Operational experience with the Sub-Picosecond Particle Source Part II

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- Project overview
- Measurements of the bunch length
- Wake fields studies
- CSR measurements
- Bunch length measurements FFTB

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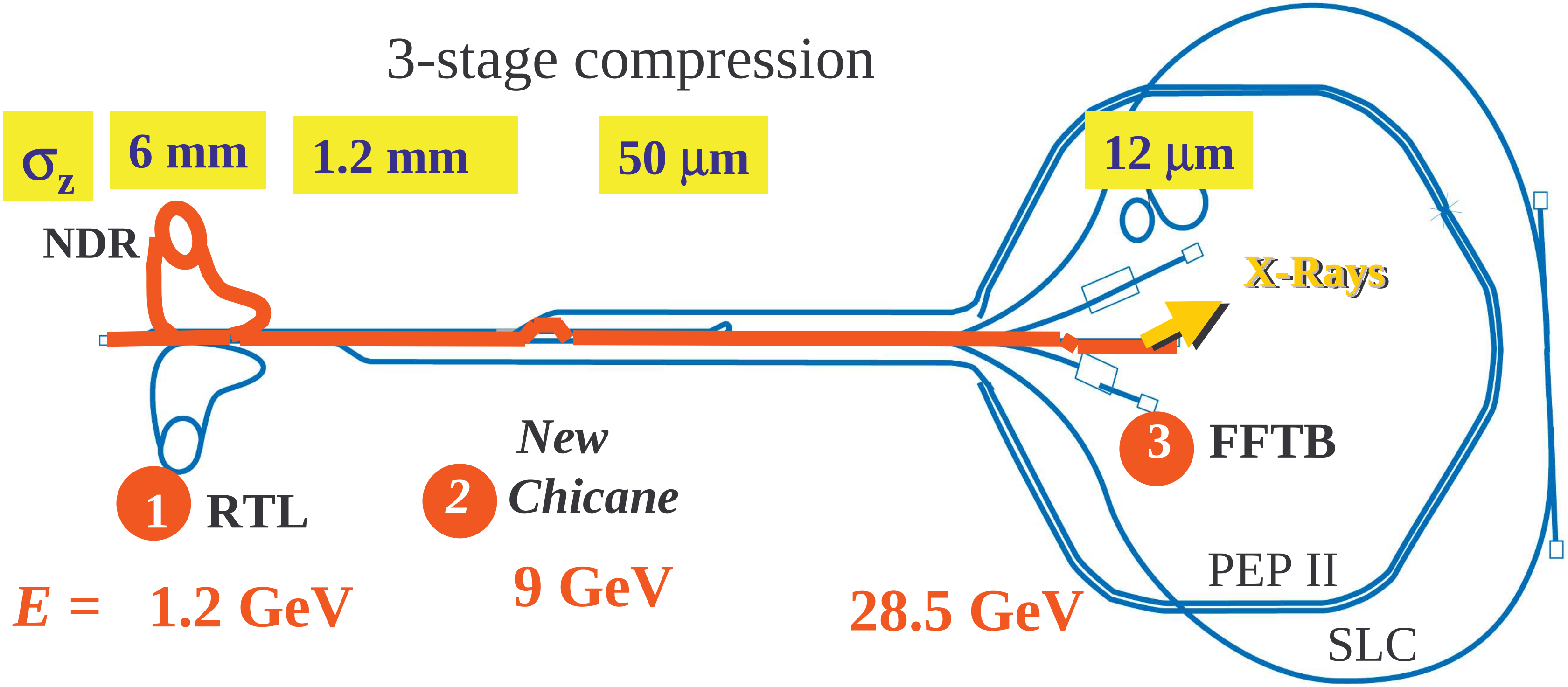
Layout of Bunch Compressor in the SLAC Linac



$2.1\ 10^{10}$ e$^-$/bunch

I_{pk}=30 kA

$\gamma\varepsilon_x$=40 μm

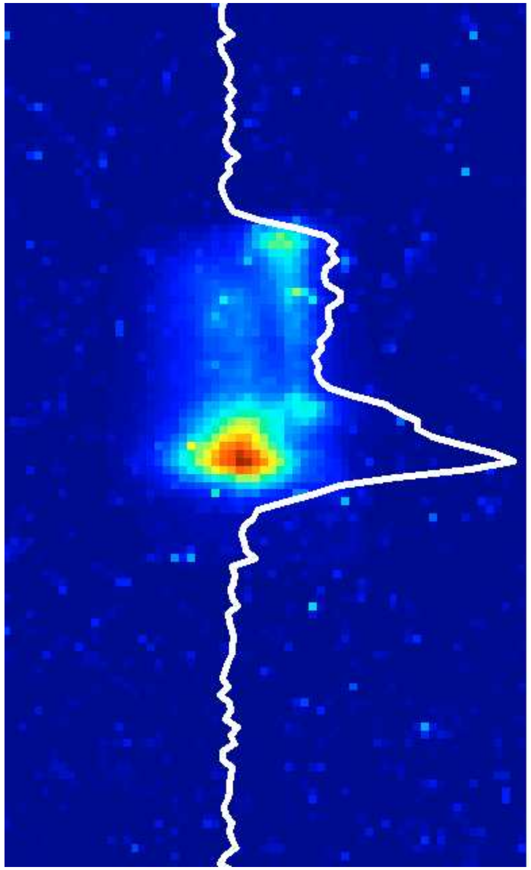
$\gamma\varepsilon_y$= 4 μm

Repetition rate 10 Hz/1 Hz

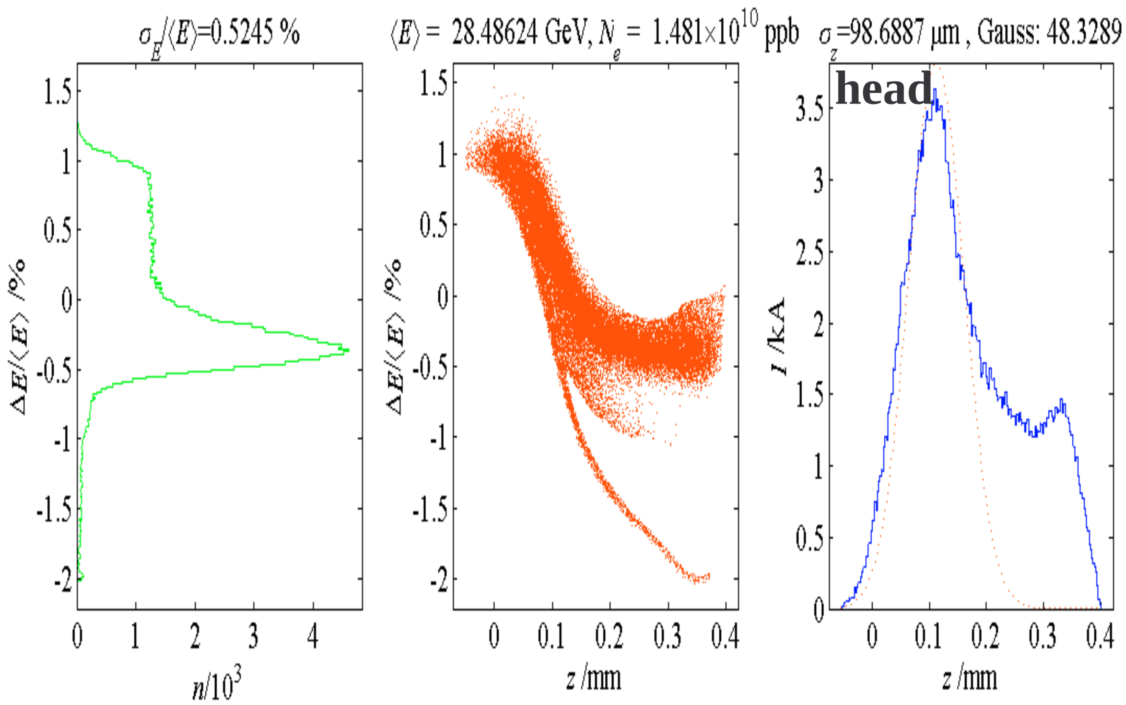
Measurements in FFTB Beam Line

- Wake loss scan had to adapted to FFTB operation
- Opportunity to measure the energy profile more accurate
- Problem: for ultra-short bunches bunch length diagnostics more difficult (even not available)
  $\Rightarrow$ Electro-Optic Sampling experiment in preparation
  $\Rightarrow$ Use THz detector to optimize bunch length

Measured and Predicted Energy Spread of a Compressed Bunch

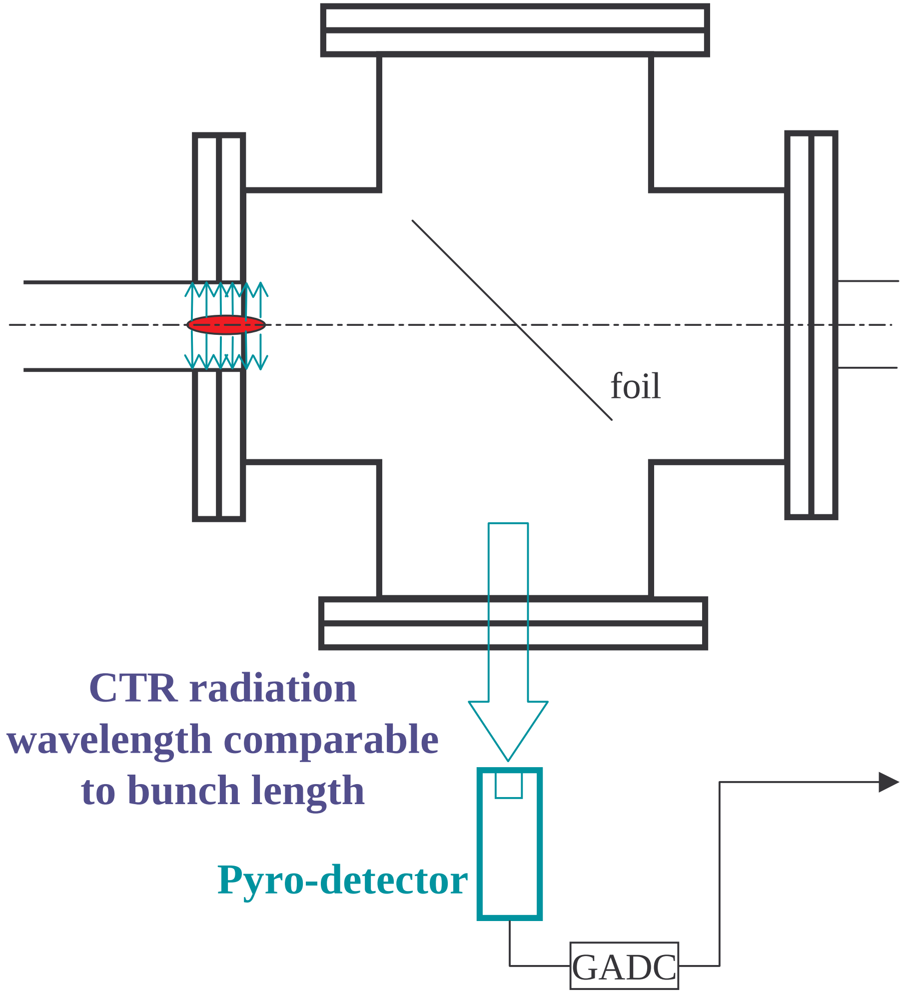


Special setup to give 100 mm bunch length with more charge at the <u>head</u> of the bunch

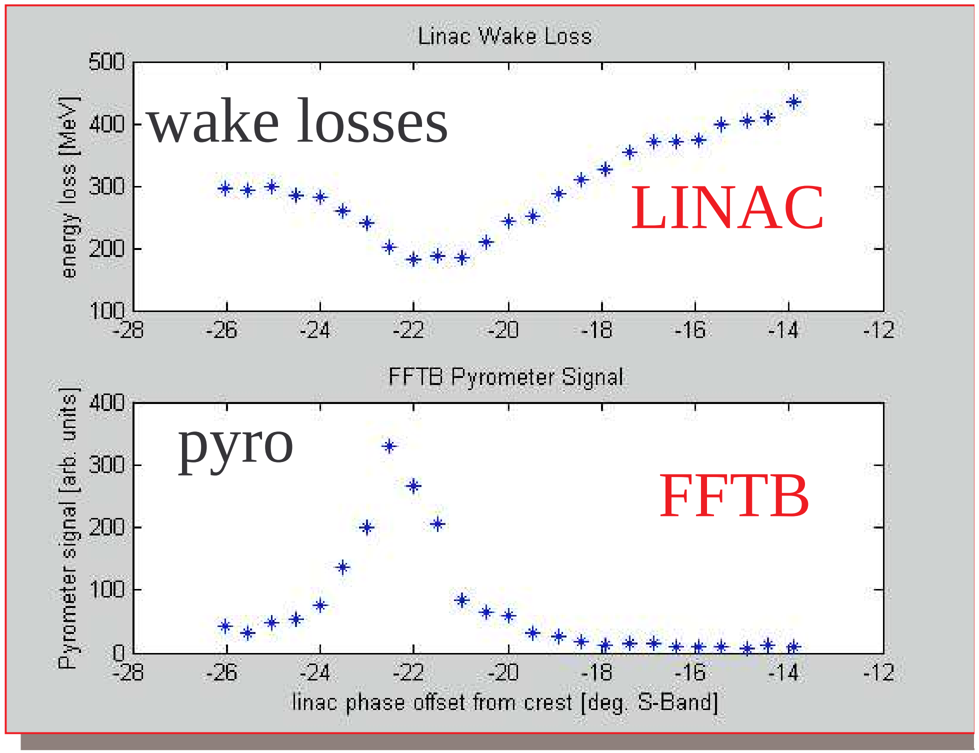


Measured at the end of FFTB
Cherenkov radiator in air gap (airogel)

Detection of Far-Infrared Radiation Emitted at a Foil

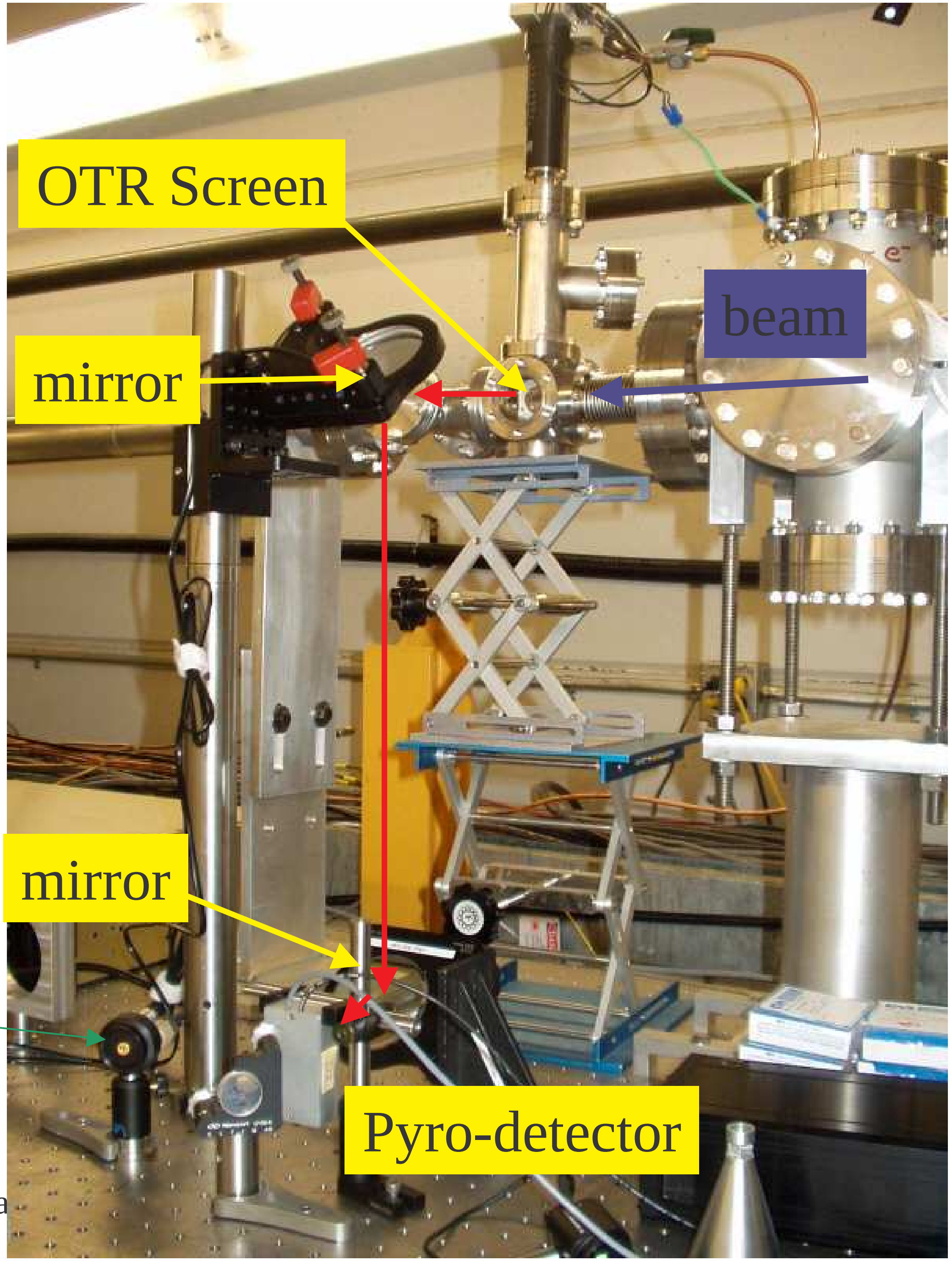


Shortest bunch in FFTB with slight over-compression in linac



THz Detection and OTR Layout

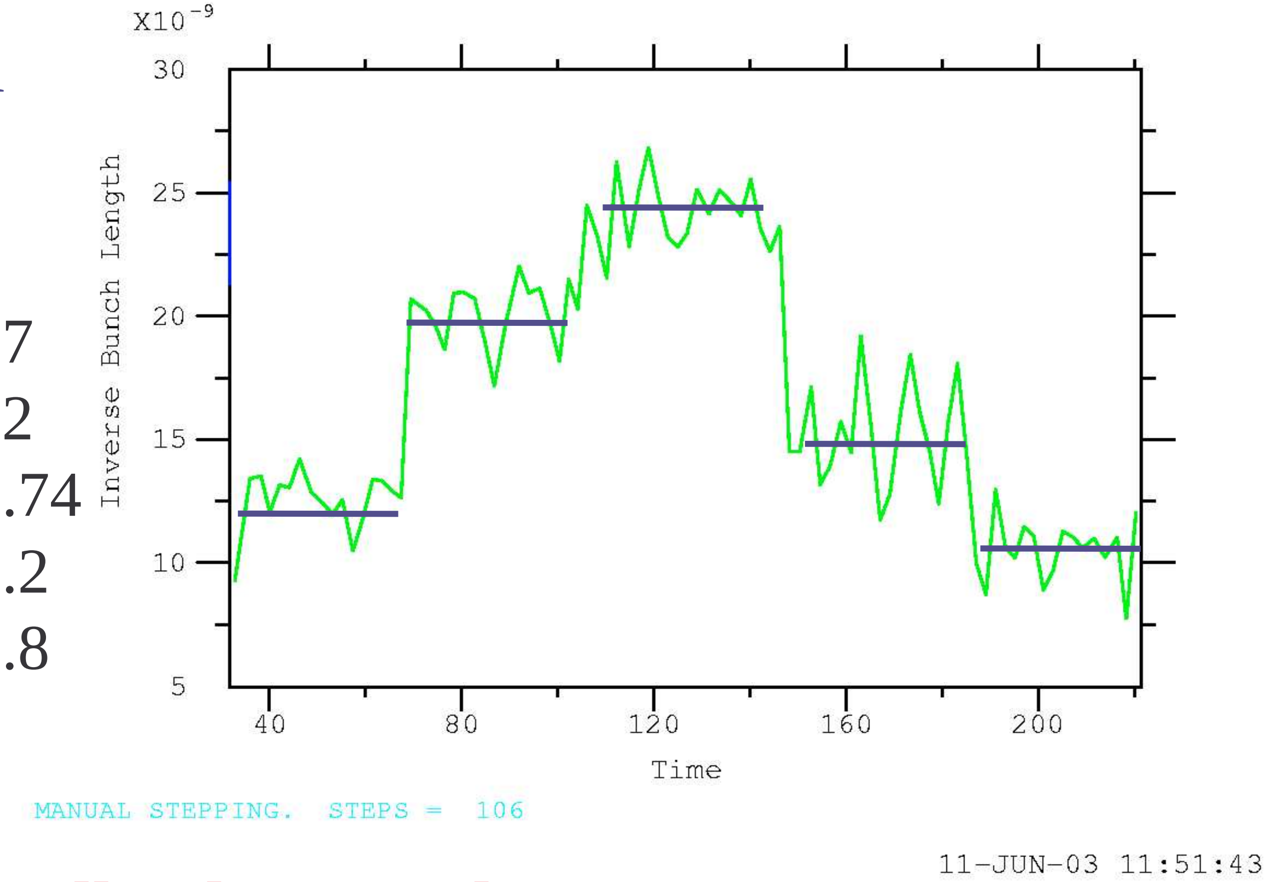
•Also used to adjust timing of EOS experiment



Realtime bunch length optimization

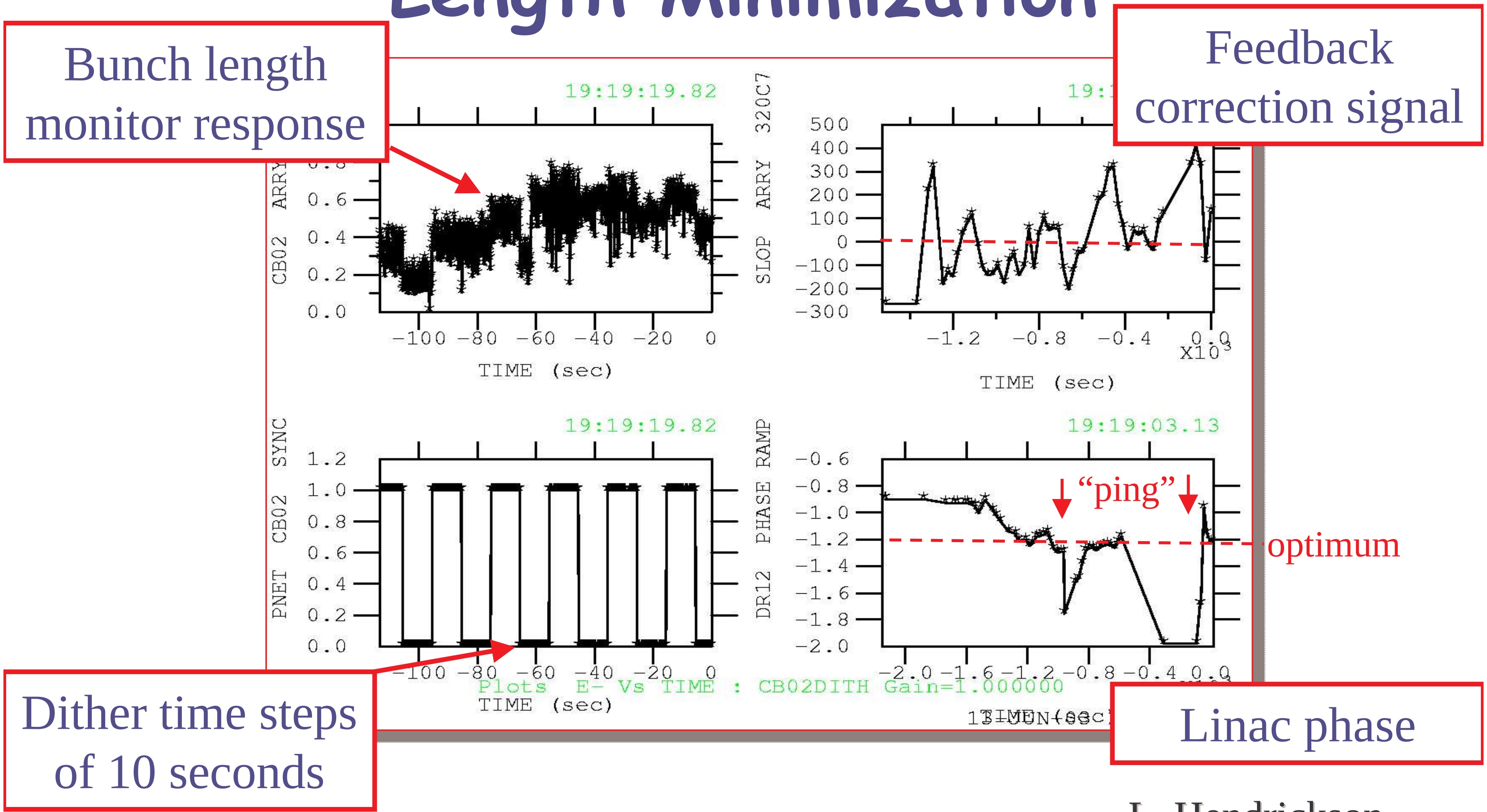
Five step changes in linac phase

t= 30, DR13 Ph 63= -2.7
t= 70, DR13 Ph 63= -2.2
t=100, DR13 Ph 63= -1.74
t=140, DR13 Ph 63= -1.2
t=180, DR13 Ph 63= -0.8



Next, try dither feedback control

Dither Feedback Control of Bunch Length Minimization



L. Hendrickson

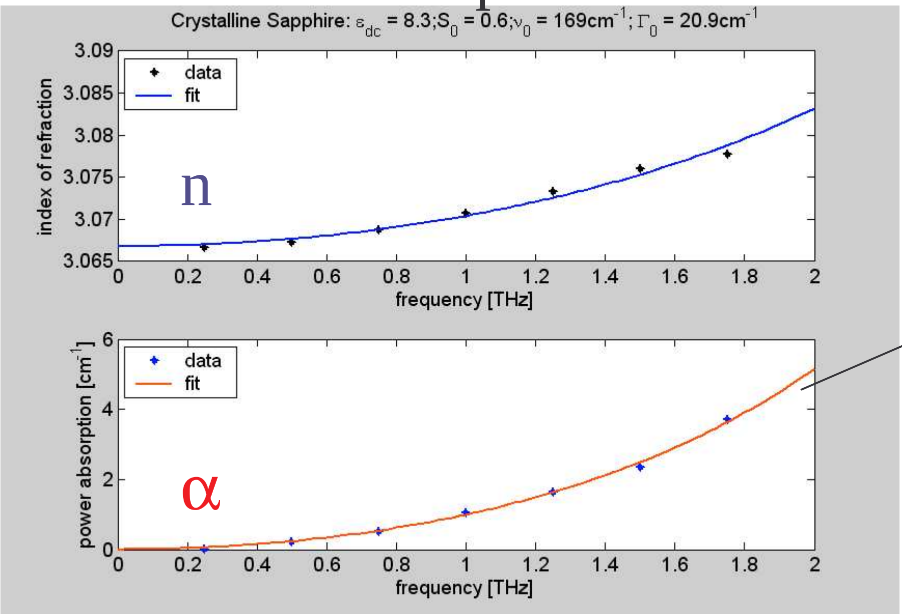
Frequency response of pyro-detector due to apparatus

Complex dielectric function:

$$\epsilon(\overline{\nu}) = \triangle\epsilon + \frac{S_0\overline{\nu}_0^2}{\overline{\nu}_0^2 - \overline{\nu}^2 - i\overline{\nu}\Gamma_0} = \hat{n}^2 = (n + i\kappa)^2$$

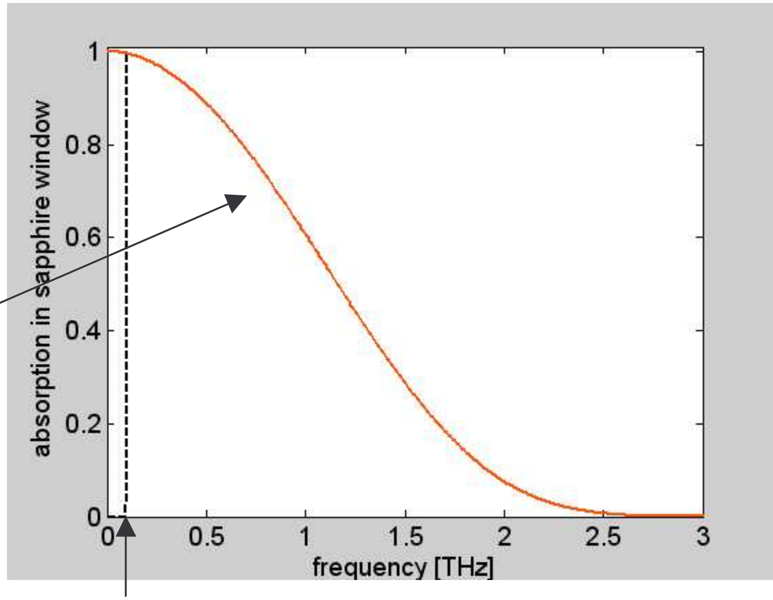
$$\alpha = 4\pi\kappa\overline{\nu} \quad \text{and} \quad \triangle\epsilon = \epsilon_{dc}$$

Fit used for extrapolation



Ref: Grischkowsky et.al. J. Opt. Soc. Am. B/Vol.7, No 10, Oct 1990

Absorption in the sapphire vacuum window: d=5mm

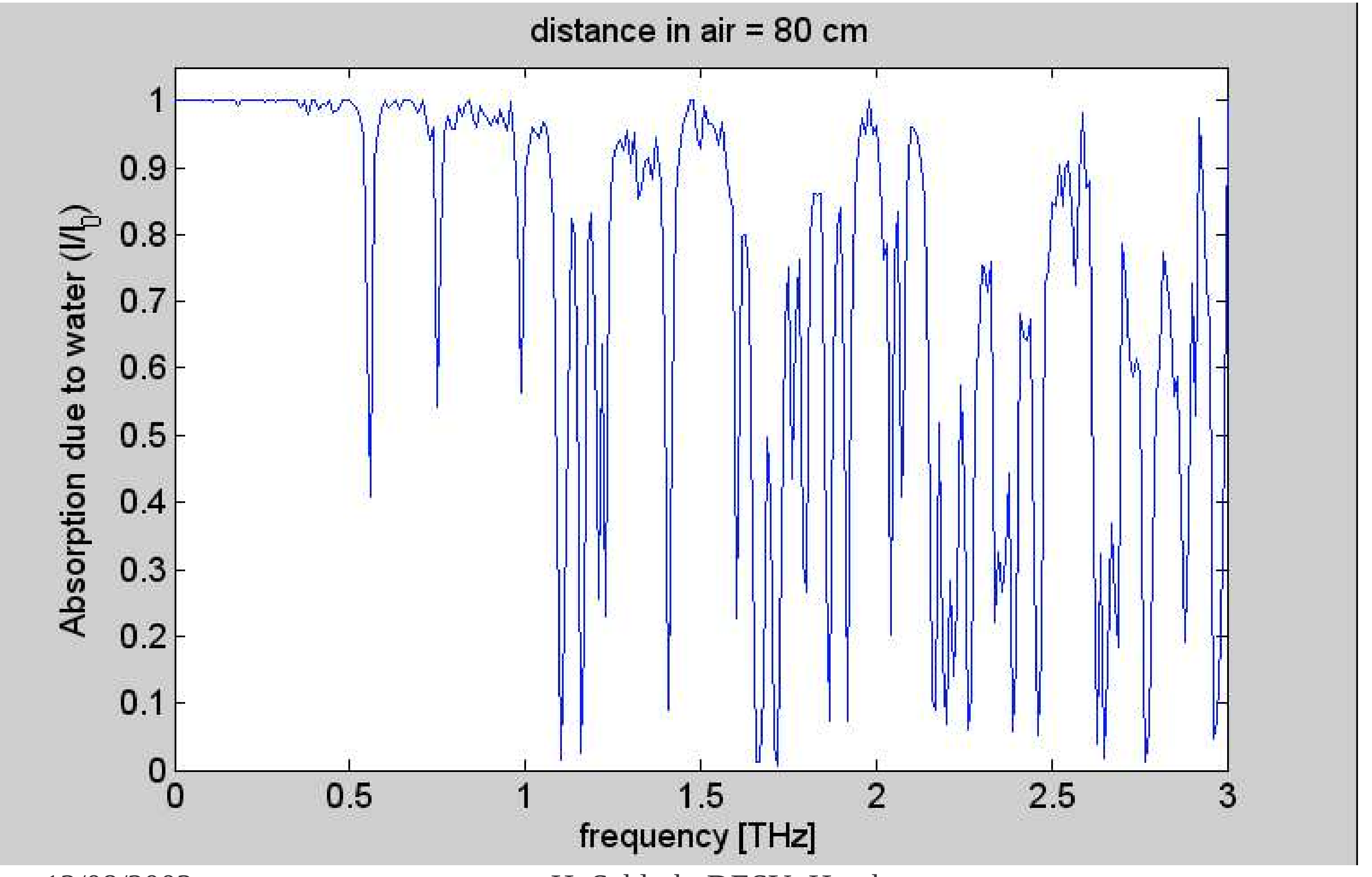


~ 0.1 THz

⇒ nearly no transmission of the CTR above 2.5 THz

Frequency response of pyro-detector due to apparatus

Water absorption after 80 cm FIR transport

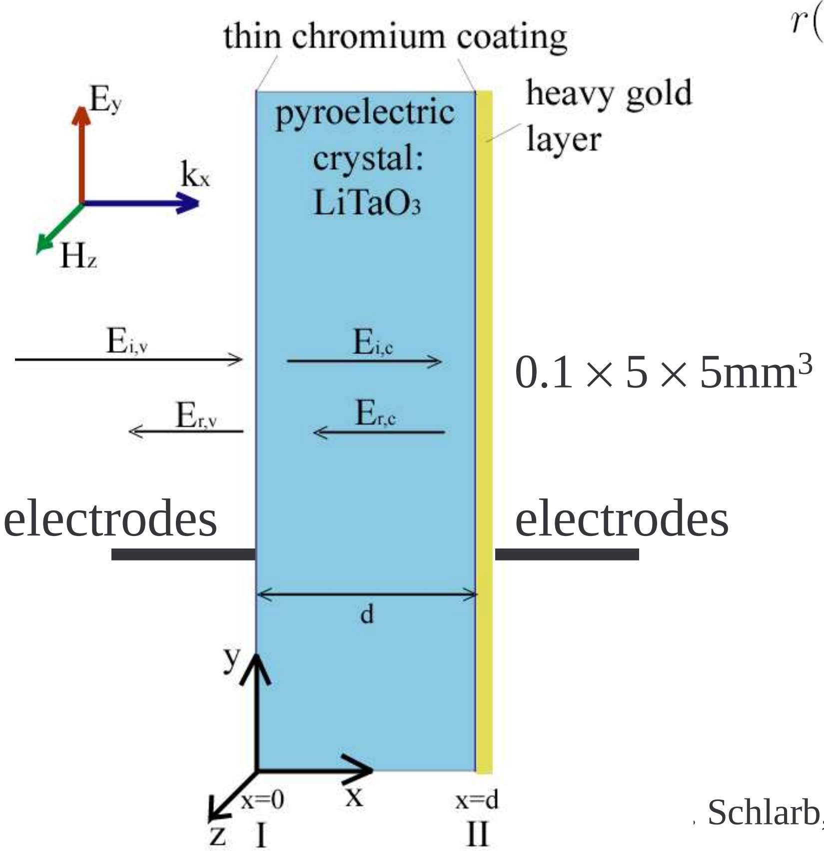


Frequency response of pyro-detector due to apparatus

Pyroelectric-sensor:

- FIR heats $LiTaO_3$ crystal
- Dielectric polarization current

is measured



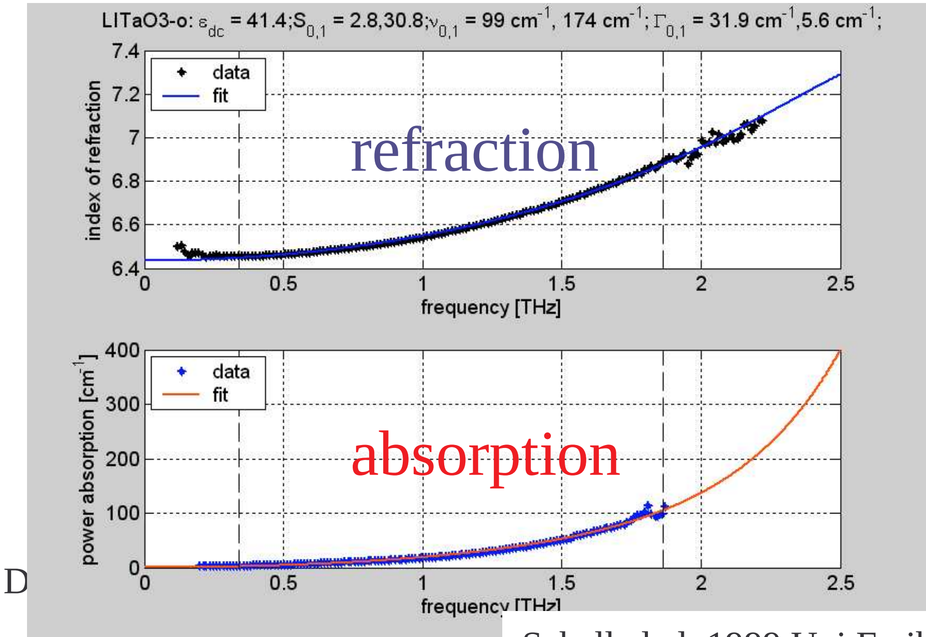
Schlarb, D

Model of detector predict:

$$\frac{P_i - P_r}{P_i} = 1 - R(\omega) = 1 - |r(\omega)|^2$$

$$r(\omega) = \frac{\left(e^{+ik_{x,c}d} - e^{-ik_{x,c}d}\right) - (n + i\kappa)\left(e^{+ik_{x,c}d} + e^{-ik_{x,c}d}\right)}{\left(e^{+ik_{x,c}d} - e^{-ik_{x,c}d}\right) + (n + i\kappa)\left(e^{+ik_{x,c}d} + e^{-ik_{x,c}d}\right)}$$

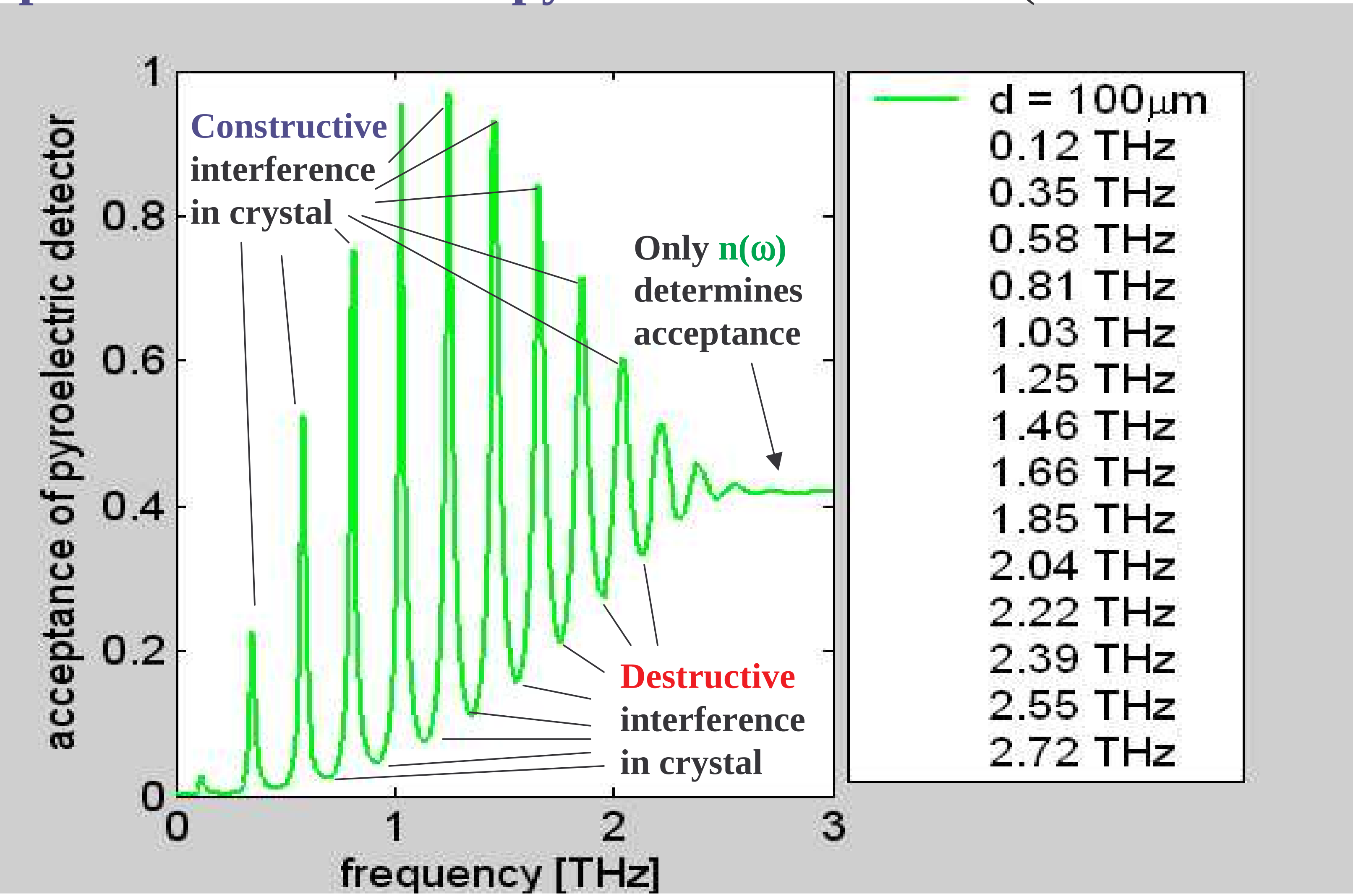
+ material properties of $LiTaO_3$ crystal with two lattice oscillator model fitted



Schall el.al, 1999 Uni Freiburg

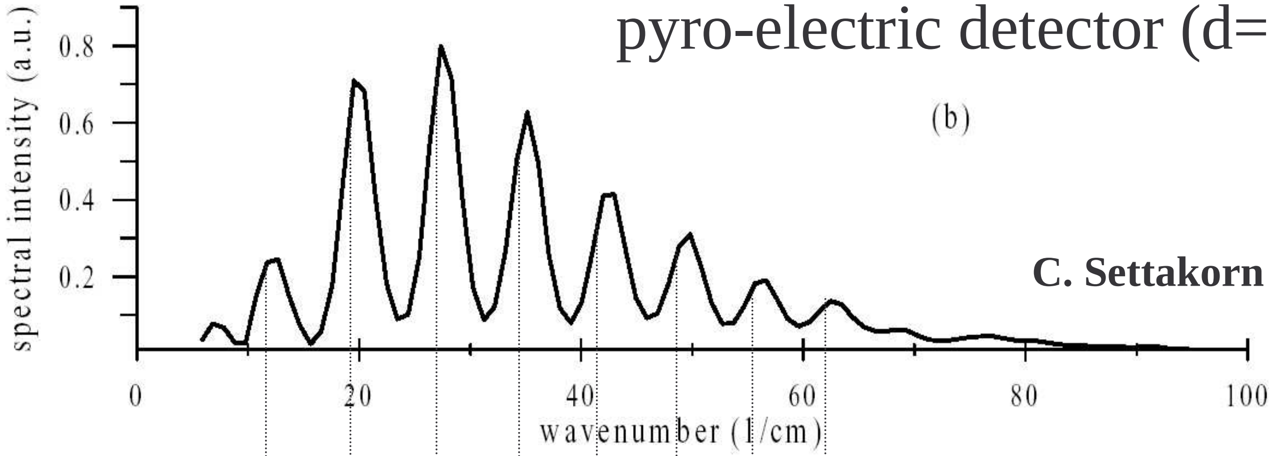
Frequency response of pyro-detector due to apparatus

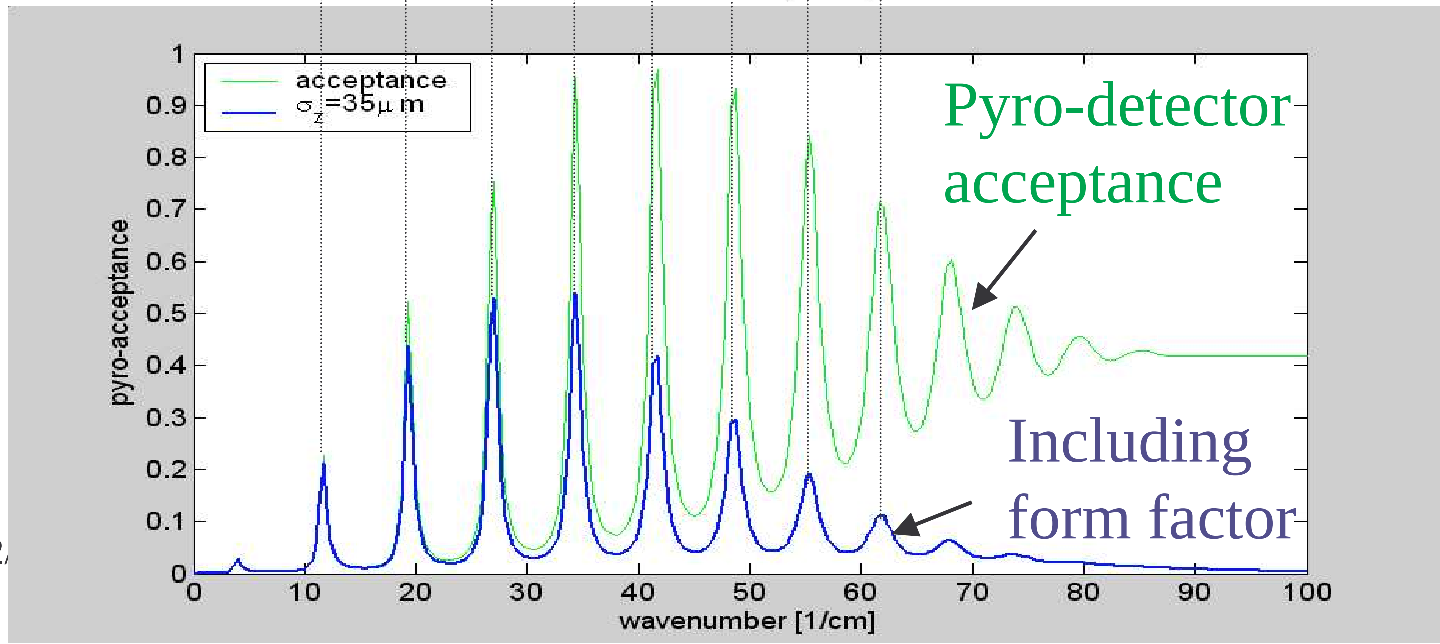
Response function of the pyro-electric detector (P1-45 Molectron)



Frequency response of pyro-detector due to apparatus

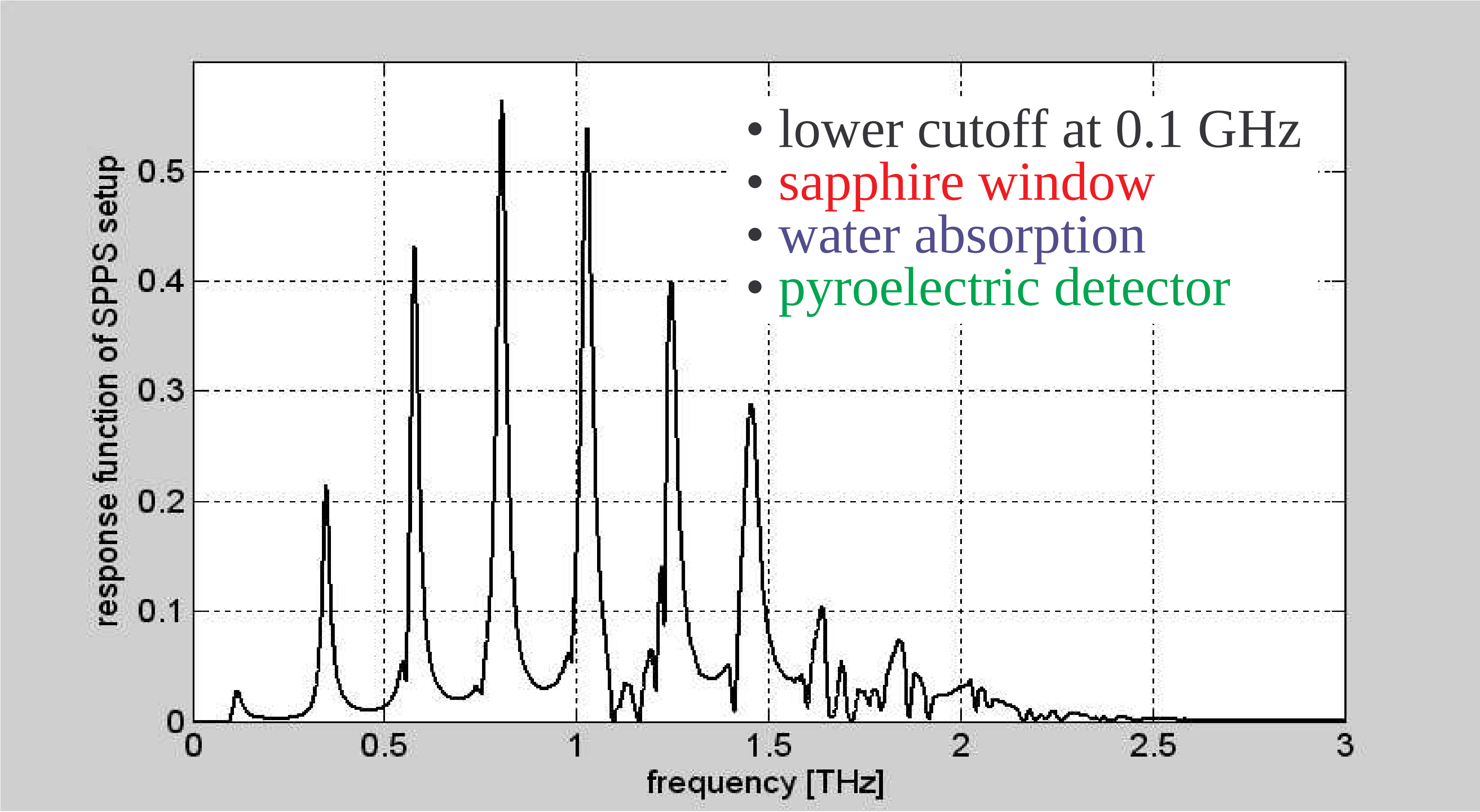
- Spectral density of a bunch with σ_z=35μm measured with pyro-electric detector (d=100 μm)



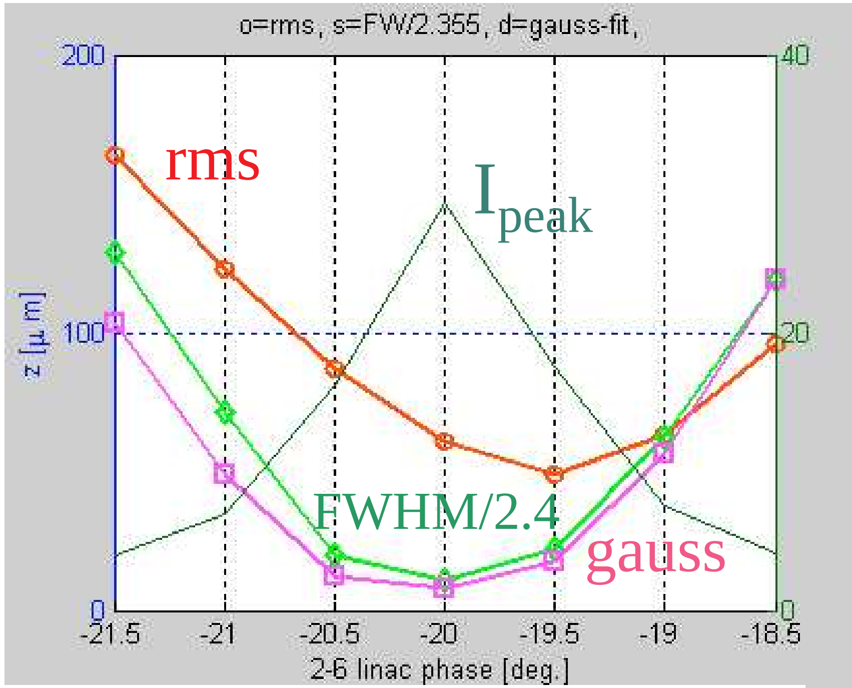


Frequency Response of Pyro-Detector due to Apparatus

Expected frequency response function for the SPPS-FFTB setup:



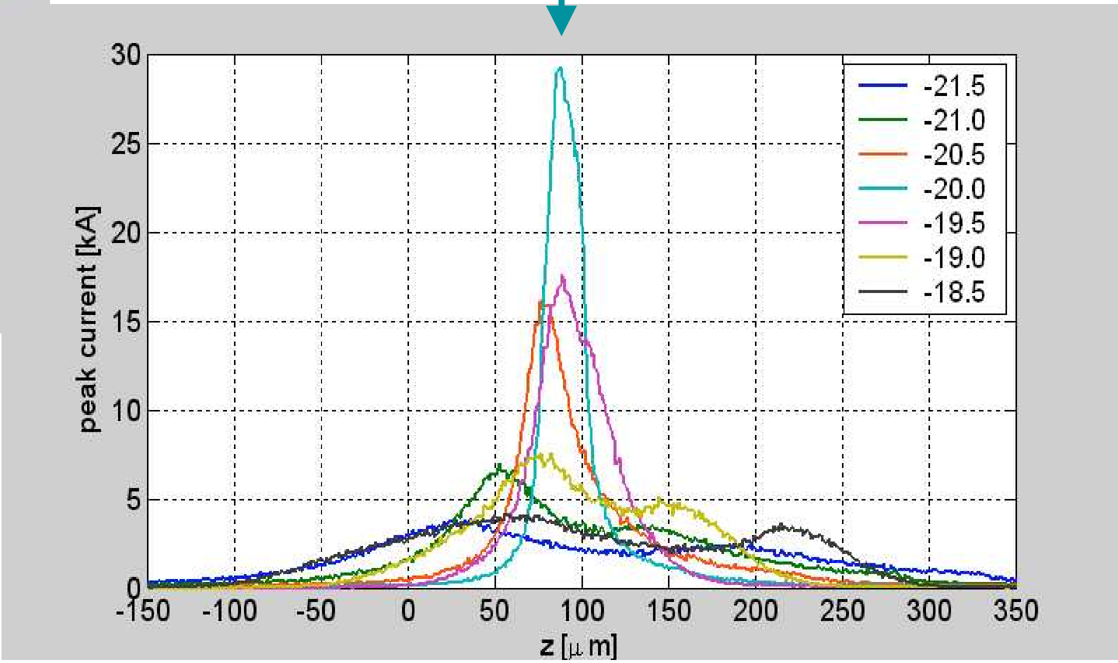
Simulation of longitudinal beam profile - FFTB -



Q = 3.5 nC

Compr. Ampl. = 42 MV/m

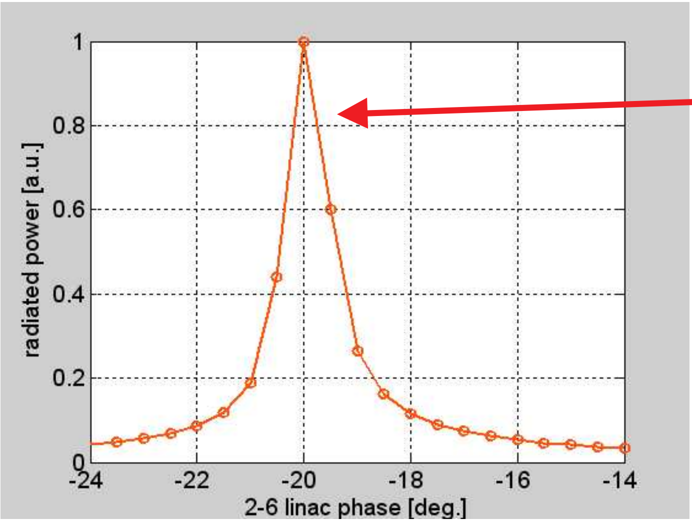
⇒ 2-6 linac phase = -20°

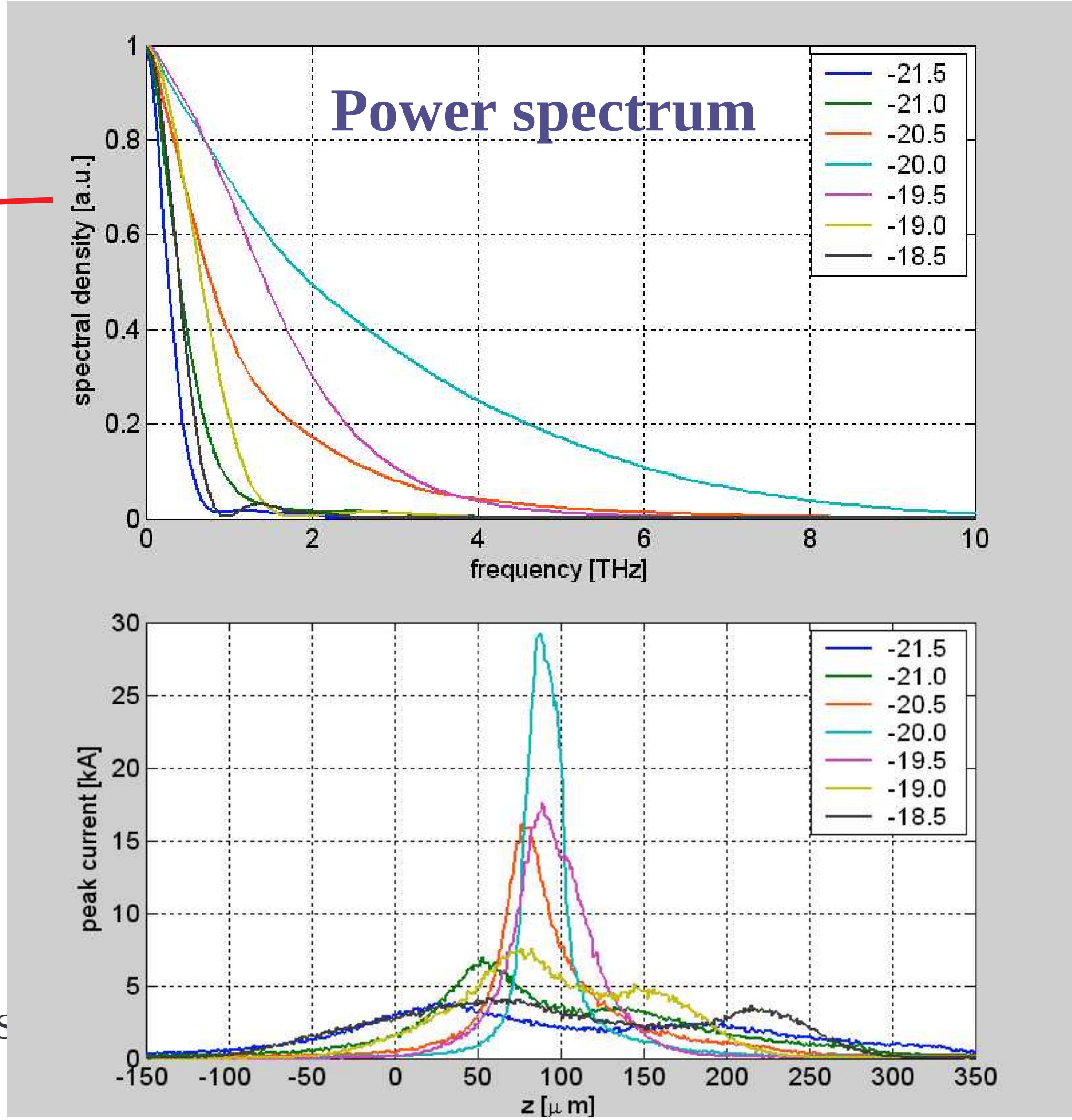


Very demanding phase tolerances

Simulation of longitudinal beam profile - FFTB -

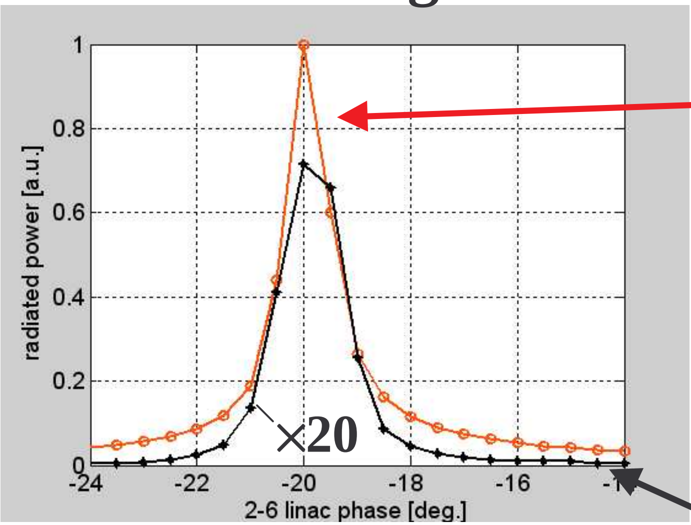
Total radiated energy

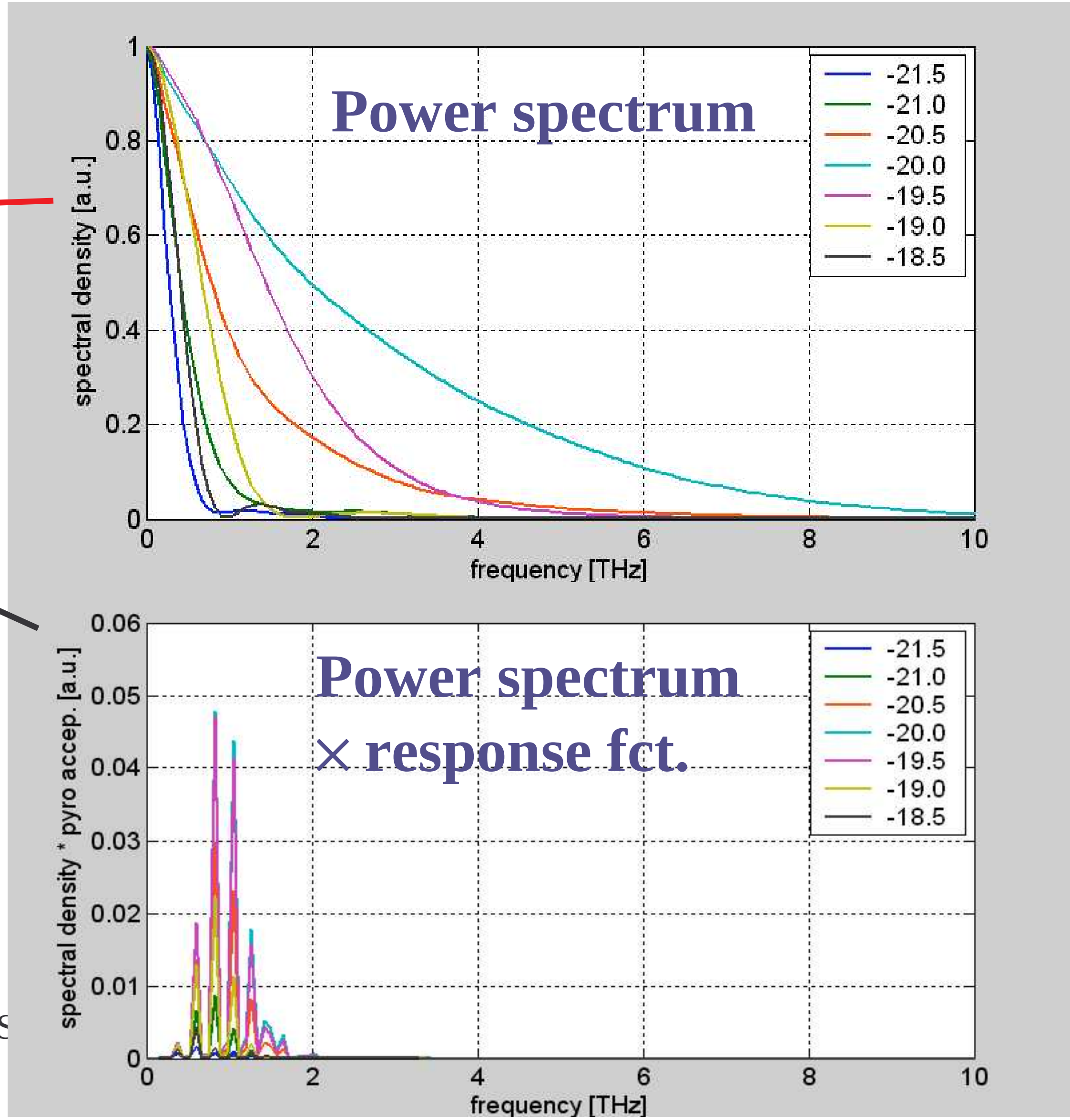




Simulation of longitudinal beam profile - FFTB -

Total radiated energy & detected signal





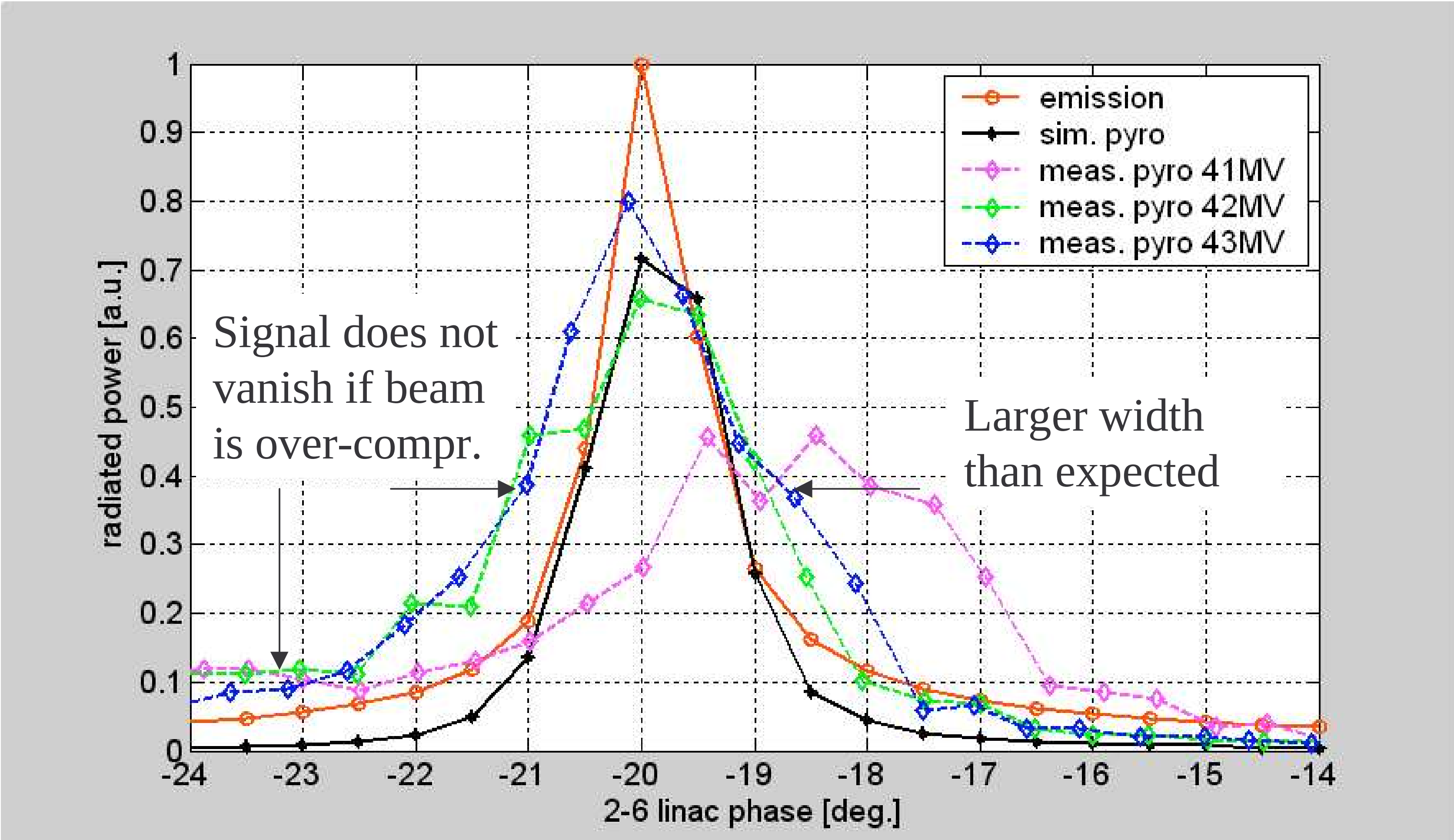
⇒ pyro-detector predicts within 0.5 deg the phase with maximum I_{peak}

low freq. cut -> narrows

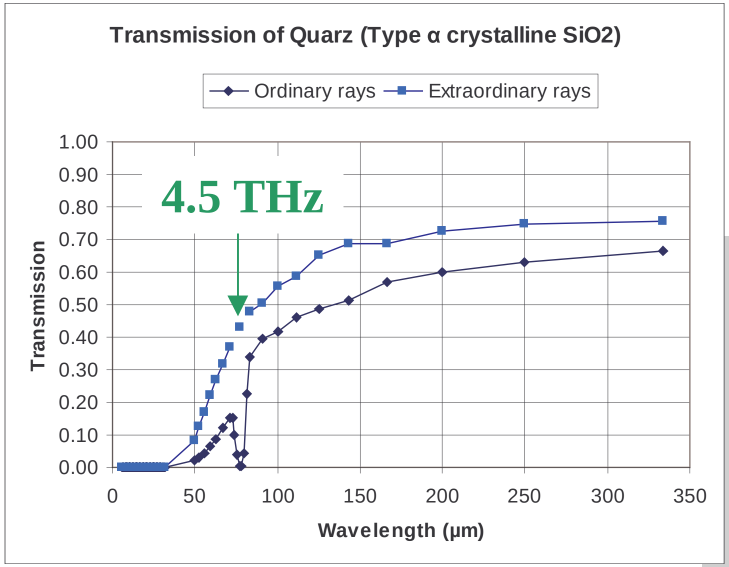
high freq. cut -> widen

Simulation of longitudinal beam profile - FFTB -

Simulation and measured pyroelectric signal

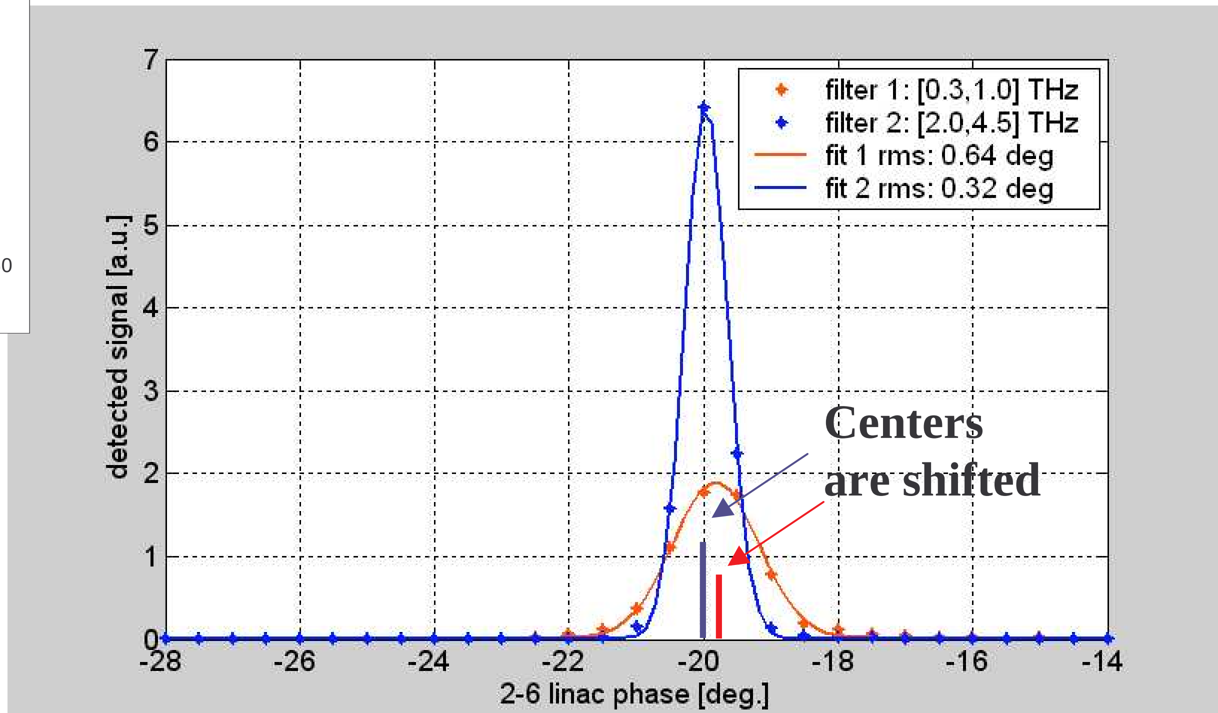


Improved version of a compression monitor



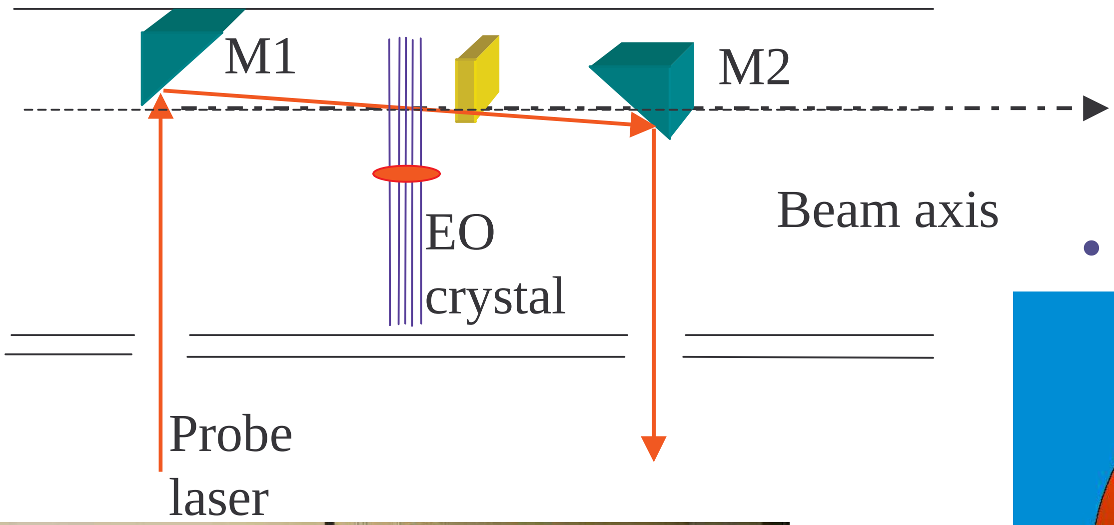
Transmission through crystalline quartz

- try air or nitrogen atmosphere
- z-cut quartz window (2 mm thickness)
- band pass filters i.e. grids, windows

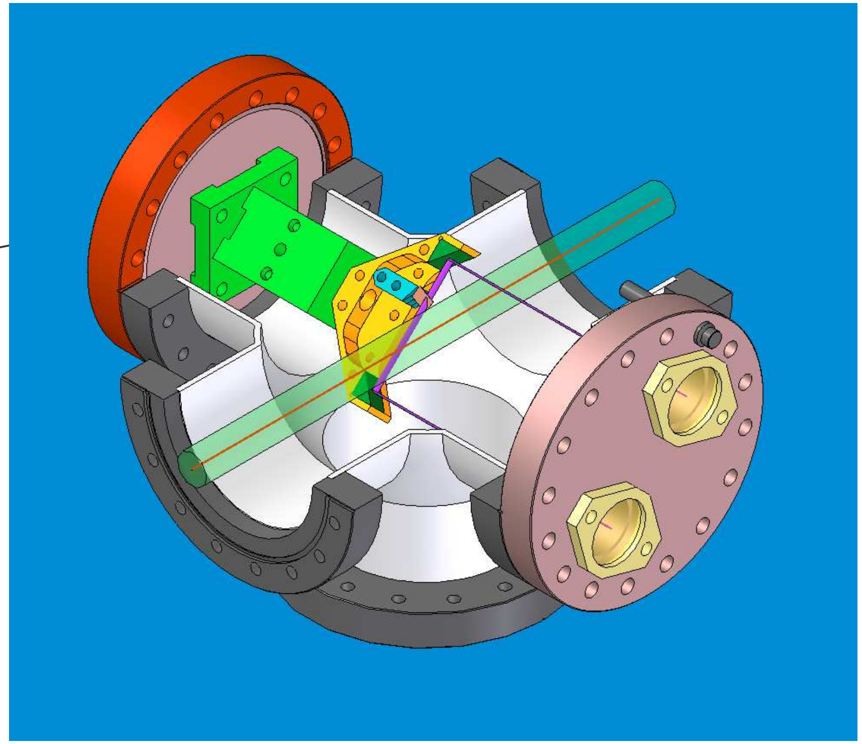


Electro Optic Bunch Length Measurement

- *Pockels effect: E_r of e^--bunch rotates laser polarization*



- EO vacuum chamber



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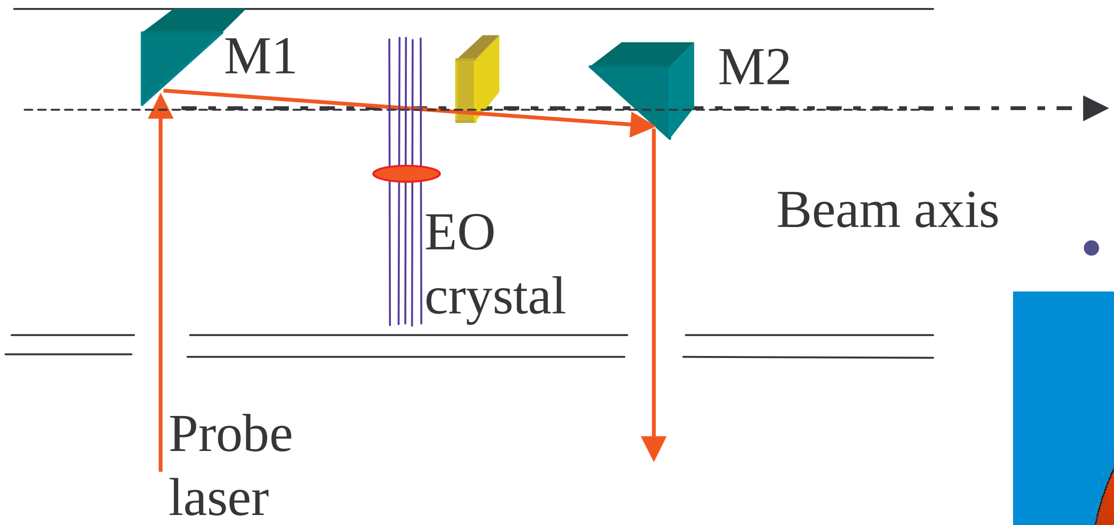
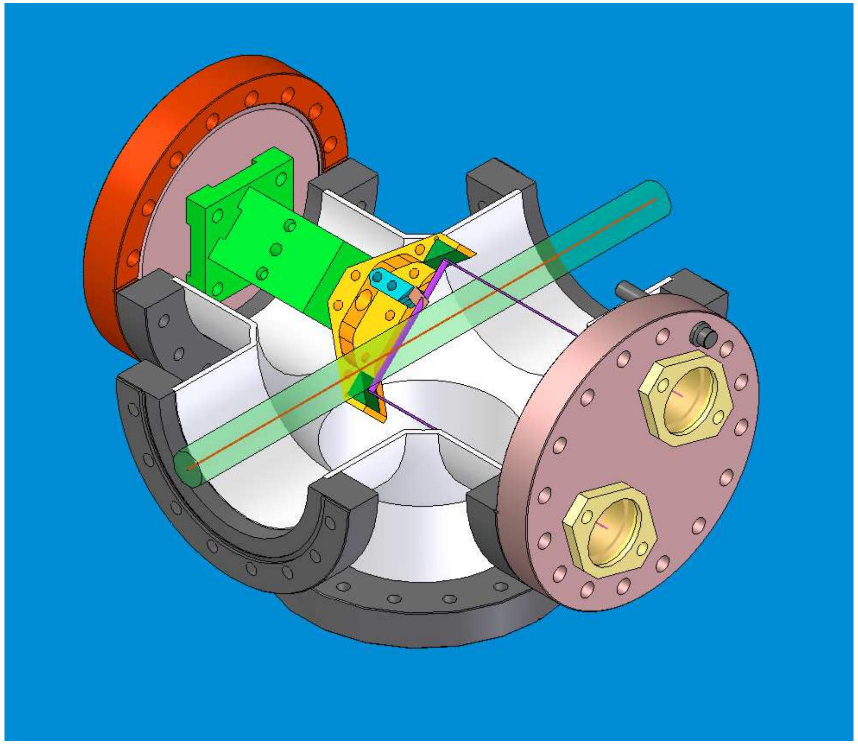


- EO vacuum chamber



Laser beam incidence with an angle

⇒ spatial-time correlation

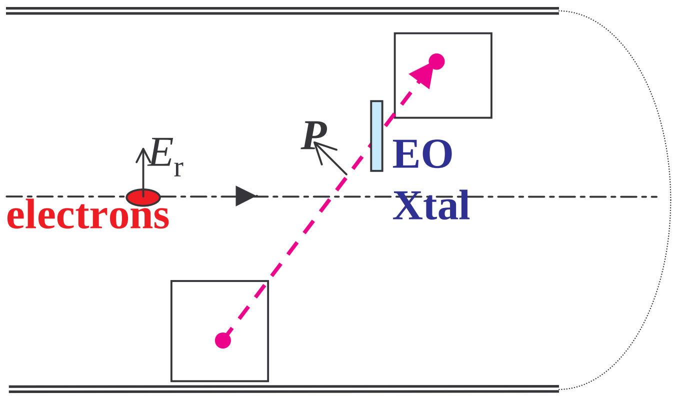
⇒ small fraction of laser is modulated

⇒ readout with line camera

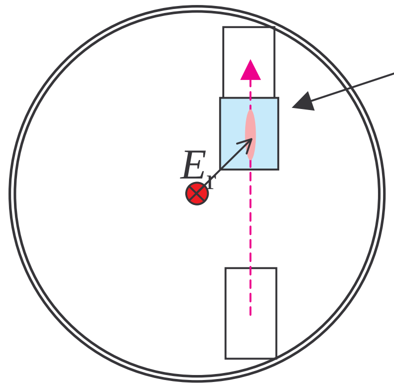
expected resolution < 100 fs

(limited by laser pulse duration)

Spatial-temporal correlation for EO



Elevation view



End view

Original planed to use Kerr effect (in glass 100 µm)

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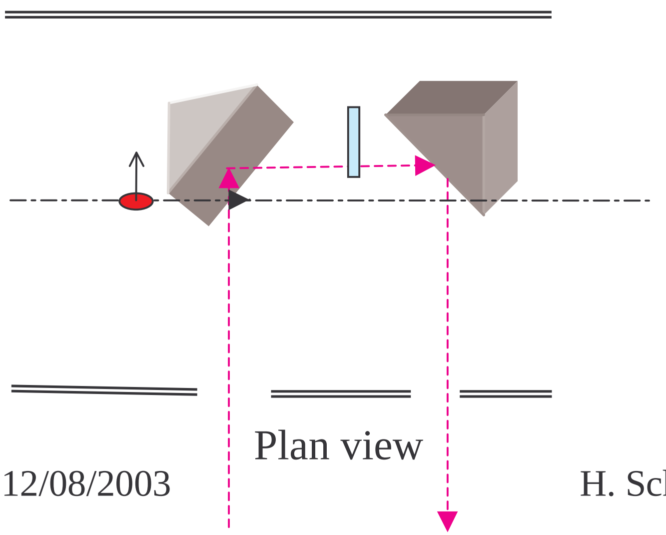
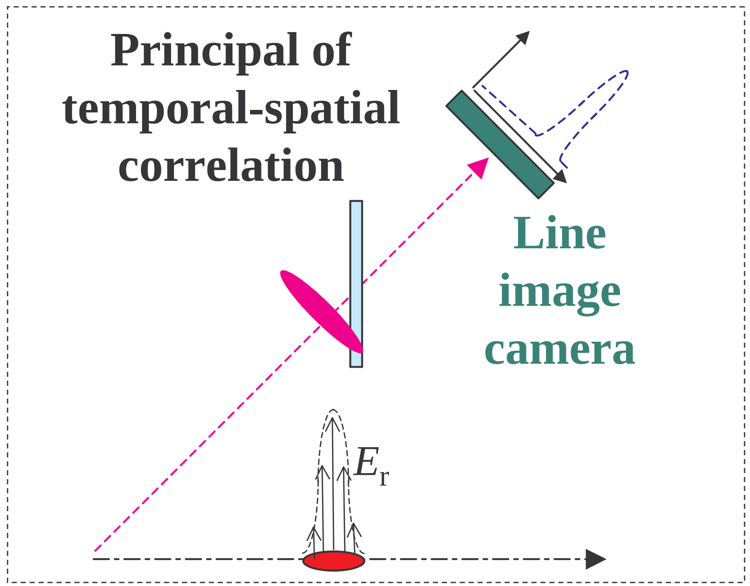
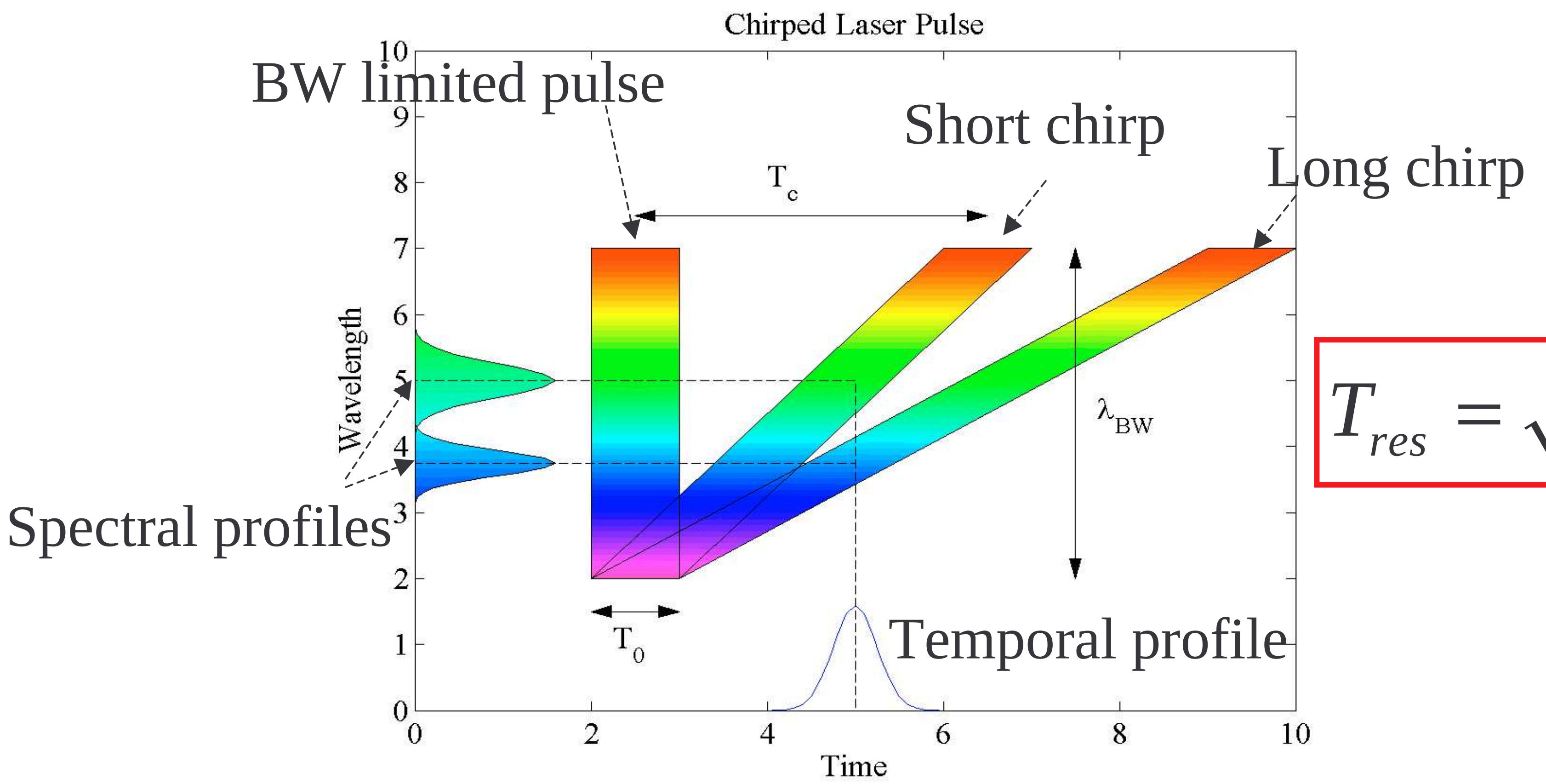
later GaAs



Plan view

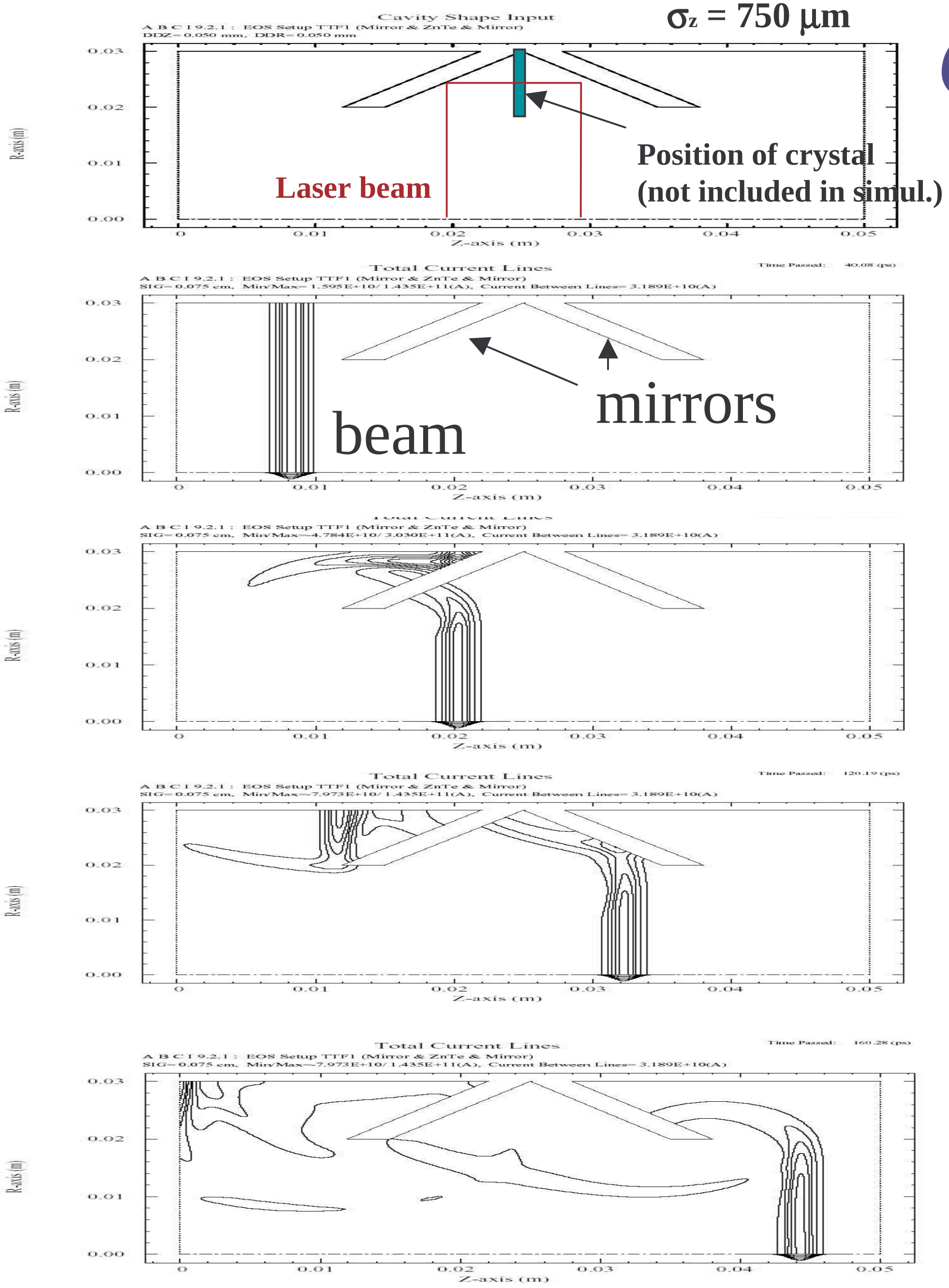


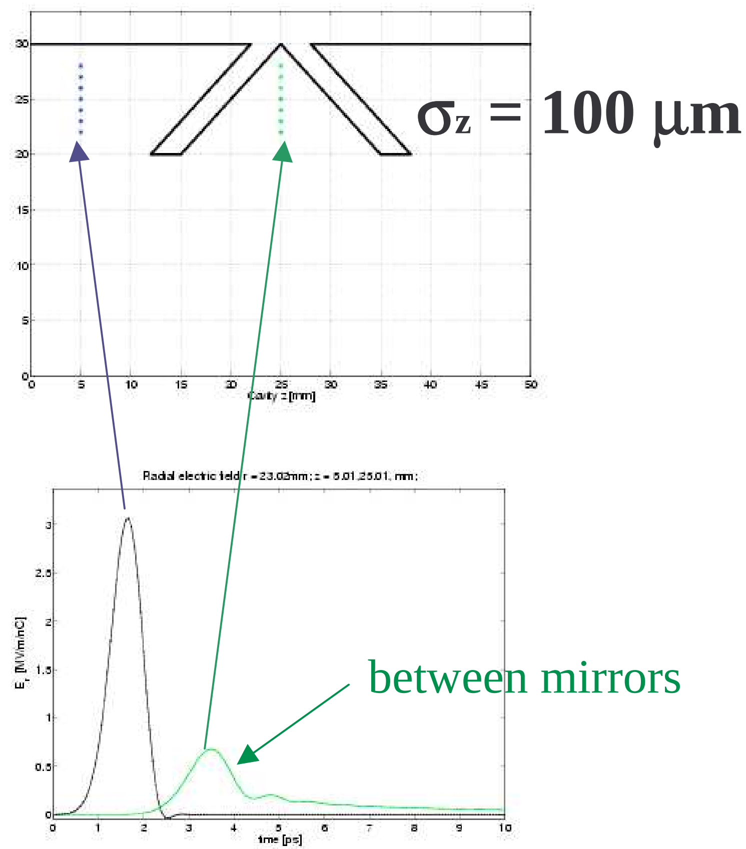
Spectral-temporal correlation for EO



$$T_{res} = \sqrt{T_0 T_C}$$

Optimization of EO vacuum chamber

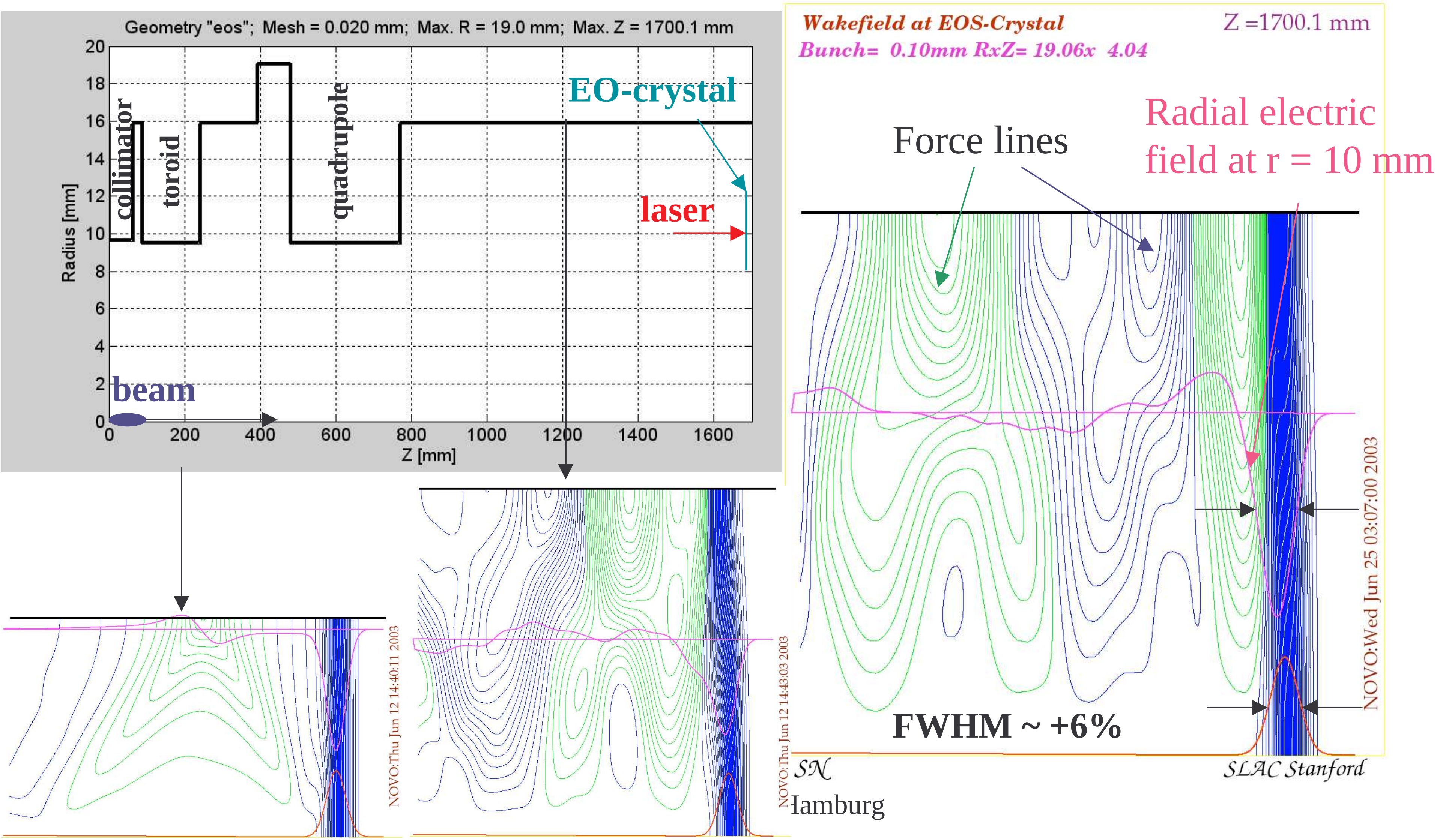




Does not work
=> mirror 45° rotated

Hamburg

Electric field distortion caused by wake fields



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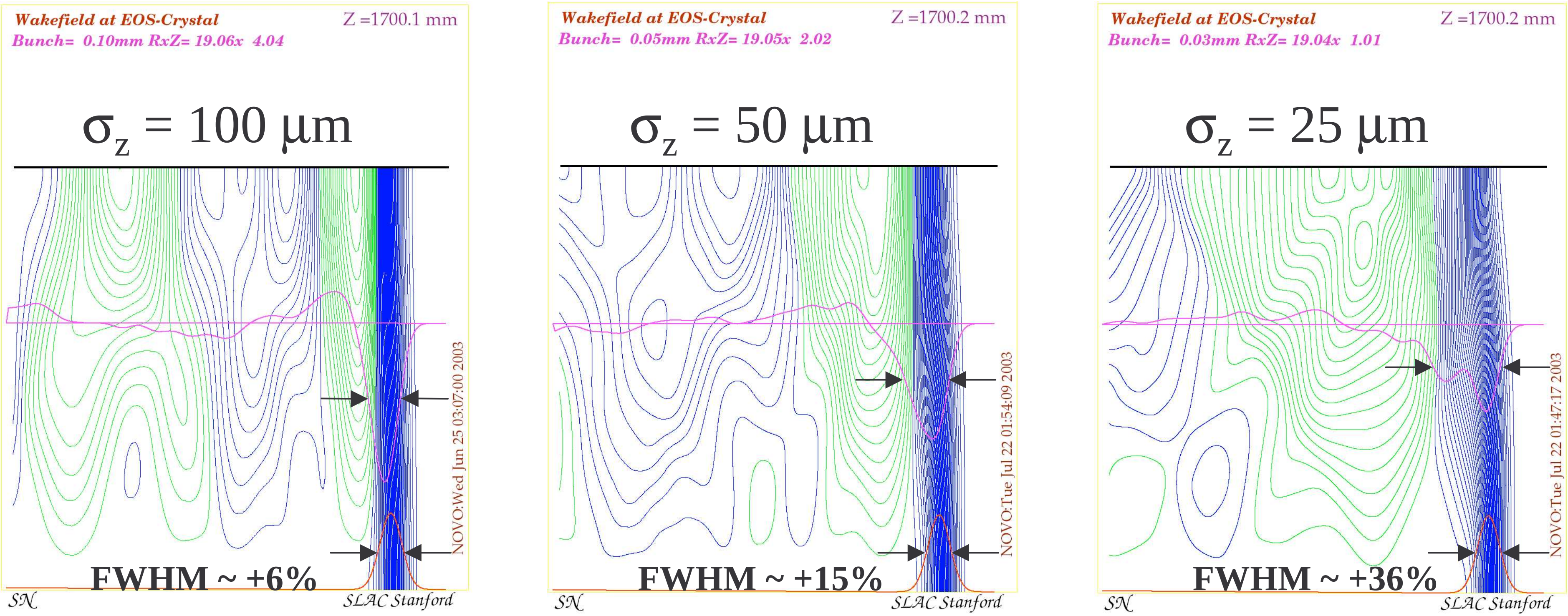
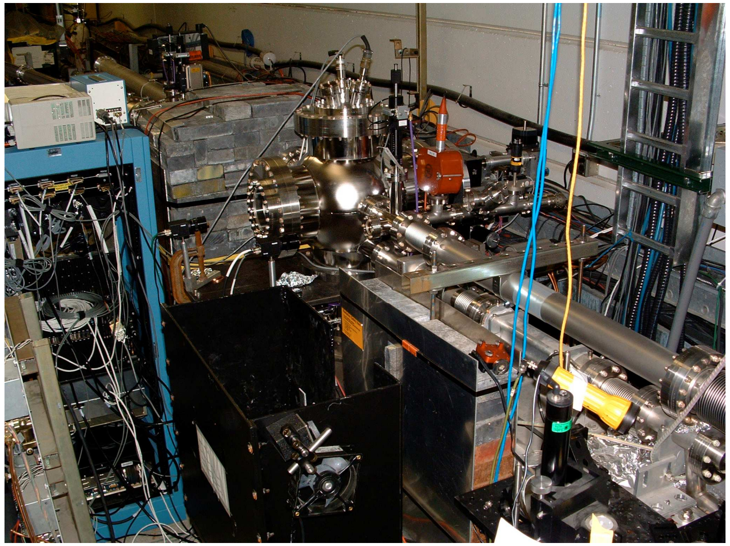
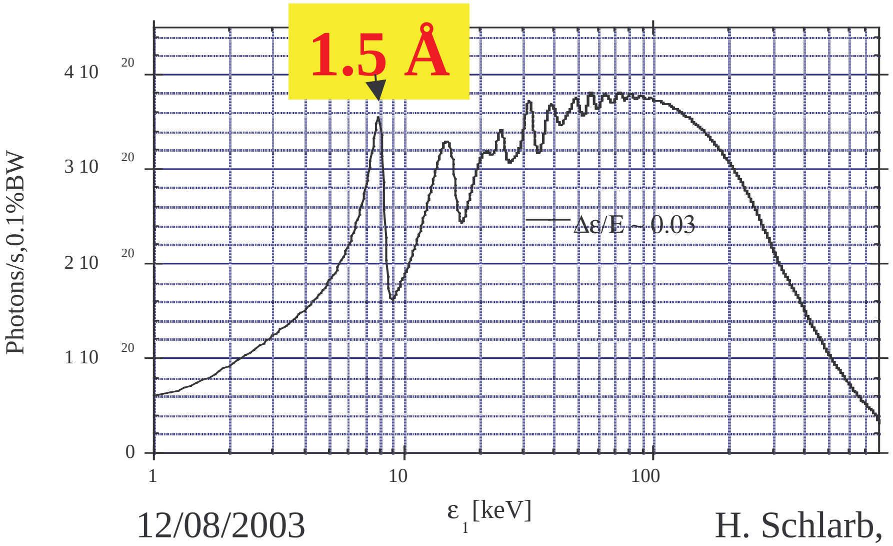


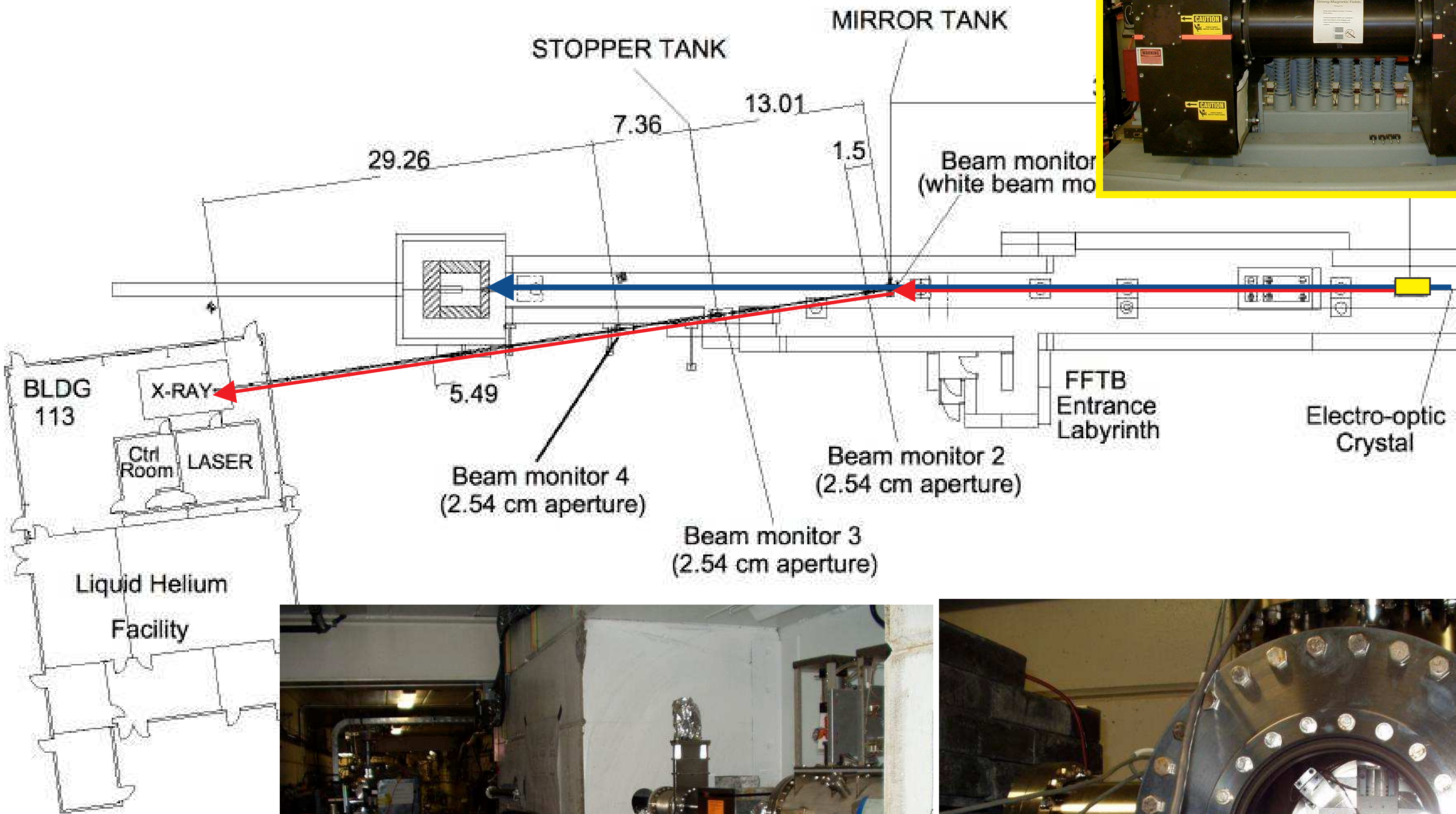
SPPS Undulator

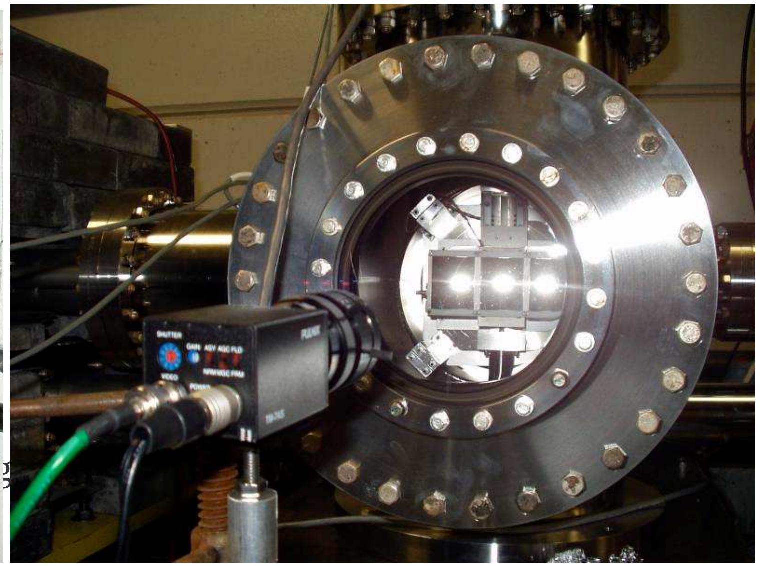




Former APS wiggler

X-ray beam line





SPPS x-ray properties

	Calculated	Measured	
Pulse length	80 fs	<< 1 ps	FWHM
Peak Brightness	$2x10^{24}$	-	Photons/s/mm^2/mrad^2/0.1%BW
Photons/pulse	10^7	$2\ x10^7$	
Source size	160 x 350	-	µm FWHM
Divergence	15 x 16	-	µrad FWHM (undulator fundamental)
Beam size in hutch (95 m)	1.5 x 1.6	~ 2 x 2	mm FWHM
Repetition rate	10	10	Hz
Average flux	10^8	$2\ x10^8$	Photons/s

Summary

- No major difficulties during commissioning LLBC and FFTB beam line
- SPPS operation is compatible with PEP II operation
- X-ray beam line has been commissioned successfully, experiment have started already
- Deflecting cavity operation has been improved and extended toward measurements in the 50 um range
- Energy loss due to wake fields in good agreement to theory for design setting, but disagree for other machine operation (not yet understood)
- Method to optimize bunch length in Linac and the FFTB have been established