Infrared Single Shot Diagnostics for the Longitudinal Profile of the Electron Bunches at FLASH

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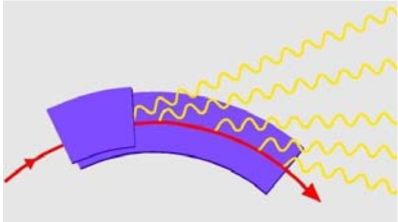
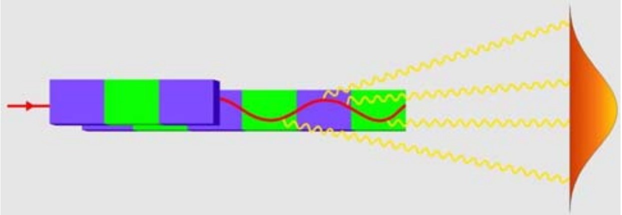
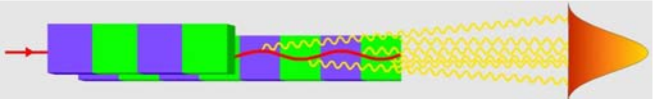
Tuesday 22 July 2008

Introduction



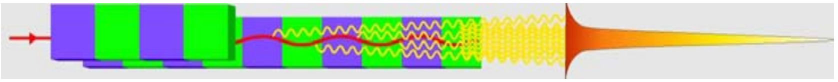


$$\omega_c = \frac{3eB\gamma^2}{2m}$$



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

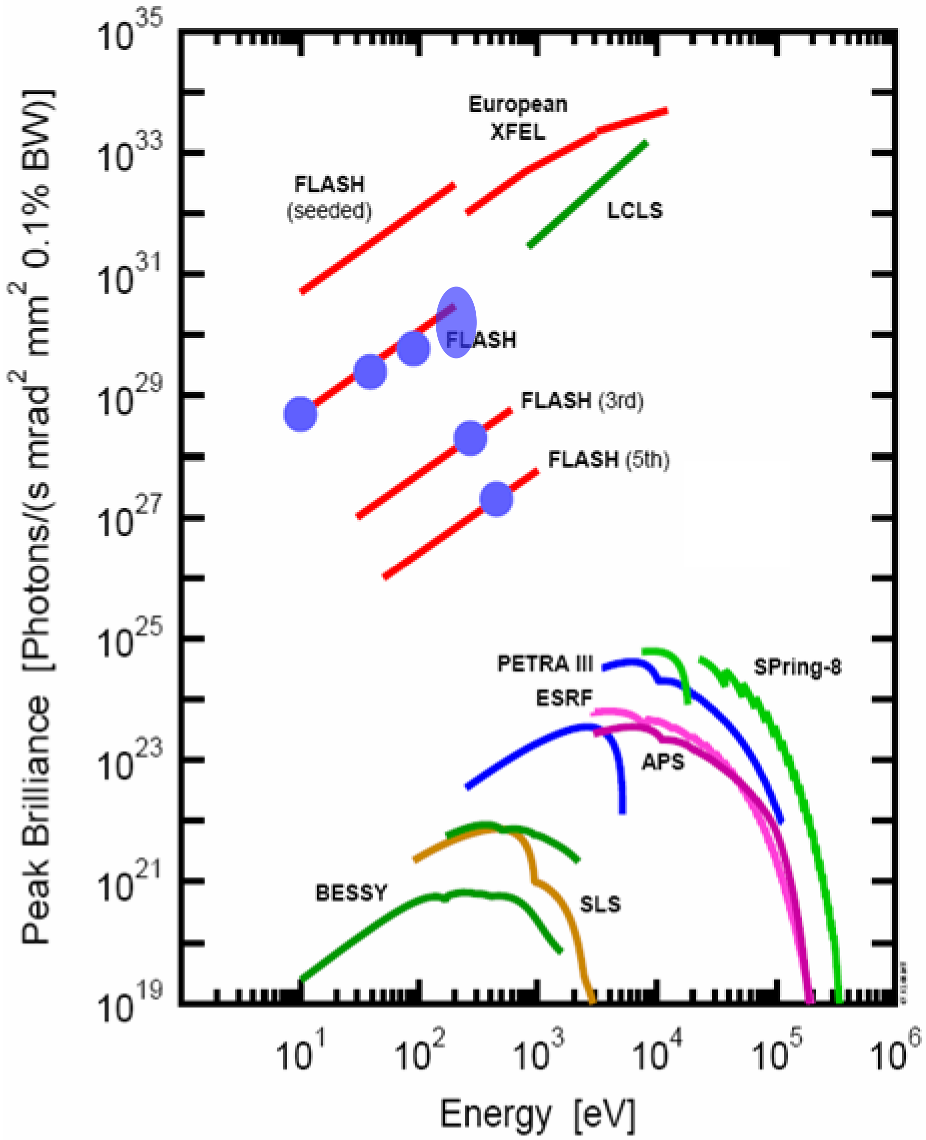
Free electron laser



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

$$I_N = N^2 I_1$$

Introduction



Very large number of electrons to be confined very close together → Hard to achieve in sub-micrometer wavelengths

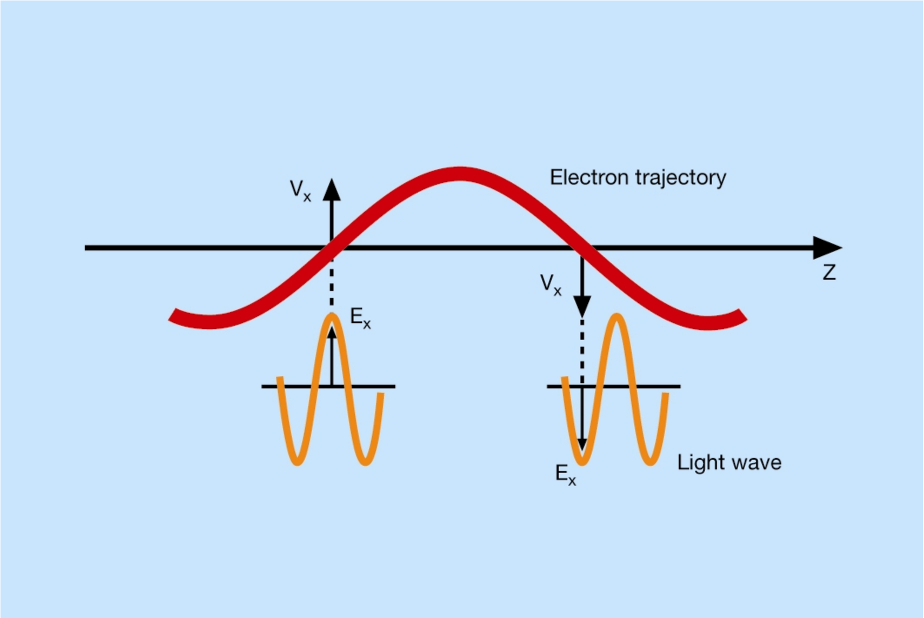
Modulating a relatively long electron beam into equally spaced bunch-lets "automatically" inside the undulator.

UV and X-ray range → "High gain FEL"

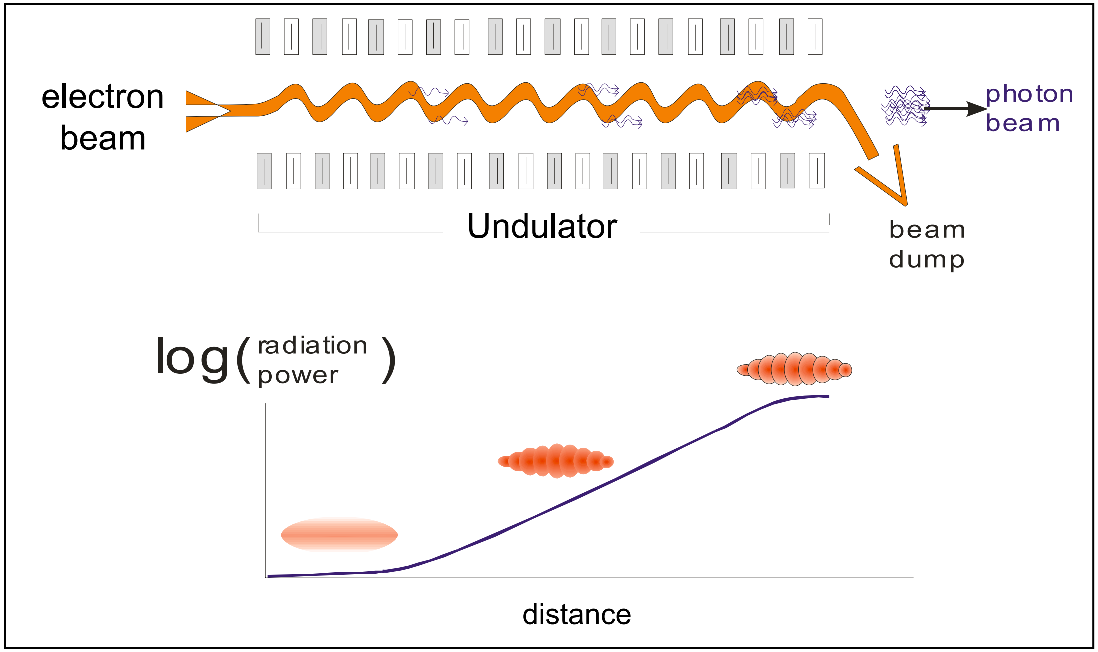
- FEL Special version starting from noise: Self-Amplified Spontaneous Emission (**SASE**)

- Seeding the electron bunches by an external laser inside undulator which is tuned to the seed laser wavelength.

How it works?



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



SASE FEL challenges

Electron beam parameters needed:

Gain Length:

$$L_g = \frac{1}{\sqrt{3}} \left[\frac{2mc\gamma^3 \sigma_r^{\ 2} \lambda_u}{\mu_0 e K^2 \hat{I}} \right]^{1/3}$$

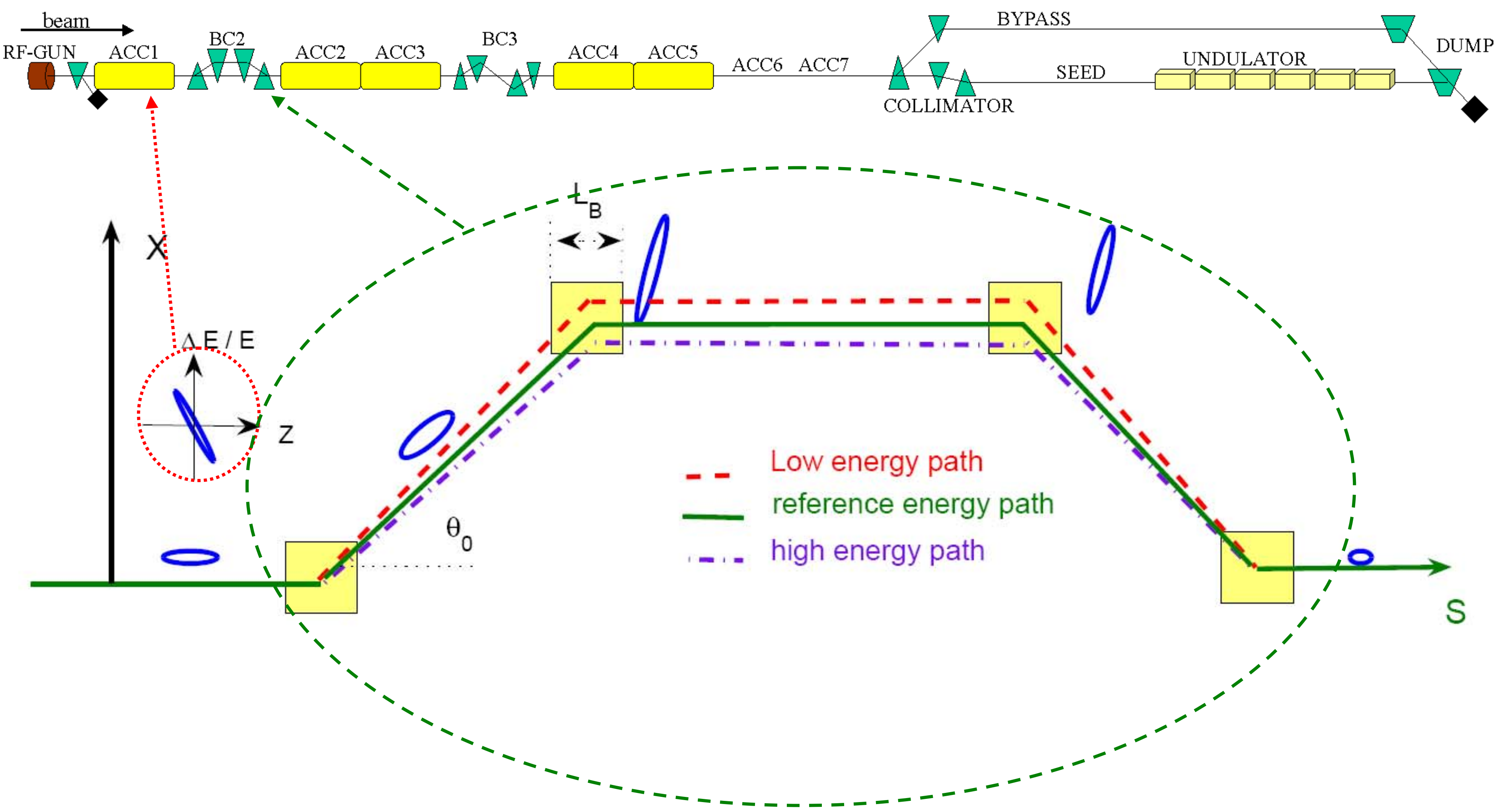
Beam transverse size

$\sigma_r \approx 50 \mu m$

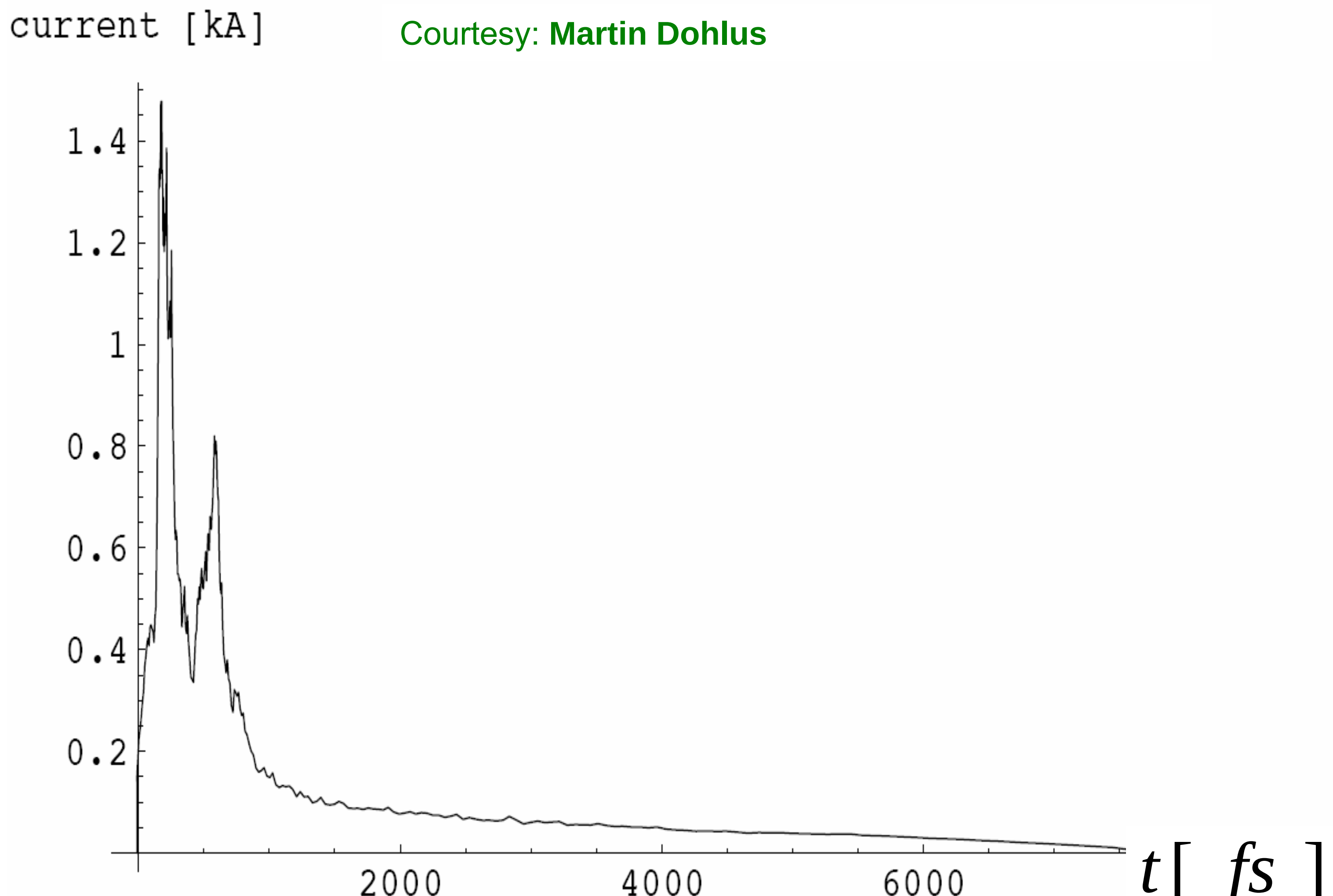
Peak current inside bunch

Î > 1 kA

Bunch compression



Courtesy: **Martin Dohlus**



Has to be diagnosed. How?

An ideal longitudinal diagnostics tool should be

- single shot (to monitor shot to shot fluctuations)
- broad-band, and with high resolution

Additional requirements would be:

- easy to operate and maintain
- compact and easy to incorporate in different parts of the machine
- operating independent of machine parameter changes

Coherent radiation diagnostics

Coherent Radiation

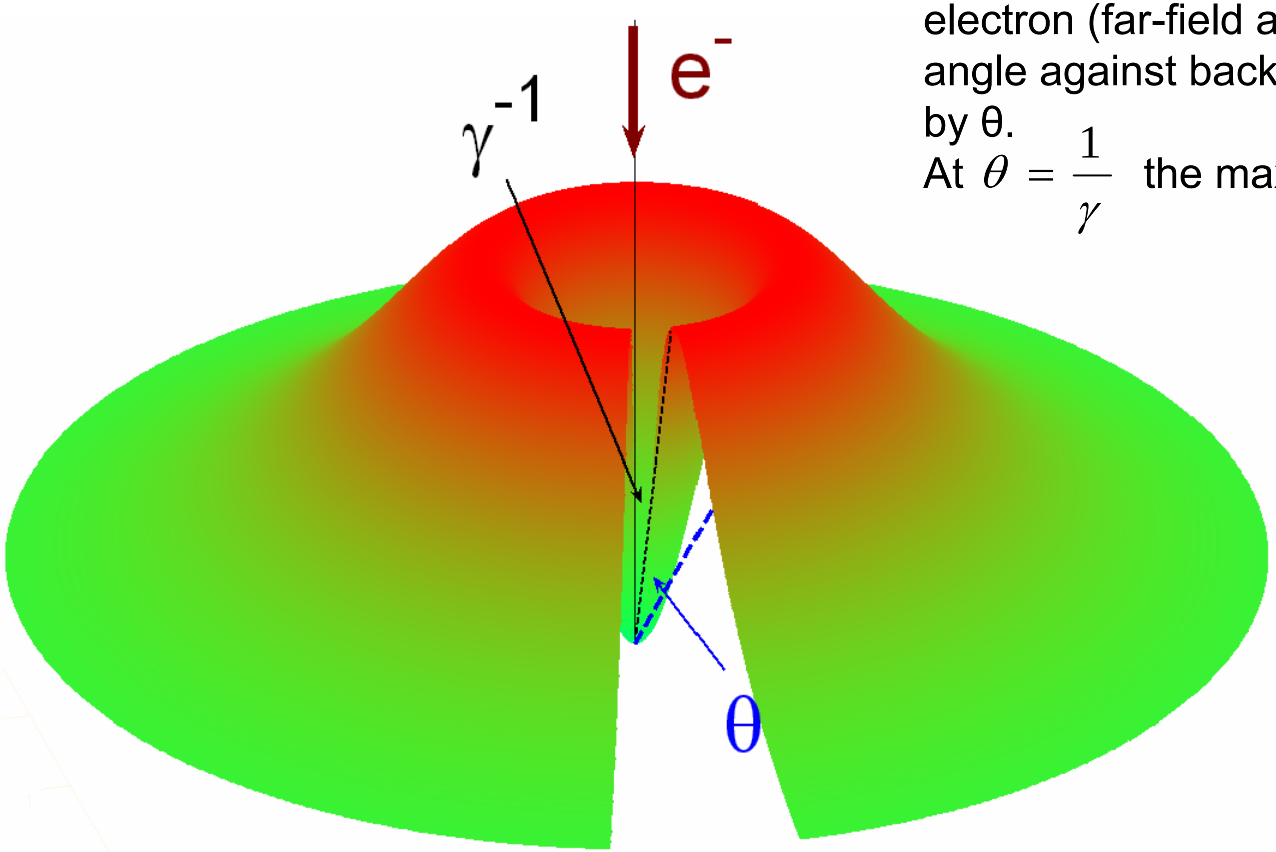
$$F_{long}(\omega) = \int_{bunch} \tilde{\rho}(t) \exp(-i\omega t)\, dt$$

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)*

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



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 (finite screen size)

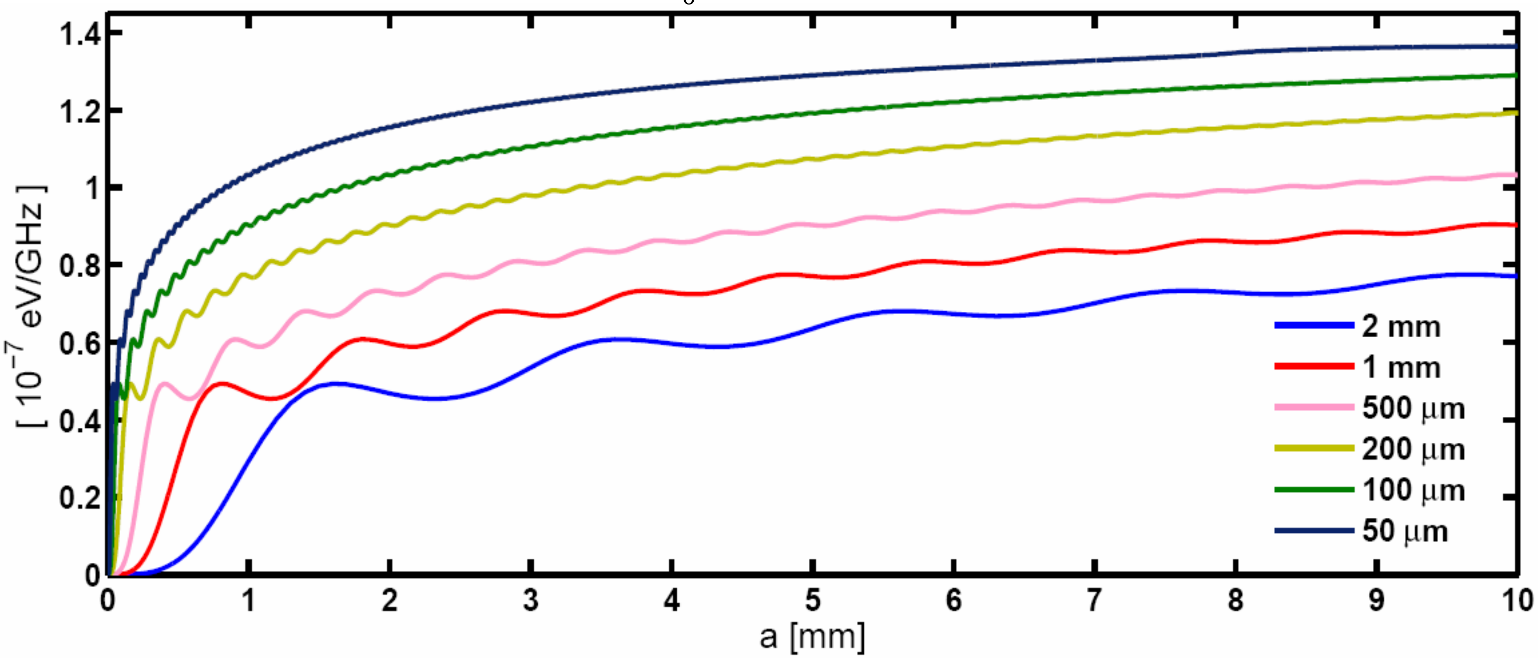
(Transition radiation of an electron bunch is described based on : TESLA report 2005-15, S. Casalbuoni et al.)

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

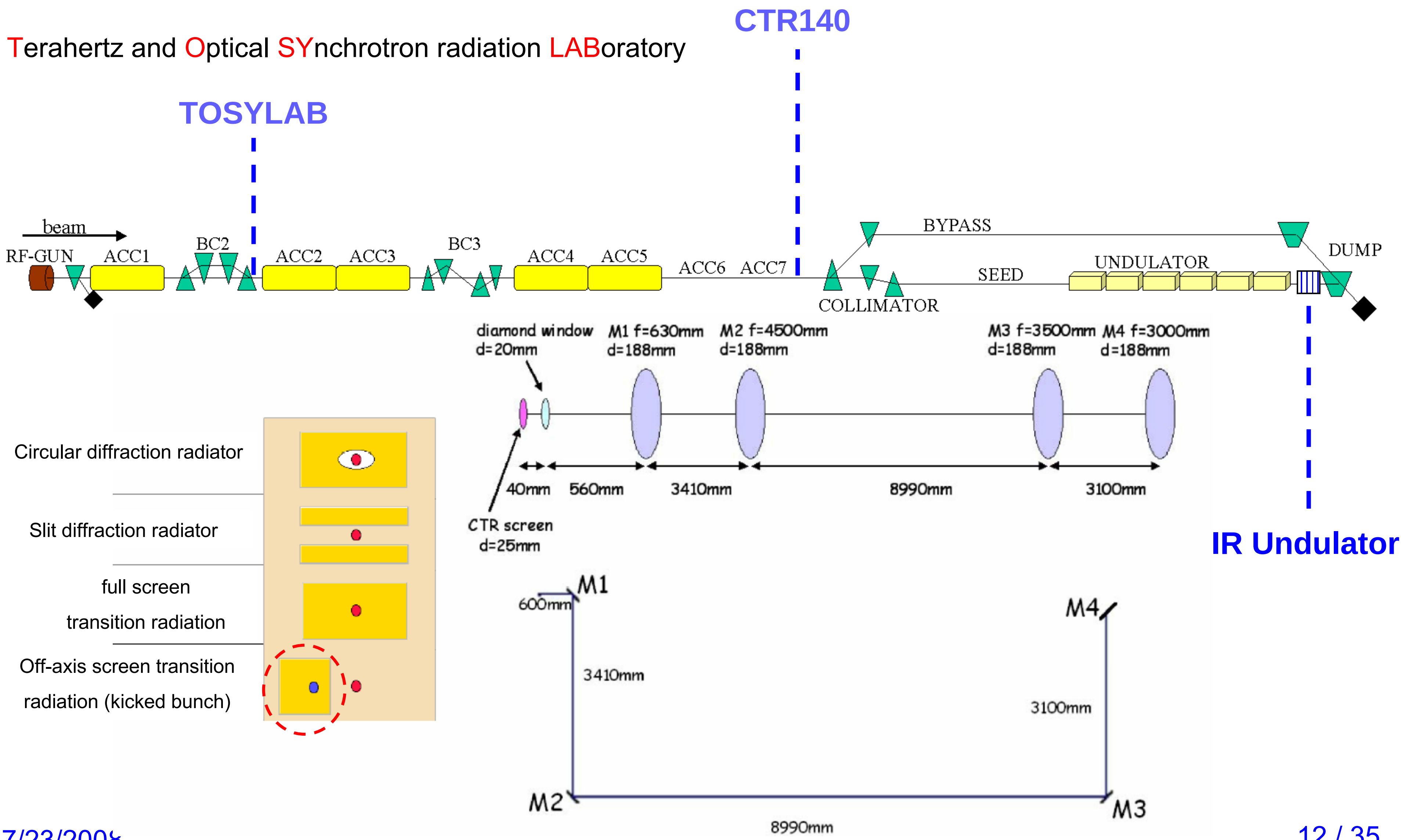
$$T_a(\theta,\omega) = \frac{\omega a}{c\beta\gamma}J_0\left(\frac{\omega a \sin\theta}{c}\right)K_1\left(\frac{\omega a}{c\beta\gamma}\right) + \frac{\omega a}{c\beta^2\gamma^2\sin\theta}J_1\left(\frac{\omega a \sin\theta}{c}\right)K_0\left(\frac{\omega a}{c\beta\gamma}\right)$$

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.

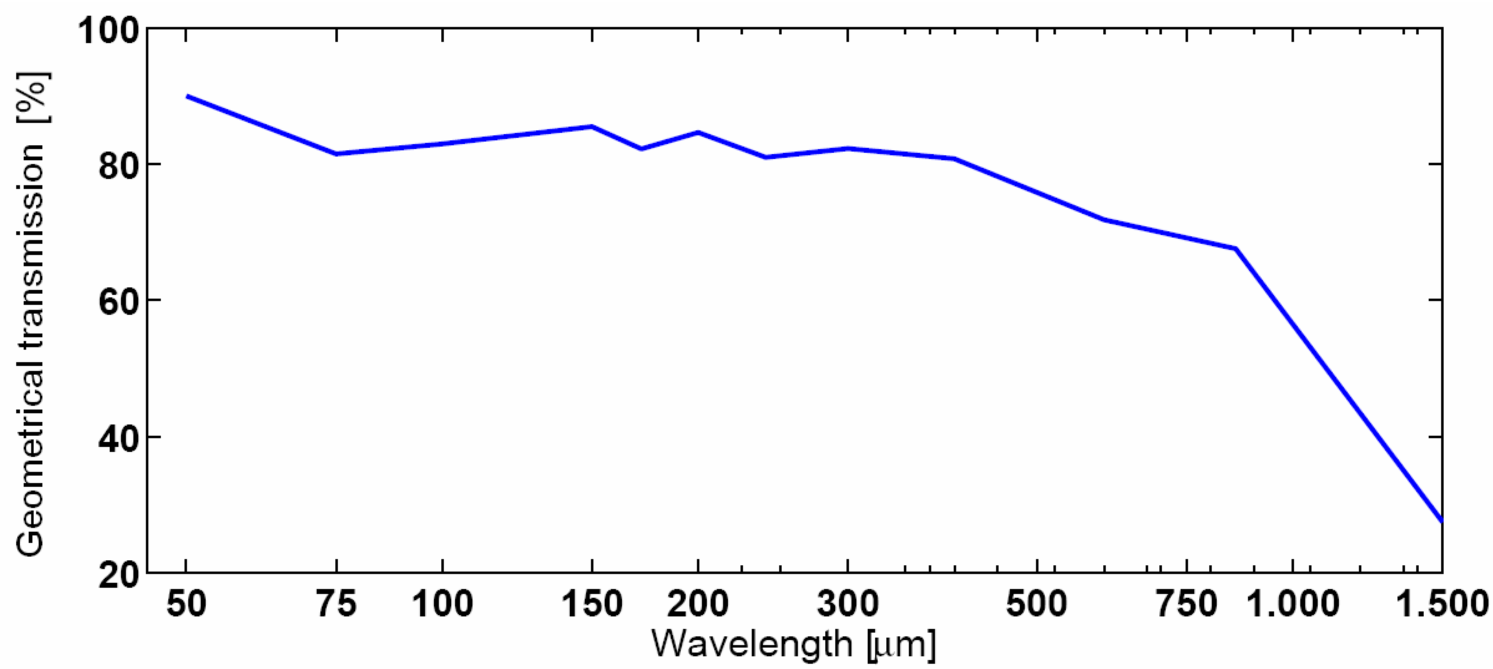
$$\frac{e^2}{2\pi^2\varepsilon_0 c}(\ln\gamma + \ln 2 - 0.5)$$



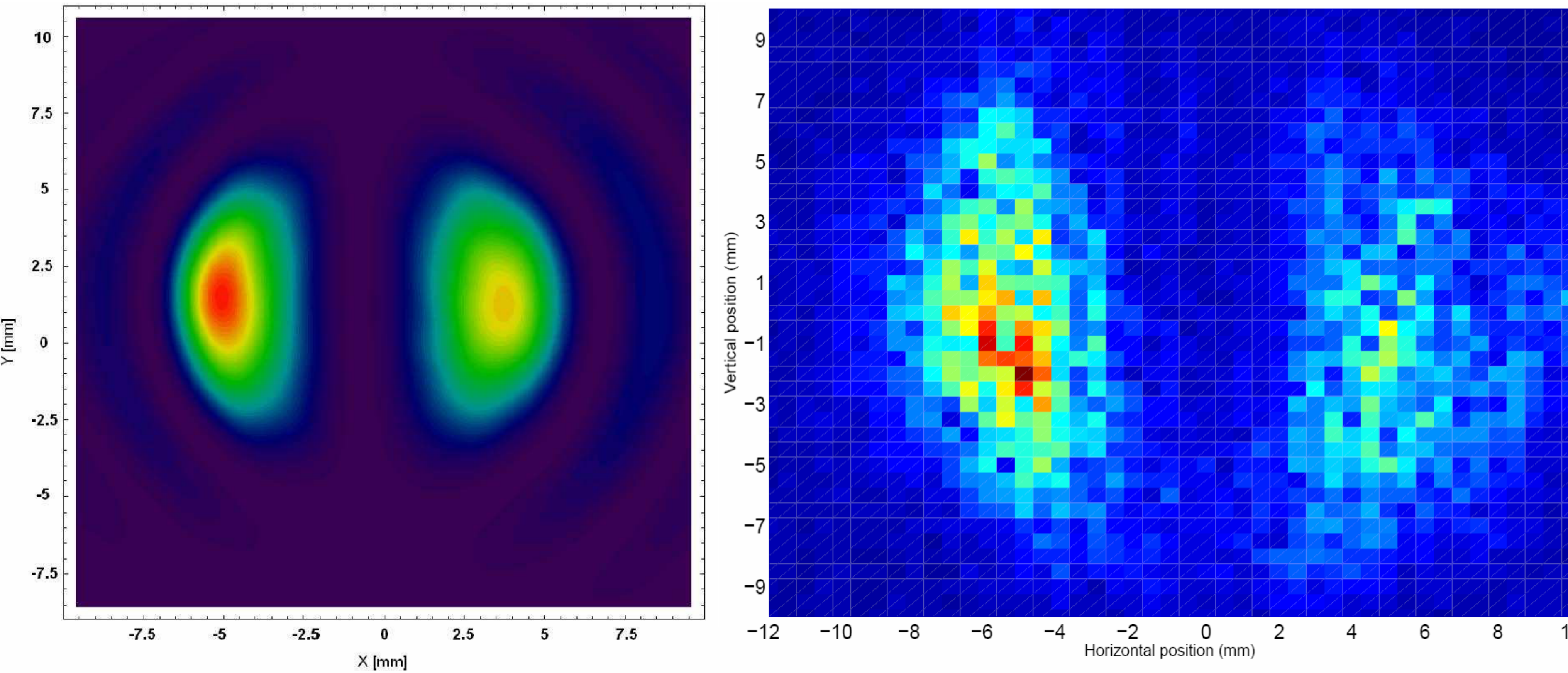
FLASH layout and infrared radiation beam-lines



THz-Transport and THz-Beamline (CTR140)



Transverse profile

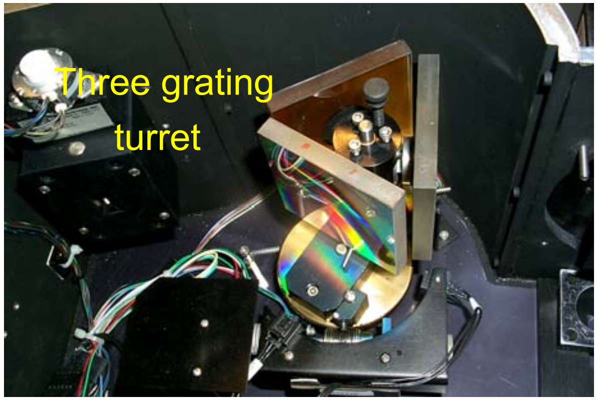


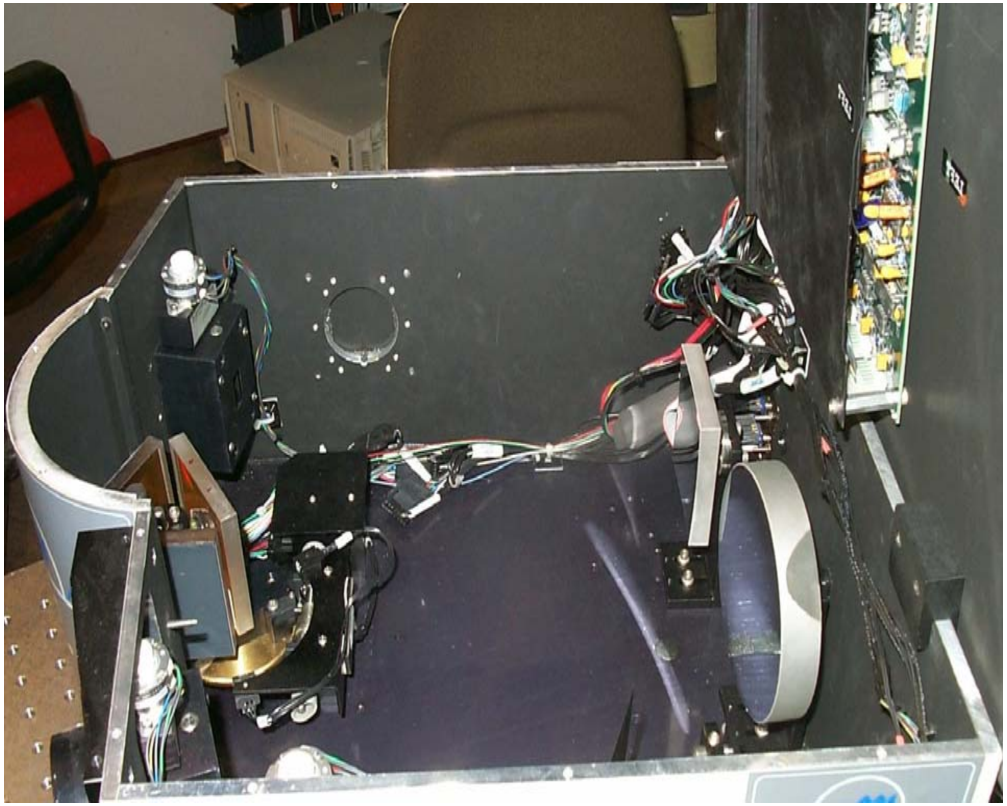
Horizontal pol. 50 µm wavelength

What type of spectrometer?

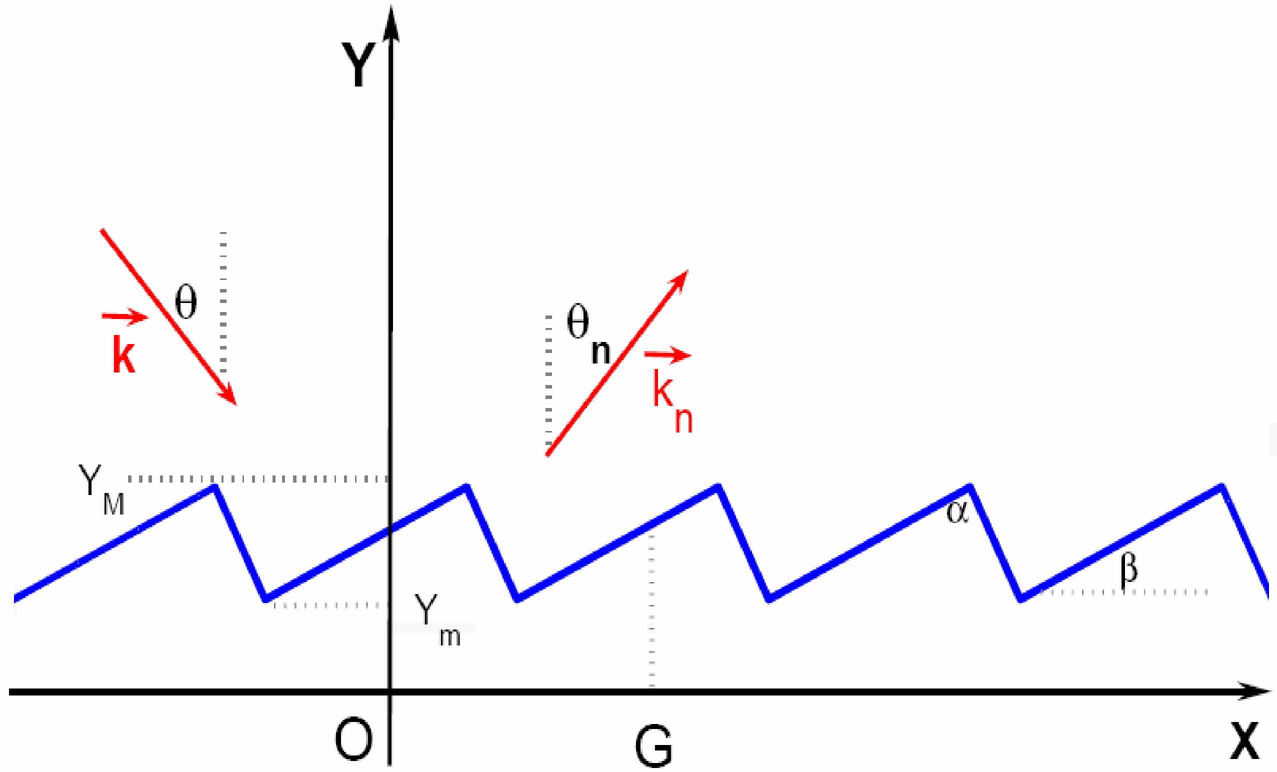
Why grating spectrometers?

Why not commercial grating-spectrometers?

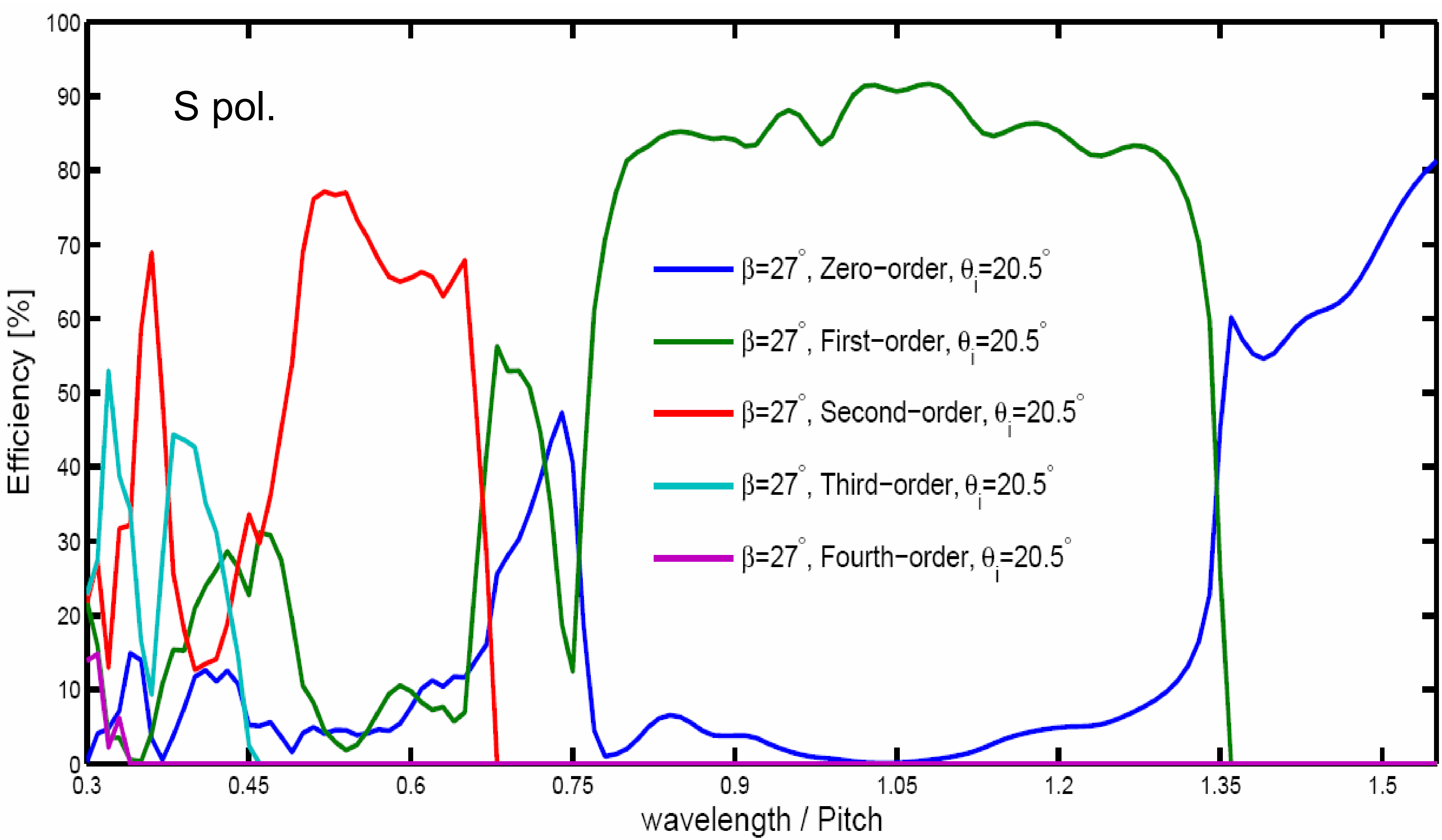




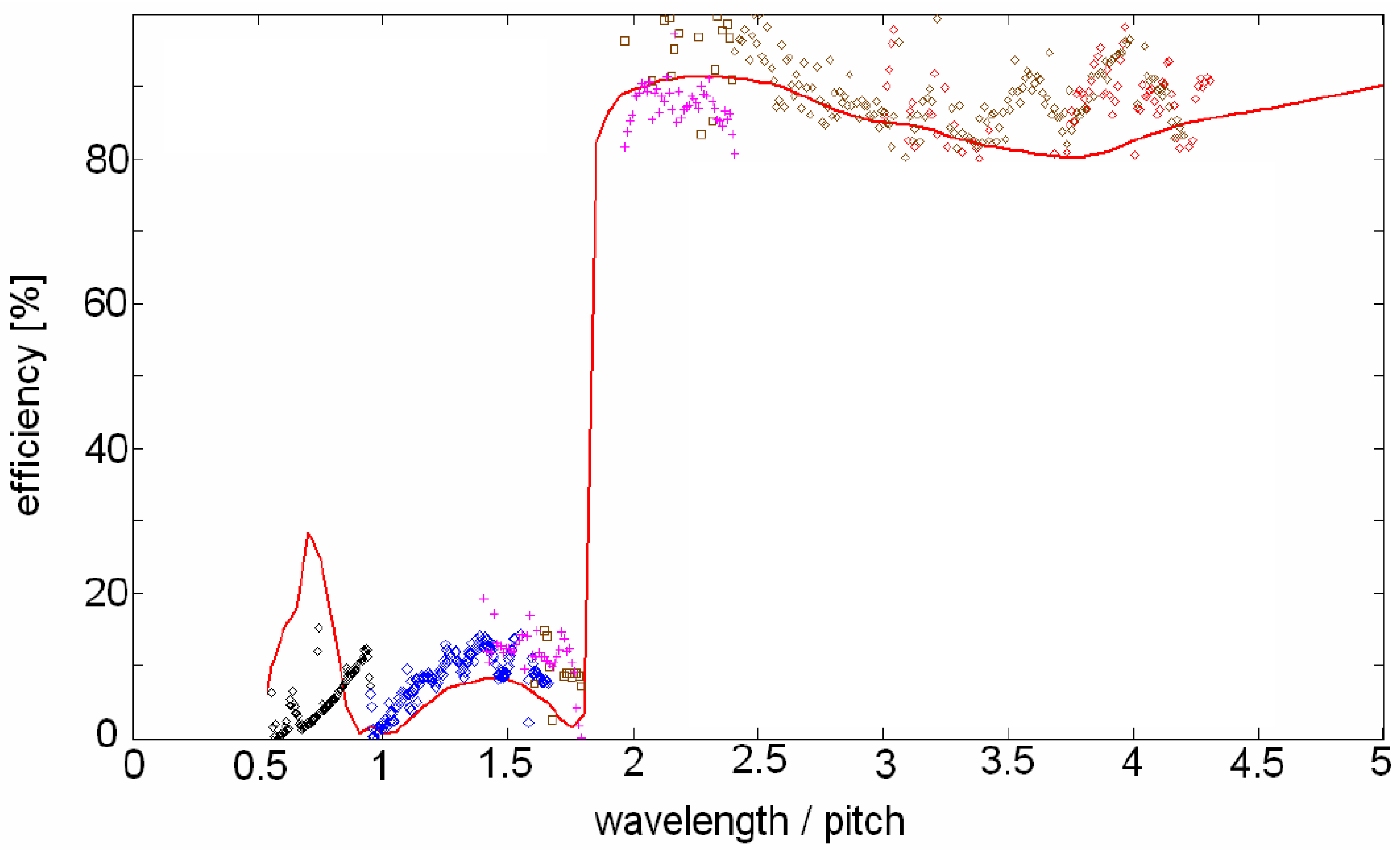
Reflectance gratings



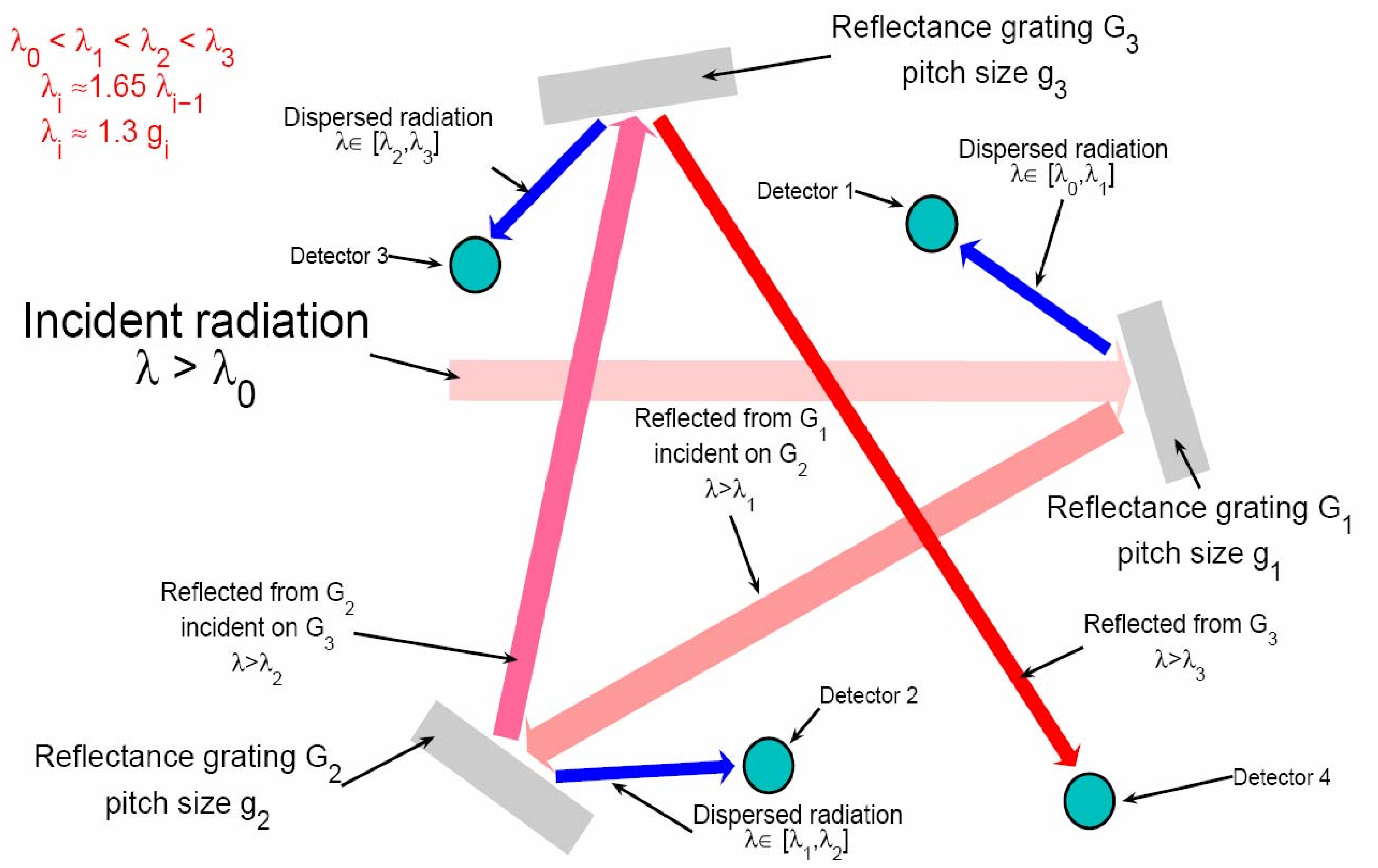
Efficiencies and distribution



Proof of principle experiment

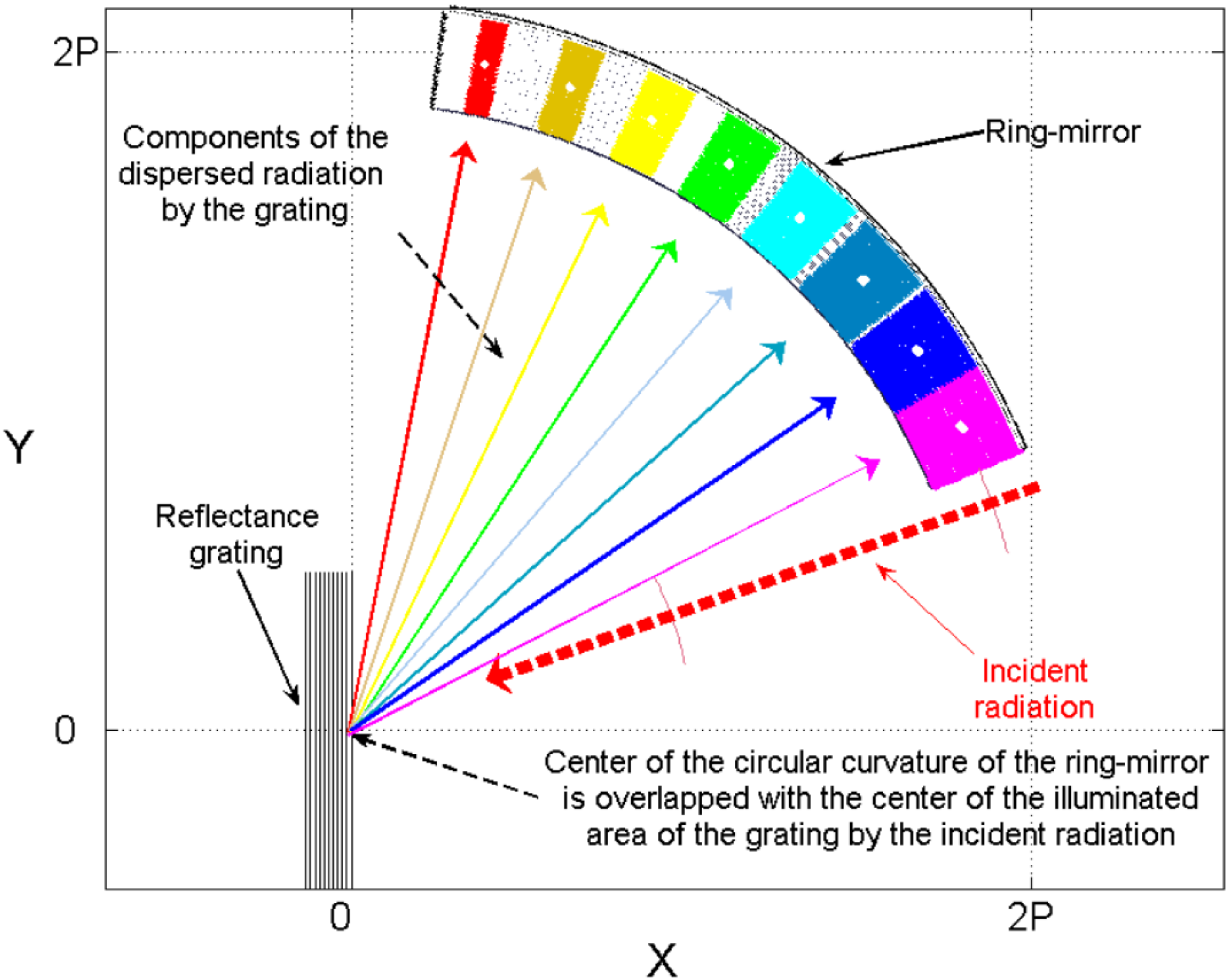


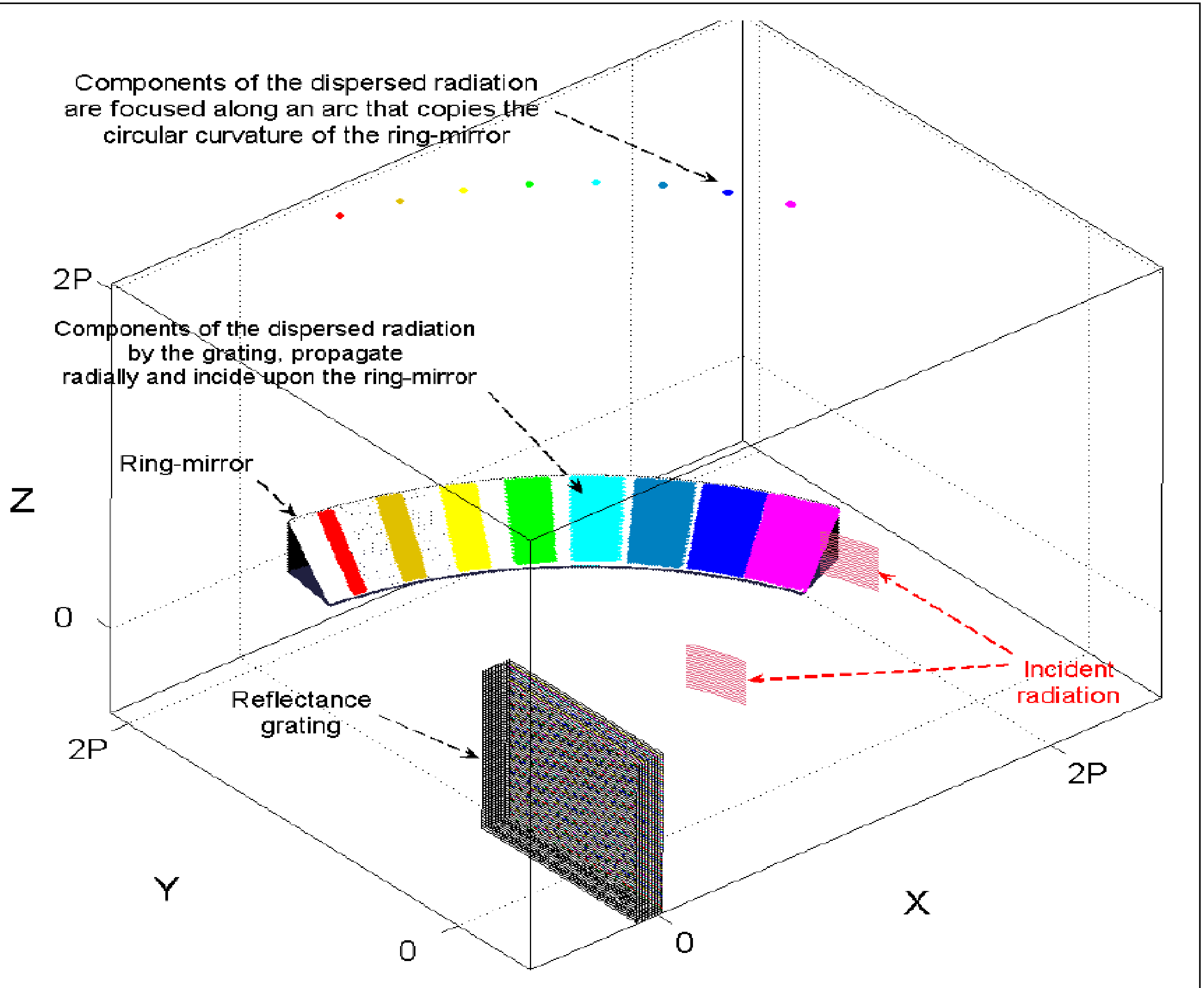
Staging



$\lambda_0 < \lambda_1 < \lambda_2 < \lambda_3$
$\lambda_i \approx 1.65\ \lambda_{i-1}$
$\lambda_i \approx 1.3\ g_i$
Reflectance grating G_3
pitch size g_3
Dispersed radiation
$\lambda \in [\lambda_2, \lambda_3]$
Dispersed radiation
$\lambda \in [\lambda_0, \lambda_1]$
Detector 1
Detector 3
Incident radiation
$\lambda > \lambda_0$
Reflected from G_1
incident on G_2
$\lambda > \lambda_1$
Reflectance grating G_1
pitch size g_1
Reflected from G_2
incident on G_3
$\lambda > \lambda_2$
Reflected from G_3
$\lambda > \lambda_3$
Detector 2
Detector 4
Reflectance grating G_2
pitch size g_2
Dispersed radiation
$\lambda \in [\lambda_1, \lambda_2]$

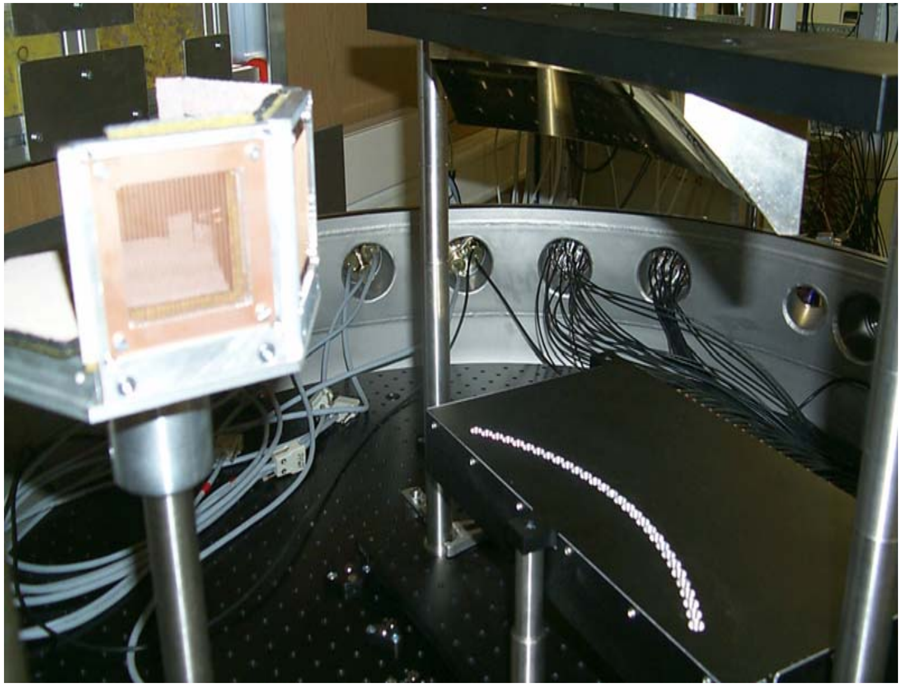
Collecting optics

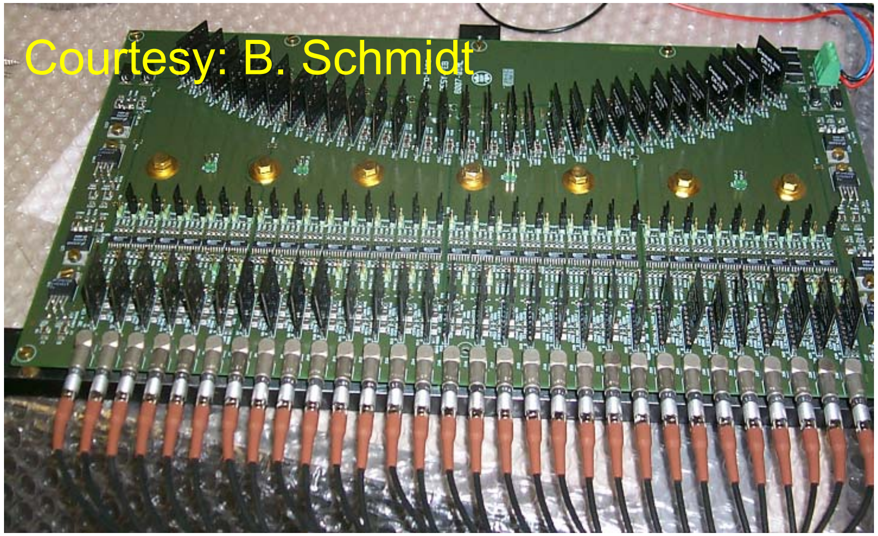


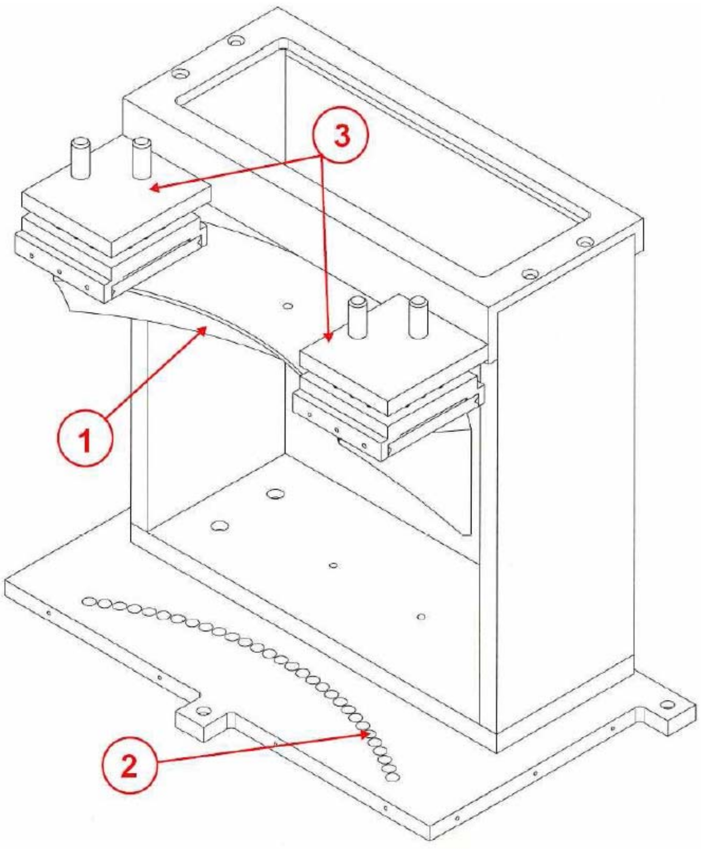


Components of the dispersed radiation
are focused along an arc that copies the
circular curvature of the ring-mirror
2P
Components of the dispersed radiation
by the grating, propagate
radially and incide upon the ring-mirror
Ring-mirror
Z
0
Incident
radiation
Reflectance
grating
2P
2P
Y
X
0
0

Next achievements

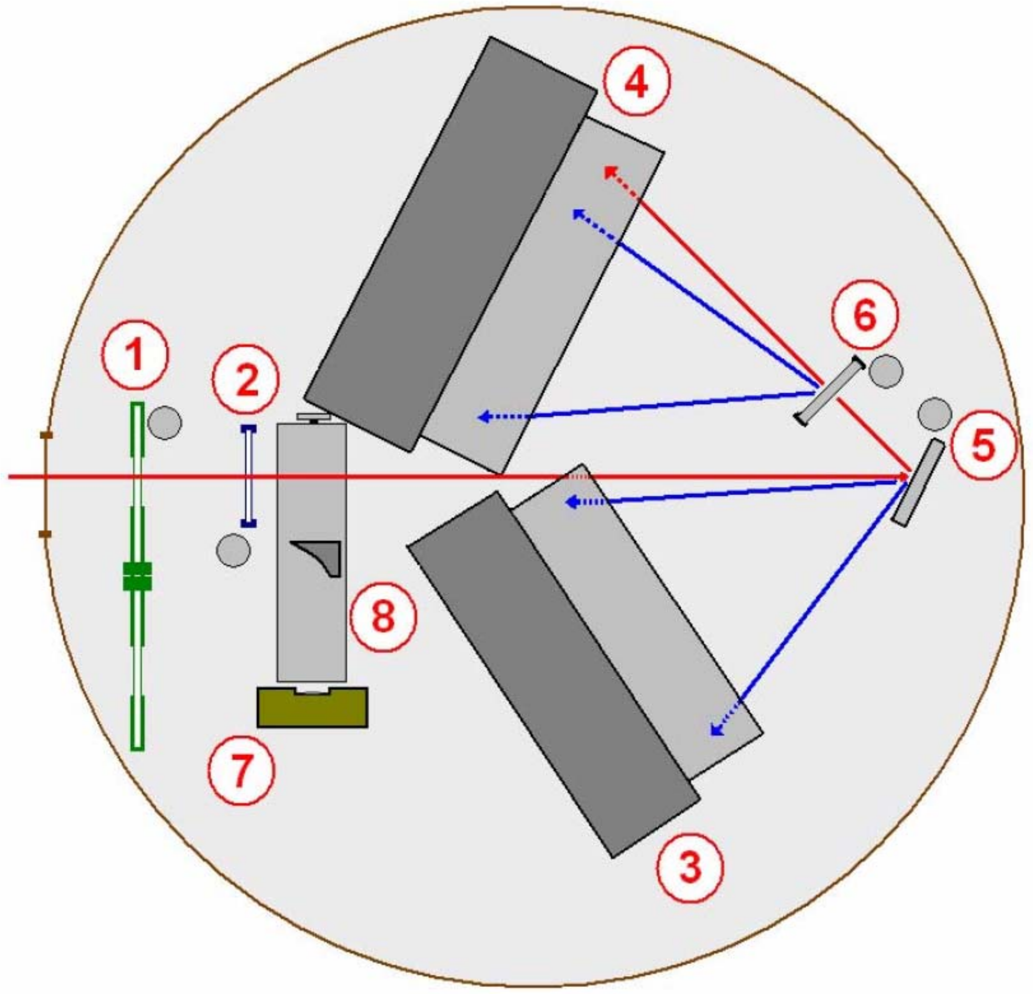






1- Ring-mirror
2- Collecting cones
3- Flat mirror holders

Two-stage multi-channel spectrometer



1- THz-filters (remote controlled)

2- Polarizer (remote controlled)

3- Reflectance grating stage

4- Transmission grating stage

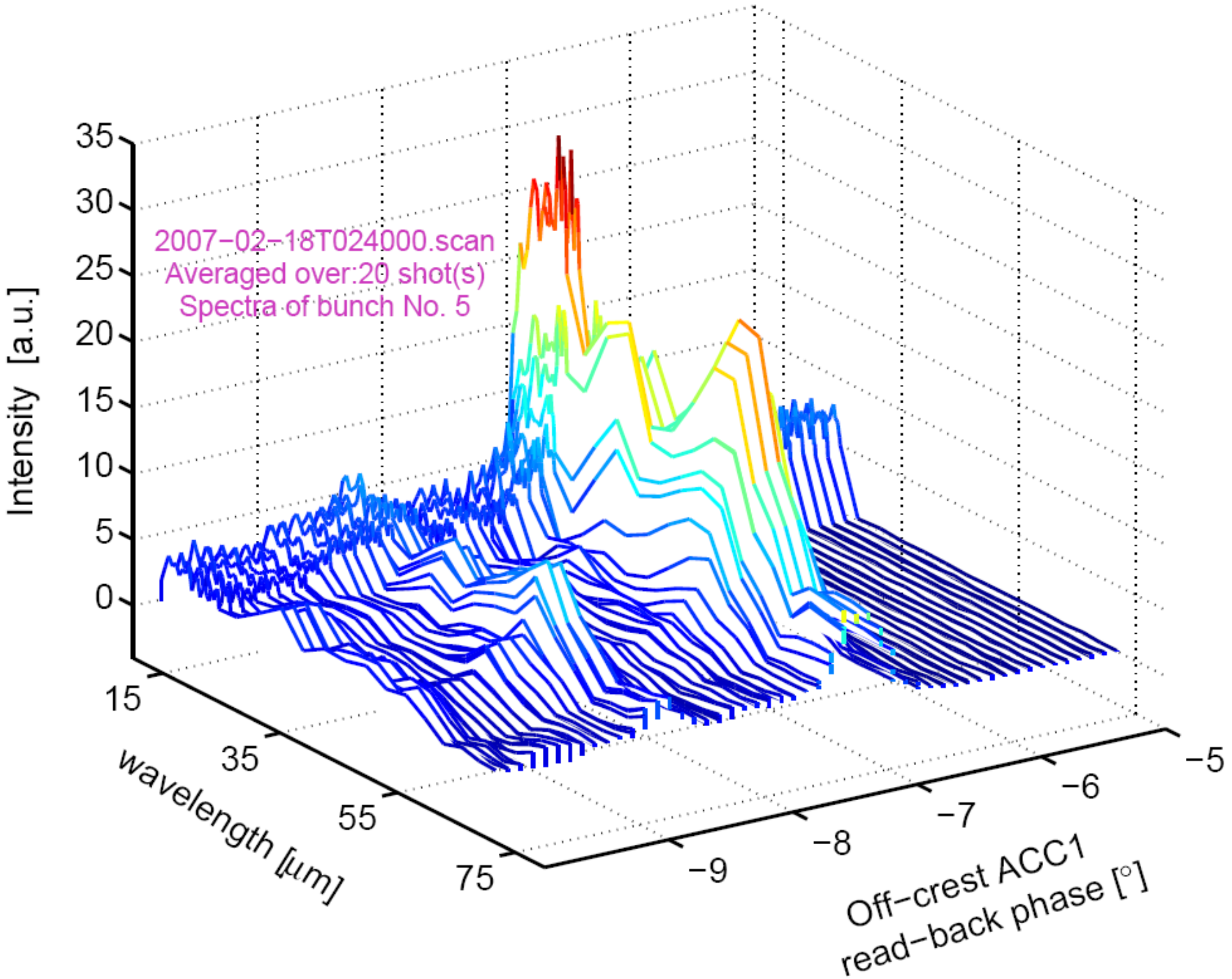
5- Reflectance gratings holder and remote controlled mover

6- Transmission gratings holder and remote controlled mover

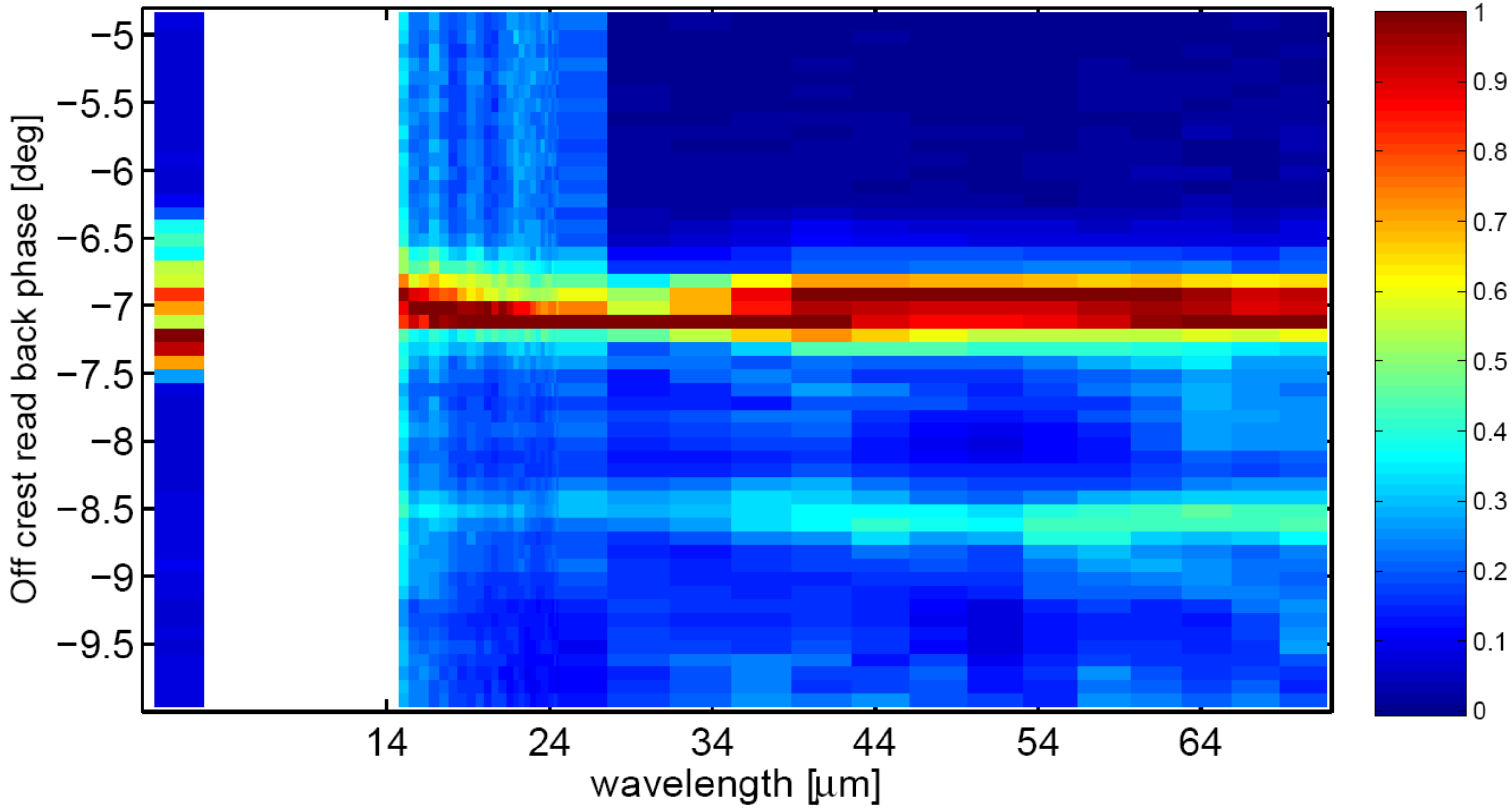
7- Pyro-camera

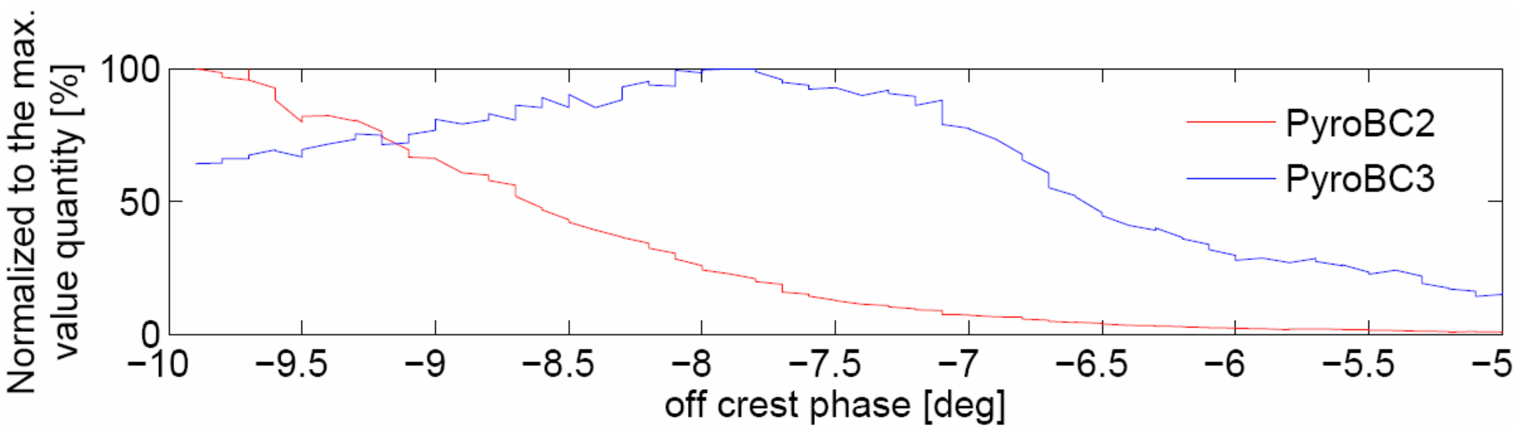
8- Parabolic mirror and its linear mover

ACC1 phase scan

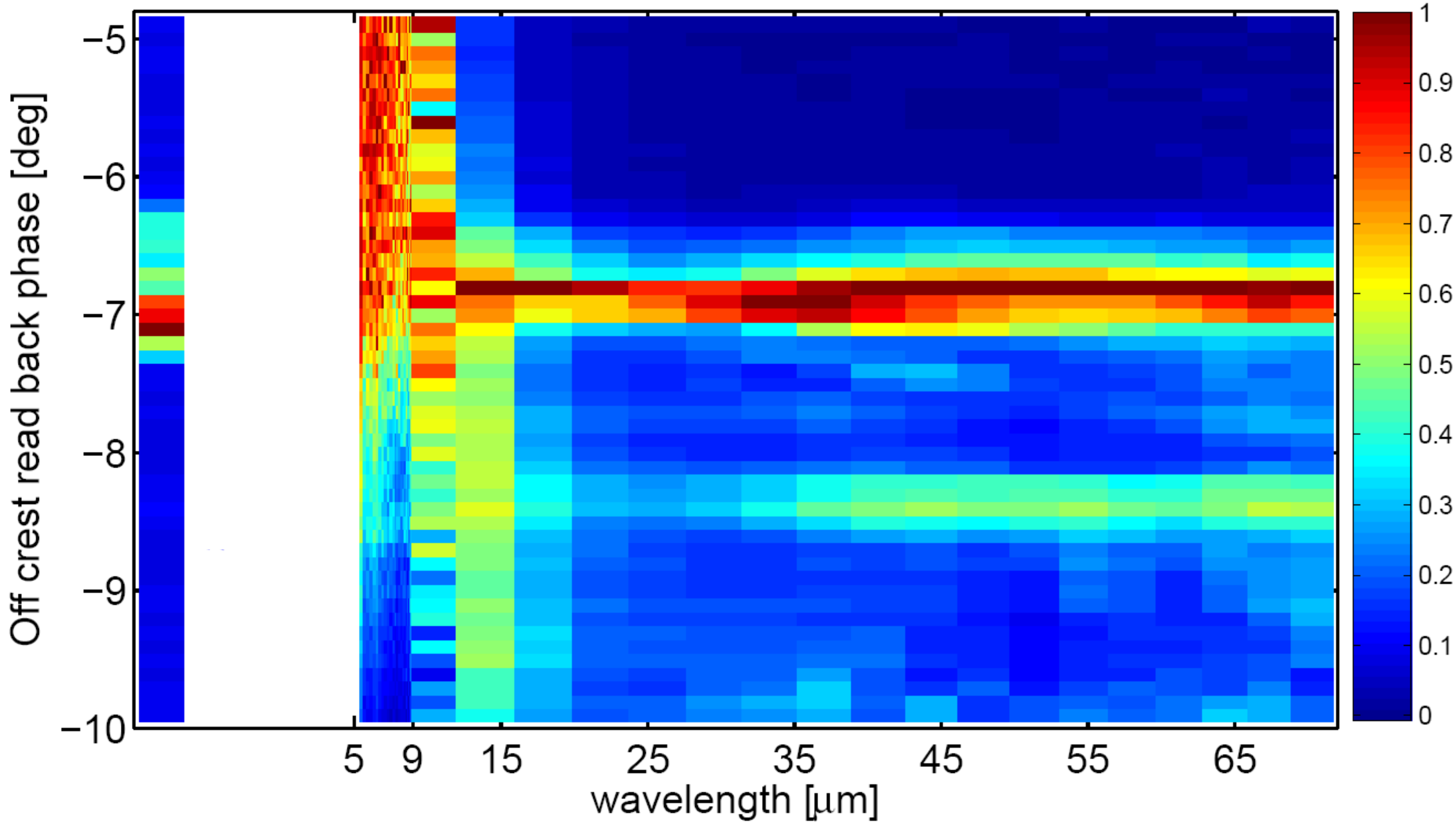


ACC1 phase scan

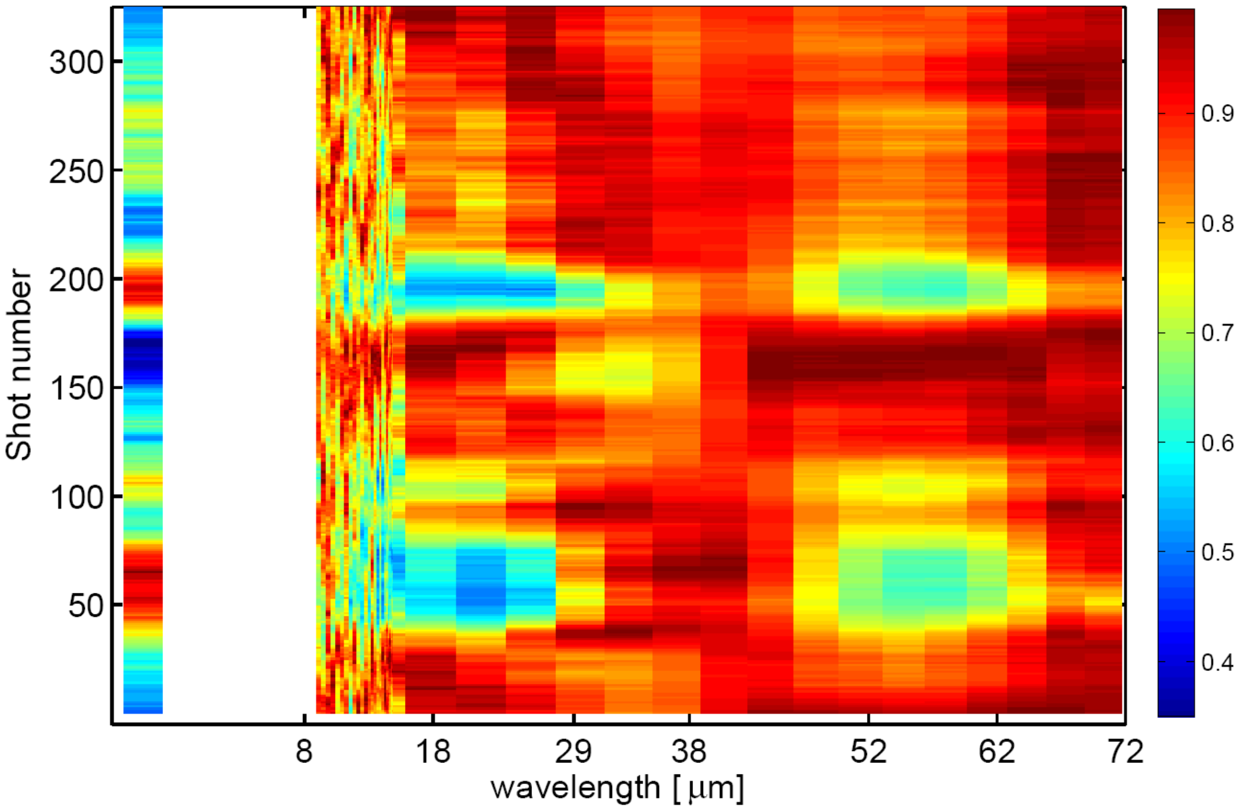


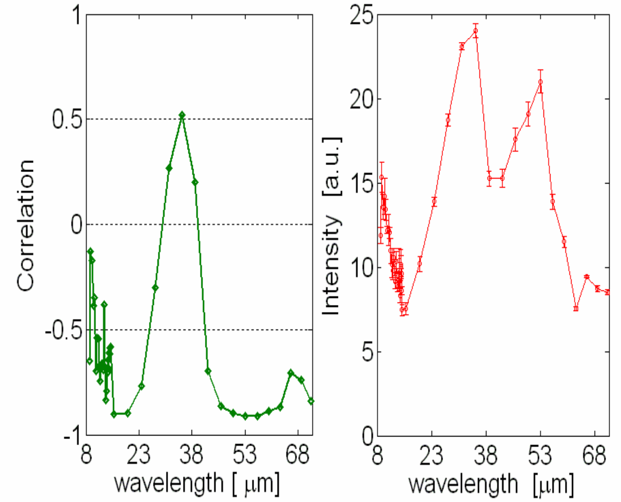


ACC1 phase scan

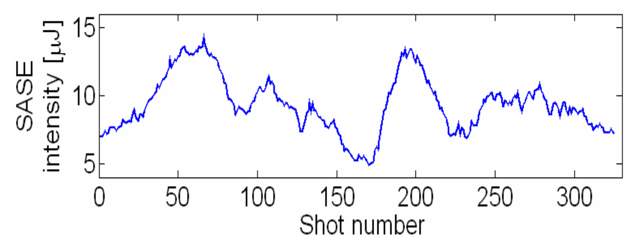


MCP-CTR spectrum correlation

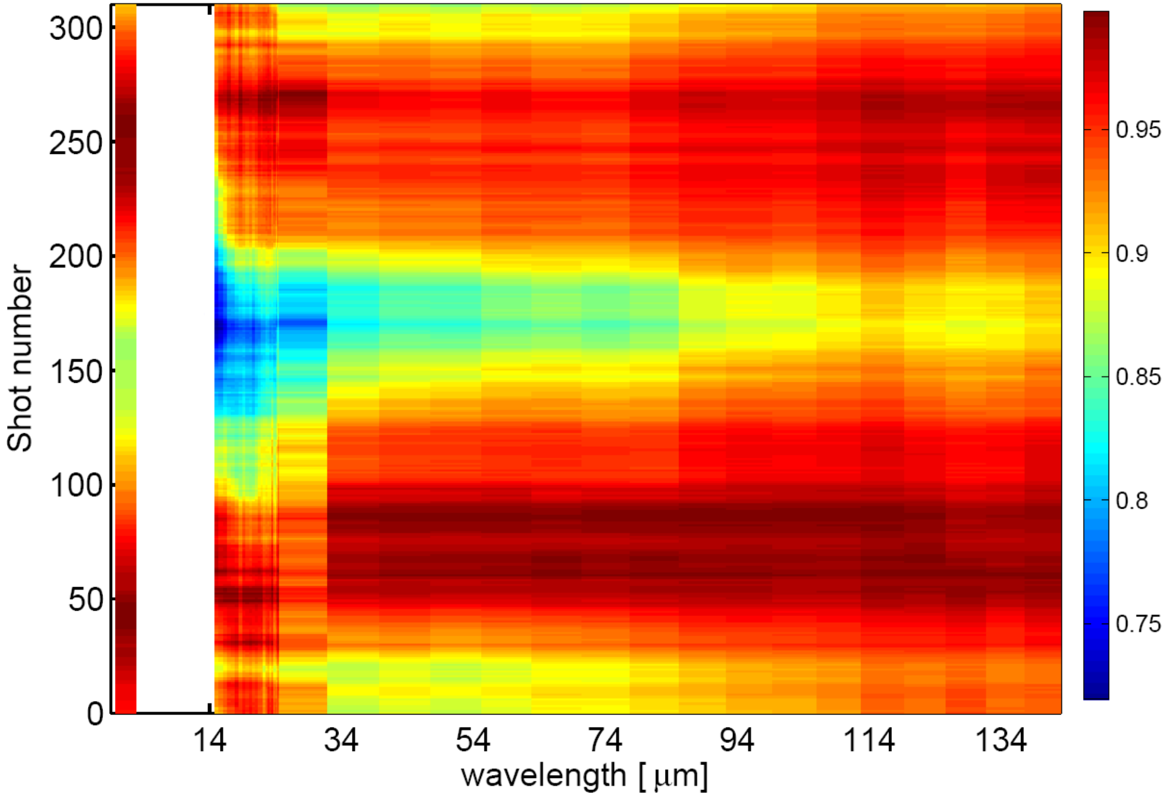


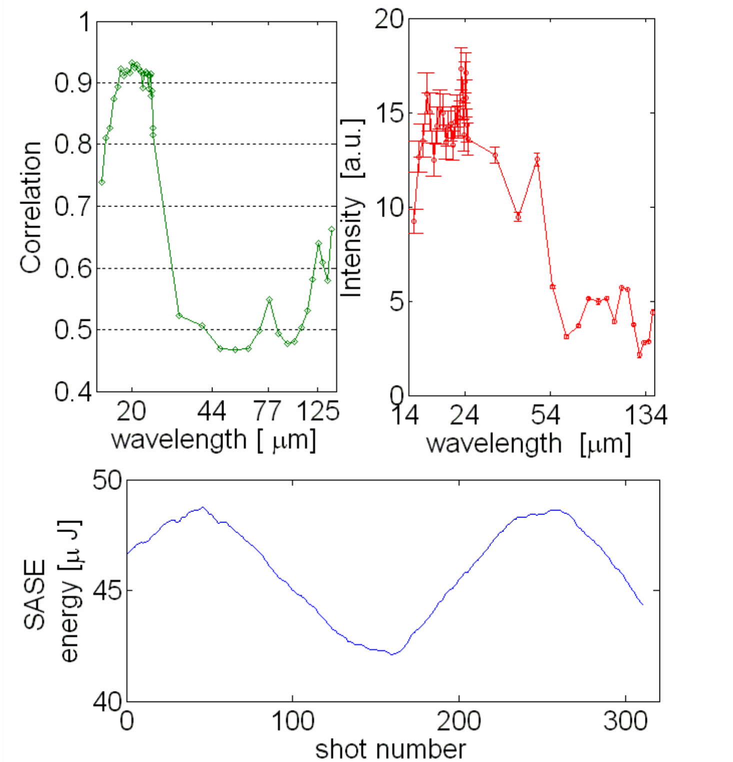


$$\cos\left(\vec{S^c} \,\hat{,}\, \vec{L^c}\right) = \frac{\vec{S^c} \cdot \vec{L^c}}{\left|\vec{S^c}\right| \left|\vec{L^c}\right|}$$



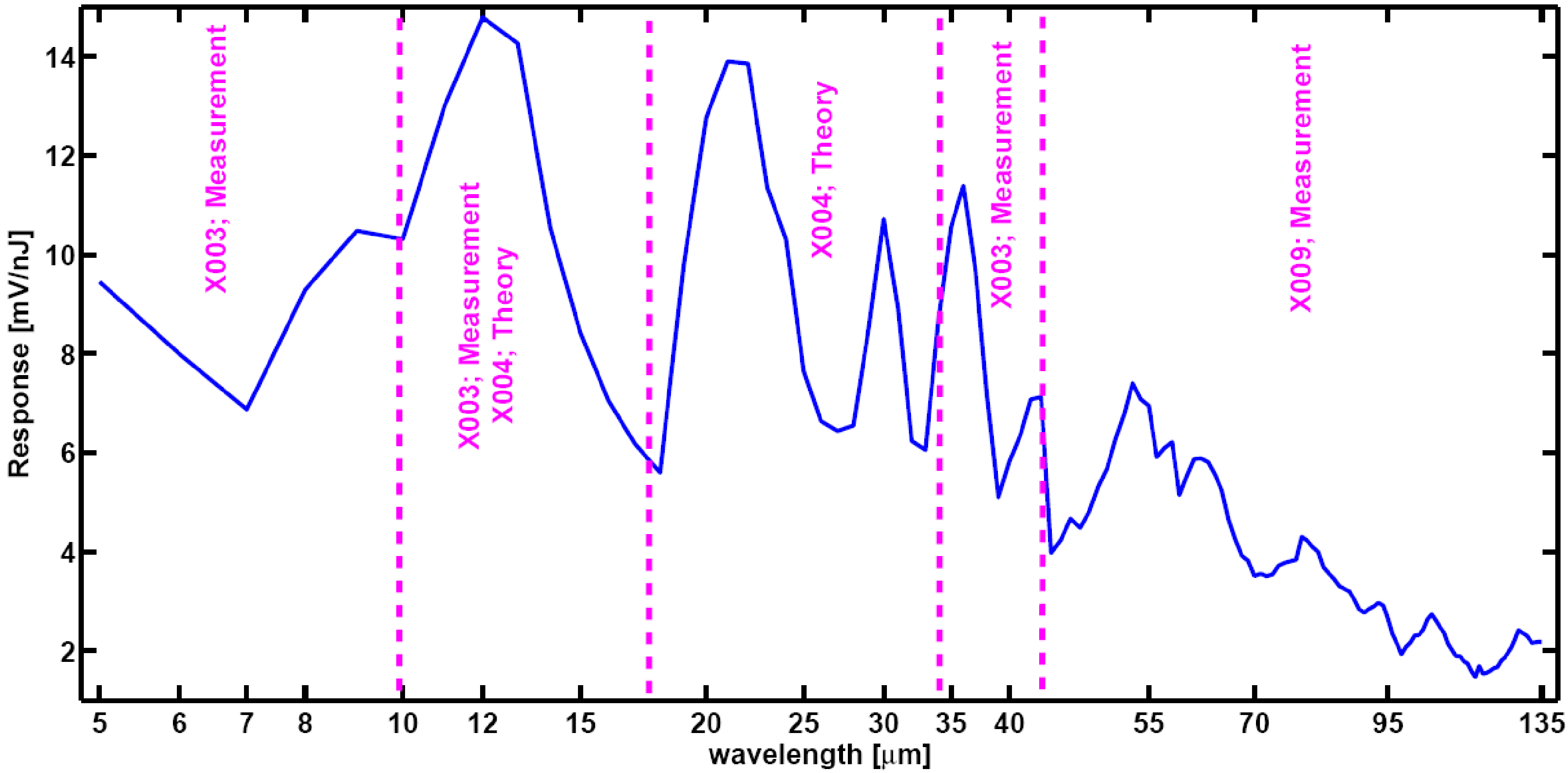
GMD-CTR spectrum correlation



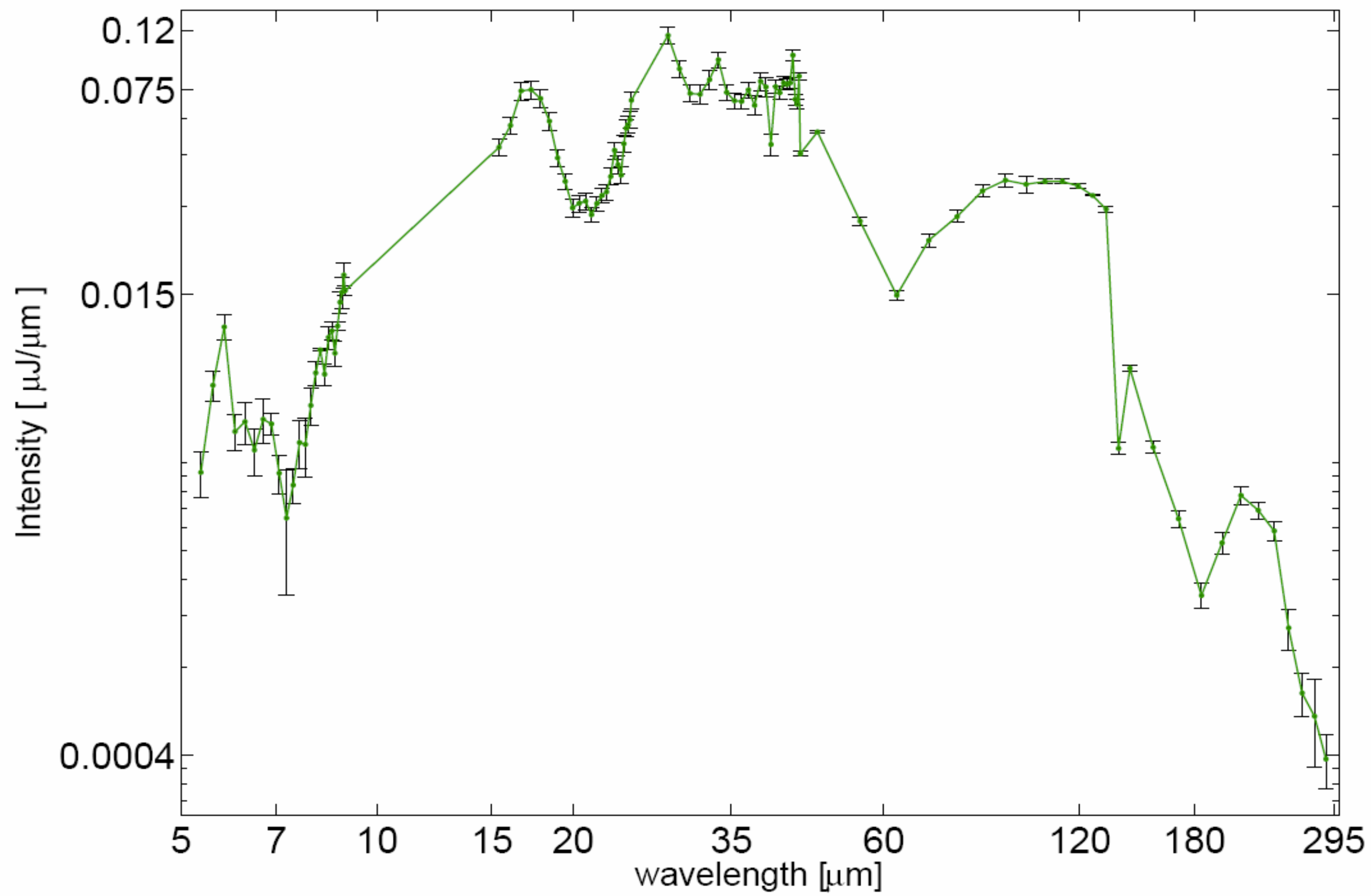


More?

Pyro-electric detector response



Combined broad-band spectrum



Bunch profile determination

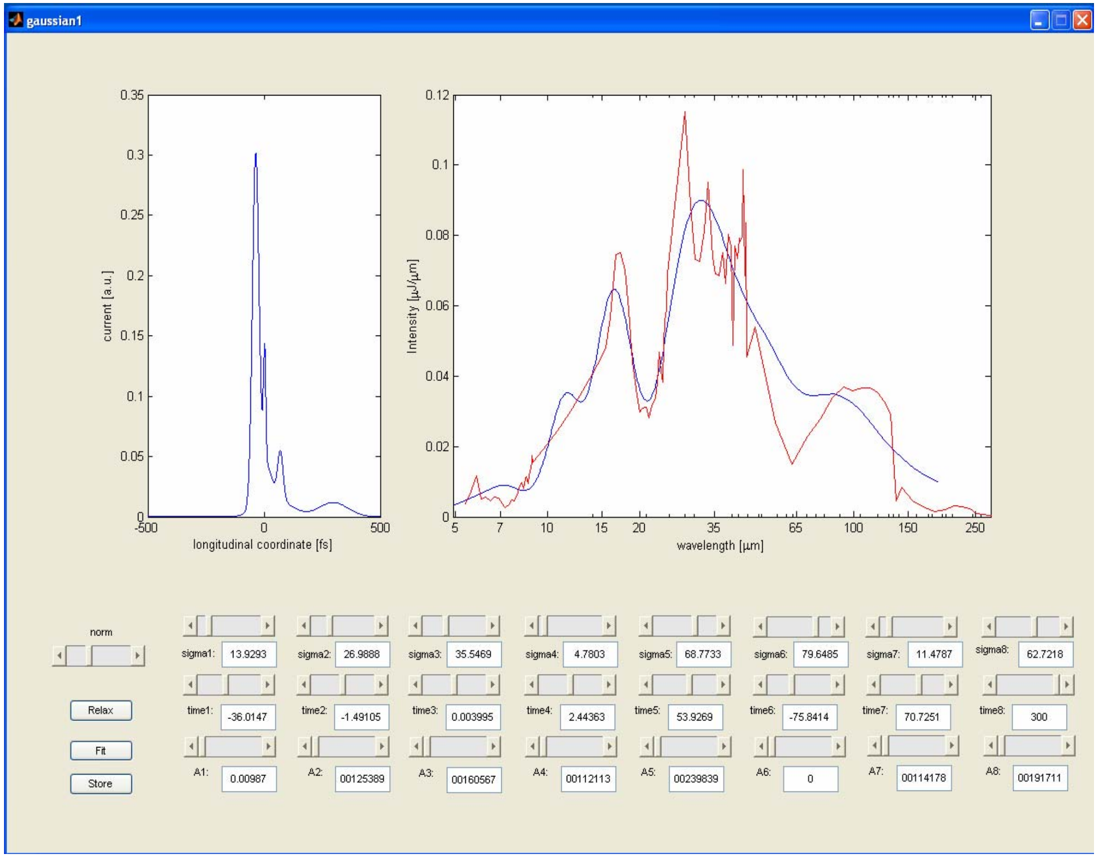
$$g_i(t) = \frac{A_i}{\sqrt{2\pi}\sigma_i} \exp\left(-\frac{(t-t_i)^2}{2\sigma_i^2}\right)$$

$$T(t) = \sum_i g_i(t)$$

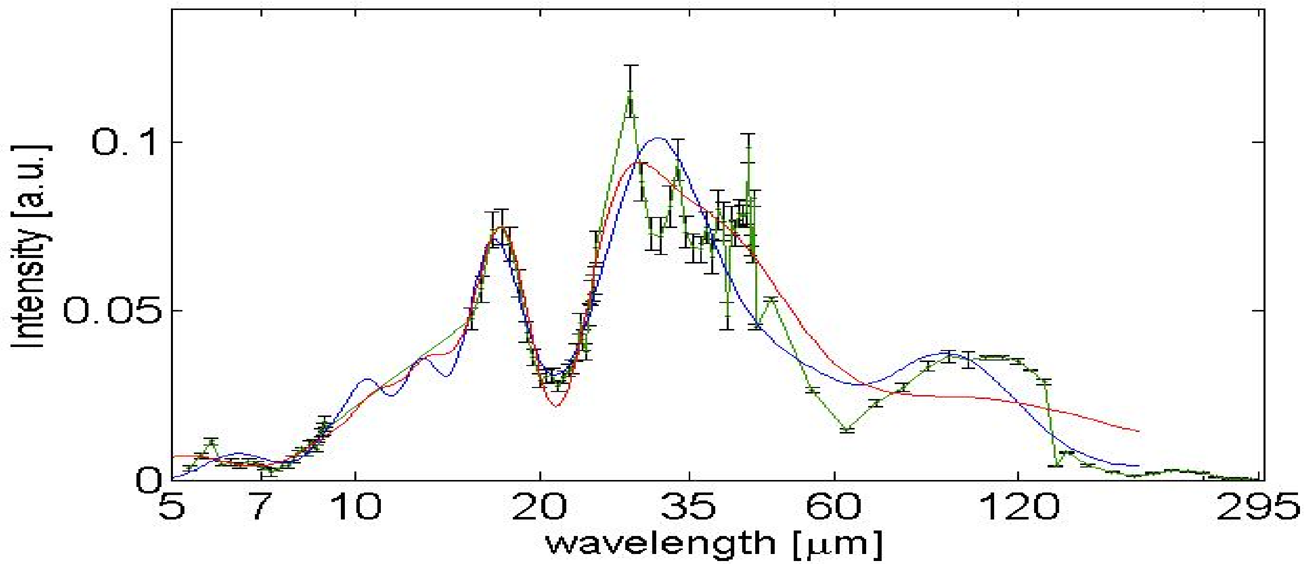
$$G_i(\omega) = A_i \exp(-\frac{\omega^2\sigma_i^2}{2}) \exp(-i\omega t_i)$$

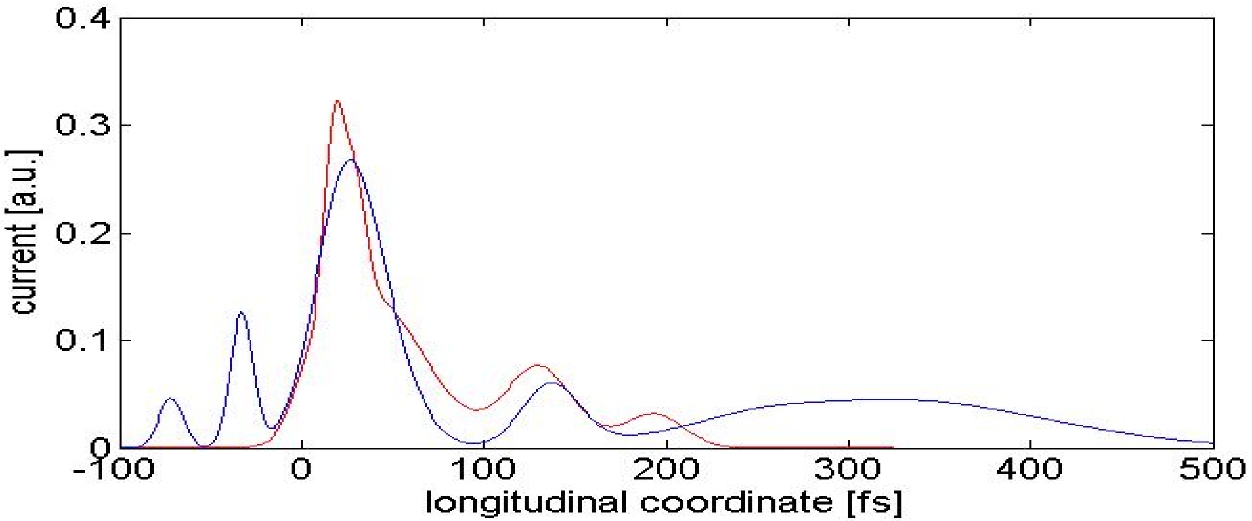
$$\Omega(\omega) = \sum_i G_i(\omega)$$

$$U(\lambda) \propto \frac{2\pi c}{\lambda^2} \left|\Omega(\frac{2\pi c}{\lambda})\right|^2$$

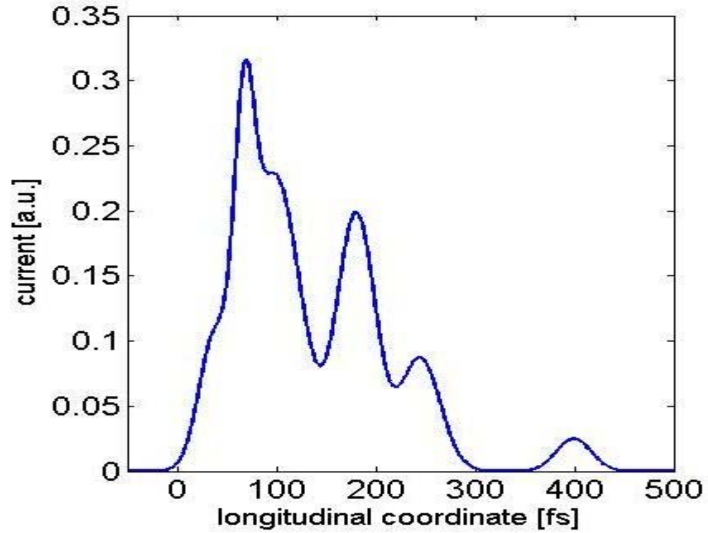


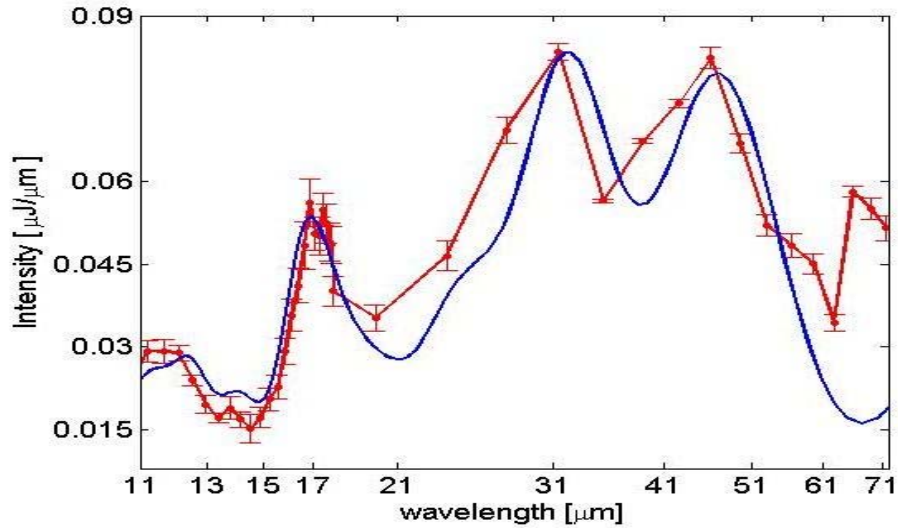
Bunch profile determination (~700 MeV)

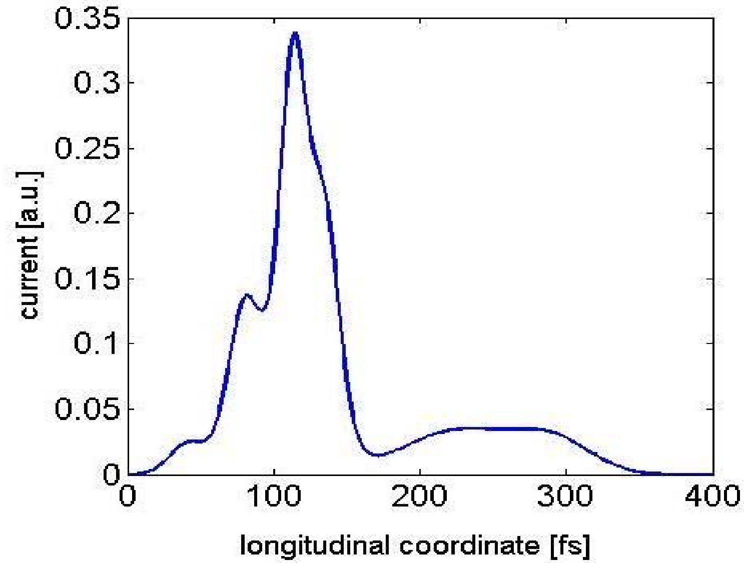


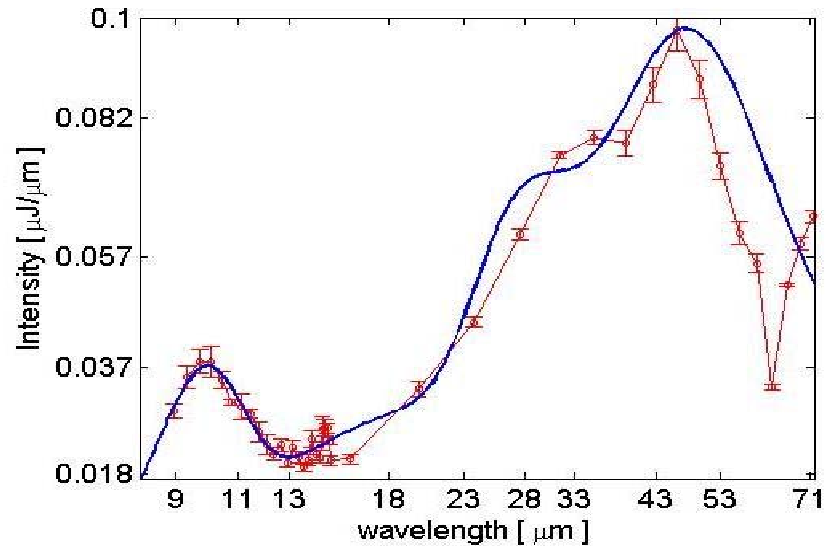


Bunch profile determination (~500 MeV)









Summary and outlook

• Compact two-stage single-shot spectrometer has been designed, constructed and used successfully.

• Single shot spectroscopy shows shot to shot fluctuations.

• Characteristics of the longitudinal bunch profile has been determined by Fourier transform methods. Unique profile reconstruction is impossible.

• Different wavelength ranges of the coherent transition radiation spectra correlate or anti-correlate to the SASE intensity.

• Structures much shorter than the characteristics length of spike have been observed that may correspond to effects like micro-bunching instability.

• Lots of useful information are contained in the spectra.

➢ The entire spectrometer has to be calibrated to obtain a measured transfer function.

➢ 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.

Thank you very much for your attention!