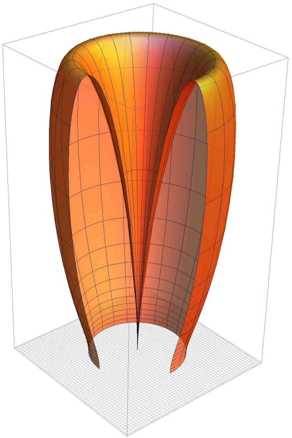
Status of THz spectroscopy as a standard diagnostic method.

Stephan Wesch, Christopher Behrens, Bernhard Schmidt

FLASH seminar – 24th February 2009

Overview

Transition radiation



Intensity distribution for single electron

Ginzburg-Frank-Formula:

$$\left.\frac{d^2U}{d\omega d\Omega}\right|_{e^-} = \frac{e^2}{4\pi^3\epsilon_0 c}\cdot\frac{\beta^2\sin^2\theta}{(1-\beta^2\cos^2\theta)^2}$$

Consideration of electron ensemble:

$$\left.\frac{d^2U}{d\omega d\Omega}\right|_{bunch} = \left.\frac{d^2U}{d\omega d\Omega}\right|_{e^-}\cdot\left(N+N(N-1)\cdot|F(\omega)|^2\right)$$

Coherent part dominates + small tranverses dimensions:

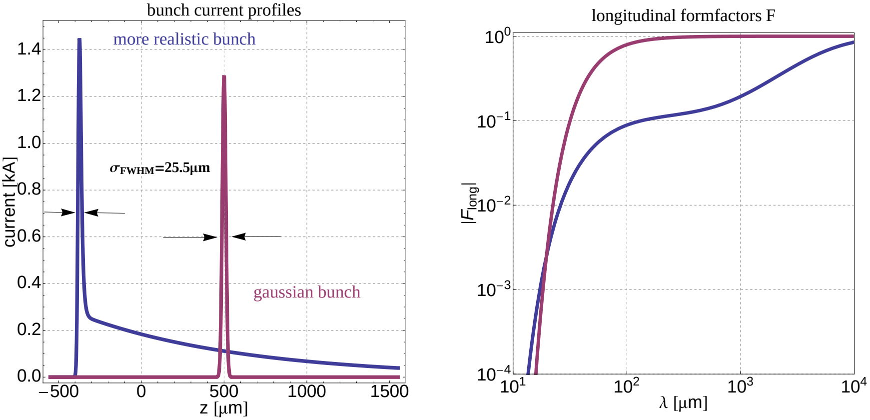
$$\left.\frac{d^2U}{d\omega d\Omega}\right|_{bunch} \approx \left.\frac{d^2U}{d\omega d\Omega}\right|_{e^-}\cdot N^2\cdot\left|F_{long}(\omega)\right|^2$$

Radiation emitted in small cone of $2/\gamma$:

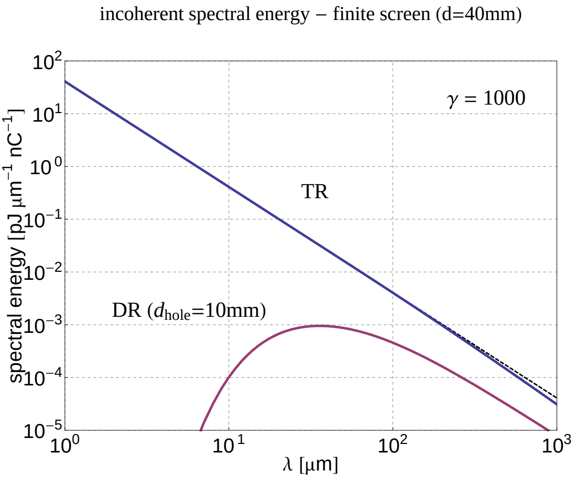
$$\boxed{\left.\frac{dU}{d\omega}\right|_{bunch} \approx \left.\frac{dU}{d\omega}\right|_{e^-}\cdot N^2\cdot\left|F_{long}(\omega)\right|^2}$$

Formfactor

$$F_{long}(\lambda) = \int dz\, \rho_{norm}(z) \cdot \exp(-2\pi\, \mathrm{i}\, z \cdot \lambda^{-1}) \quad \text{with} \quad \int dz\, \rho_{norm}(z) = 1$$



TR vs. DR



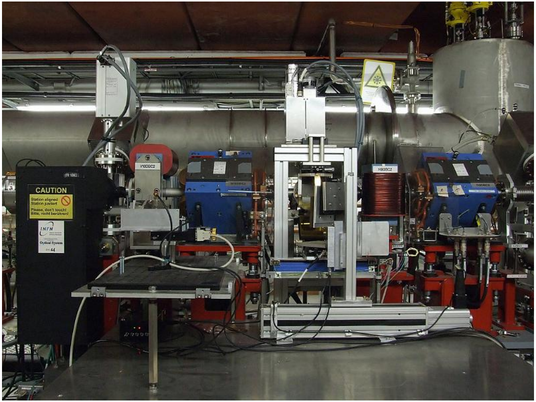
Extension to finite screen sizes:

TR finite full screen
→ cutoff at long wavelengths

DR hole in screen
→ damping smaller wavelengths

→ TR is recommended for small structures!

Compression monitor



CDR monitor behind BC2

Coherent diffraction monitor:

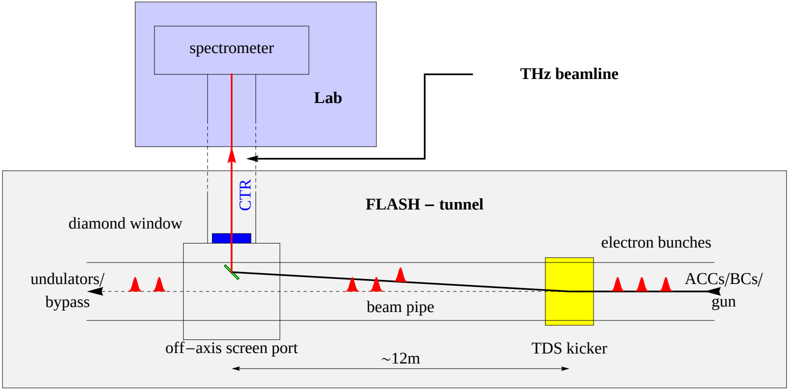
- parasitic detection (non destructive)
- integrated energy measured via pyroelement
- cut-off wavelength at 80 μm (window)

$\rightarrow$ empirical value on which phase of ACC1/ACC23 is regulated

Setup I

Intention:

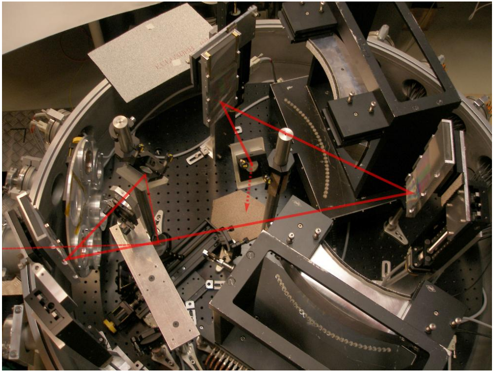
Do broadband spectroscopy of CTR from compressed electron bunches.



Scheme of radiation generation FLASH@140m

Setup II

Broadband single shot grating spectrometer. Developed by H. Delsim-Hashemi.

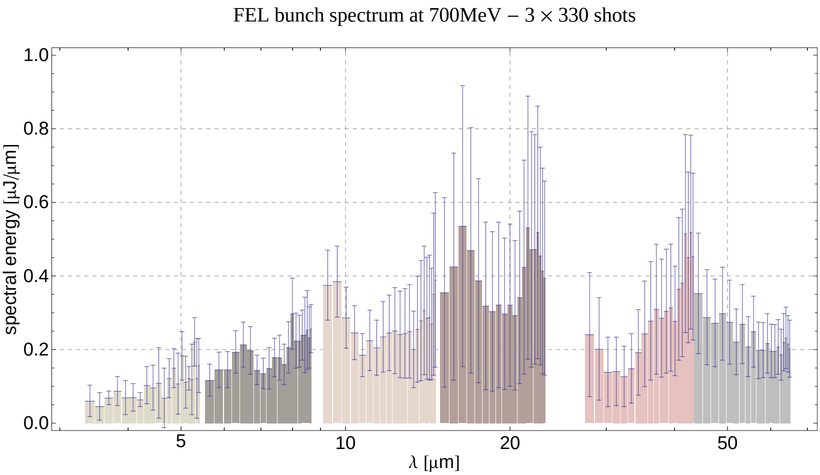


Last spectrometer configuration used (S. Wesch)

Characteristics:

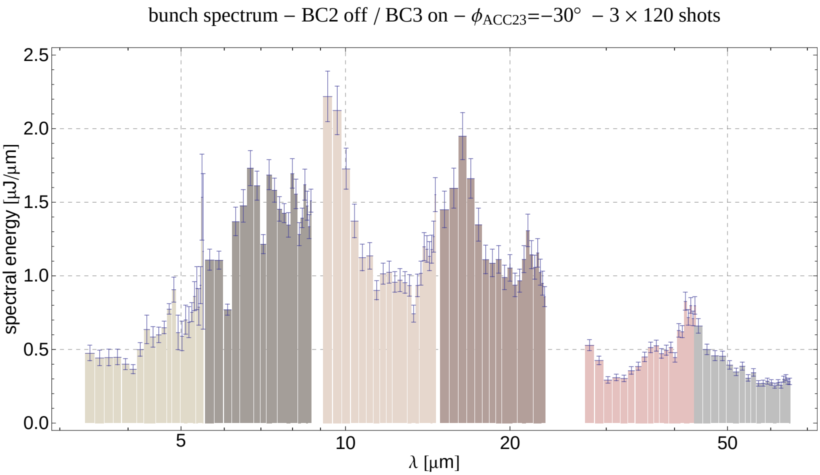
- 3 staged reflective blazed gratings
  (filter + 2 dispersive elements)
- focussing ring mirrors
- 2×30 pyro detectors
- 3 grating combinations
  ($3\,\mu$m up to $65\,\mu$m)
- limit of $|F| = 0.001$ at $1\,$nC
- experimental setup to establish method

FEL spectrum



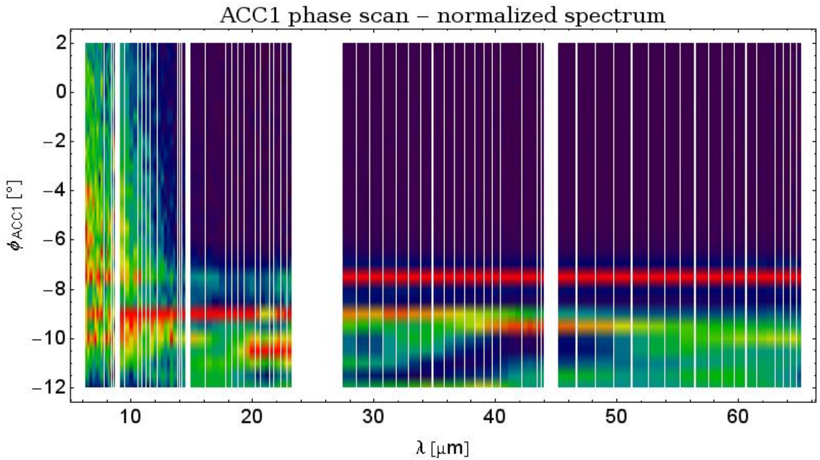
- coherent radiation down to spectrometer limit
- strong fluctuations due to machine stability

Spectrum BC3 only



- enhancement of intensity at short wavelengths
- fluctuations on lower level

Behavior at phase variations



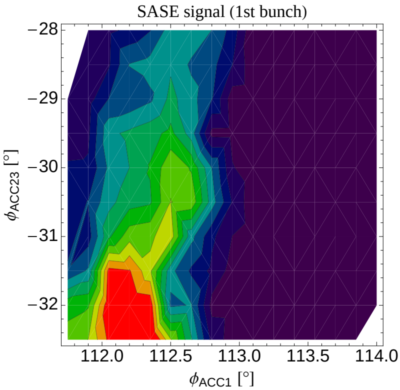
- extremely strong dependence near SASE condition (sharpness not understood)

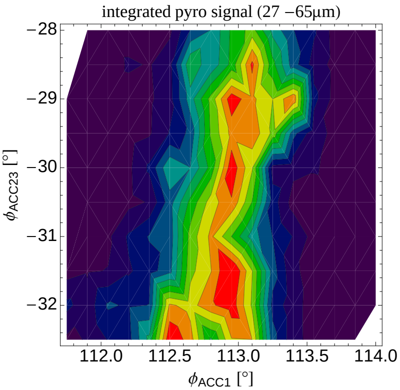
→ setpoint to monitor compression

- phase independent radiation (microbunching)

→ complicates profile reconstruction

SASE - CTR correlation





- maximum SASE intensity shifted about $\Delta\phi_{ACC1} = 0.6°$ with respect to maximum CTR signal

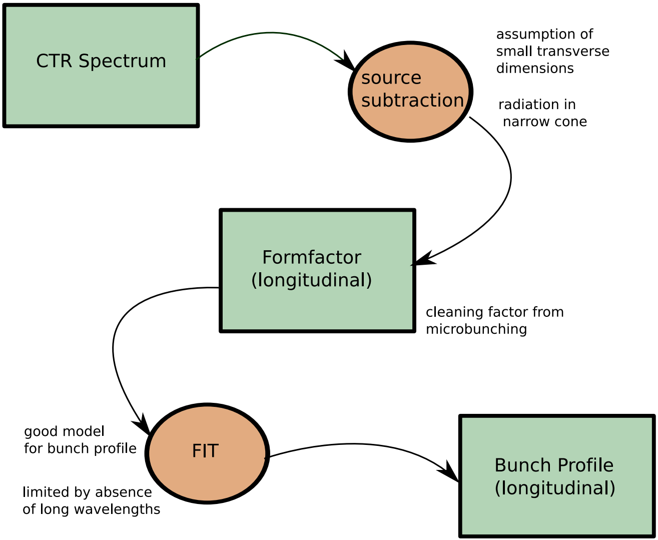
$\longrightarrow$ @140m compression is not completed (dogleg)

$\longrightarrow$ position not ideal to correlate SASE with spectrum

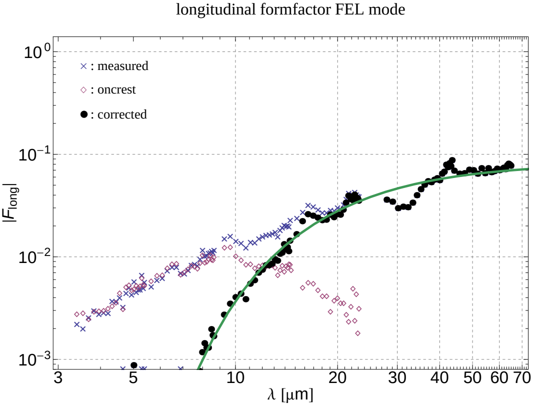
Reconstruction method

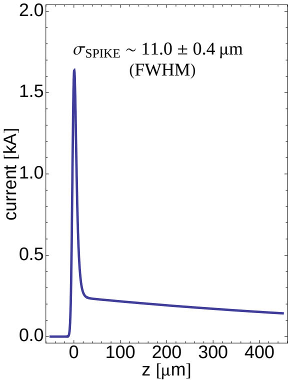
Spectroscopy indirect method of measuring the longitudinal shape of bunch.

$\longrightarrow$ determination of $|F|$, but phase information gets lost!

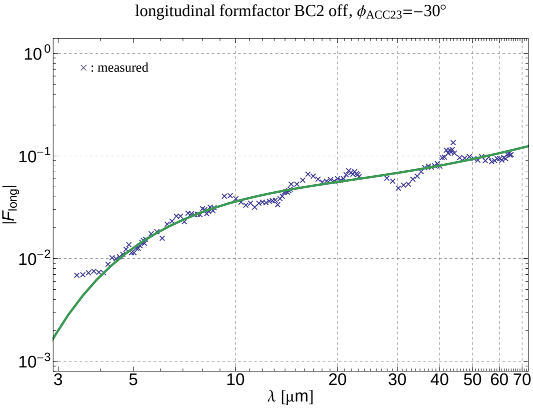


Example I

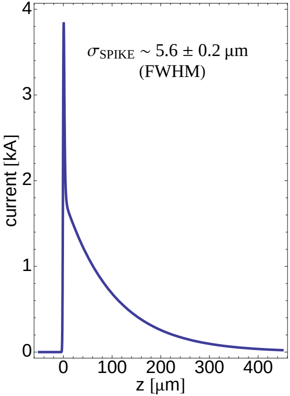

longitudinal formfactor FEL mode
× : measured
◇ : oncrest
● : corrected
$|F_{long}|$
10^0
10^{-1}
10^{-2}
10^{-3}
3
5
10
20
30
40
50
60
70
λ [μm]


$\sigma_{SPIKE} \sim 11.0 \pm 0.4$ μm
(FWHM)
current [kA]
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
z [μm]

Example II



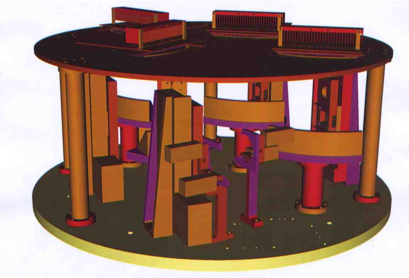
longitudinal formfactor BC2 off, ϕ_{ACC23}=−30°
× : measured
10^0
10^{-1}
10^{-2}
10^{-3}
$|F_{long}|$
3
5
10
20
30
40
50
60
70
λ [μm]



σ_{SPIKE} ~ 5.6 ± 0.2 μm
(FWHM)
current [kA]
0
1
2
3
4
0
100
200
300
400
z [μm]

New Spectrometer I

Engineered and improved version of spectrometer.



CAD picture (Courtesy K. Ludwig)

Charateristic:

- 4 stages
- 2 grating combinations

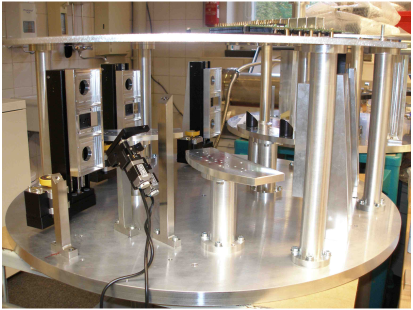
$\rightarrow$ spectral range 2 μm - 200 μm

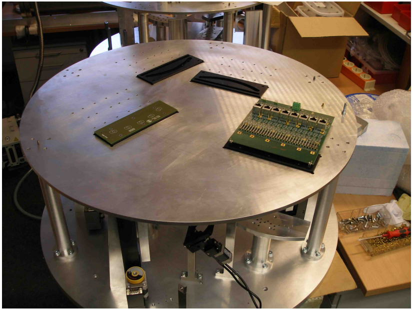
- 120 pyros
- motorized beam alignment
- more compact

Additional new location:

- in front of 1st undulator
- uses same (O)TR station as LOLA

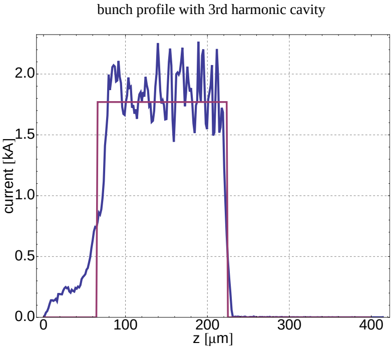
New Spectrometer II



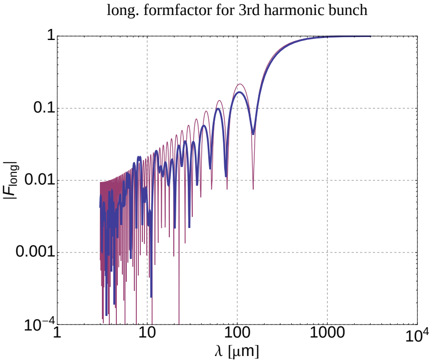


3rd harmonic bunch

Outlook to formfactor of bunch



simulation I. Zagorodnov



location of minima determines bunch length

Conclusions

2 stage spectrometer (prototype):

i. bunch profile construction $\rightarrow$ spike width in μm range.

ii. extensively used for microbunch studies

iii. not ideal to correlate SASE with spectra (dogleg)

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engineered 4 stage spectrometer:

I. spectrometer leaves *experimental* status
II. larger spectral range
III. additional location in front of undulators