Longitudinal bunch profile studies using infrared spectroscopy techniques

Hossein Delsim-Hashemi

….for the CRD team

…….. before I begin

Transition radiation of an electron bunch is described based on :

TESLA report 2005-15, B. Schmidt et al.

Details on pyro-electric detectors including the sensor design and the electronics are not covered in this talk. Please have a look to the CRD web-page for the relevant papers by B. Schmidt et al. (http://tesla.desy.de/fla/crd/crd.html)

Experimental results shown in this talk cover measurements which were carried out before the FLASH shut down (March 2007), therefore are quite old! For more recent results see talks given by O. Grimm, C. Behrens, B. Schmidt (on **2007-12-11** as FLASH talks) and wait for up-coming talks by CRD folks.

I have to give a review on the old works that are presented as FLASH talks or elsewhere.

Coherent Radiation

$$F_{long}(\omega) = \int_{bunch} \tilde{\rho}(t) \exp(-i\omega t) dt$$

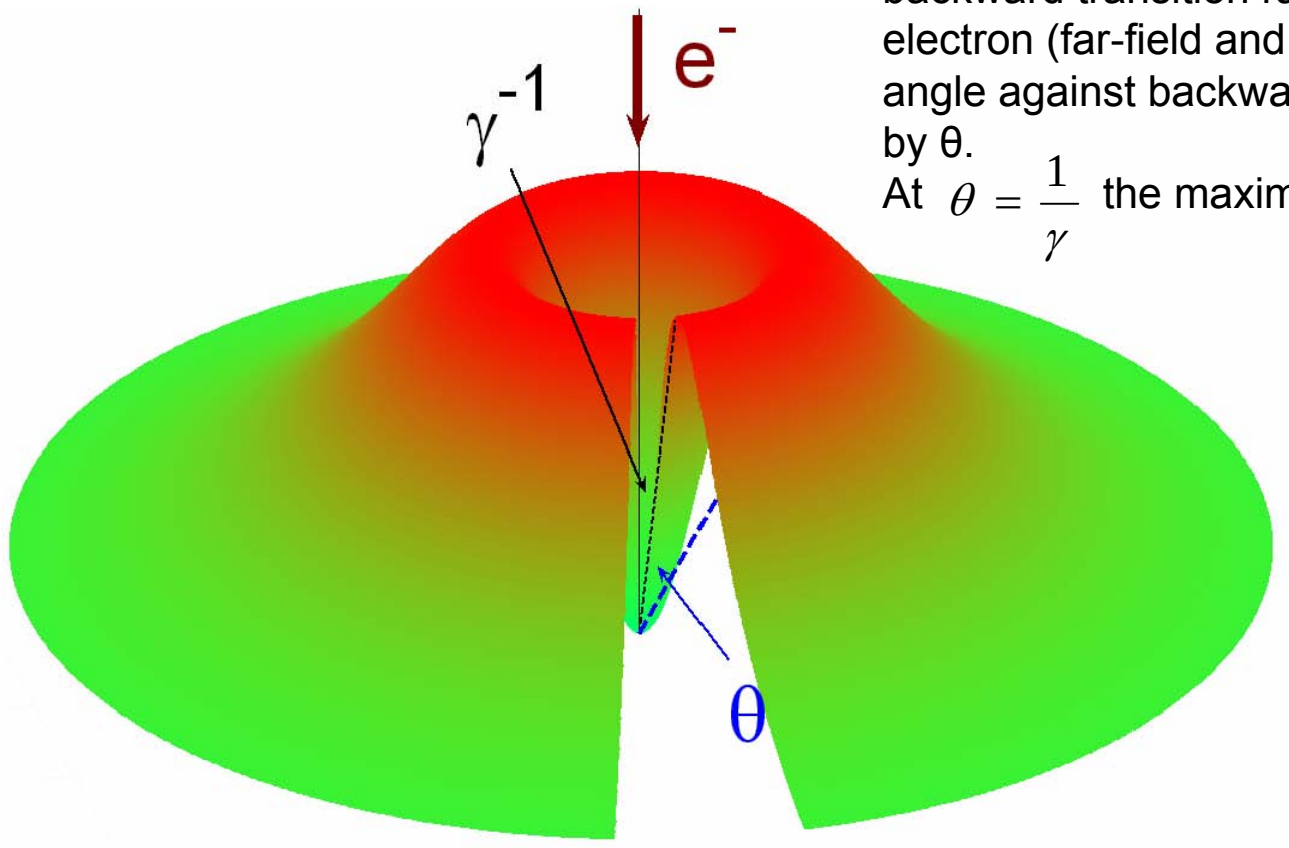
normalized line-charge density

$$\frac{dU_N}{d\omega} = N^2 \left| F_{long}(\omega) \right|^2 \frac{dU_1}{d\omega}(\omega, \gamma, source)$$

spectral energy density *(only coherent term)*

Transition Radiation

$$\frac{d^2U_{GF}}{d\omega d\Omega} = \frac{e^2}{4\pi^3\epsilon_0 c}\frac{\beta^2\sin^2\theta}{(1-\beta^2\cos^2\theta)^2}$$



Ginzburg-Frank spatial distribution for the backward transition radiation by a single electron (far-field and infinite screen). The angle against backward direction is shown by θ.

At $\theta = \frac{1}{\gamma}$ the maximum intensity appears.

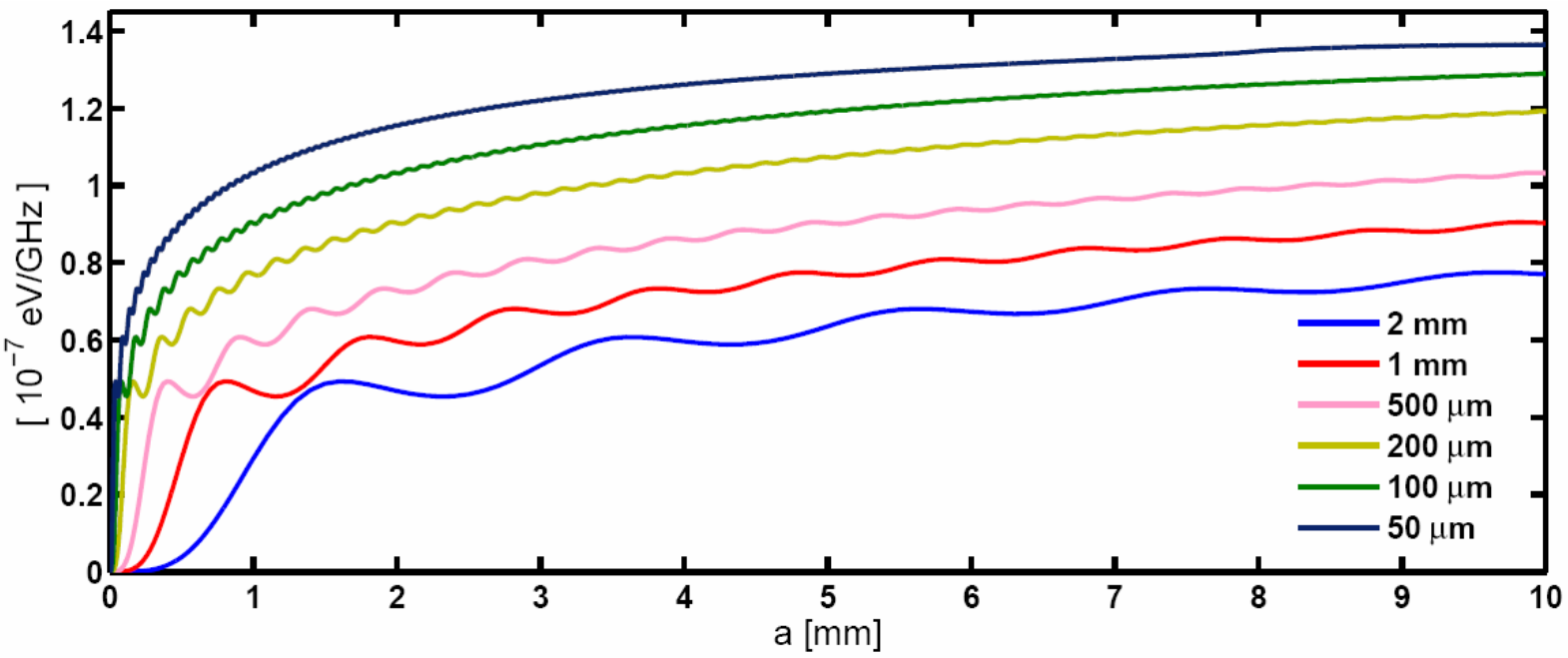
Transition Radiation

$$\frac{d^2U_{generalized-GF}}{d\omega d\Omega} = \frac{d^2U_{GF}}{d\omega d\Omega}[1 - T_a(\theta,\omega)]^2$$

$$T_a(\theta,\omega) = \frac{\omega a}{c\beta\gamma} J_0\left(\frac{\omega a \sin\theta}{c}\right) K_1\left(\frac{\omega a}{c\beta\gamma}\right) + \frac{\omega a}{c\beta^2\gamma^2 \sin\theta} J_1\left(\frac{\omega a \sin\theta}{c}\right) K_0\left(\frac{\omega a}{c\beta\gamma}\right)$$

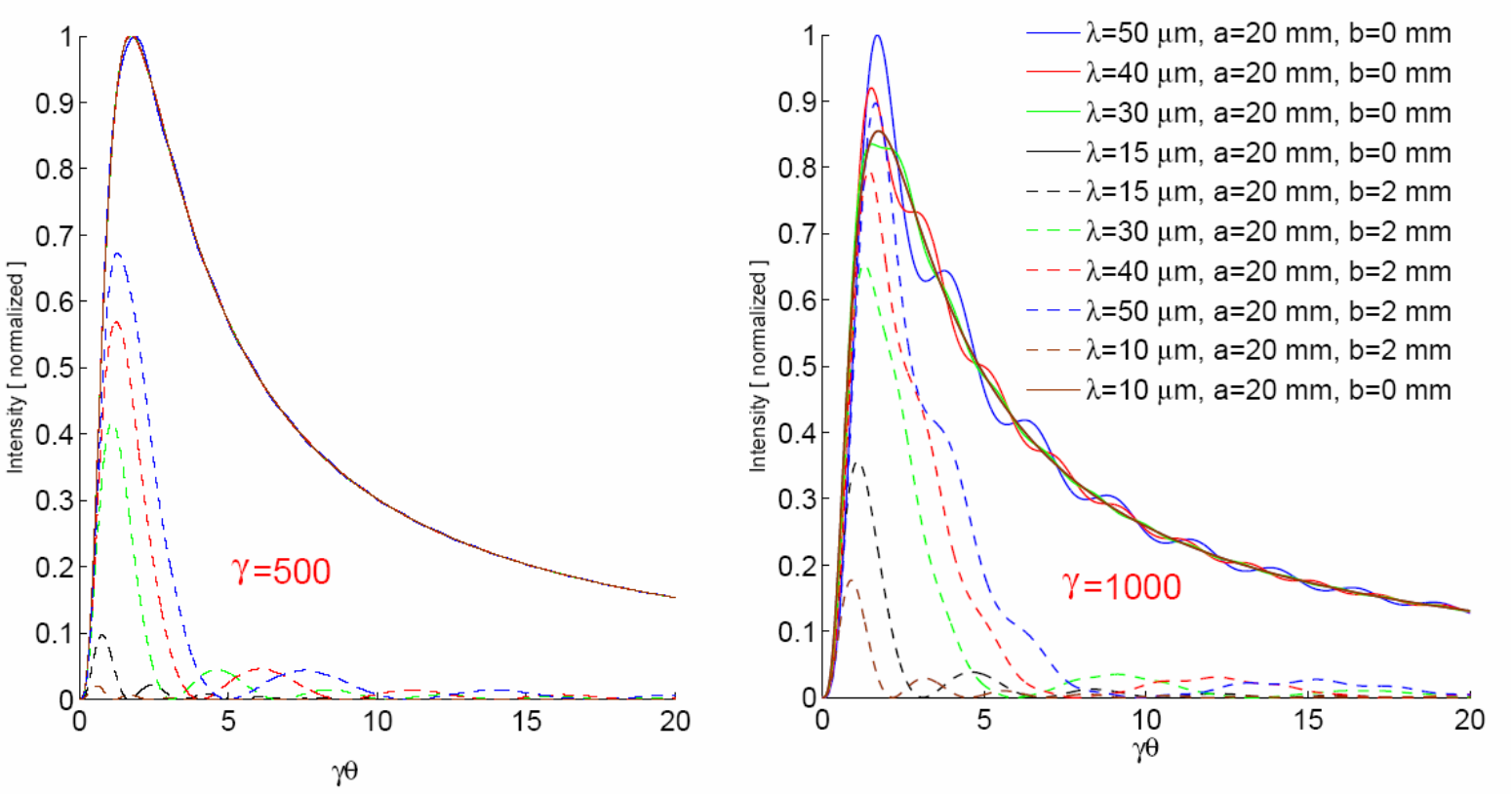
TR energy per frequency interval f = 1 GHz that is emitted by an electron with γ= 1000 is plotted as a function of the TR screen radius a. The wavelength is varied between 50 μm to 2 mm. All curves show a rise with increasing TR screen radius. For large enough screen size they all approach asymptotically to

$$\frac{e^2}{2\pi^2\varepsilon_0 c}(\ln\gamma + \ln 2 - 0.5)$$



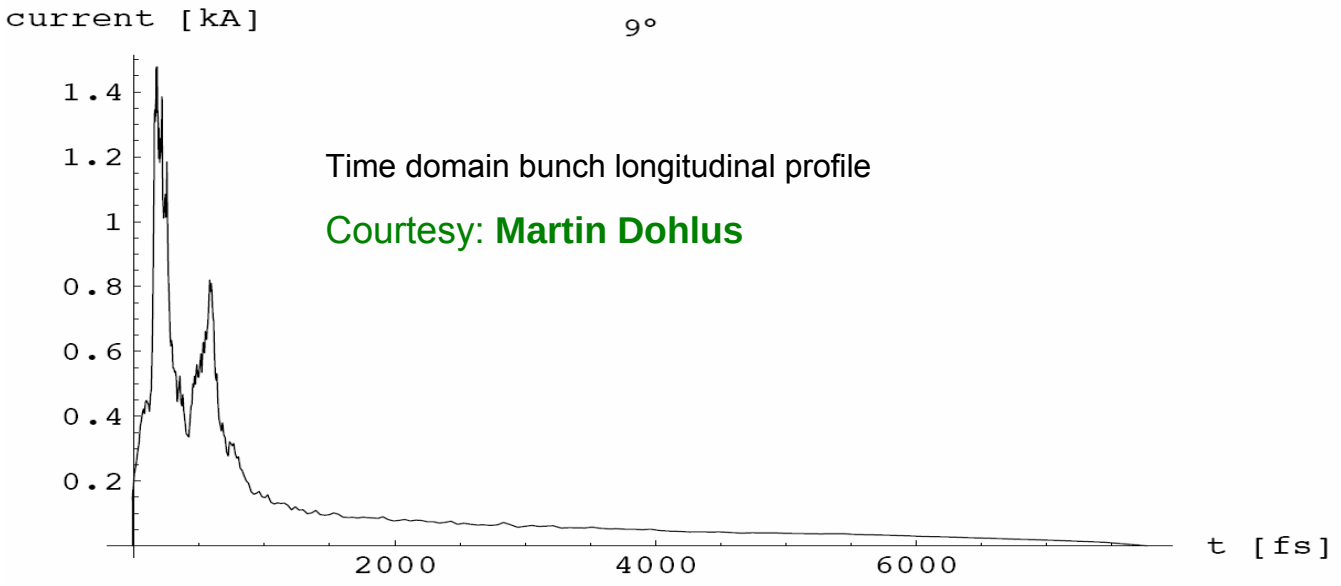
Transition Radiation versus Diffraction Radiation

$$\frac{d^2U}{d\omega d\Omega} = [T_a(\theta,\omega) - T_b(\theta,\omega)]^2 \frac{d^2U_{GF}}{d\omega d\Omega}$$



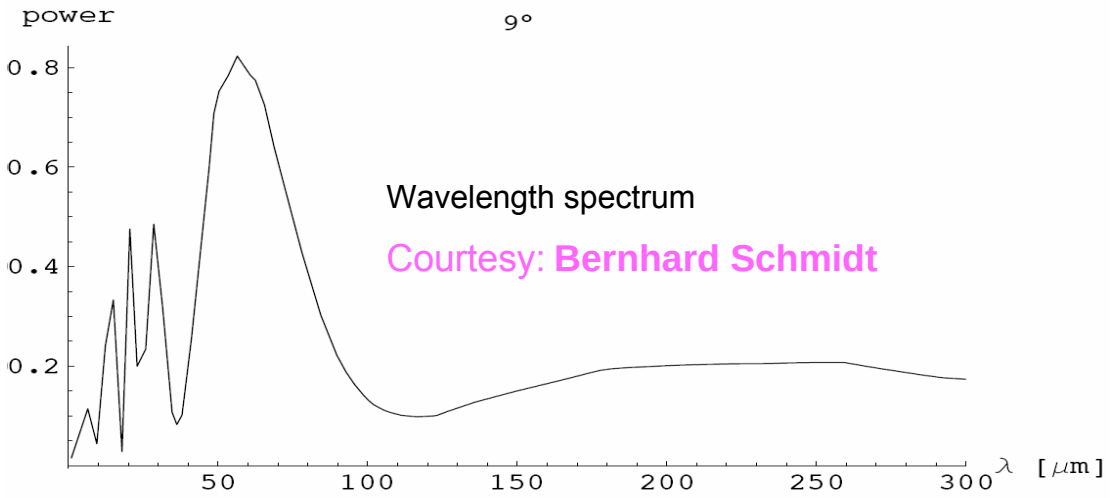
Angular distribution of transition and diffraction radiation from a circular disk (radius a = 20 mm) target. Solid curves are TR on a disk without hole, the other curves refer to DR on a disk of radius a = 20 mm which has a central hole of radius b = 2 mm.

Coherent transition radiation spectrum



Time domain bunch longitudinal profile

Courtesy: **Martin Dohlus**

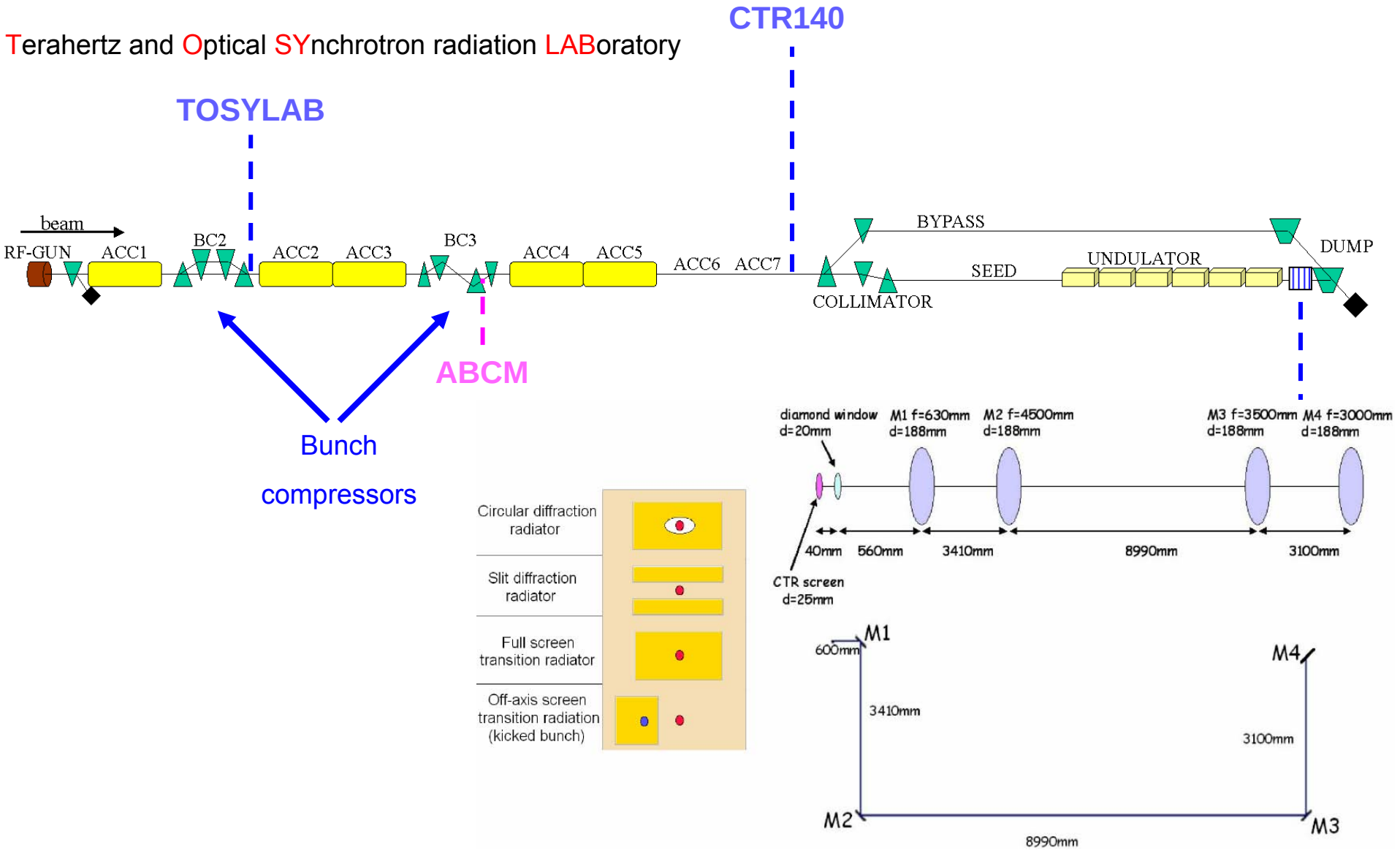


Wavelength spectrum

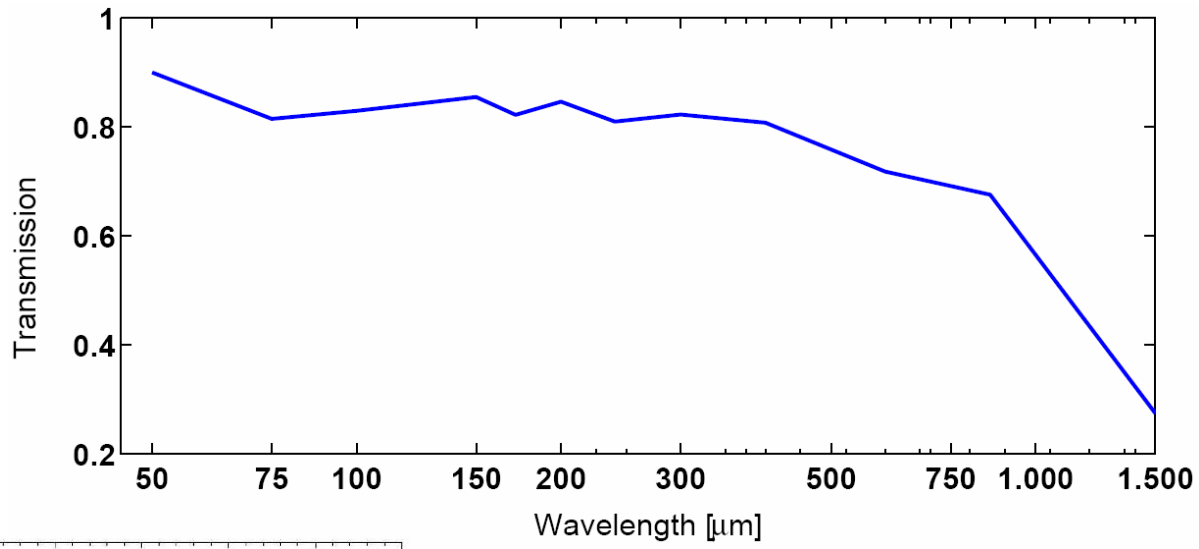
Courtesy: **Bernhard Schmidt**

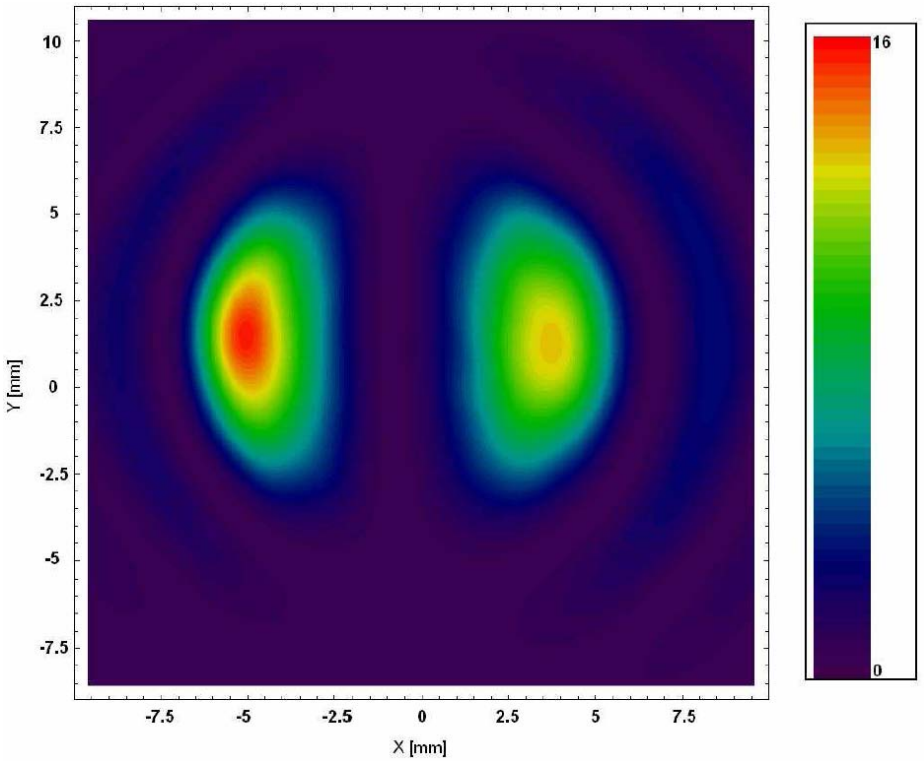
FLASH layout and infrared radiation beam-lines

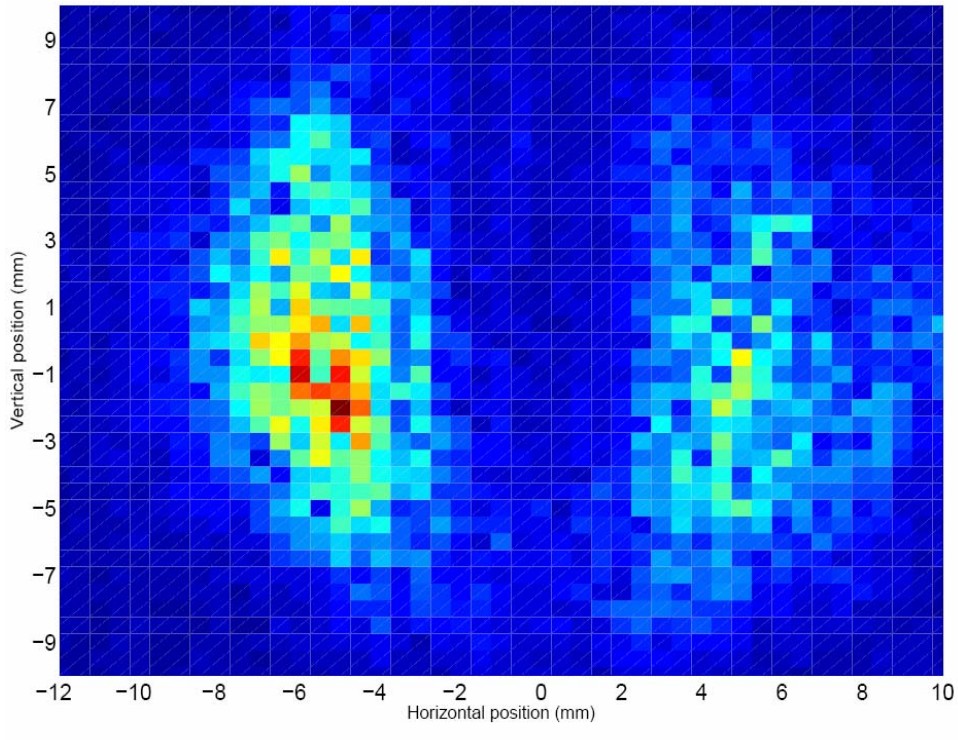
Terahertz and Optical SYnchrotron radiation LABoratory

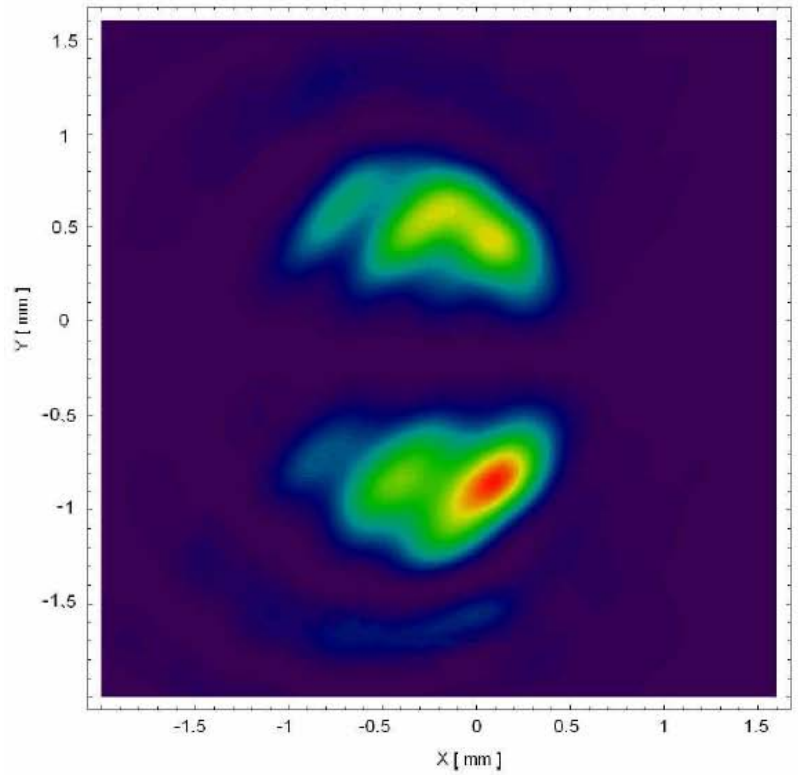


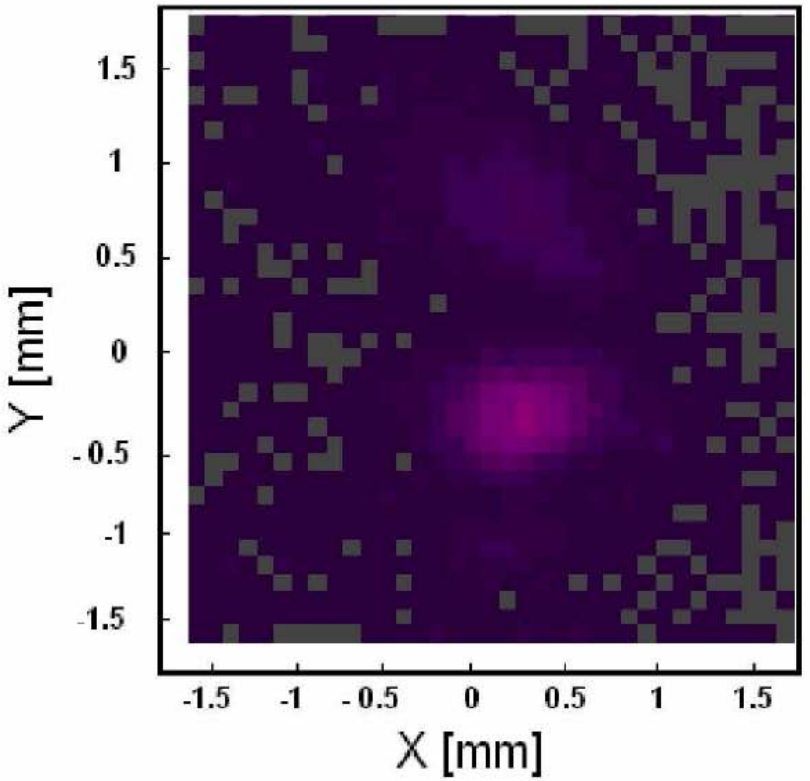
THz-Transport and THz-Beamline (CTR140)





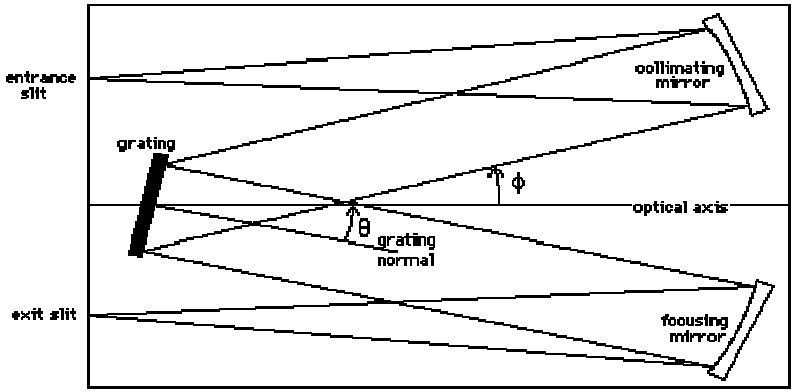


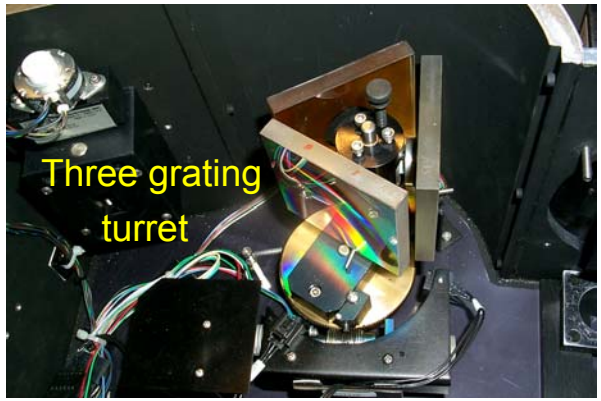

1.5
1
0.5
0
-0.5
-1
-1.5
Y [mm]
-1.5
-1
-0.5
0
0.5
1
1.5
X [mm]

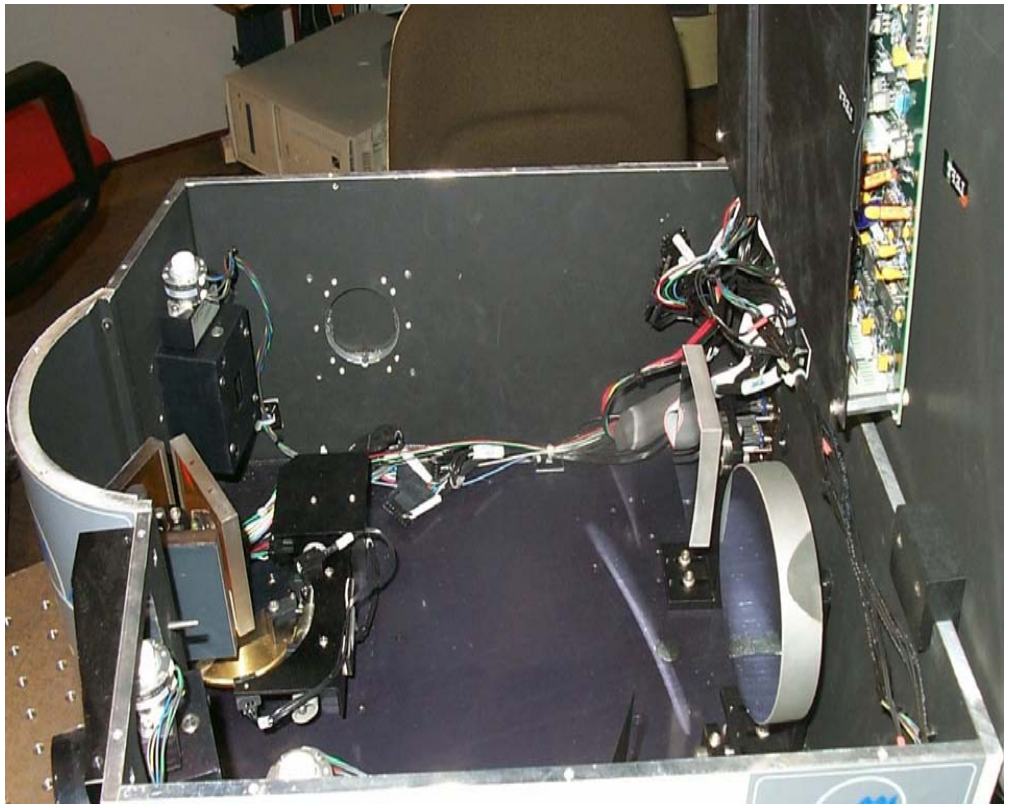

1.5
1
0.5
0
- 0.5
-1
-1.5
Y [mm]
-1.5
-1
- 0.5
0
0.5
1
1.5
X [mm]

Why grating spectrometers?

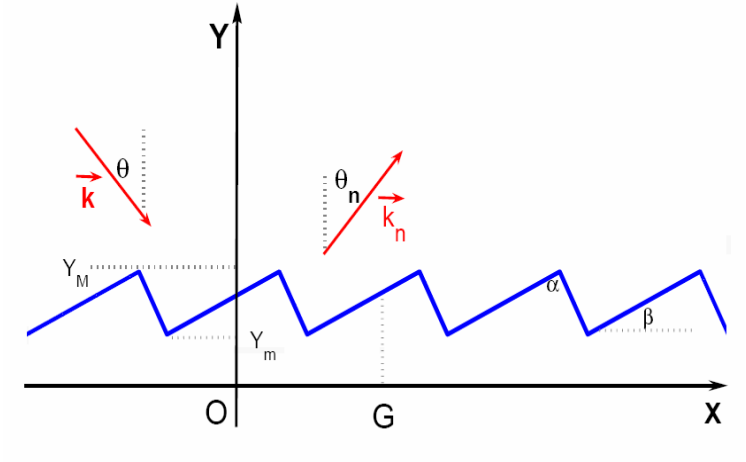
Why not commercial grating-spectrometers?

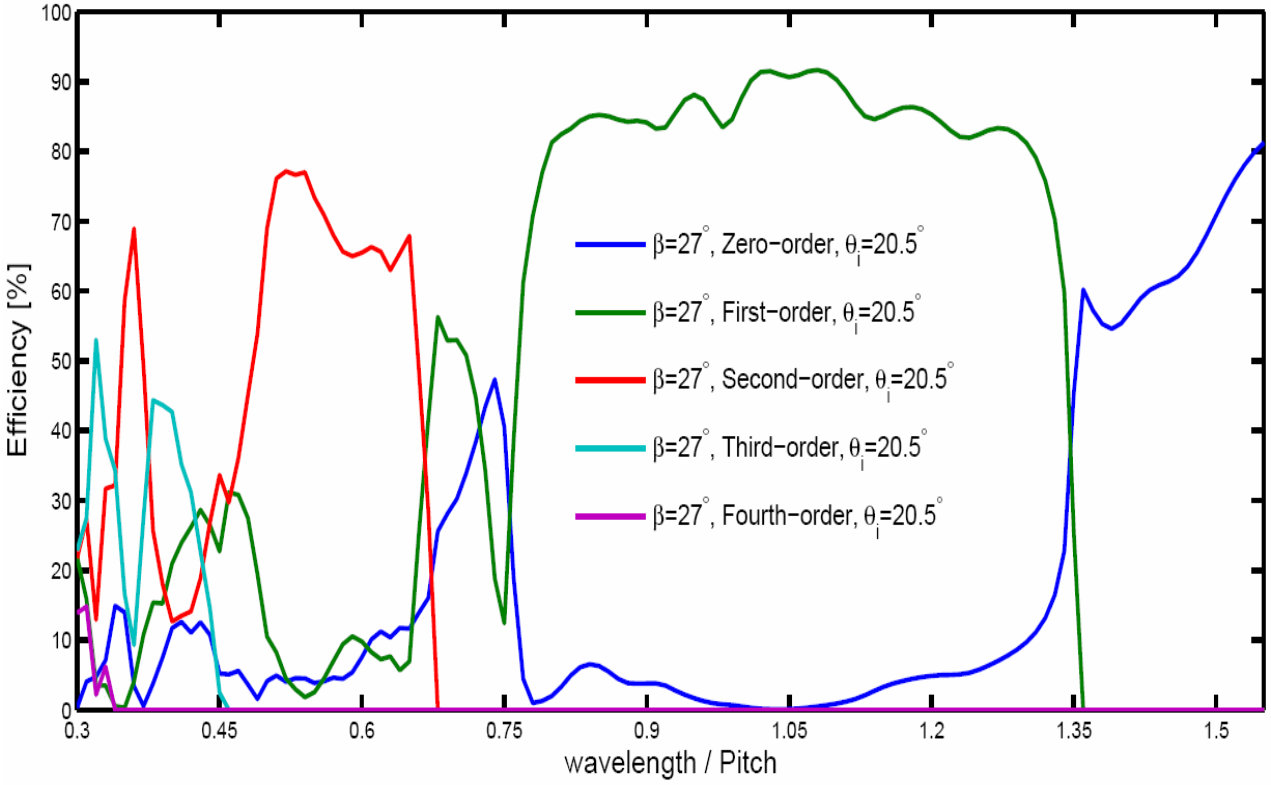




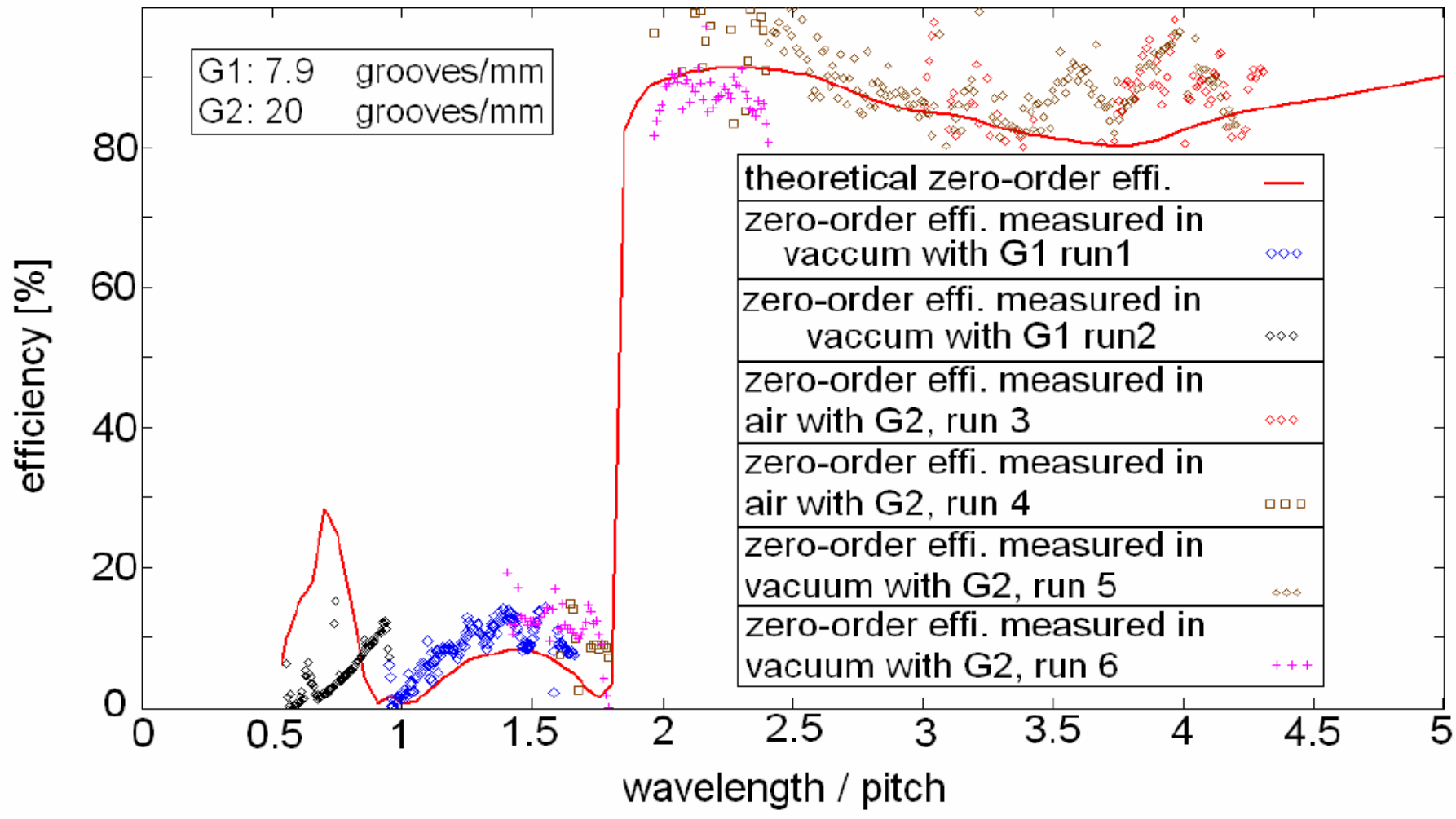


Reflectance gratings



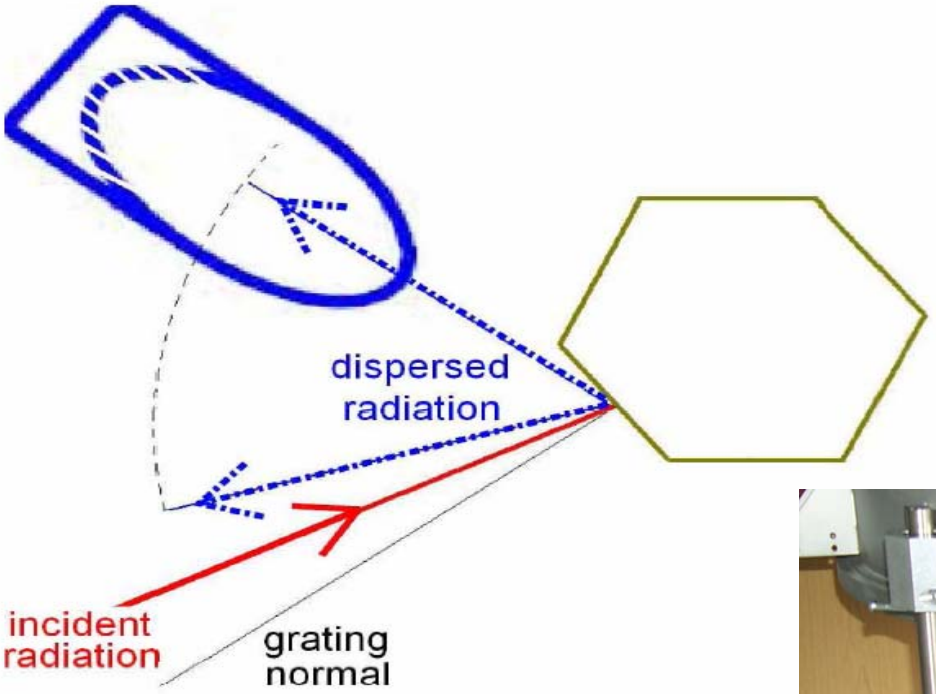


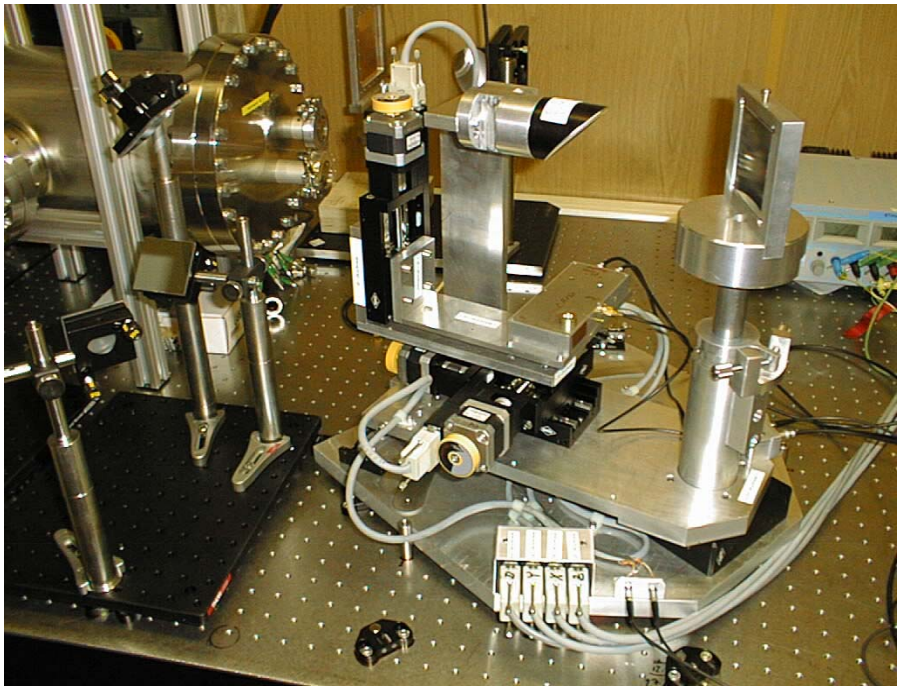
Reflectance gratings

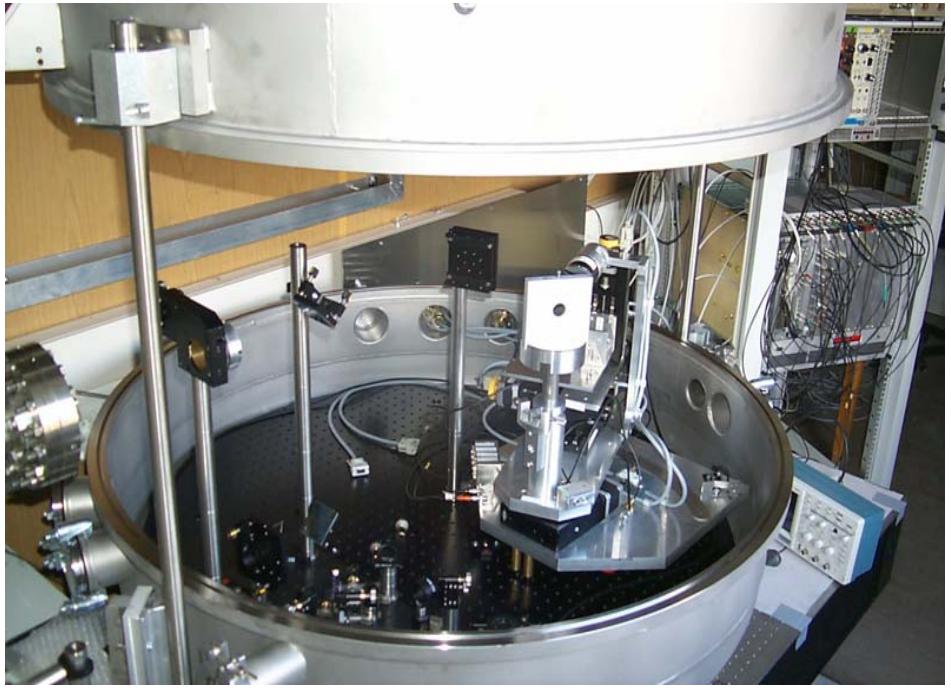


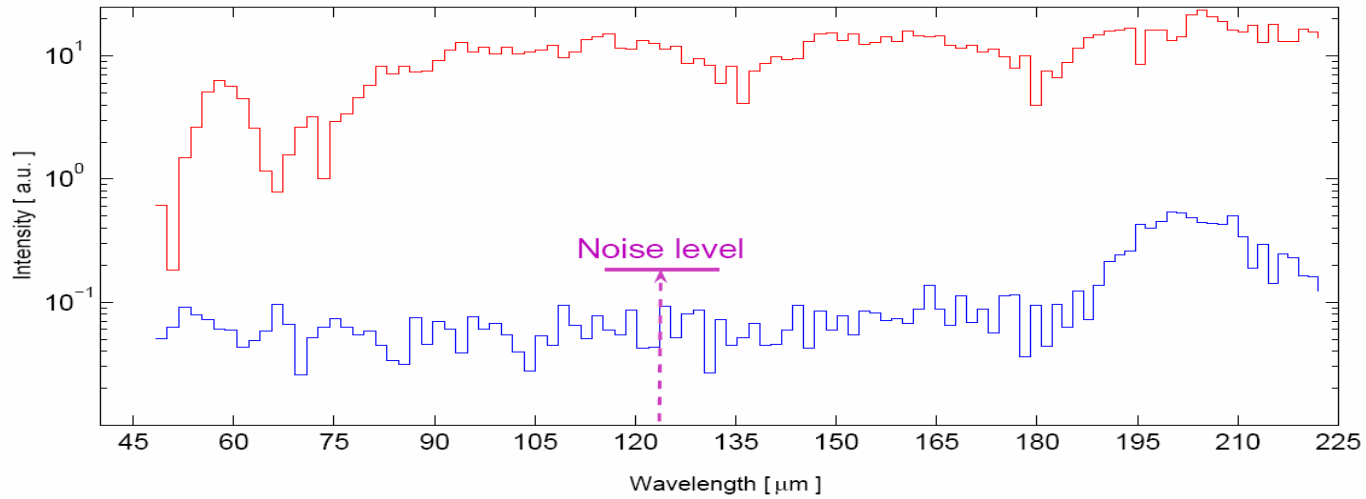
Broad-band single-shot spectrometer, Proceedings FEL2005

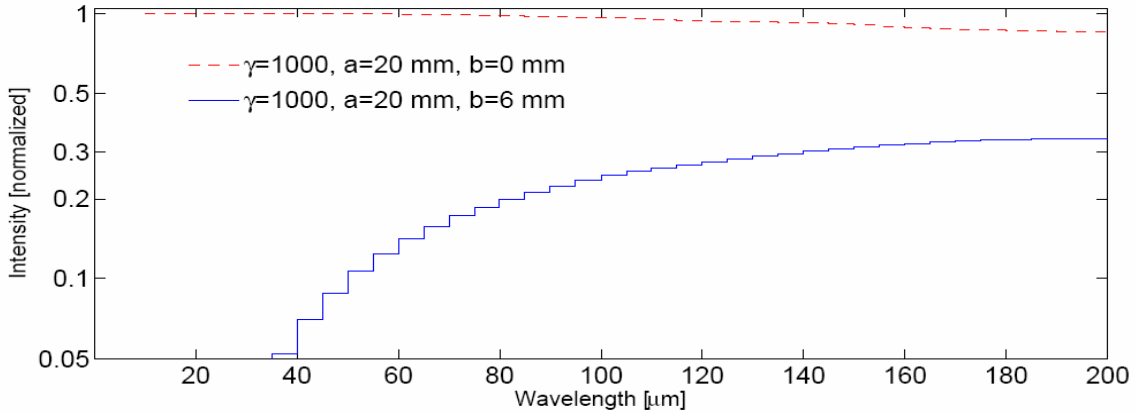
Rotating Mirror Spectrometer

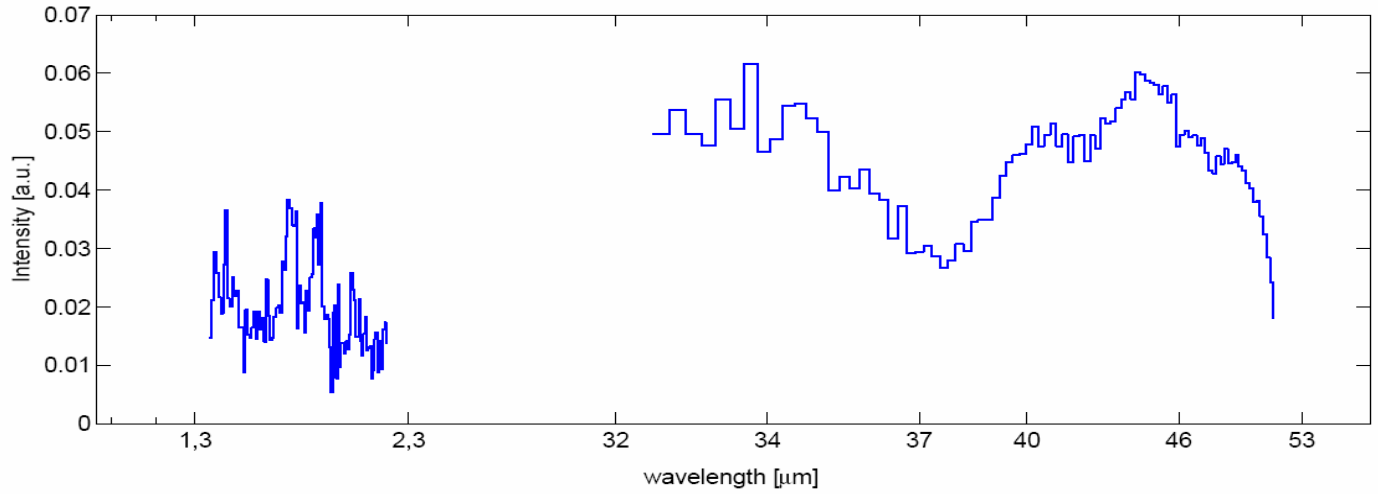




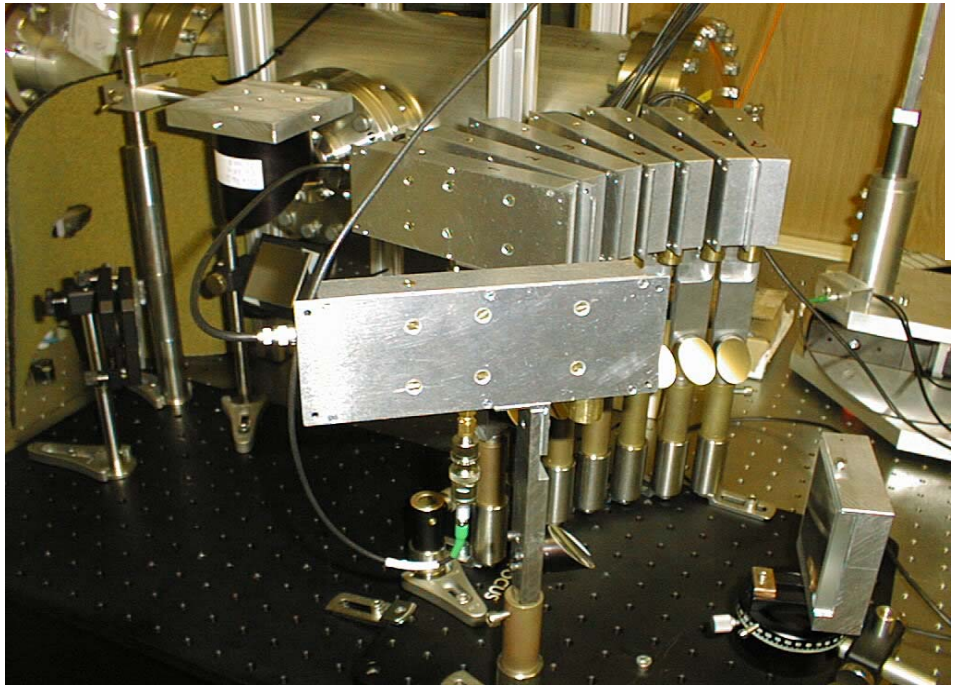


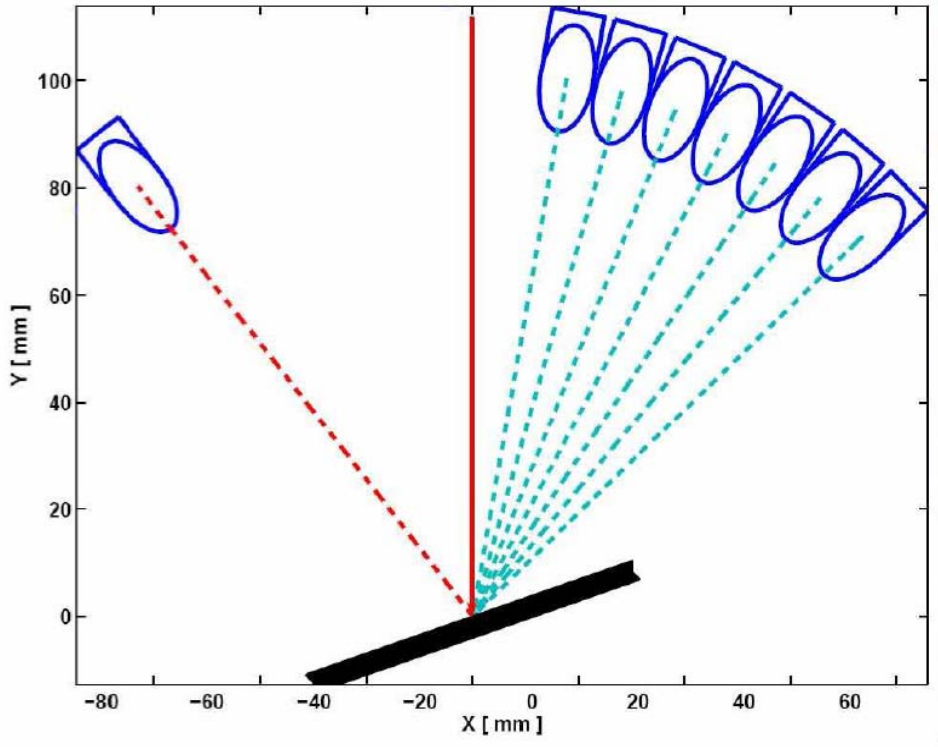

Intensity [a.u.]
Noise level
Wavelength [μm]

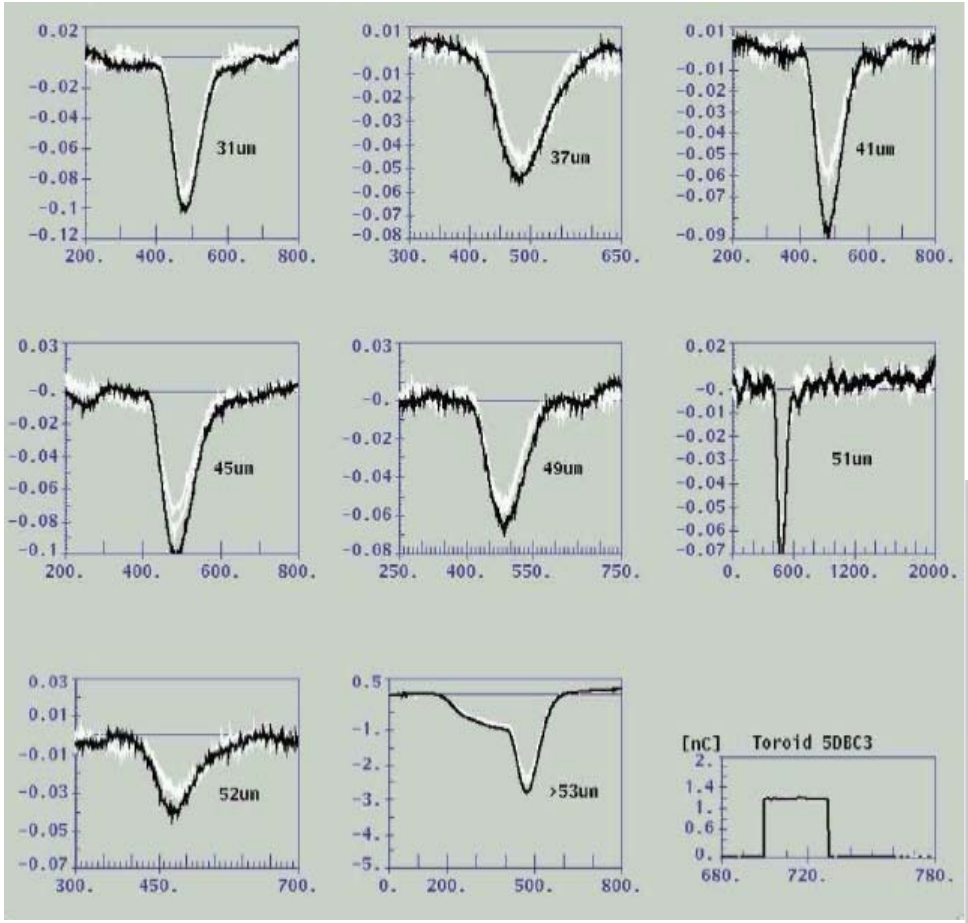

γ=1000, a=20 mm, b=0 mm
γ=1000, a=20 mm, b=6 mm
Intensity [normalized]
Wavelength [μm]

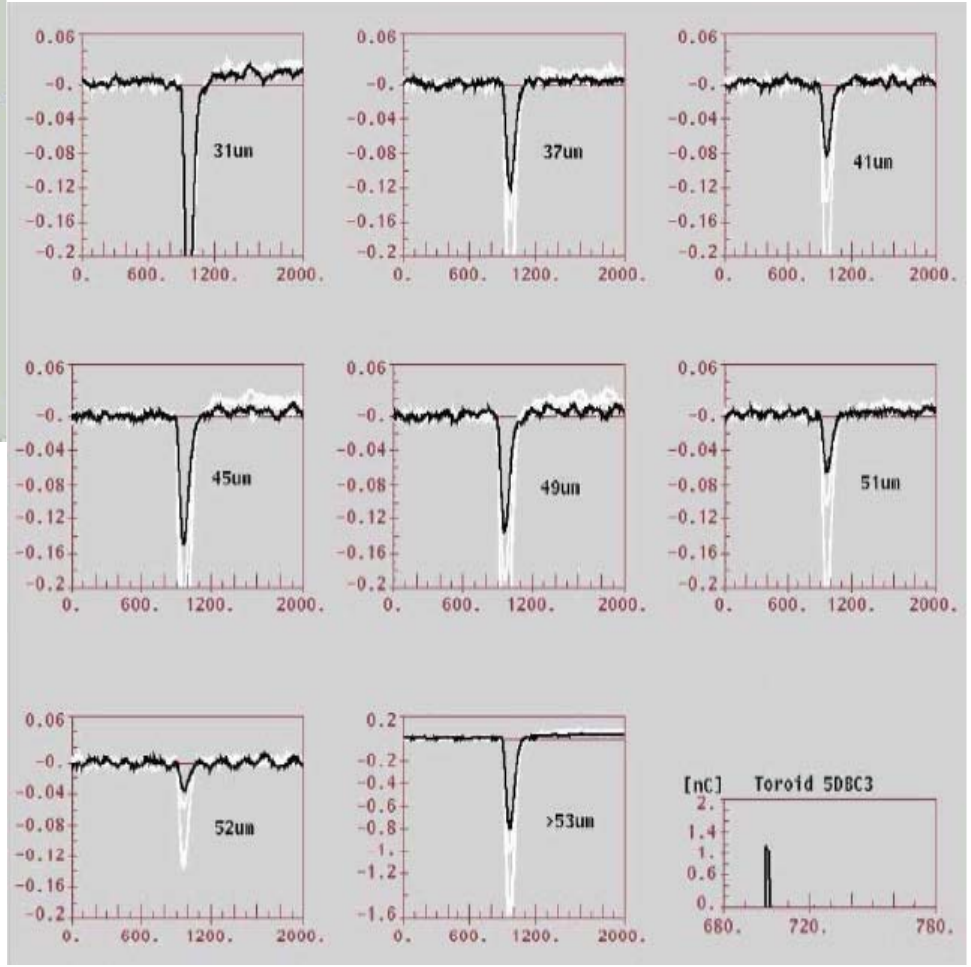

Intensity [a.u.]
wavelength [μm]

Eight-channel single-shot spectrometer (one-stage)



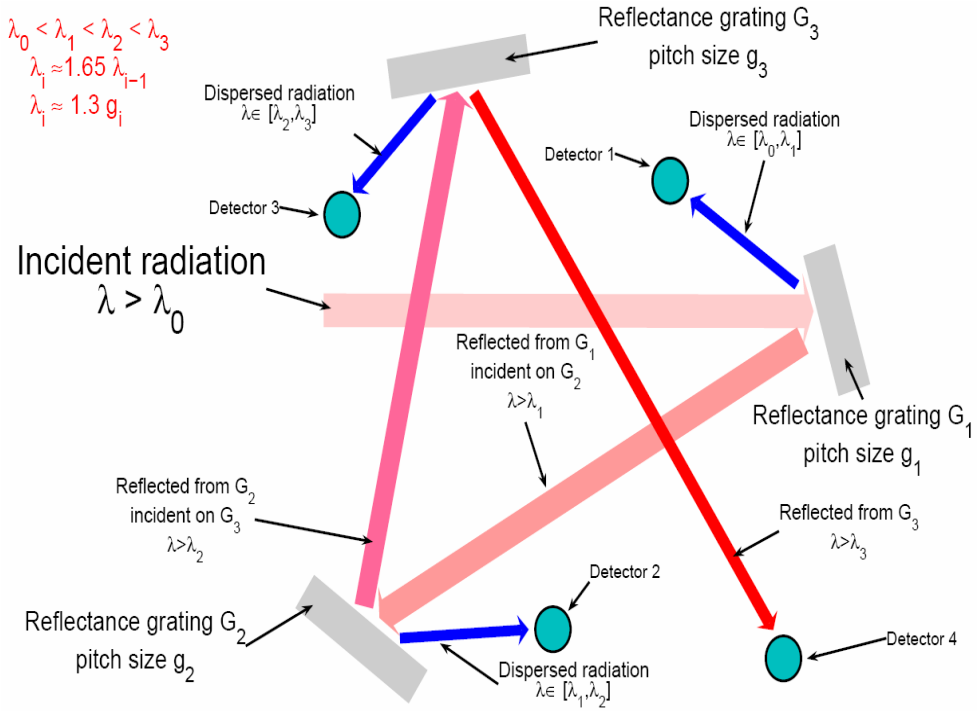


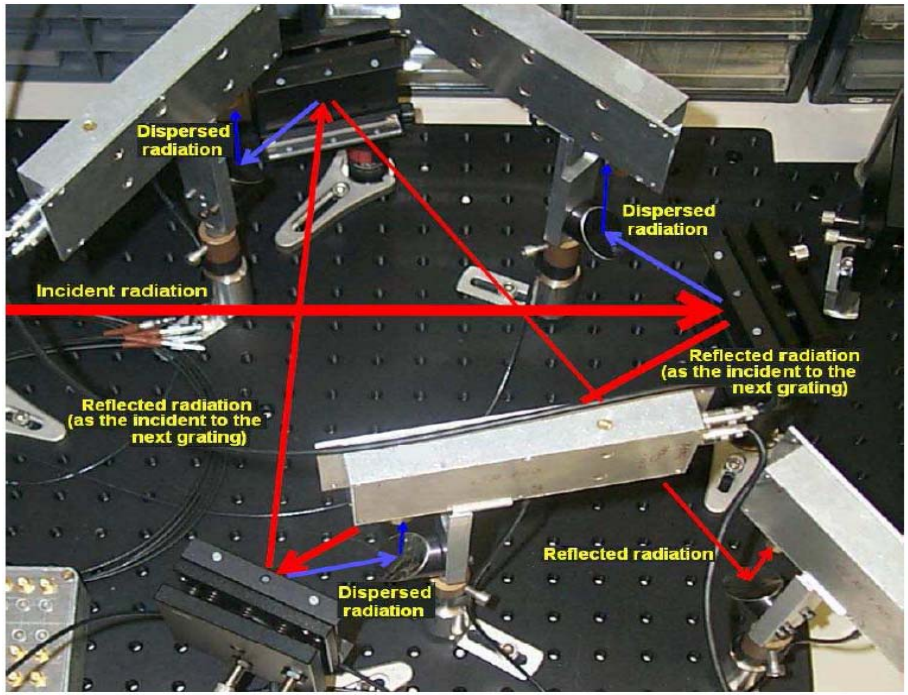




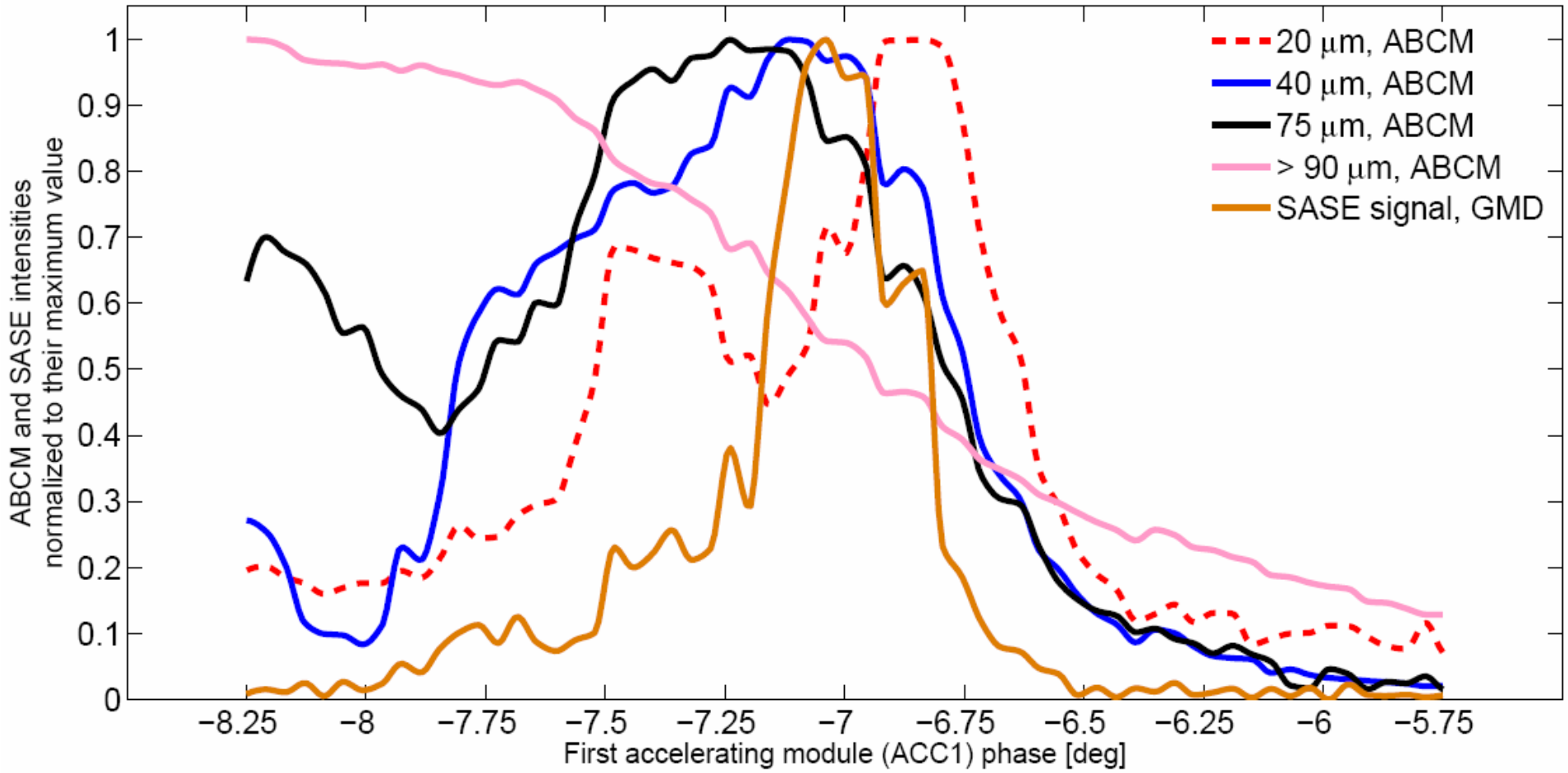
Single-shot spectrum recorded by eight-channel single-shot spectrometer. Each individual ADC channel spectrum shows the output of the amplifier that corresponds to the specific channel. The horizontal axis is time and every ≈ 13 units correspond to 1 μs (The toroid time scale is in μs and shows 30 μs for thirty bunches). The above shot is taken when one bunch is kicked out of the train of many bunches. In the middle plot of the third row a long tail is present which is the contribution of the non-kicked bunches that pass several millimeters away from the screen and produce diffraction radiation. This radiation is horizontally polarized and can be suppressed if a polarizer is used.

Four-channel ABCM



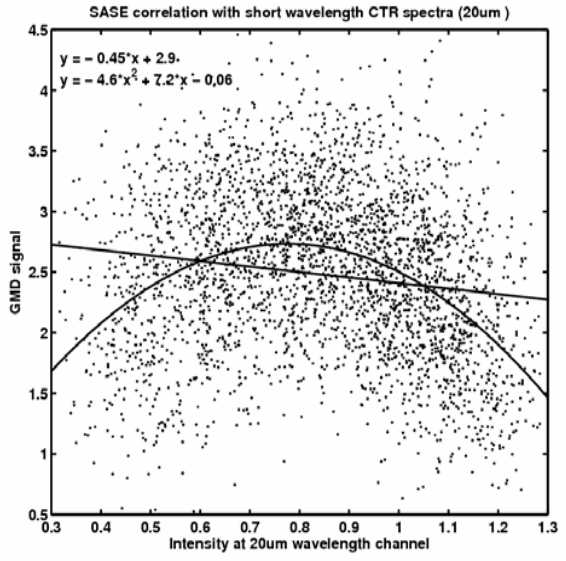


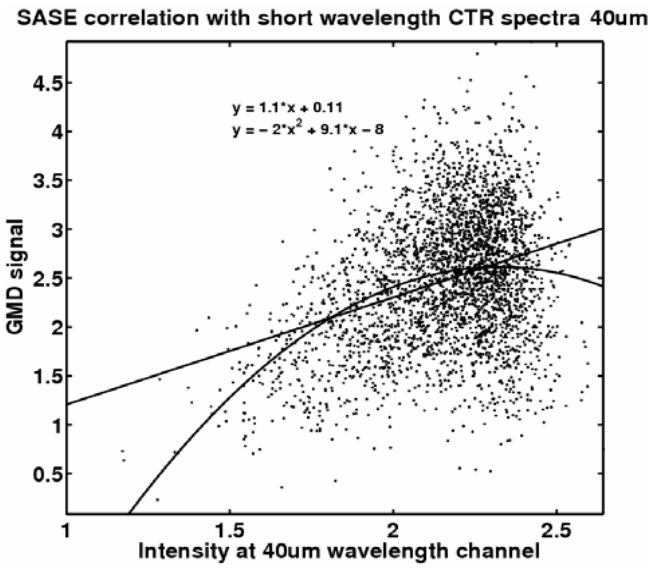
Advanced Bunch Compression Monitor

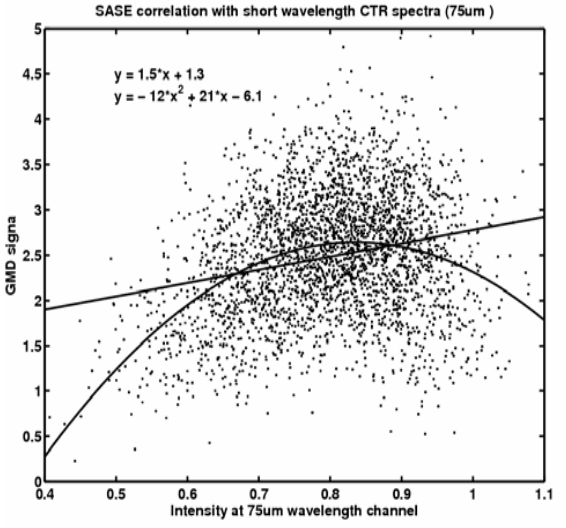


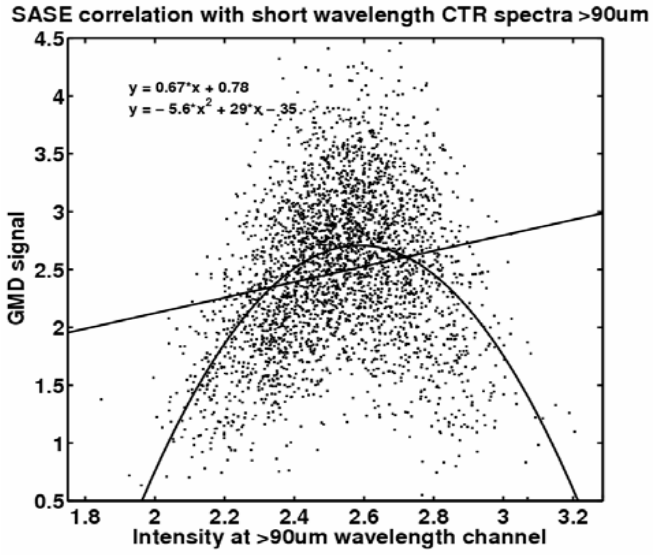
Bunch Compression Monitor , Proceedings EPAC2006

Correlation of SASE-CTR intensities (old runs)

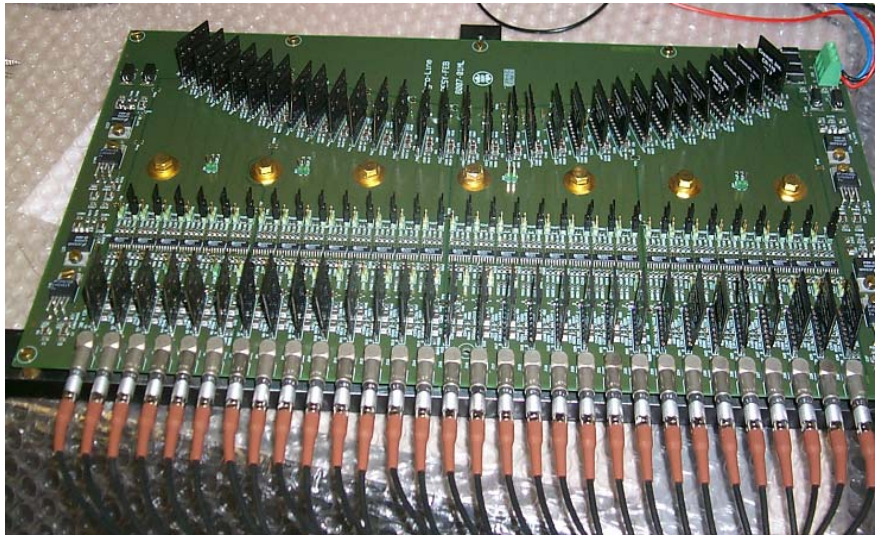


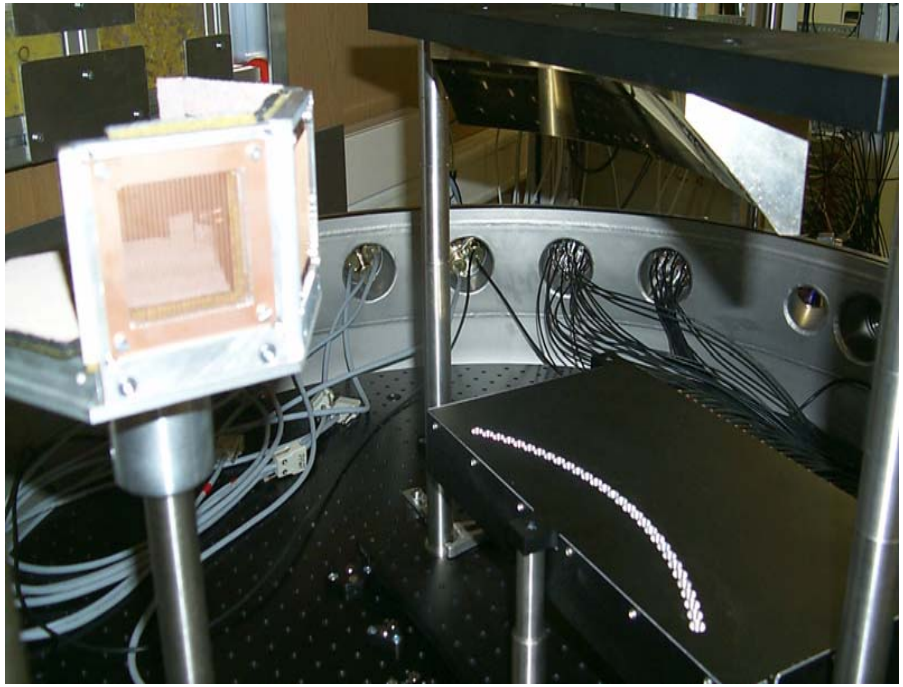


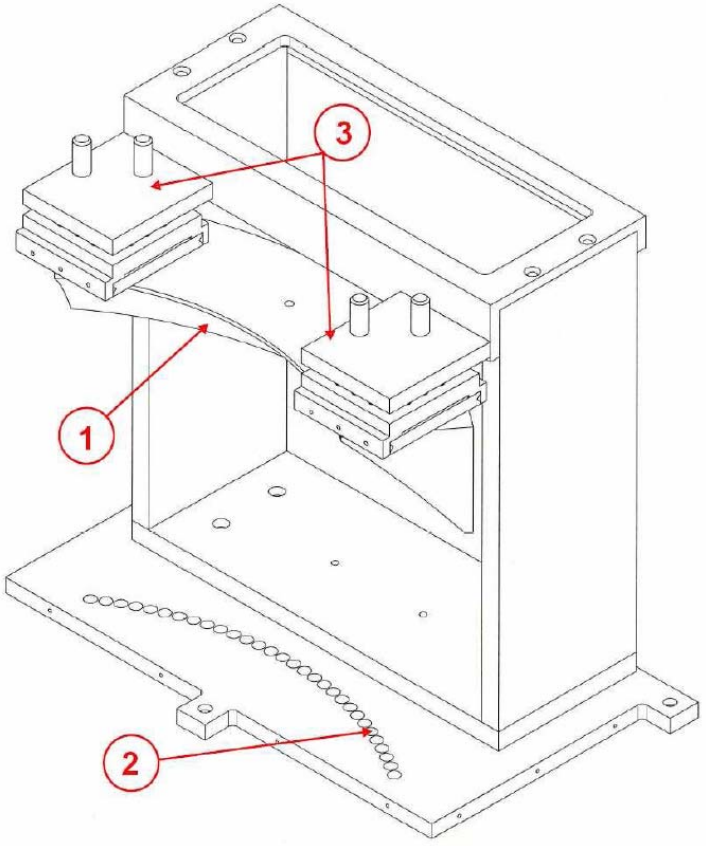




Next achievements!

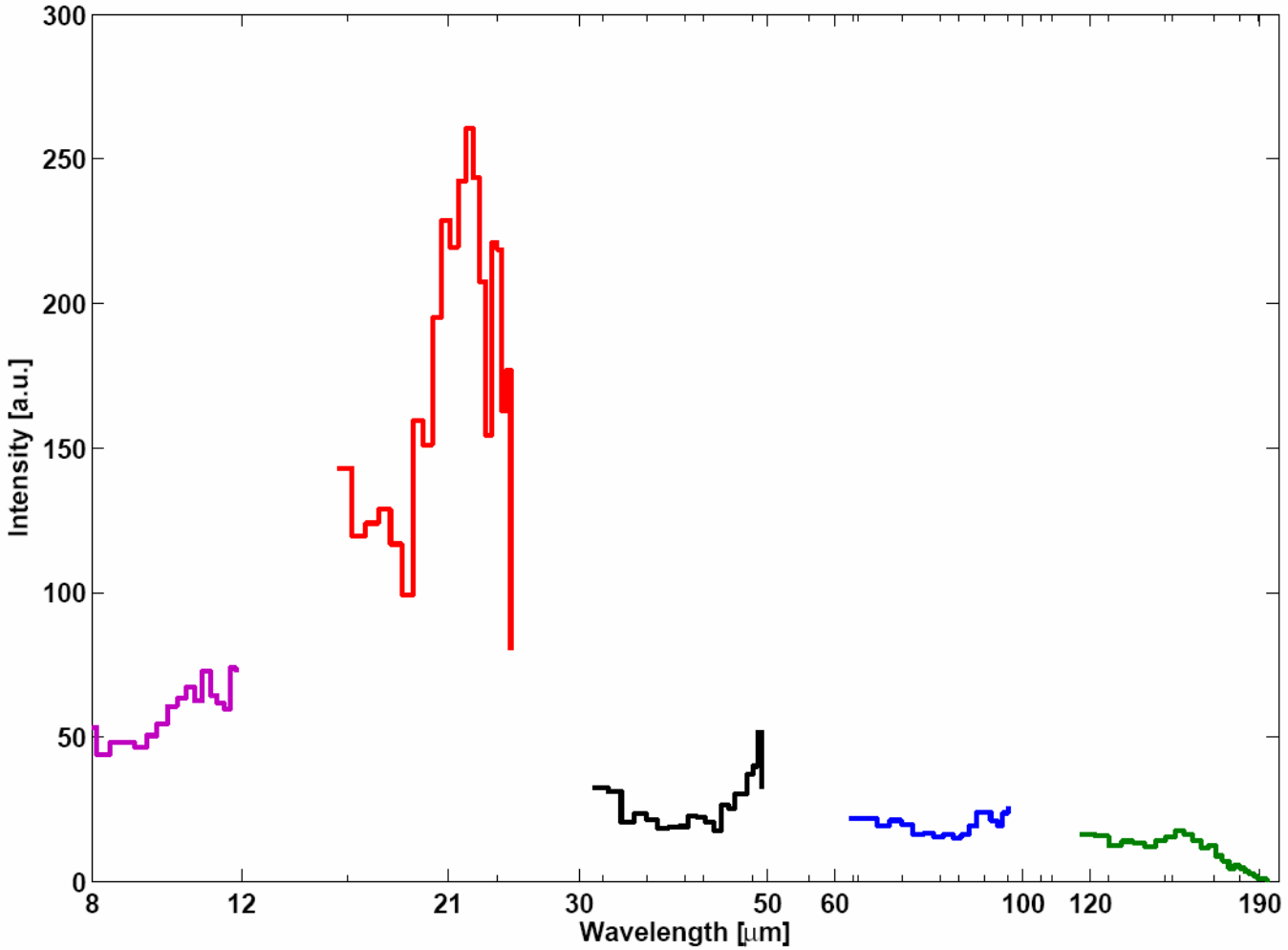






1- Ring-mirror
2- Collecting cones
3- Flat mirror holders

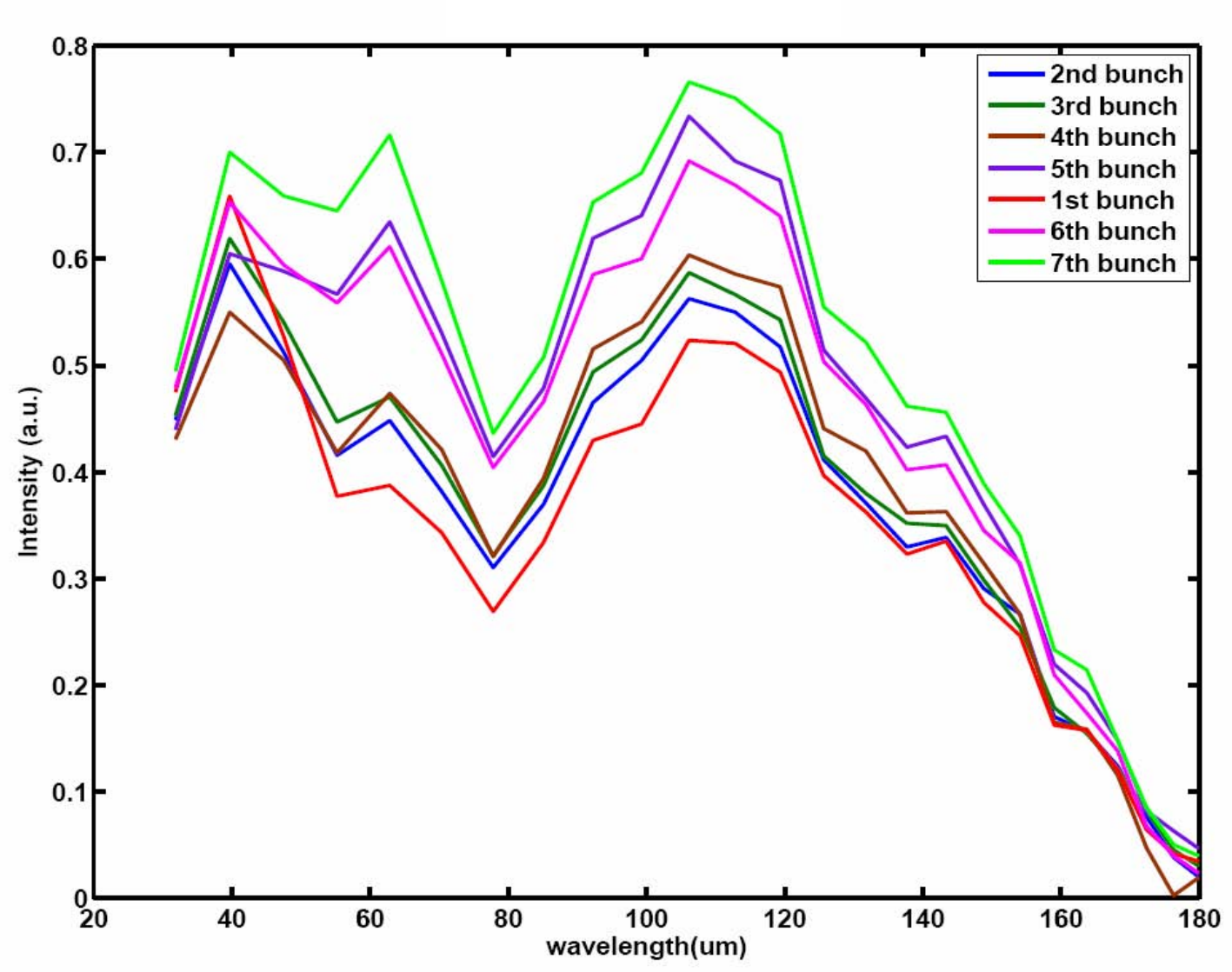
One-stage multi-channel spectrometer



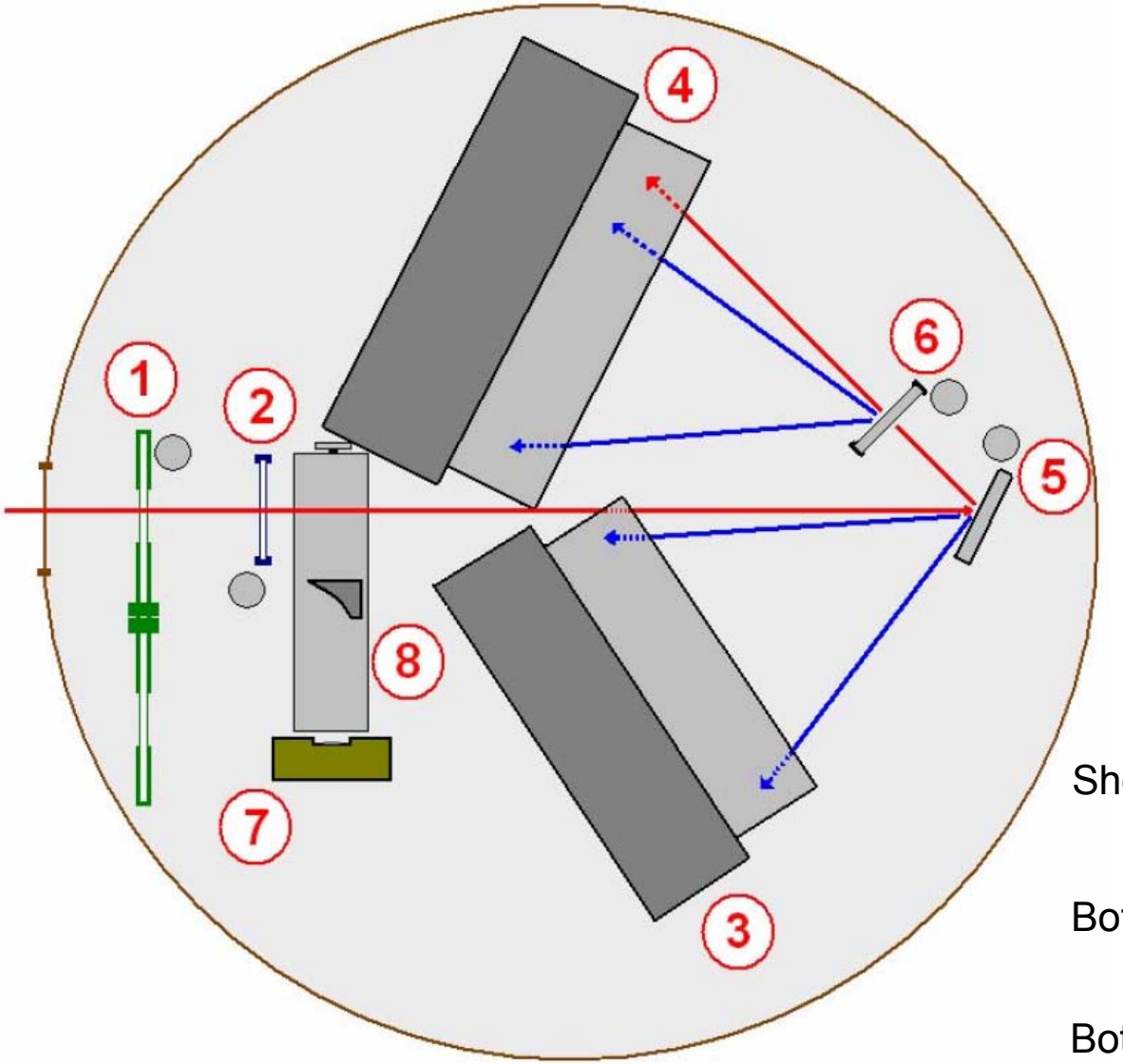
For a Gaussian profile: $\lambda_{I_{\max}}(\mu m) = 0.8 FWHM_t(fs)$

Single-Shot Longitudinal Diagnostics with THz Radiation at the Free-Electron Laser FLASH Proceedings FEL2006.

Variation of the CTR spectrum along the train



Two-stage multi-channel spectrometer



1- THz-filters (remote controlled)
2- Polarizer (remote controlled)
3- Reflectance grating stage
4- Transmission grating stage
5- Reflectance gratings holder and remote controlled mover
6- Transmission gratings holder and remote controlled mover
7- Pyro-camera
8- Parabolic mirror and its linear mover

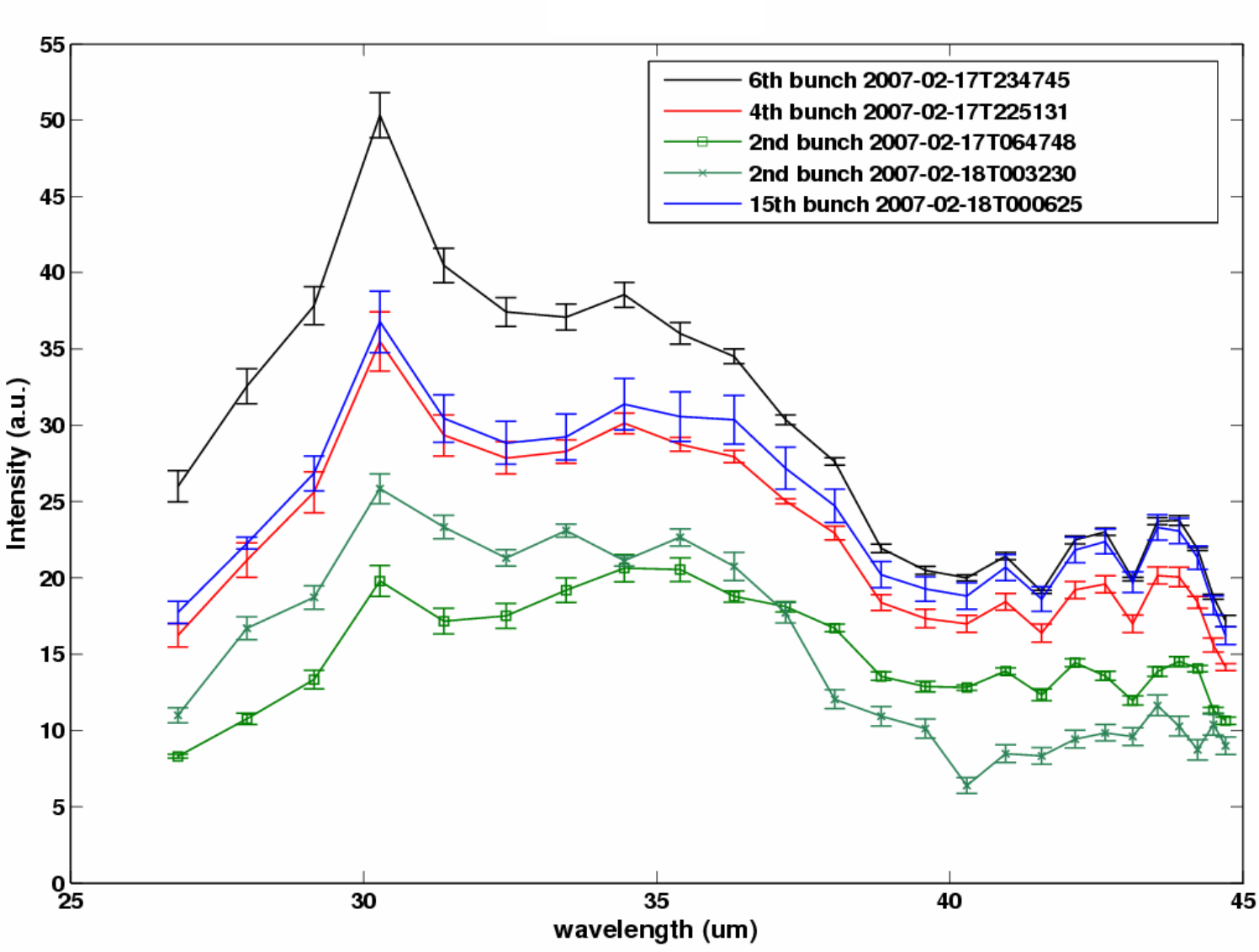
Short wavelength range, last days

Both stages, last days

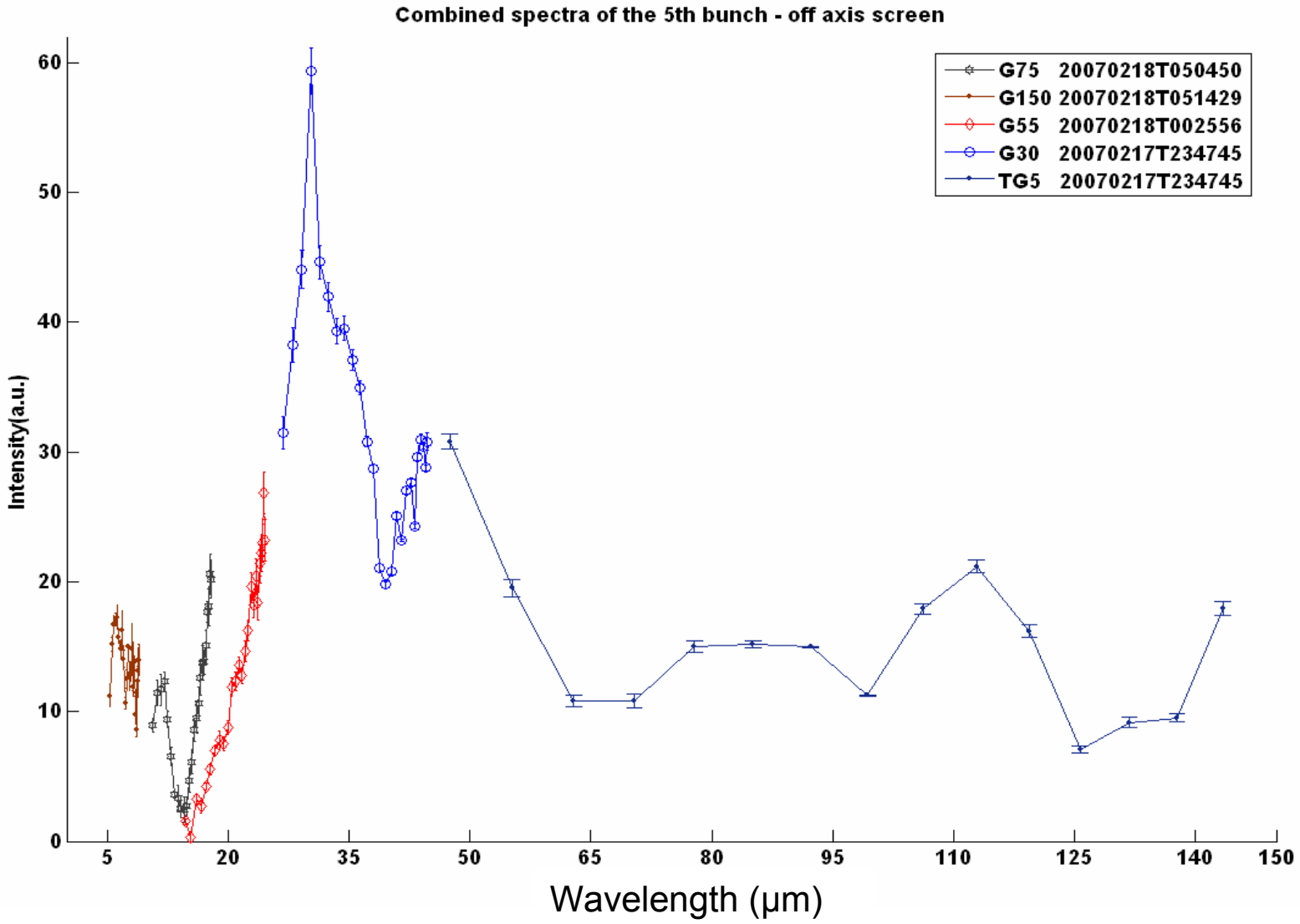
Both stages, last months

Both stages (long film), last months

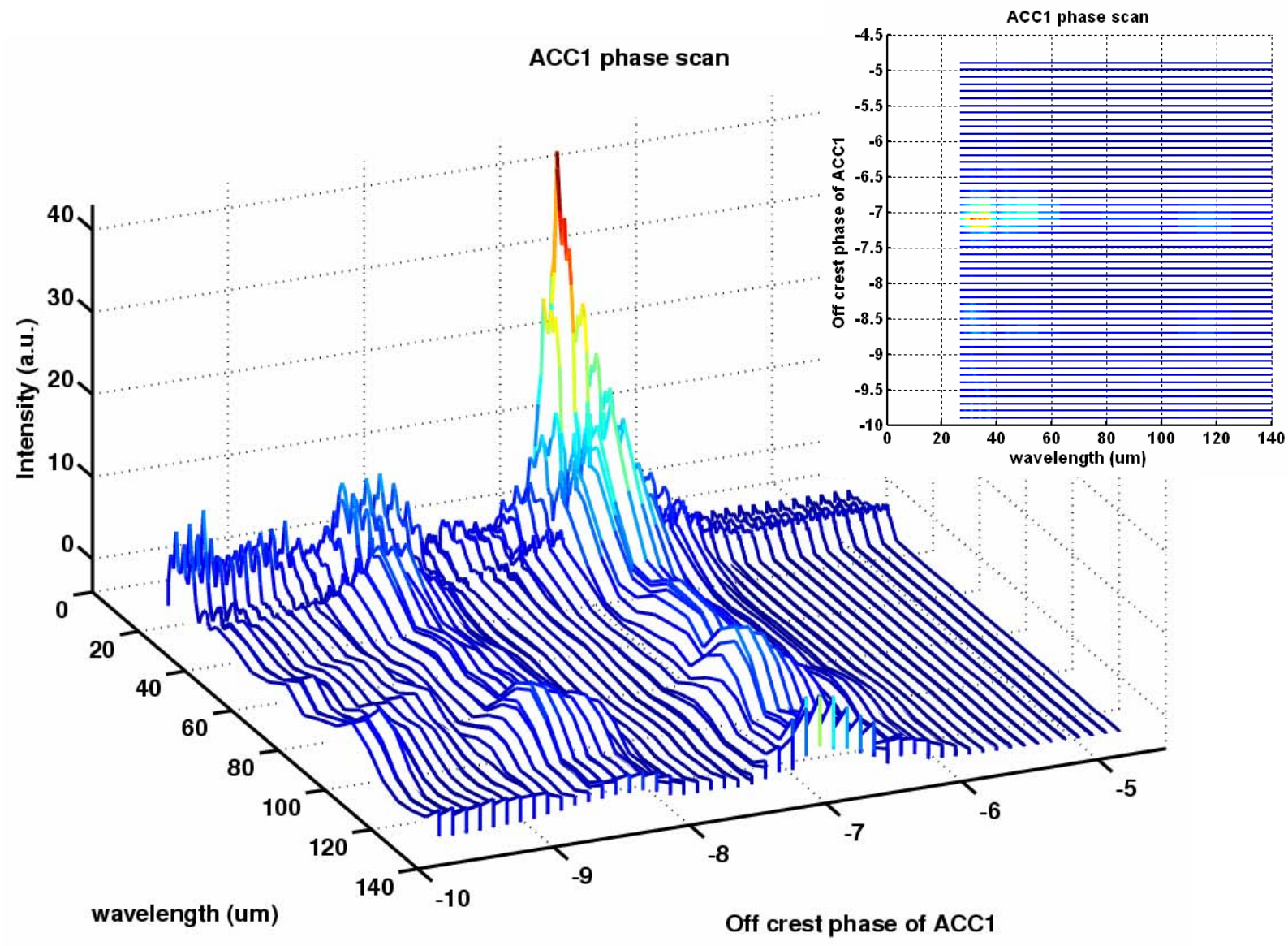
Variation of the CTR spectrum along the train



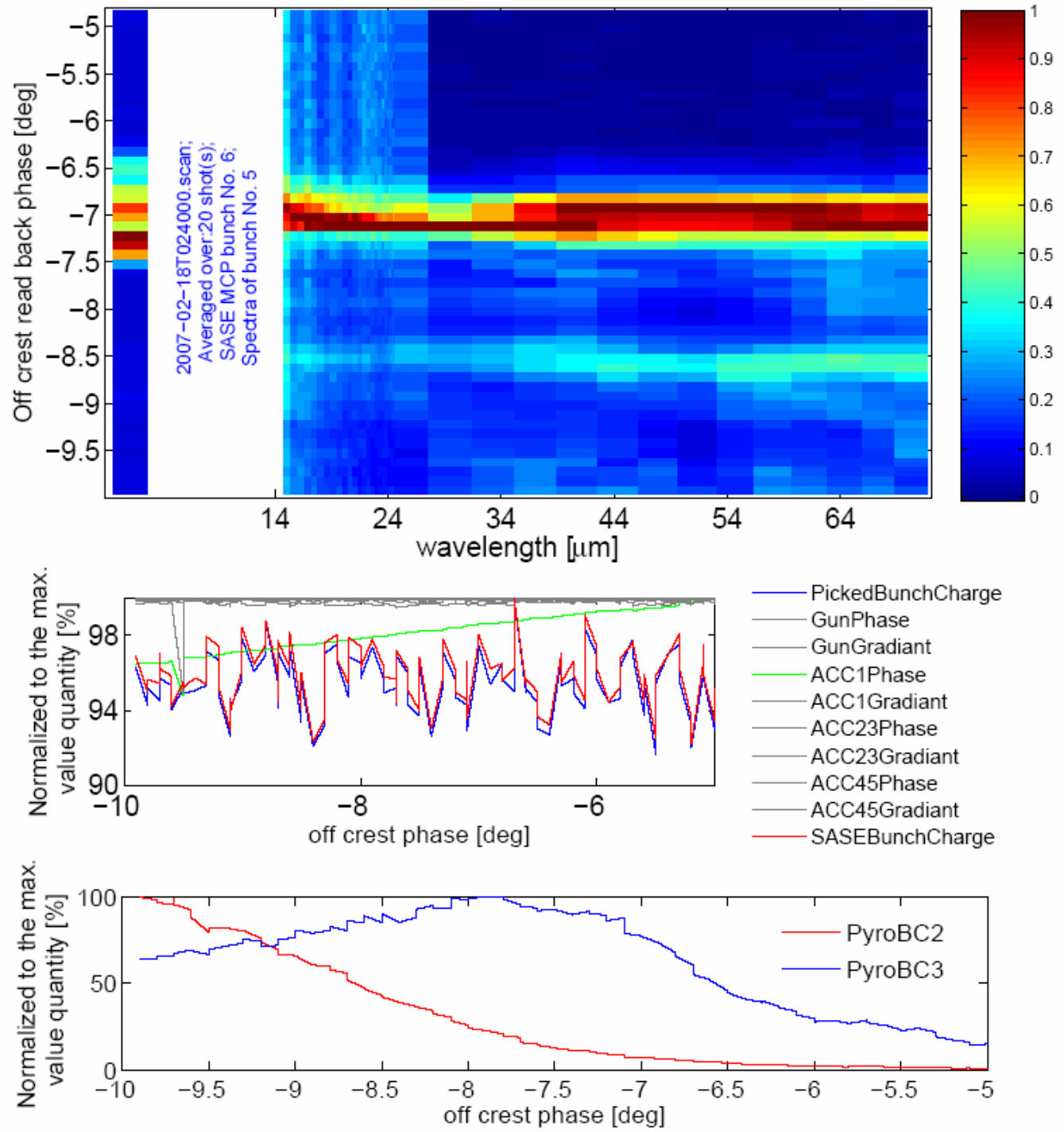
Broad-band CTR spectrum



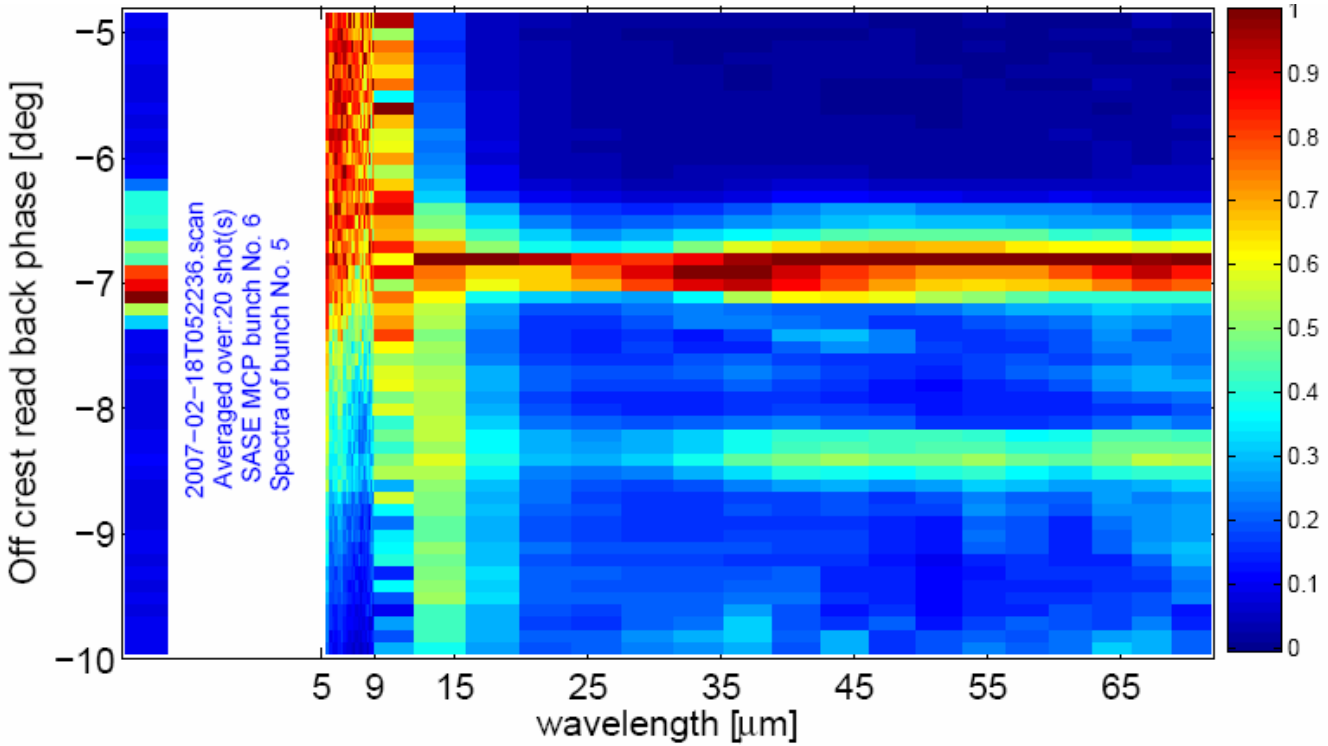
ACC1 phase scan

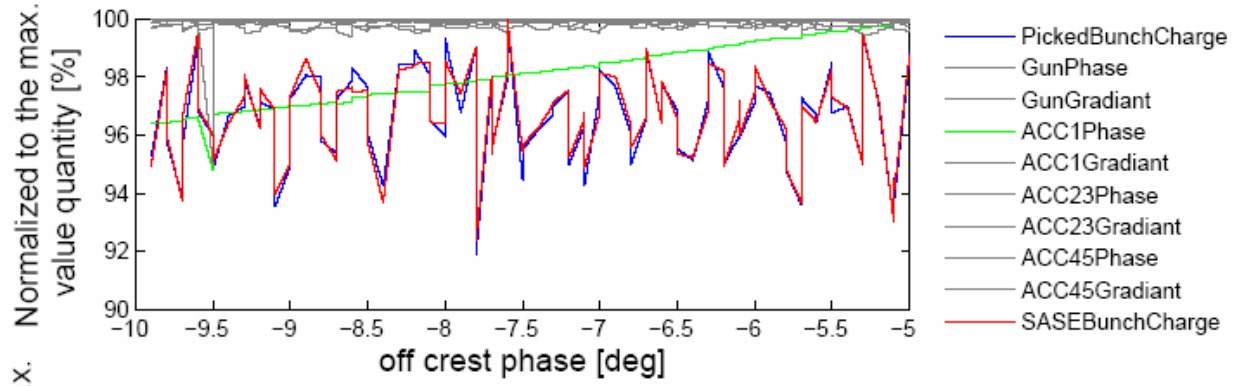


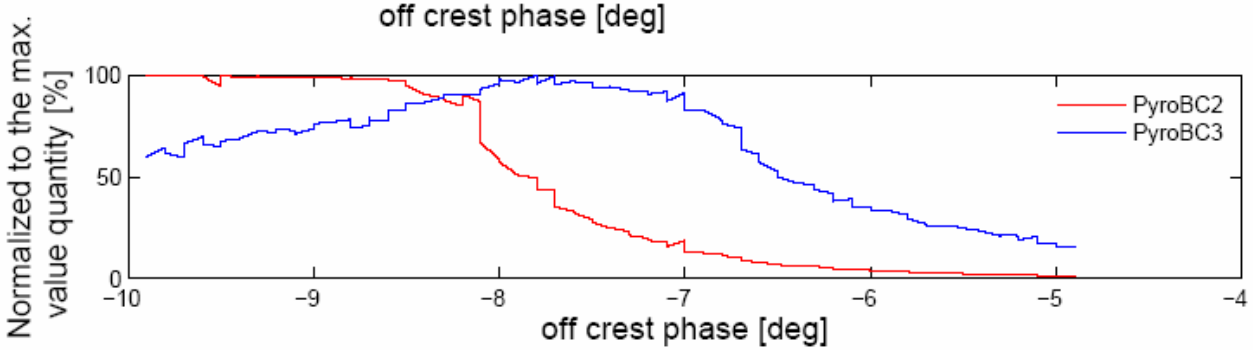
ACC1 phase scan



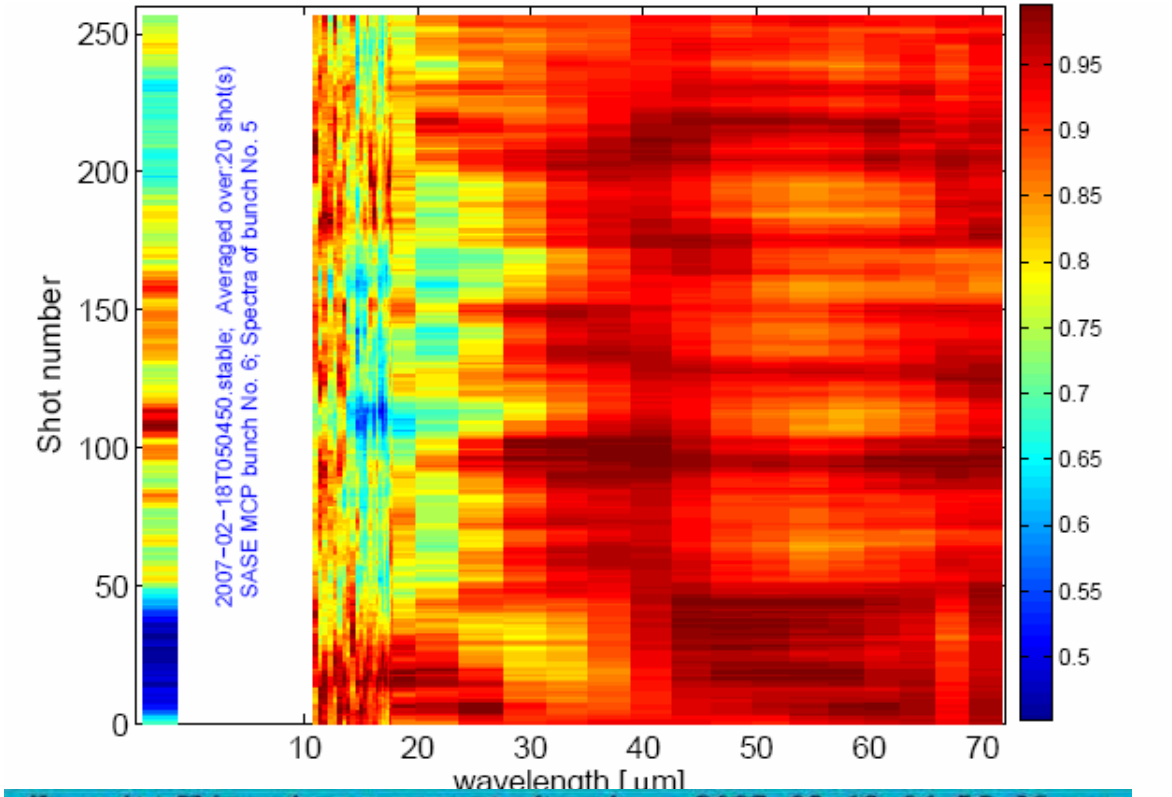
ACC1 phase scan

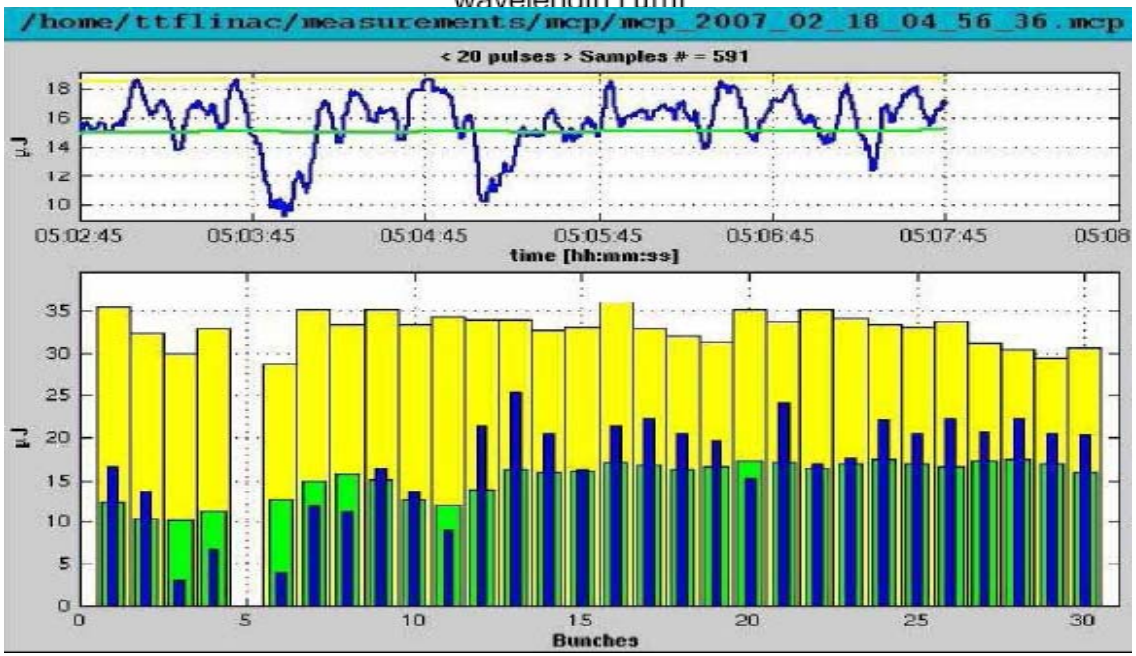




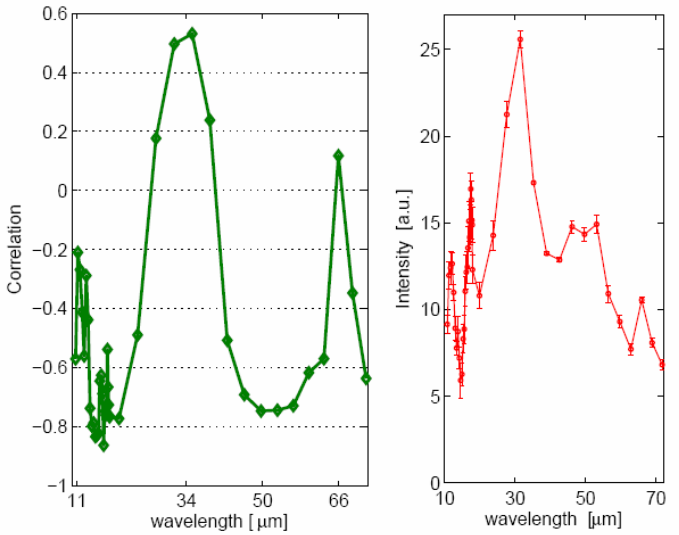


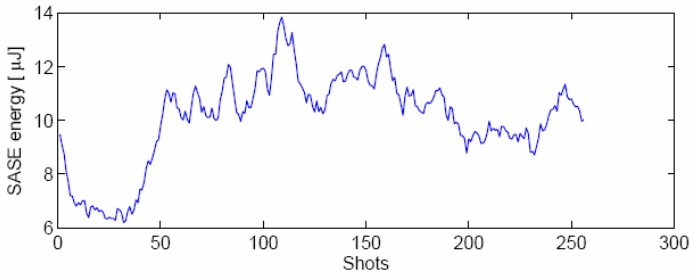
MCP-CTR spectrum correlation



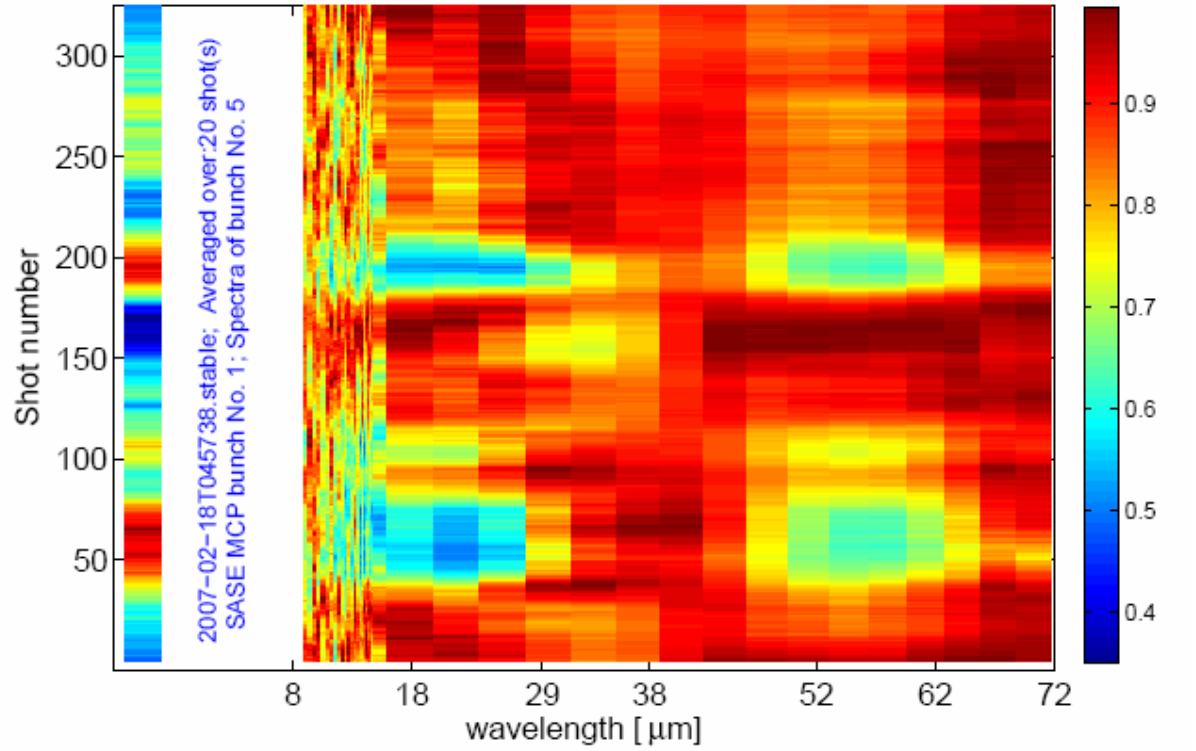


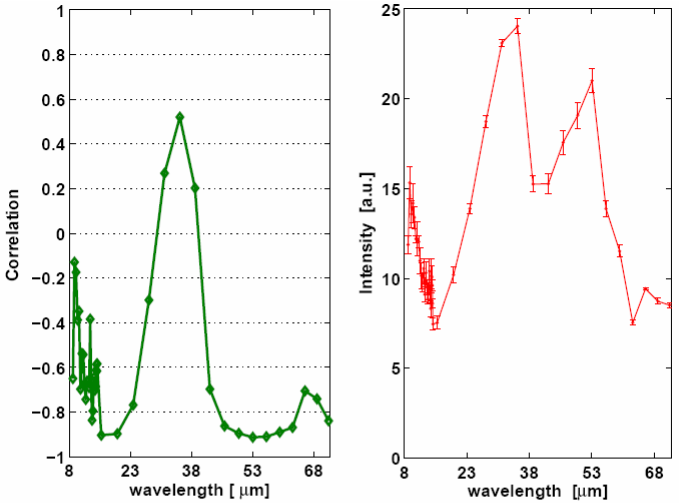
$$\cos\left(\hat{\vec{S}^c, \vec{L}^c}\right) = \frac{\vec{S}^c \cdot \vec{L}^c}{\left|\vec{S}^c\right| \left|\vec{L}^c\right|}$$

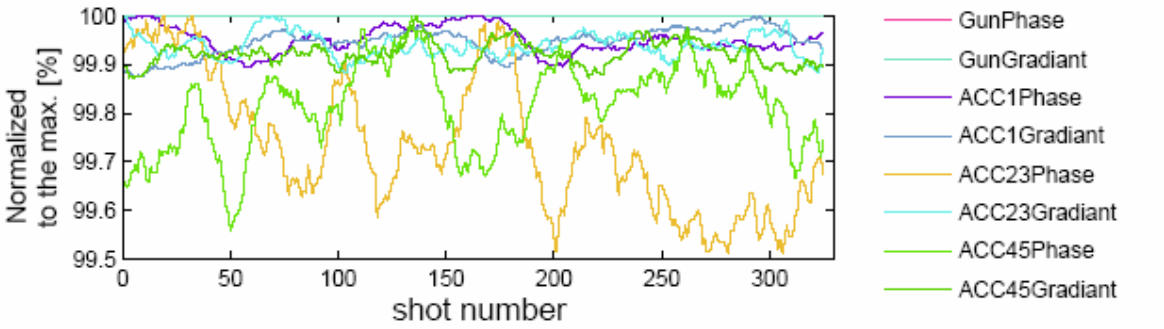


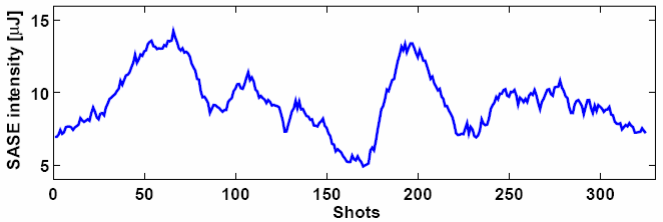


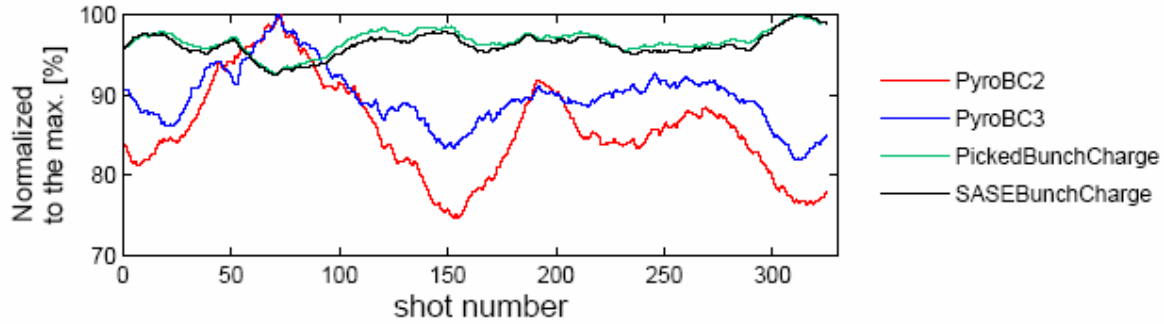
MCP-CTR spectrum correlation



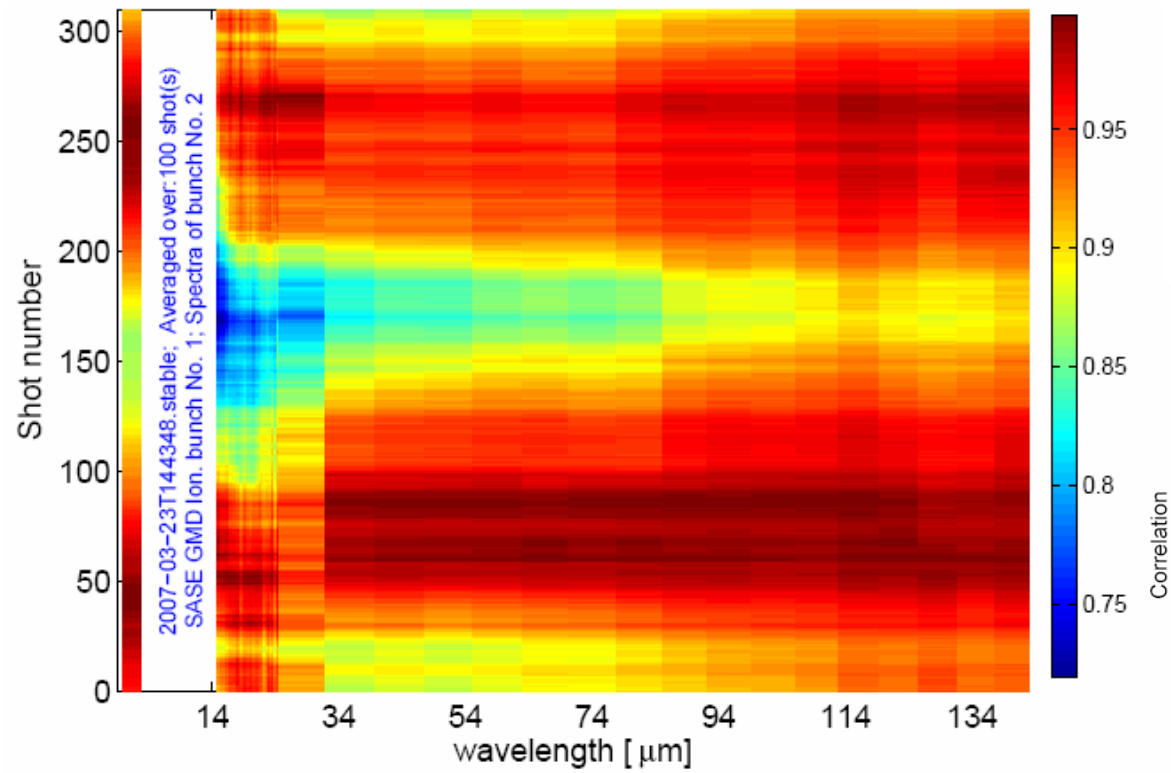


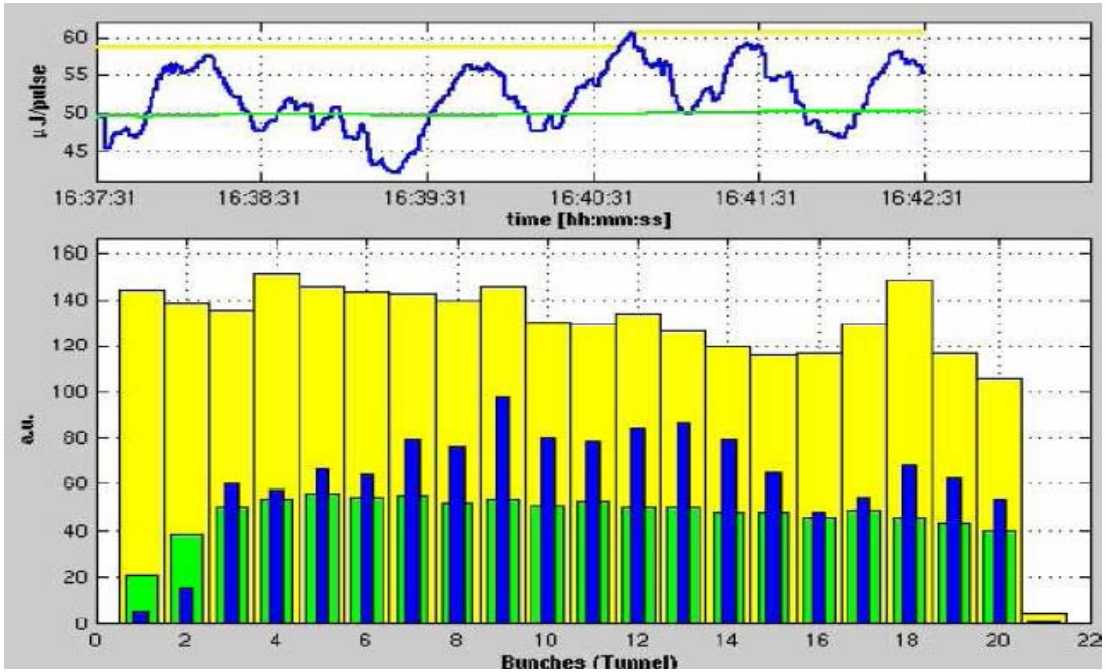


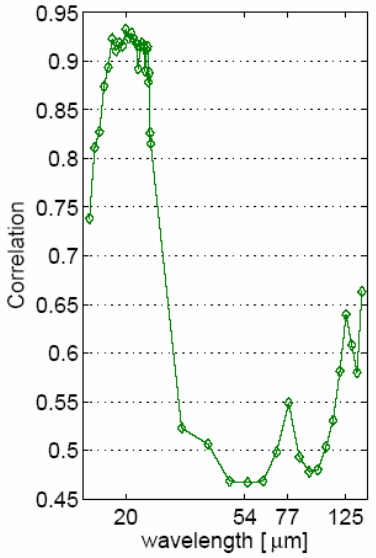


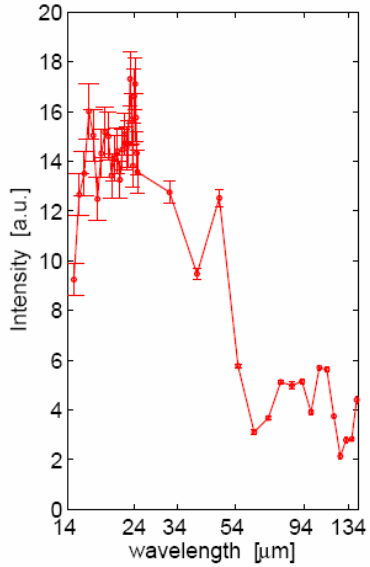


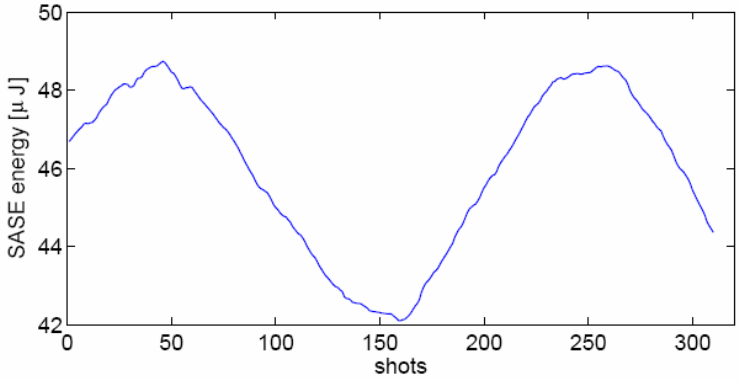
GMD-CTR spectrum correlation

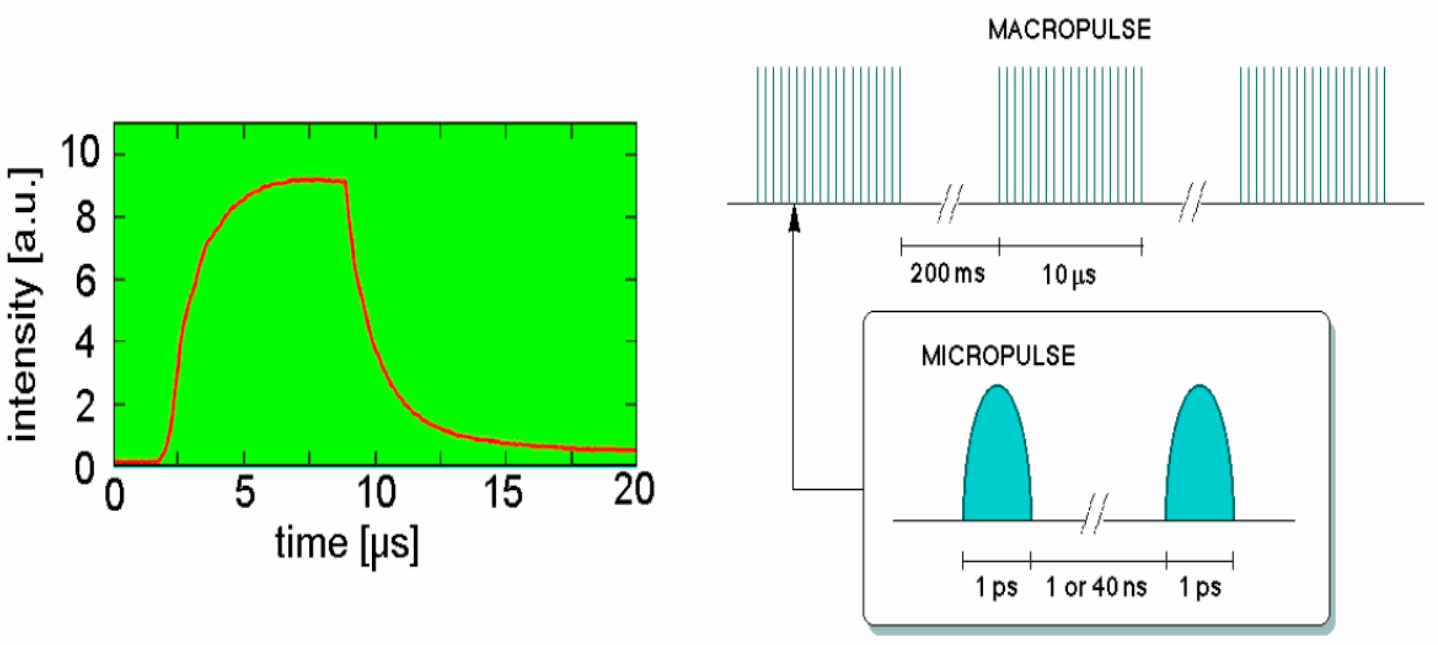


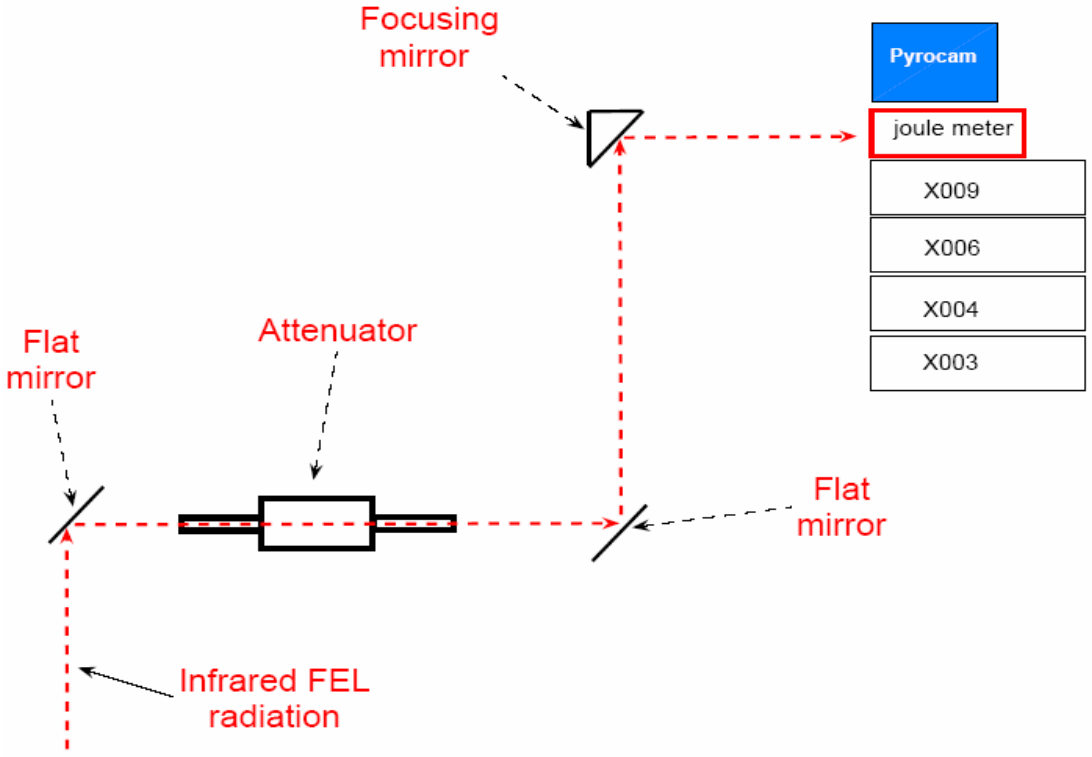




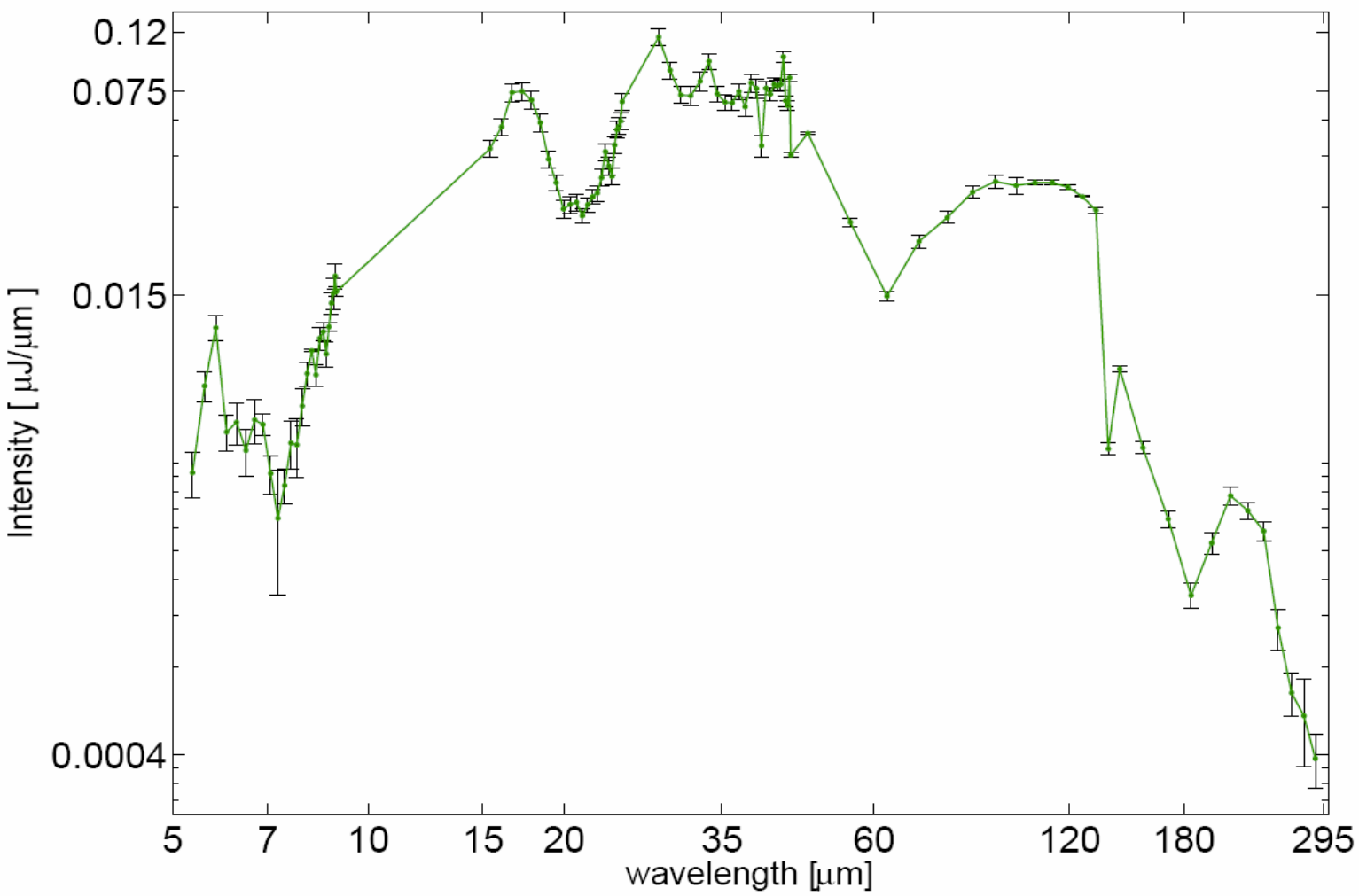




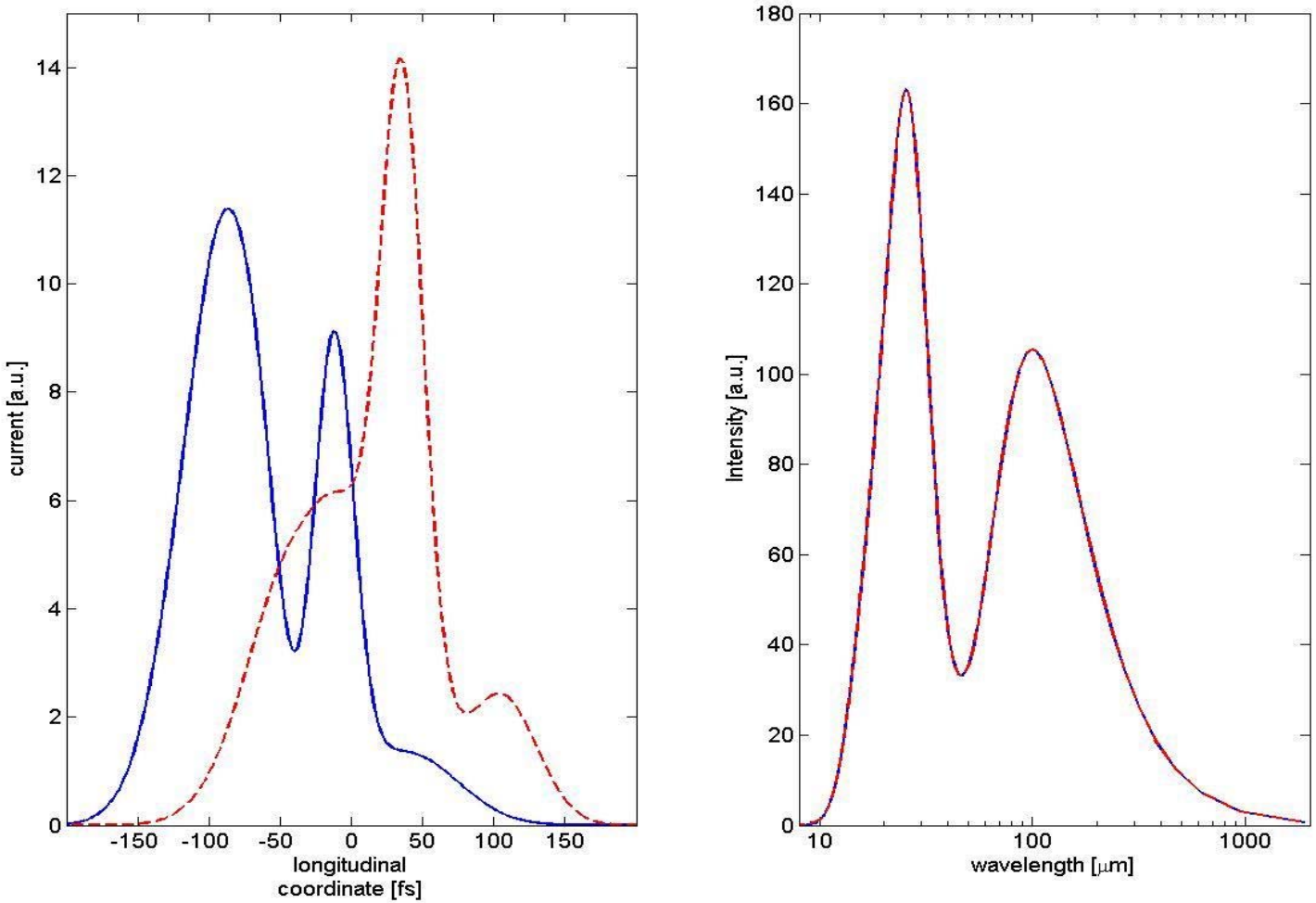

intensity [a.u.]
0
2
4
6
8
10
0
5
10
15
20
time [μs]
MACROPULSE
200 ms
10 μs
MICROPULSE
1 ps
1 or 40 ns
1 ps


Focusing mirror
Pyrocam
joule meter
X009
X006
X004
X003
Flat mirror
Attenuator
Flat mirror
Infrared FEL radiation

Combined broad-band spectrum

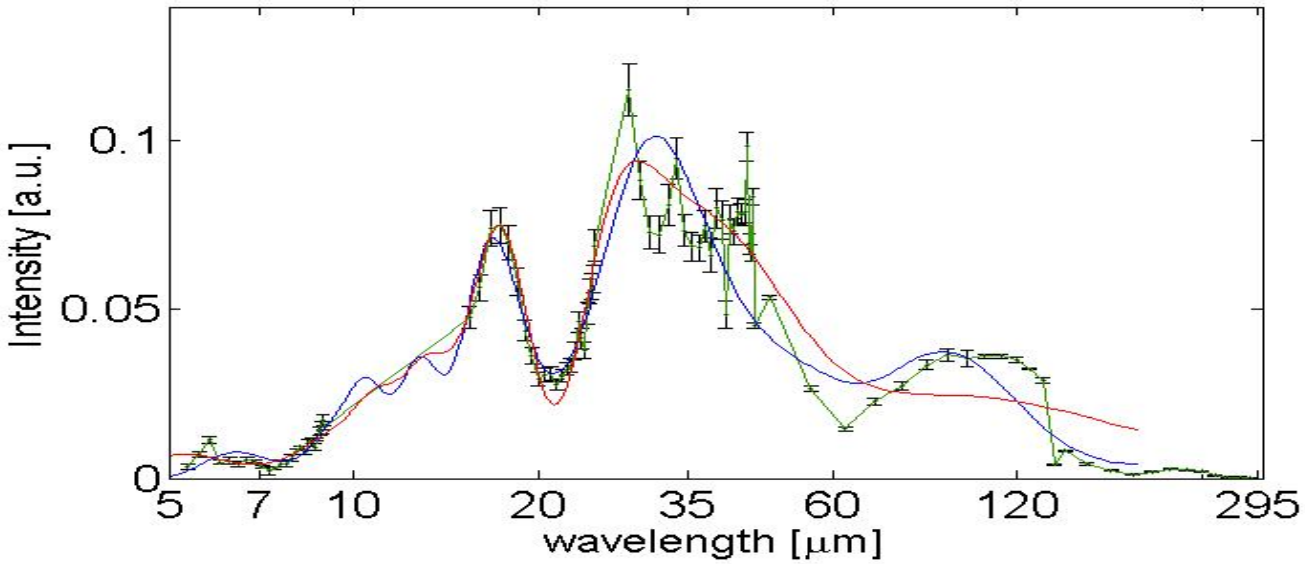


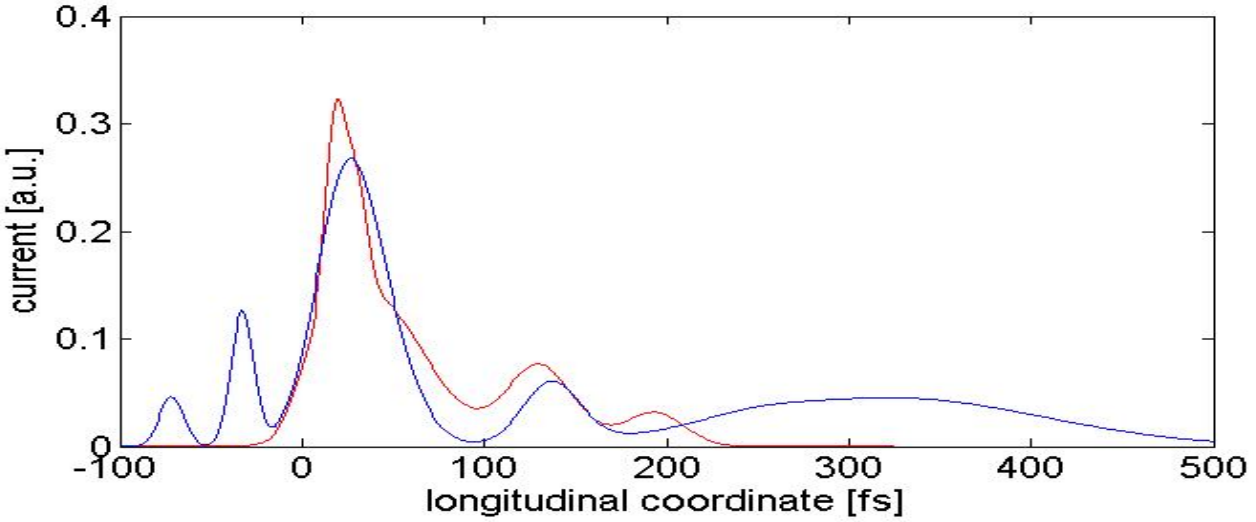
Time profiles degeneracy corresponding to a spectrum



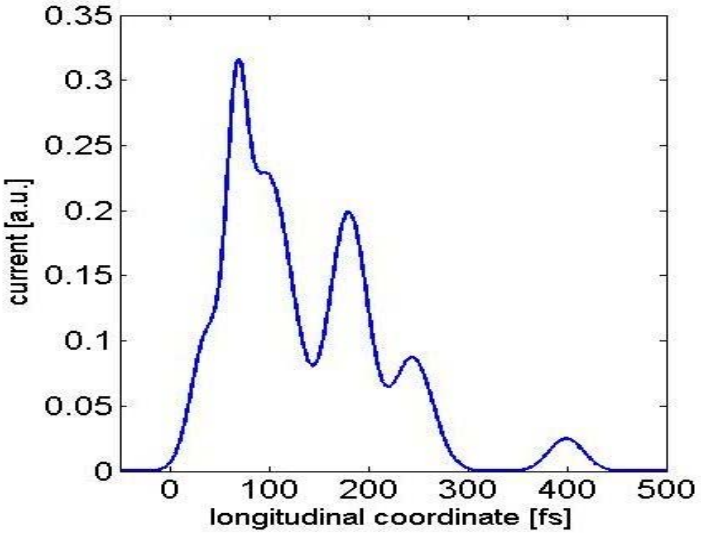
An example of two time domain profiles that fit to the same spectrum

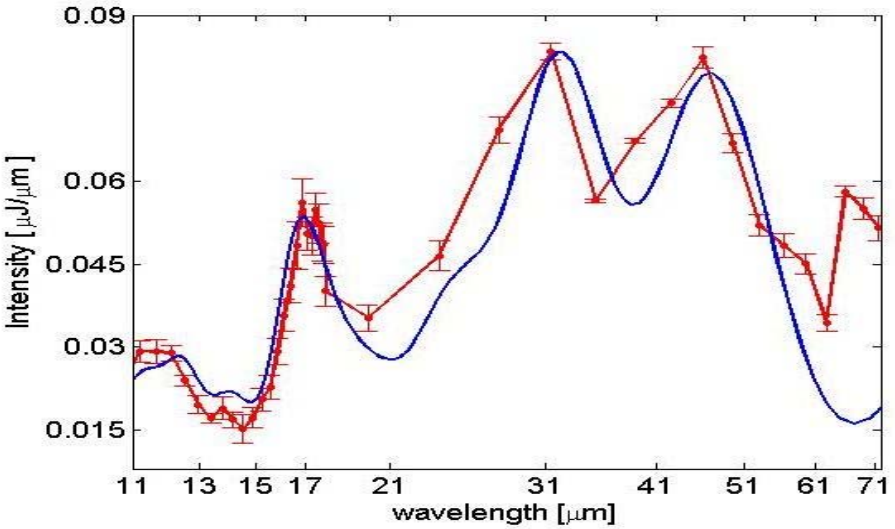
Bunch profile determination (~700 MeV)

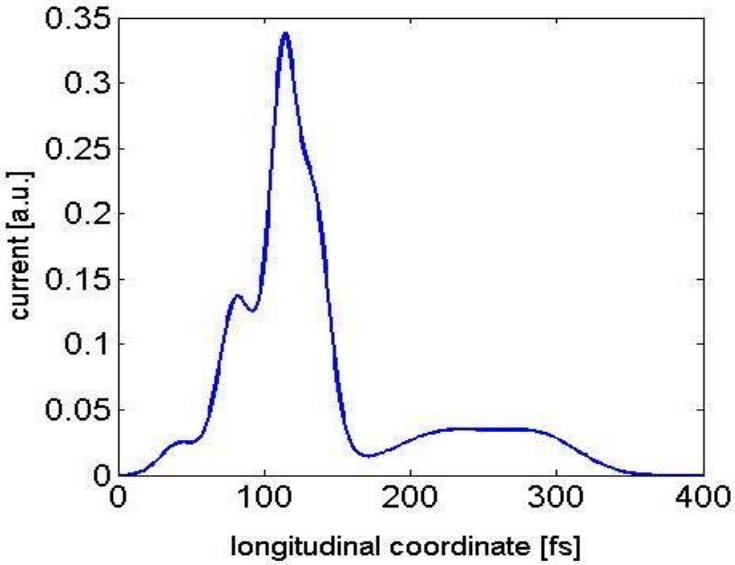


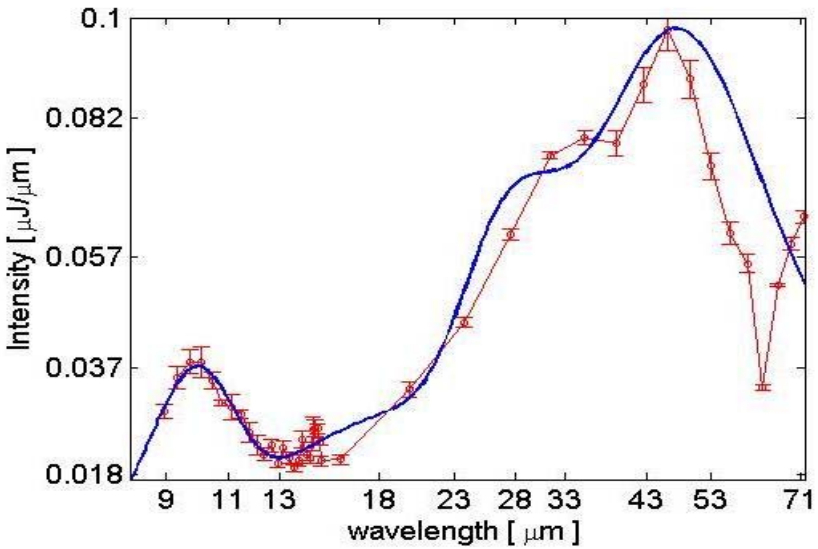


Bunch profile determination (~500 MeV)

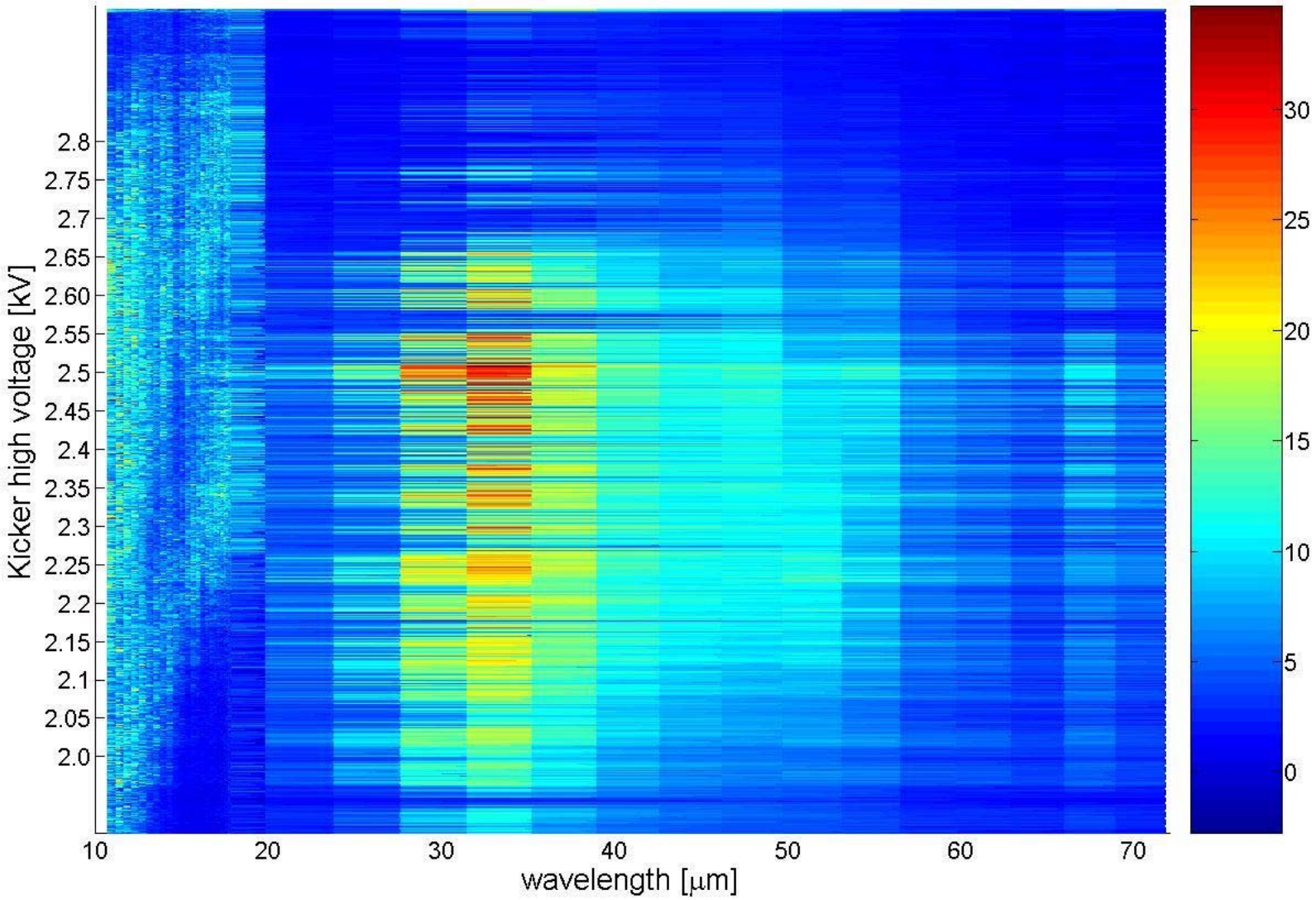




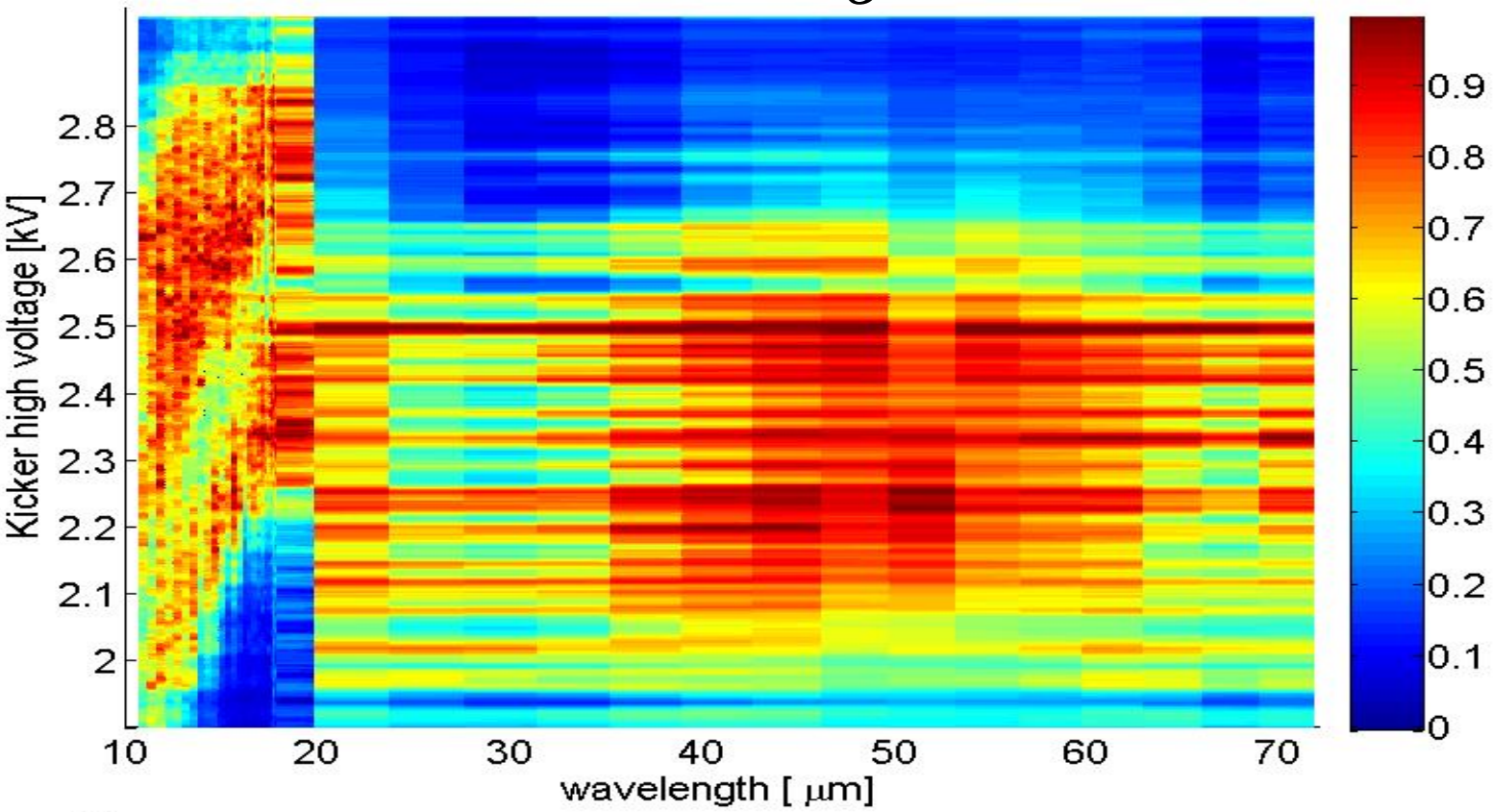


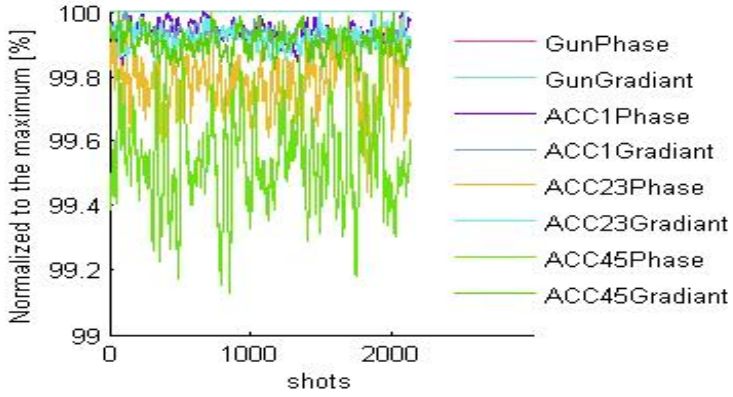


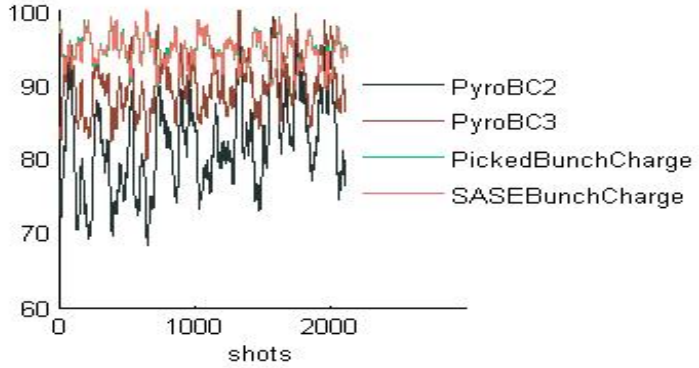
Kicker strength



Kicker strength







Summary

Compact two-stage single-shot spectrometer has been designed, mounted and used in several series of measurements.

The correlation studies show different wavelength ranges of the Coherent Transition Radiation spectra that correlate or anti-correlate to the SASE intensity.

For the bunch profile determination from a measured broad-band spectrum a fit method used.

The attempt to reconstruct the bunch time profile is probably not the most appropriate way of extracting the useful information contained in the spectra.

Outlook

Detector calibration has to be continued, in particular, for the short wavelengths below 35 µm.

Transmission gratings are not studied in terms of an experimental evaluation of different order efficiencies.

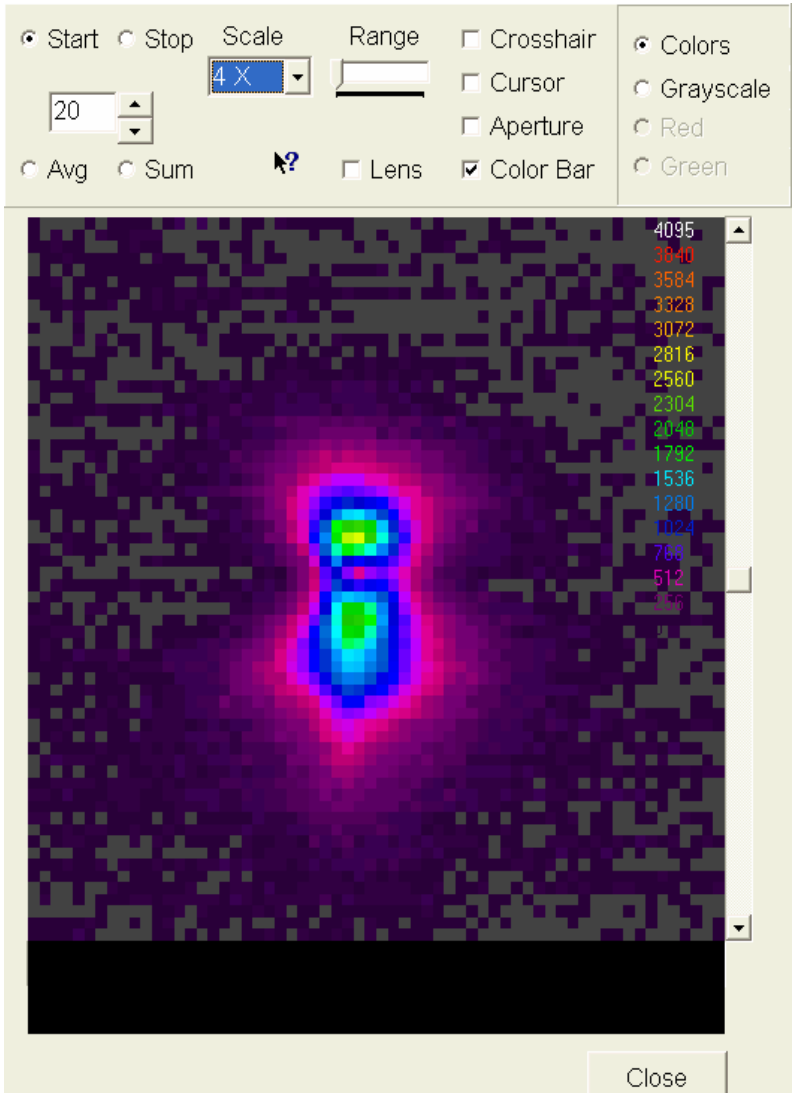
Having good experimental knowledge on these calibrations the entire spectrometer has to be calibrated to obtain a measured transfer function of the entire device. In a later step systematic errors have to be studied as well.

The ongoing efforts to setup a multi-stage device composed of more compact detection units could provide a wider wavelength range coverage in a single-shot mode.

……..

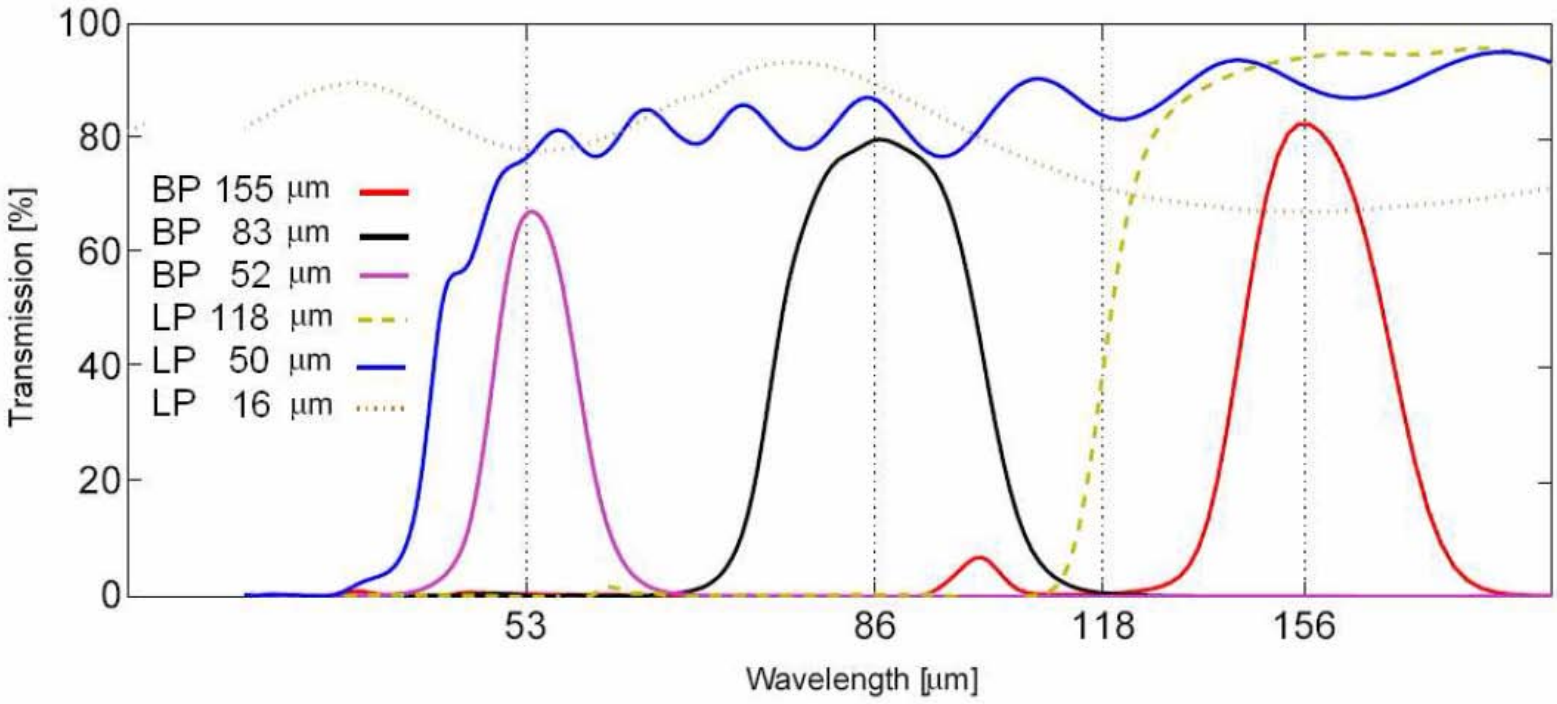
Thanks

Pyrocam



124x124 pixels
100 µm pitch
7 nJ per pixel noise limit

THz filters


100
80
60
40
20
0
Transmission [%]
BP 155 µm
BP 83 µm
BP 52 µm
LP 118 µm
LP 50 µm
LP 16 µm
53
86
118
156
Wavelength [µm]