diagnostics by Electro-Optic Sampling

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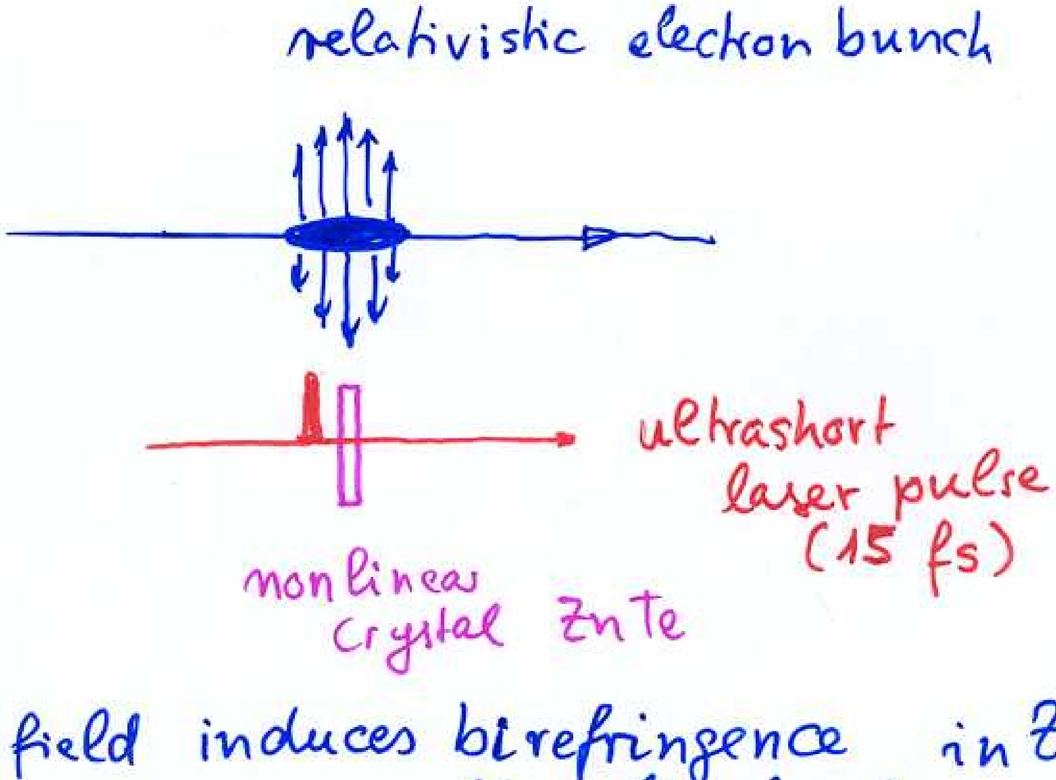


$\vec{E}$ field induces birefringence in ZnTe (Doppelbrechung)

optical anisotropy is sampled with ultrashort linearly polarized laser pulse

Electro-optic sampling (EOS) at the infrared FEL FELIX in Holland

G. Knippels et al

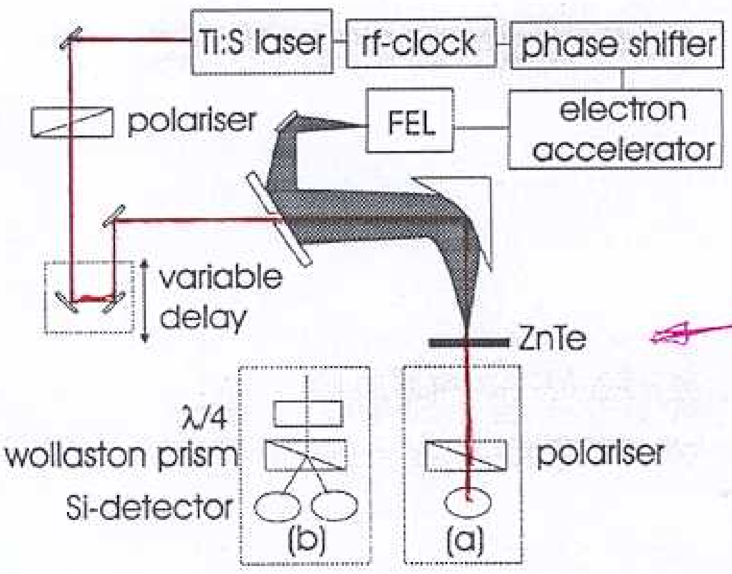
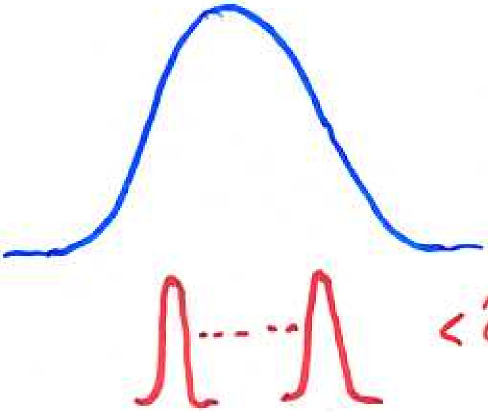


FIG. 2. The EO cross-correlation setup with two different detectors (a) and (b). In (a) the measured photodiode intensity is proportional to the FEL intensity. In (b) the measured photodiode intensity is proportional to the instantaneous electric field strength of the FEL pulse.

electro-optic crystal Zn Te



THz signal from FEL several ps wide

<20 fs titanium-sapphire laser pulse

electric field induces birefringence (Doppelbrechung)

sampled with ultrashort

as the refer-
double-balanced mixer (DBM),
the electron gun and the ac-
enerate the electron beam that
icon diode (Si-PIN) detects the
train and filters out the 1-GHz
with the 1-GHz clock in the
ding the phase difference. Af-
Hz low-pass filter (LPF) and a
Hz), the error signal is sent to a
T) driver for adjustment of the
ter is used to control temporal
BPF, bandpass filter.

tween the two lasers in a
tion experiment. The sum
hrough a calcite polarizer
ire background. As shown
lay line to vary the optical
er pulses, and the individ-
re correspond to a 50-shot-
er successive macropulses.
apphire laser pulses was
an autocorrelator that was
ple and was found to be
-hand-side inset in Fig. 2).
n was similarly measured
elator[6] to be 435 fs FWHM
hand-side inset). The jit-
ion signal was thus esti-
-900 fs FWHM, assuming
). The degree of synchro-
l was present over many
system was competitive
ailable systems that allow
to an external clock. For
nd Coherent systems typi-
s than 3 ps rms (~6 ps
cale or shorter for table-
ne FEL was located 40 m
nd the excellent synchro-
demonstrates the intrin-
of the Ti:sapphire laser
of the FEL to its 1-GHz
n between the laser led
synchronization of ~1 ps

d the synchronization of
e FEL at an IR wave-

experiment we used the intense IR FEL pulse (pulse duration, 0.5–1 ps; energy, ~1 μJ per micropulse) to heat the electron gas by promoting electrons from lower to higher states in the conduction band, by means of an intraband absorption process. We then used the delayed Ti:sapphire pulse to measure a change in transmission of the interband transition at wavelengths near the bandgap of GaAs.

In Fig. 3 the results at room temperature are given for different FEL wavelengths. The results clearly show a FEL-induced enhanced absorption that decays on a time scale of several picoseconds. The fast rising edge of the signal is another indication of the good synchronization between the two lasers. The transmission is decreased because after FEL excitation more states near the bottom of the conduction band to which electrons can be excited from the valence band at the Ti:sapphire wavelength become available. The decay time of the signal agrees with the typical cooling times of the hot electron gas, caused by longitudinal-optical–phonon emission.[10] The longer decay time in

Knippels et al.

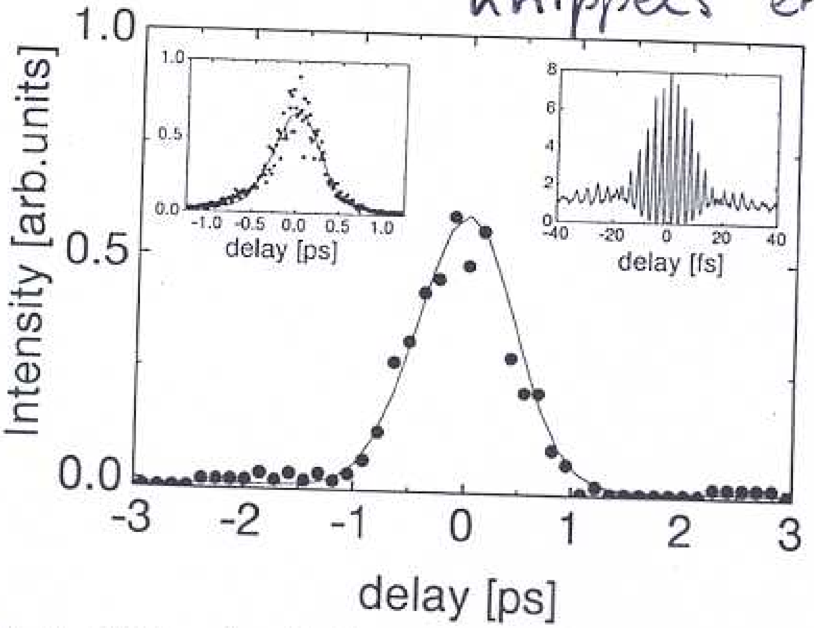
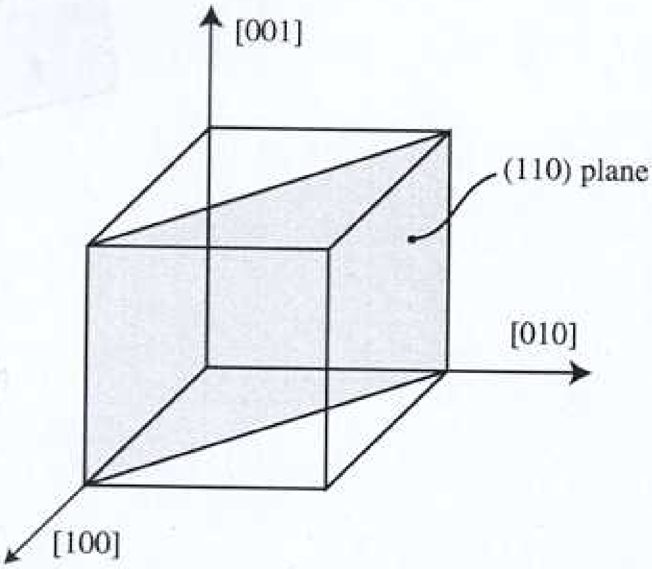
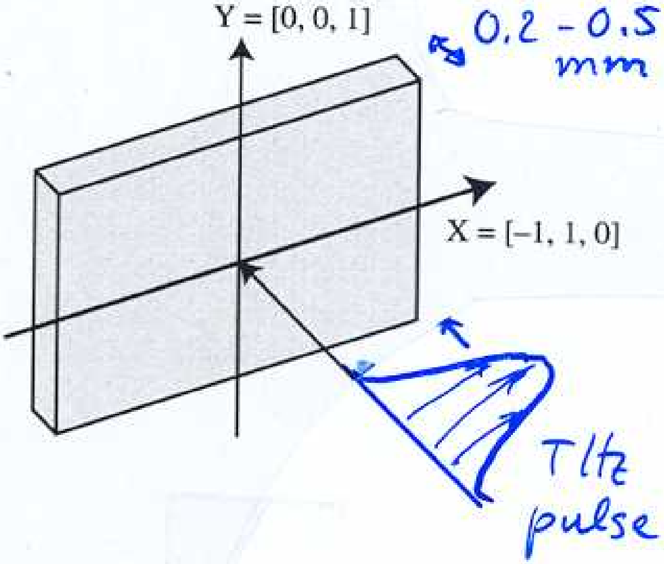


Fig. 2. Measured optical cross correlation between the FEL running at 9 μm and the Ti:sapphire laser at 800 nm in a 100-μm-thick $AgGaS_2$ crystal. The inset on the left-hand side shows the background-free autocorrelation measurement of the 435-fs FEL pulse with a homebuilt autocorrelator based on CdTe,[6] and the inset on the right-hand side shows the 10-fs fringe-resolved autocorrelation function of the Ti:sapphire pulse. The derived jitter is 400 fs rms (~900 fs FWHM). The scan took approximately 2 min to record.

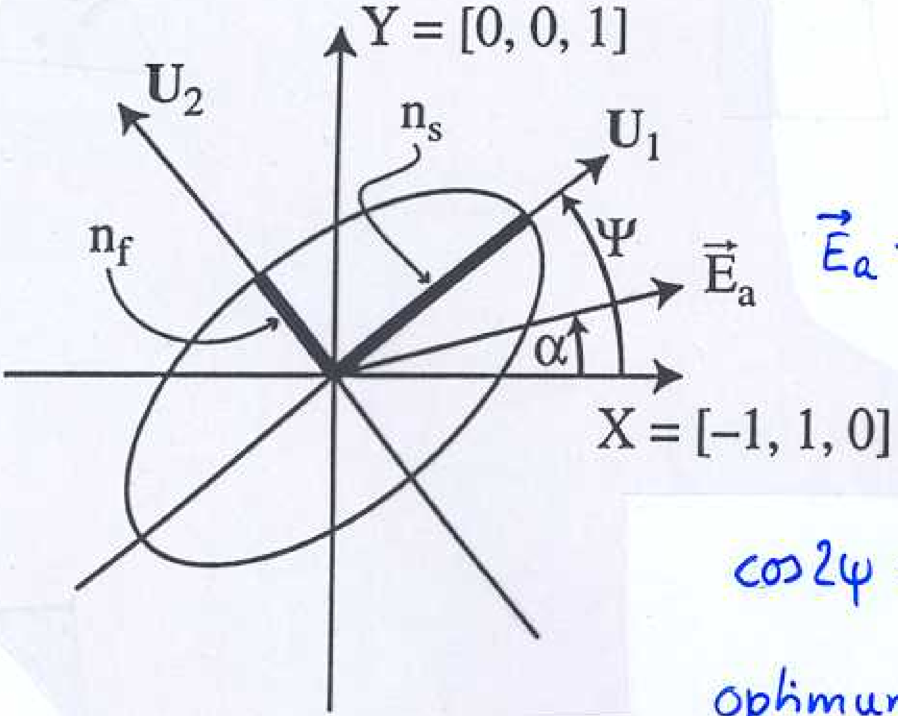
Electro-optic effect in zinc-telluride

ZnTe is optically isotropic without $\vec{E}$-field





with electric field: refractive index ellipsoid



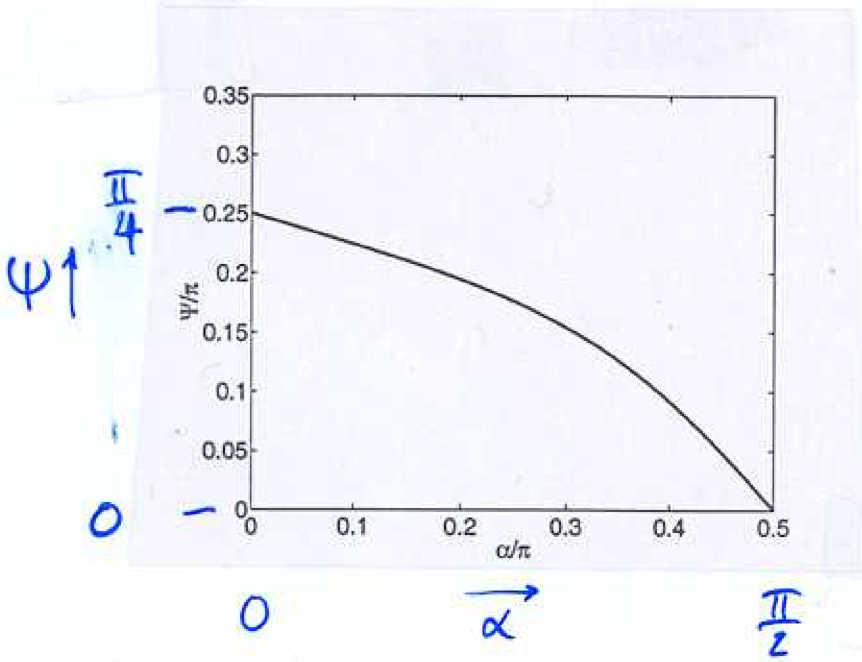
$\vec{E}_a = \vec{E}_{THz}$

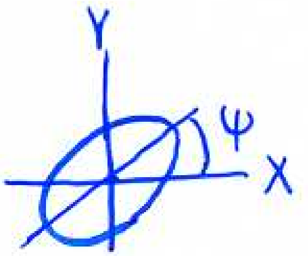
$$\cos 2\psi = \frac{\sin\alpha}{1+\sqrt{1+3\cos^2\alpha}}$$

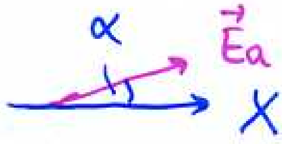
optimum: $\alpha = 0$

$$\Rightarrow \psi = \frac{\pi}{4} \mathrel{\hat{=}} 45°$$

orientation of ellipse in (110) plane







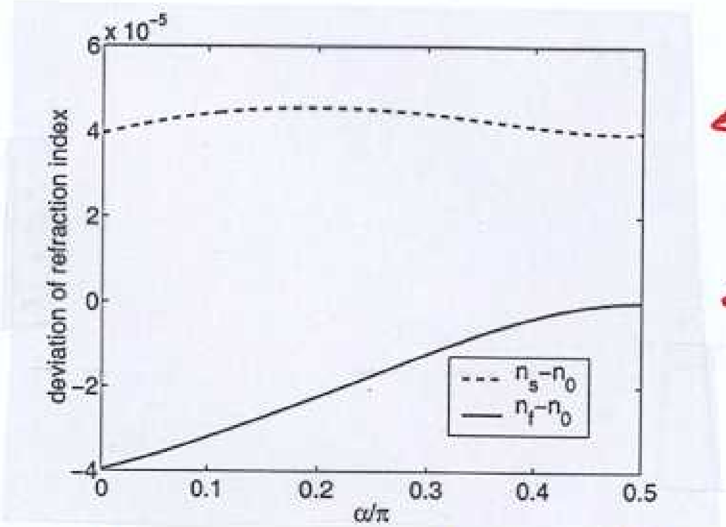
main refractive indices:

$$n_{slow} = n_1 = n_0 + \frac{1}{4} n_0^3 \, r_{41} \cdot E_a \cdot \left(\sin\alpha + \sqrt{1 + 3\cos^2\alpha} \right)$$

$$n_{fast} = n_2 = n_0 + \frac{1}{4} n_0^3 \, r_{41} \cdot E_a \cdot \left(\sin\alpha - \sqrt{1 + 3\cos^2\alpha} \right)$$

electro-optic coefficient of ZnTe:

$$r_{41} = 4 \cdot 10^{-12} \, \frac{m}{V}$$

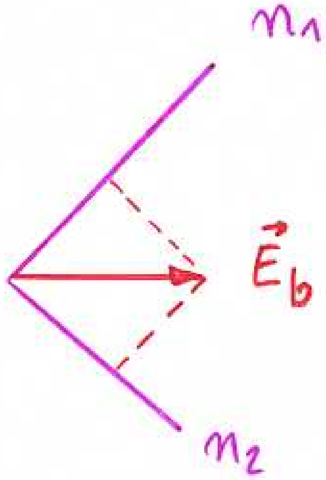


$n_1 - n_2 = max$

for $\alpha = 0$

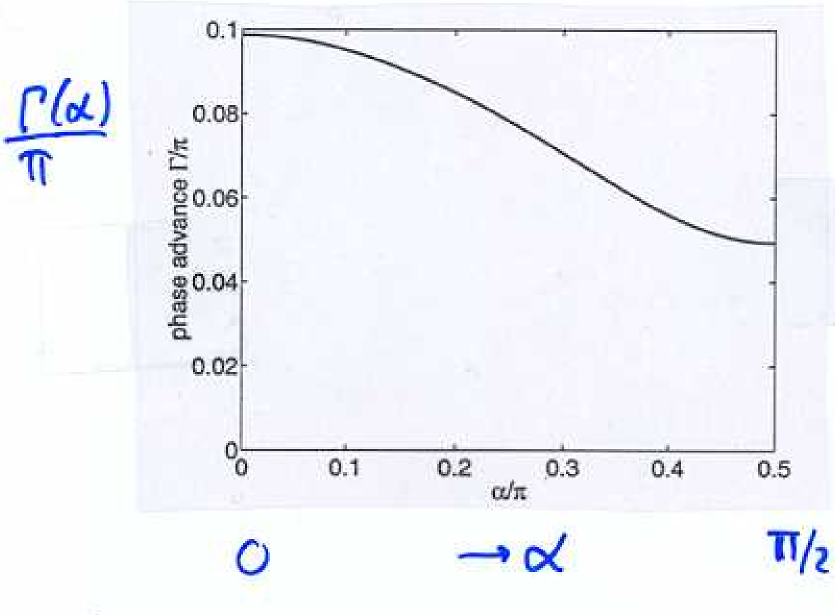
Consider horizontally polarized Ti:Sa laser pulse

$$\vec{E}_b \equiv \vec{E}_{TiSa}$$



projections of $\vec{E}_b$ on the n_1 axis and the n_2 axis receive different phase shifts

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



$\Gamma = 0{,}1\,\pi$

for $E_{THz} \approx 10^6\,V/m$

$d = 0.5\,mm$

(at $\alpha = 0$)

The Ti:Sa beam is elliptically polarized behind the ZnTe crystal

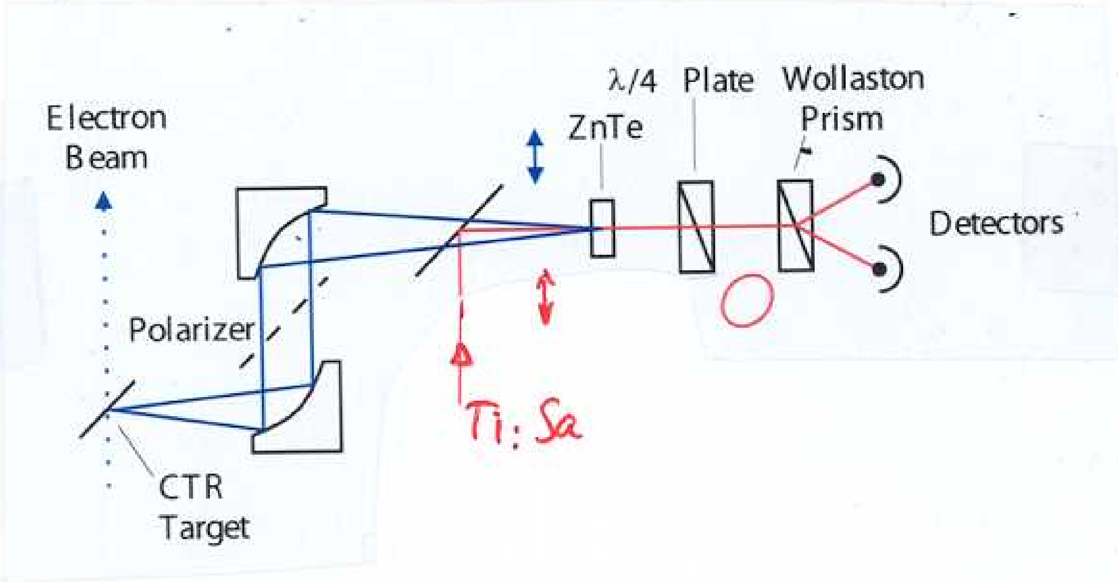
How to detect elliptic polarization?

a) Crossed polarizer

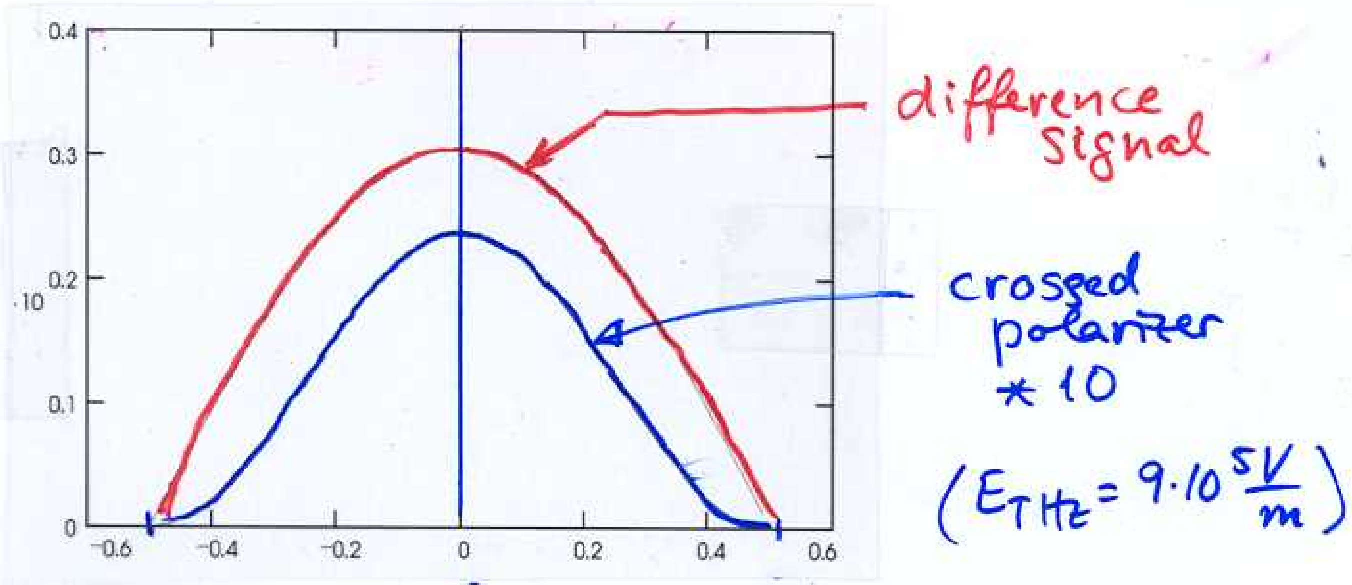
Detector signal

$$S(\alpha) = E_{TiSa}^2 \cdot \sin^2(2\psi(\alpha)) \cdot \sin^2\left(\frac{\Gamma(\alpha)}{2}\right)$$

b) $\frac{\lambda}{4}$ plate, Wollaston prism, balanced diode detector

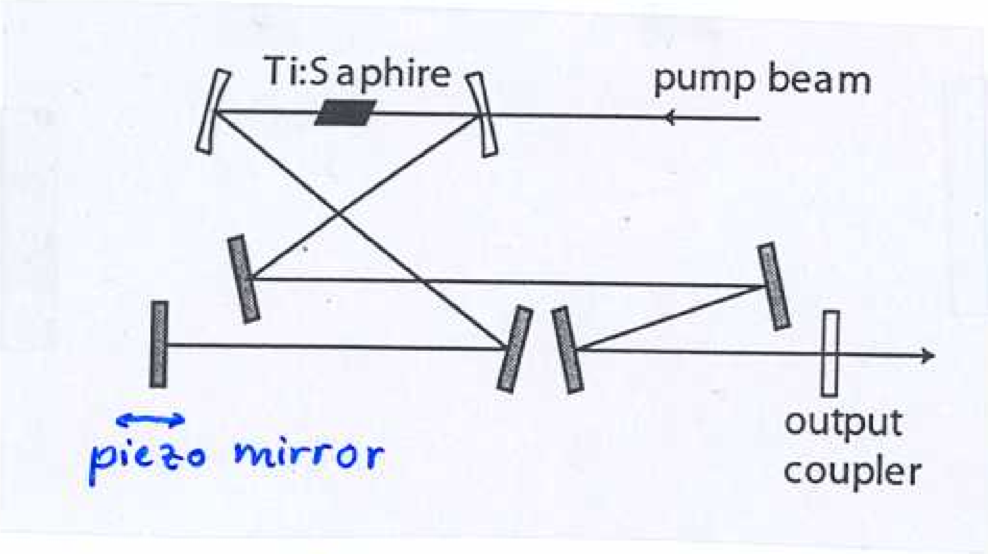


difference signal $\sim E_{TiSa} \cdot \sin(\Gamma(\alpha))$

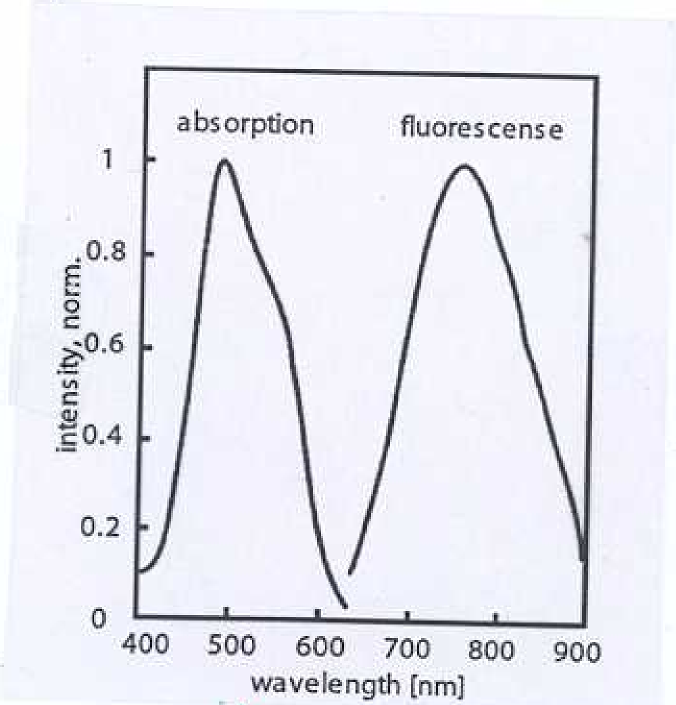


Titanium-Sapphire (Ti:Sa) laser

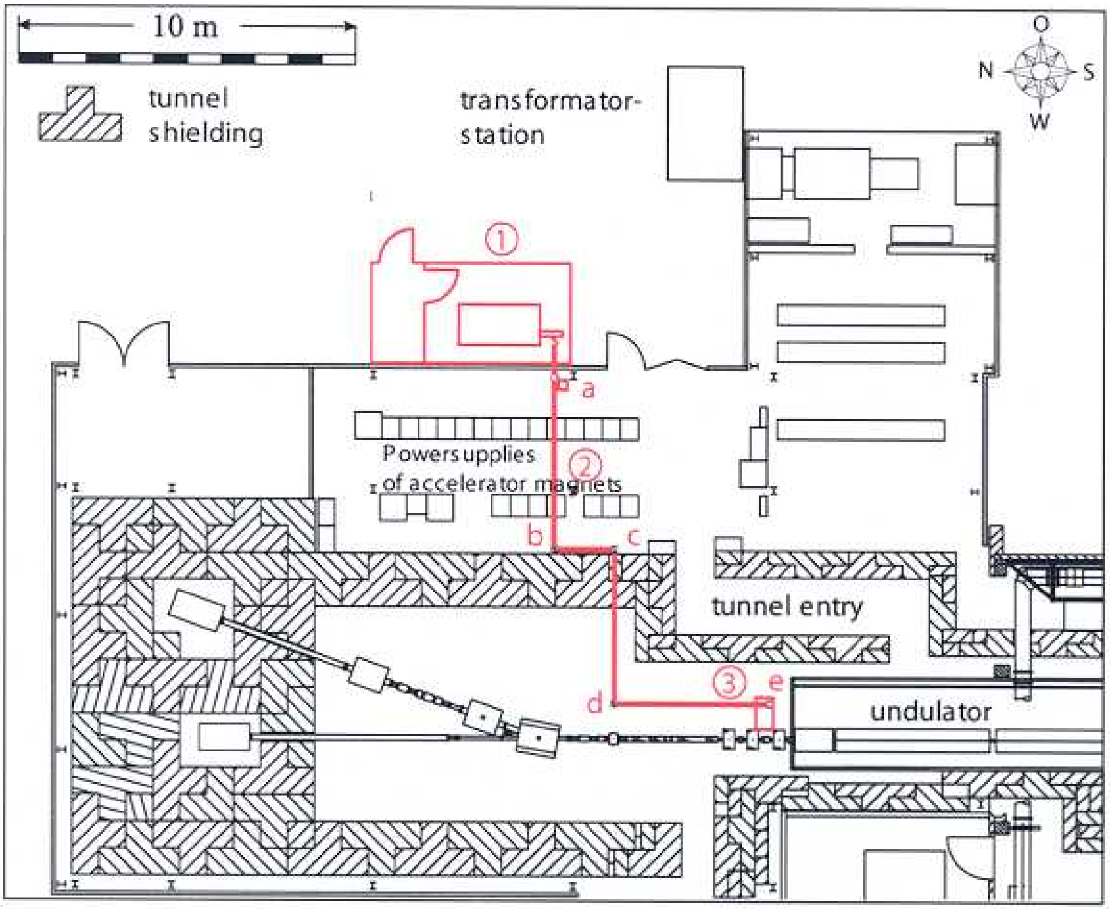
Femtosource Compact by Femtolasers, Vienna

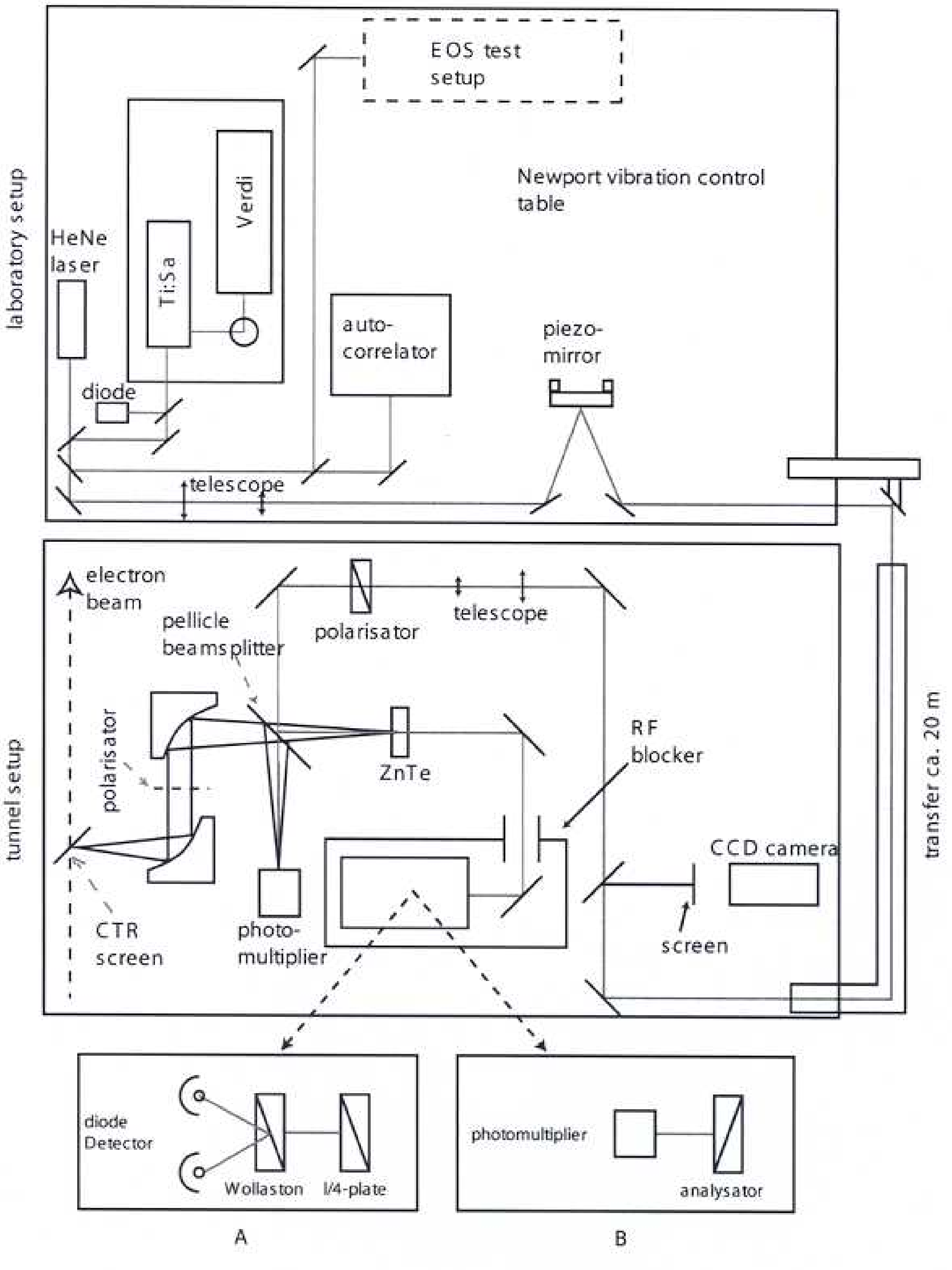


bandwidth 770 - 840 nm
pulse width 15 fs (FWHM)
repetition rate 81 MHz



↑
pumplaser 532nm
5W cw
Verdi by Coherent


10 m
tunnel shielding
transformator-station
O
N
S
W
①
a
Powersupplies of accelerator magnets
②
b
c
tunnel entry
③
d
e
undulator


EOS test setup
Newport vibration control table
laboratory setup
HeNe laser
Ti:Sa
Verdi
auto-correlator
piezo-mirror
diode
telescope
electron beam
pellicle beamsplitter
polarisator
telescope
tunnel setup
polarisator
ZnTe
RF blocker
CCD camera
transfer ca. 20 m
CTR screen
photo-multiplier
screen
diode Detector
Wollaston
l/4-plate
photomultiplier
analysator
A
B

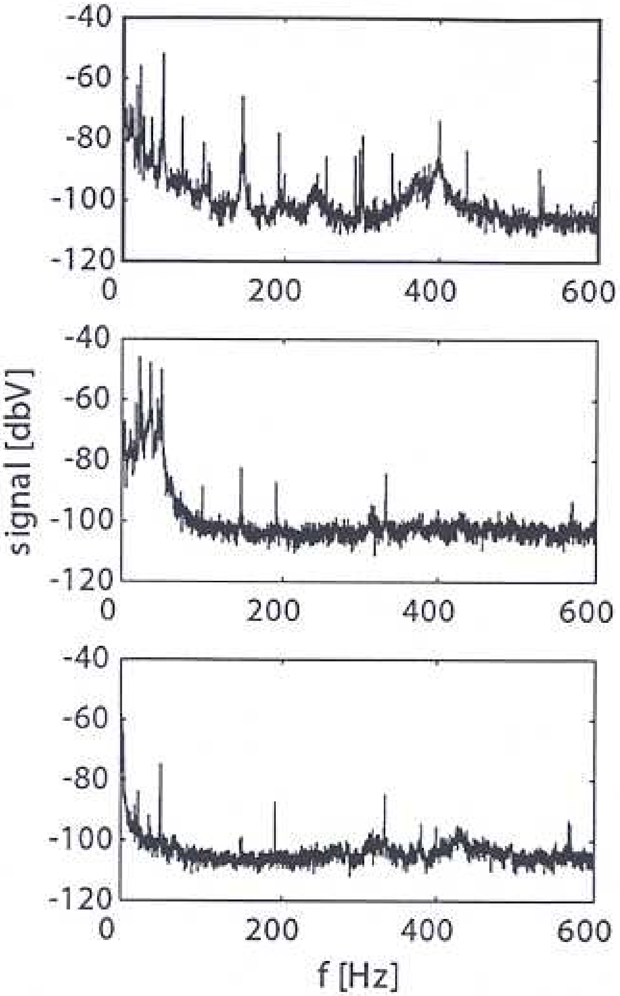


Figure 13: *Vibrational noise in laser beam transport. Top and middle: two positions on a vertical I-beam in Hall 3. Bottom: vibrational noise at a mirror mounted on a vibration-damped vertical pillar.*

h

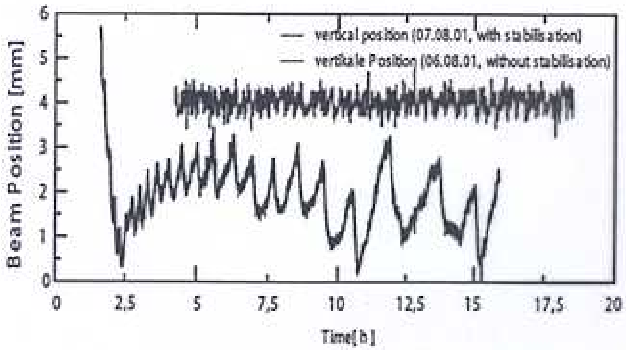
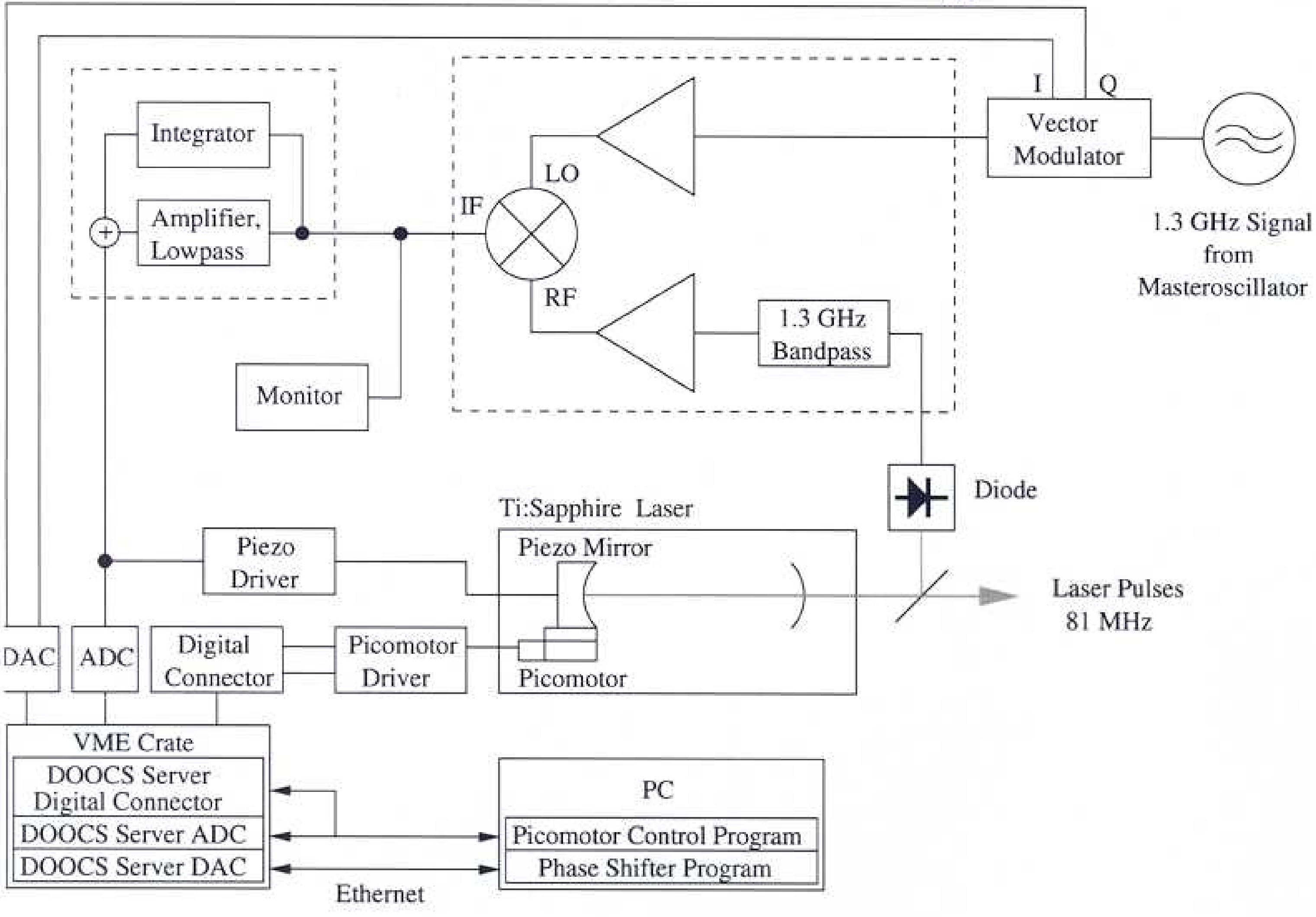


Figure 14: *Time variation of vertical laser beam position without and with feedback control.*

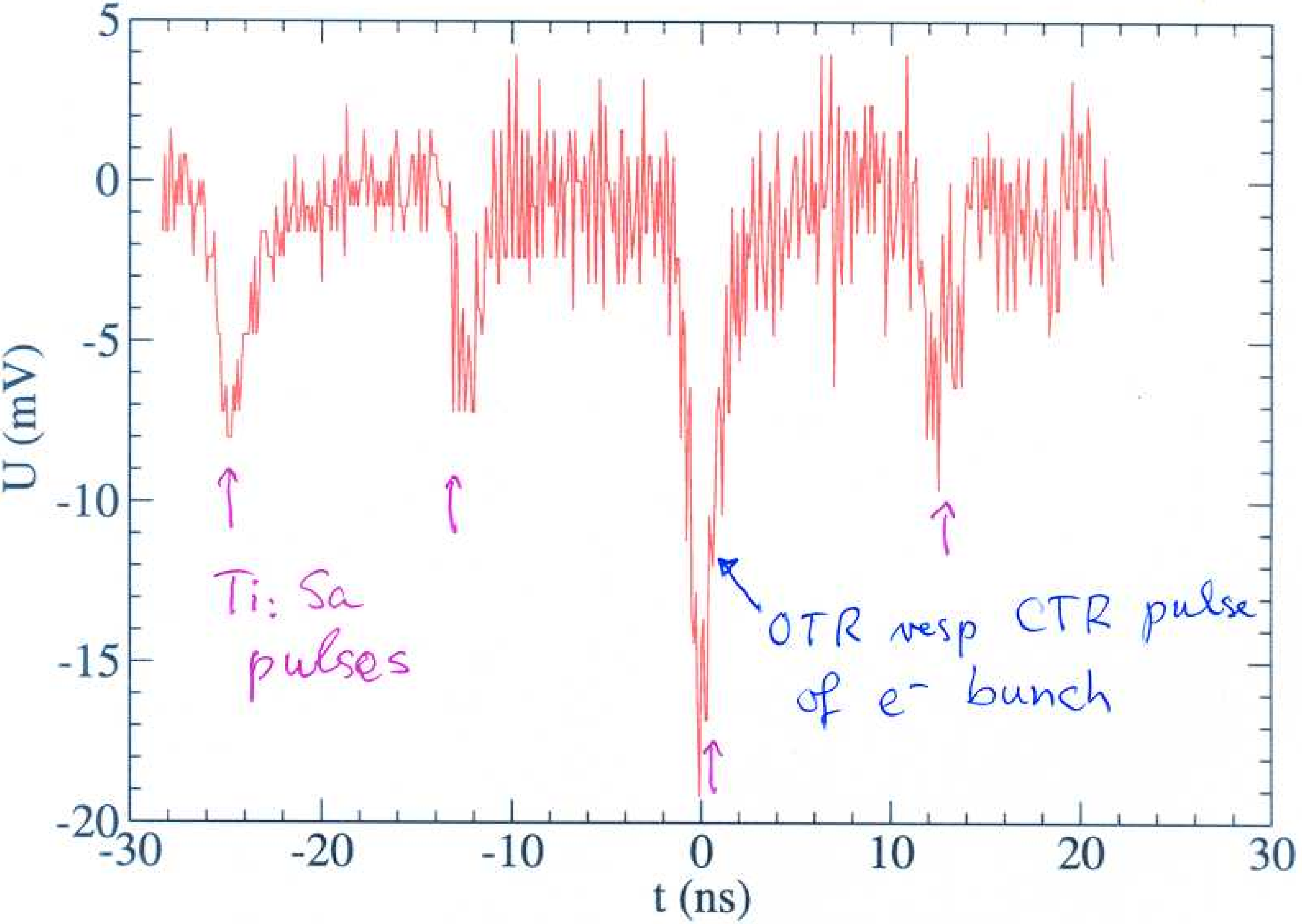
crystal the Ti:Sa laser beam is guided into the box through a 100 mm long aluminium synchronization Ti: Sa laser to rf

$81\ \mathrm{MHz} = \frac{1}{16} \cdot 1300\ \mathrm{MHz}$



detector signal on 20 Gs scope

(setup: crossed polarizers, photo multiplier as detector)

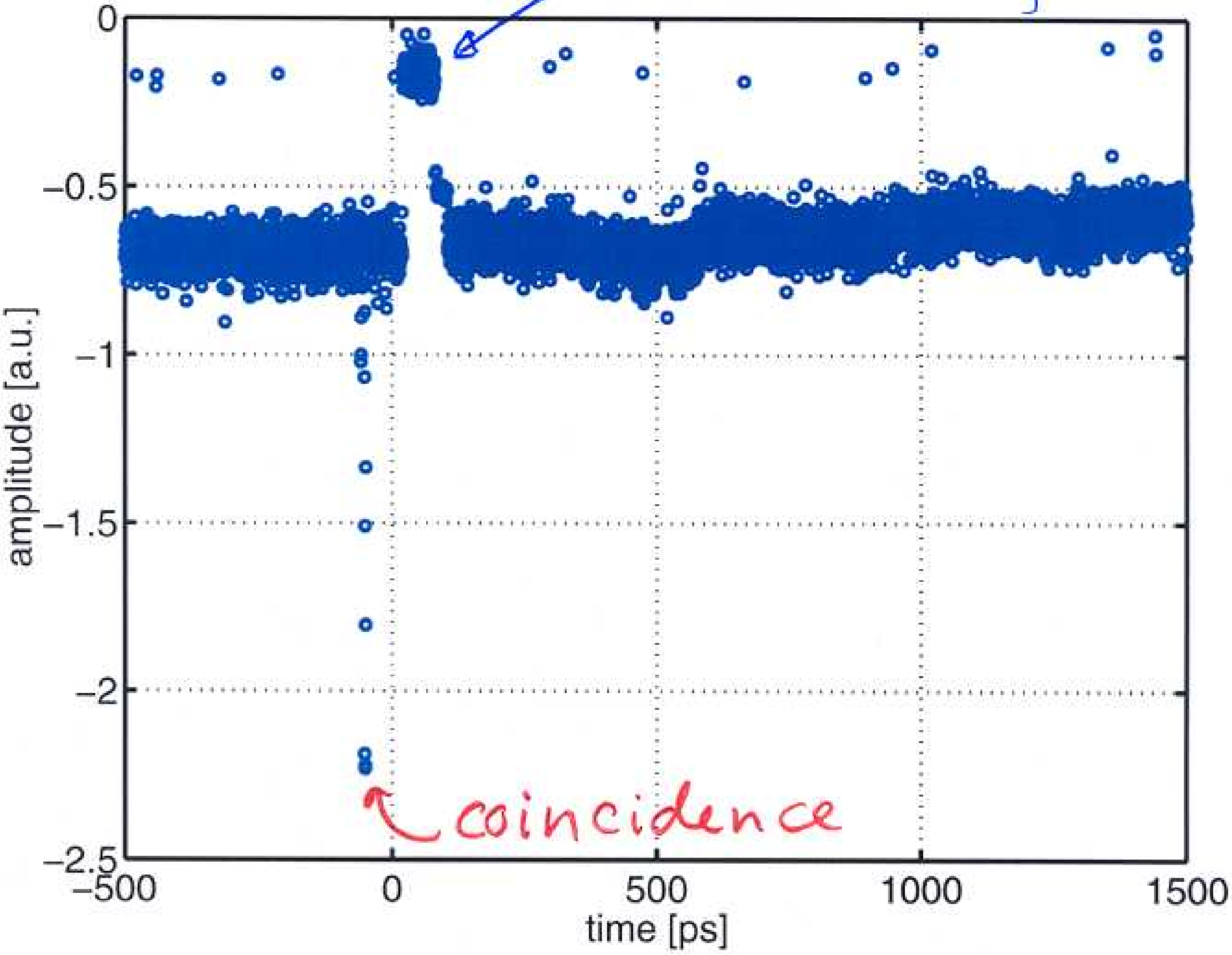


March 2002

Coincidence scan to find overlap of Ti:Sa pulse (<20 femtosec) with CTR-pulse of e-bunch

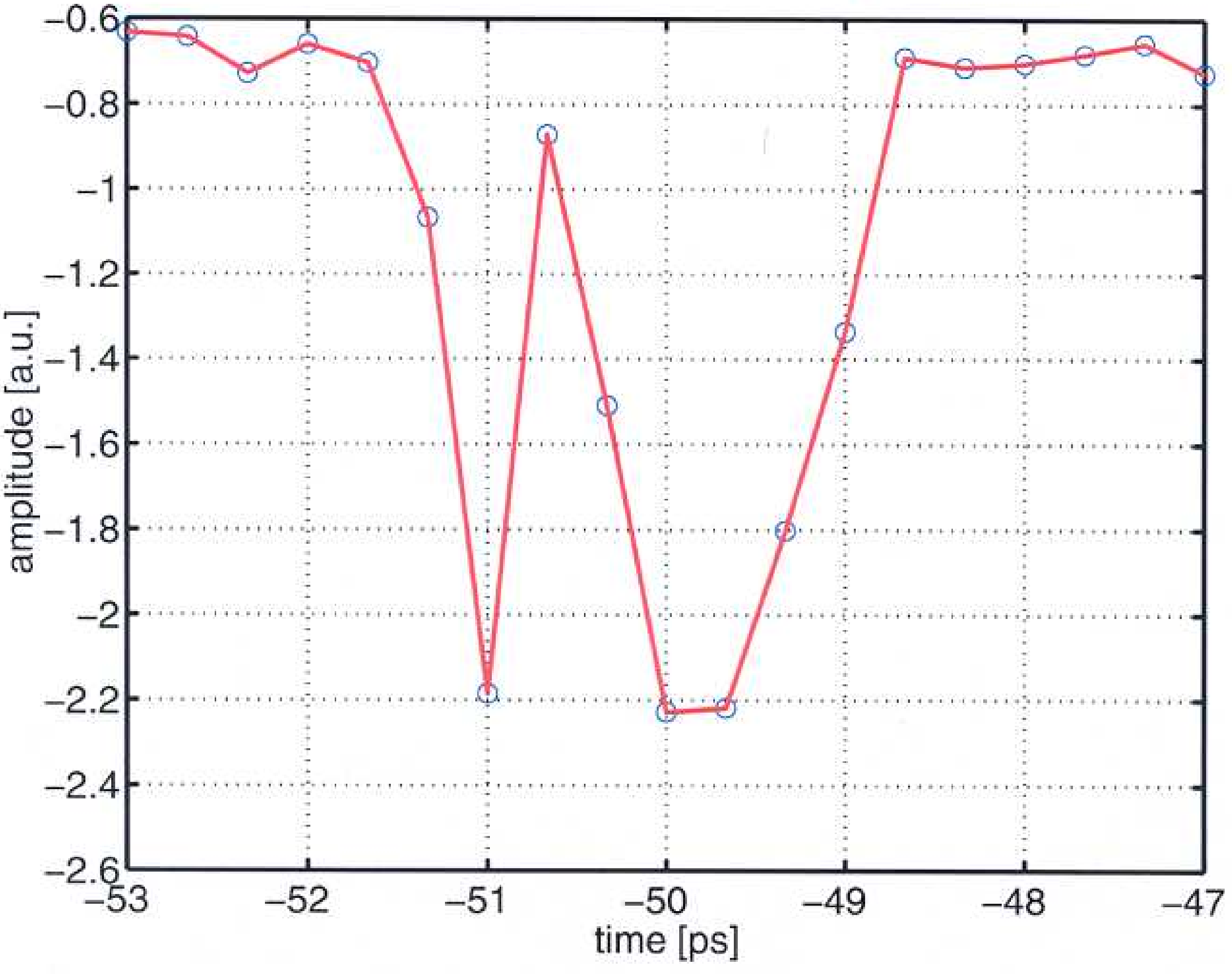
Scan over 2000 ps

bunches missing

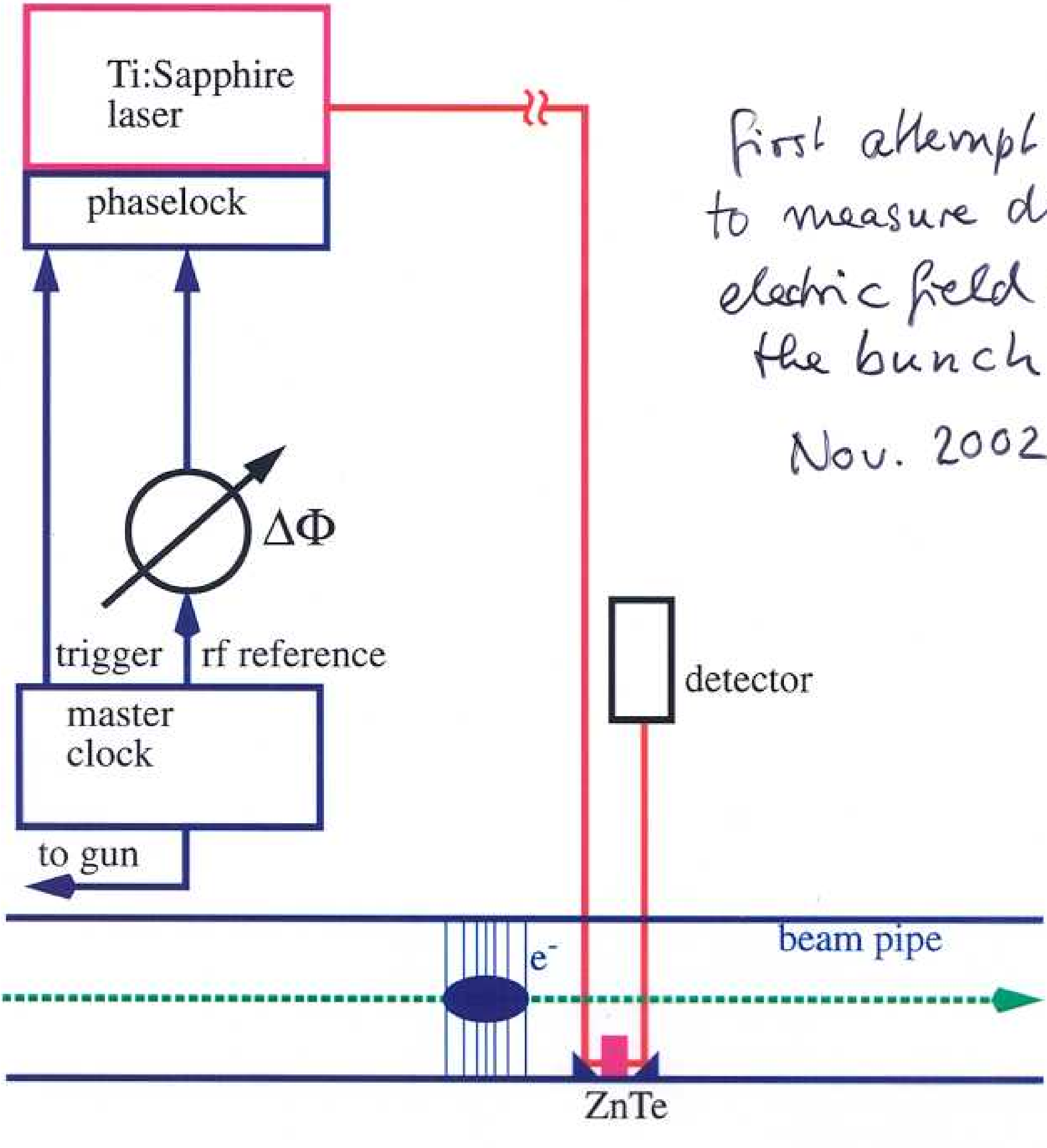


coincidence

zoom of coincidence
Ti:Sa pulse / CTR pulse



Experimental Setup



first attempt
to measure directly
electric field of
the bunch

Nov. 2002

- direct measurement of the co-propagating electrical field
- nonintercepting