– Microbunching at FLASH – Measurement of Coherent Radiation from 350 nm to 23 um.

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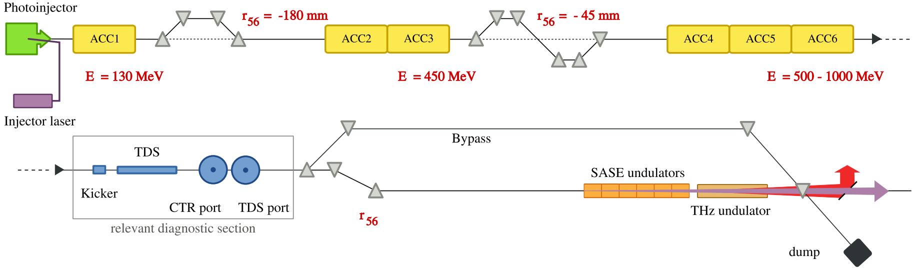
Workshop on the Microbunching Instability III – Frascati

FLASH - Overview

Status 2009 - before shutdown

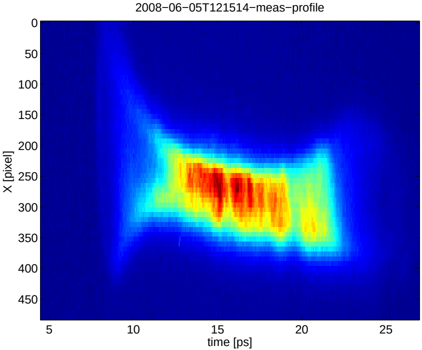


Inspection of incoherent and coherent transition radiation:

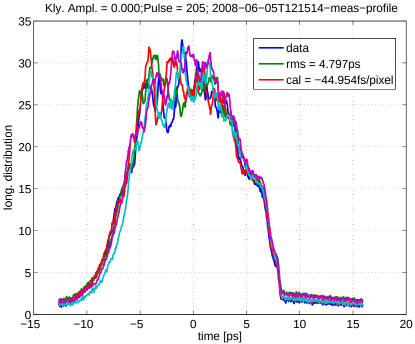
- deflection of single bunch onto off-axis screens (distance CTR-TDS port: $\sim 2\,\mathrm{m}$)
- CTR port leads to external lab via evacuated beamline ($\sim 20\,\mathrm{m}$)
- TDS port leads to optical table inside tunnel ($\sim 1\,\mathrm{m}$)
- position in front of dogleg ($\rightarrow$ not entirely compressed bunch)

First Microbunching observations

Transverse deflecting device



screen image of streaked electron bunch



longitudinal projection

Uncompressed bunch: (nearly oncrest phases)

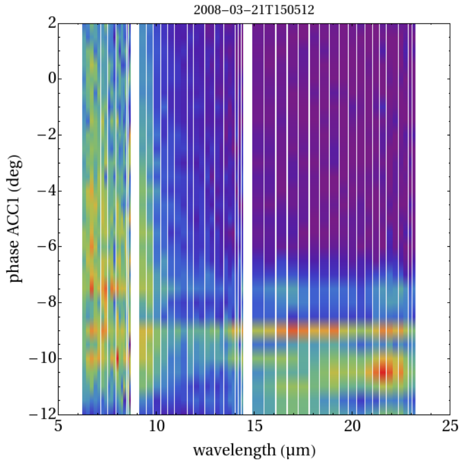
→ ripples on longitudinal charge image

→ strong fluctuation from shot to shot

courtesy Holger Schlarb

First Microbunching observations II

2 stage single shot spectrometer



Phasescan of ACC1:

- → leading spike generates coherent signal over full wavelength range for $\varphi_{\mathrm{ACC1}} < -7°$
- → CTR intensity below $\lambda \leq 13\ \mu\mathrm{m}$ is nearly indepenent of phase changes
- → indication of microstructures inside electron bunch
- → triggered intensive studies at smaller wavelengths

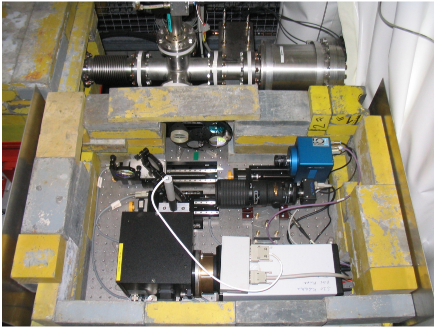
Experimental Equipment

Used spectrometers

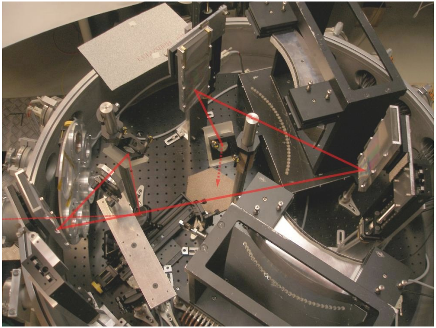
regime	spectrometer	detector	range	location	sensitive to incoh. level
VIS	commercial SP2150 $g = 1200 1 \cdot \mathrm{mm}^{-1}$	ICCD ($S20$)	$0.3 - 0.85\ \mu\mathrm{m}$	tunnel	YES
NIR	commercial SP2150 $g = 300 1 \cdot \mathrm{mm}^{-1}$	CCD ($InGaAs$)	$0.8 - 1.6\ \mu\mathrm{m}$	lab	NO
FIR	2 stage single shot $g = \{240, 150\}\, 1 \cdot \mathrm{mm}^{-1}$ $g = \{90, 54\}\, 1 \cdot \mathrm{mm}^{-1}$	pyro ($LiTaO_3$)	$3.4 - 23\ \mu\mathrm{m}$	lab	NO

Experimental Equipment II

Installations



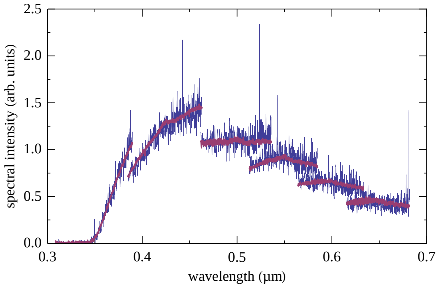
setup of optical table near TDS viewport



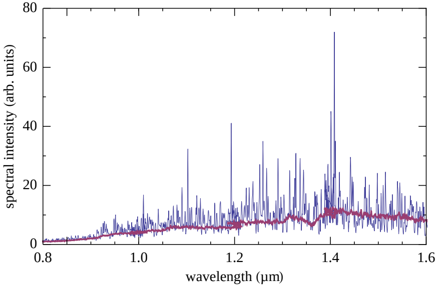
2 stage spectrometer in external labortory

Measurement

Raw data examples



VIS spectra at $\lambda_c \in \{350, 425, 500, 550, 600, 650\}$ nm



NIR spectra at $\lambda_c \in \{0.9, 1.1, 1.3, 1.5\}$ μm

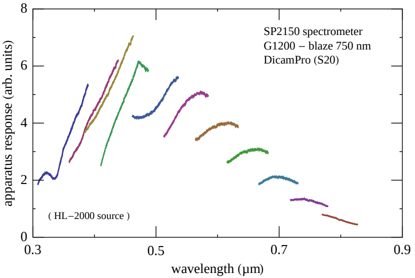
Analysis procedure

VIS + NIR regime

Relative adjustment in VIS:

- camera $\mathrm{QE}(\lambda)$
- camera $\mathrm{QE}(x, y)$
- grating efficiency
  (simulation with *PCGrate6.1* failed)

→ response function of the whole system measured with calib. source!



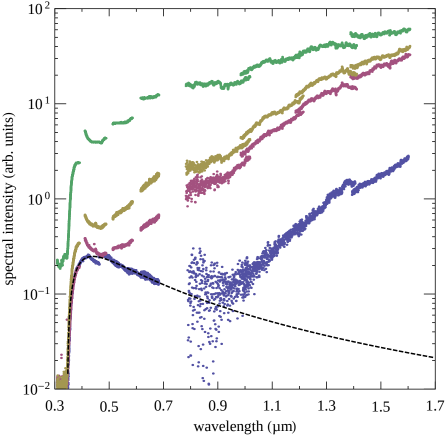
response of grating and camera in VIS regime

Relative adjustment in NIR:

- line array $\mathrm{QE}(\lambda)$
- grating efficiency
  (simulation delivers pausible results)

Data analysis

VIS + NIR spectra



- FEL mode
  $r_{56,\mathrm{BC2}} = -185$ mm / $r_{56,\mathrm{BC3}} = -55$ mm
- oncrest phases
  $r_{56,\mathrm{BC2}} = -185$ mm / $r_{56,\mathrm{BC3}} = -55$ mm
- oncrest phases
  $r_{56,\mathrm{BC2}} = -130$ mm / $r_{56,\mathrm{BC3}} = -55$ mm
- oncrest phases
  $r_{56,\mathrm{BC2}} = -130$ mm / $r_{56,\mathrm{BC3}} = -20$ mm
- -- FEL mode fit

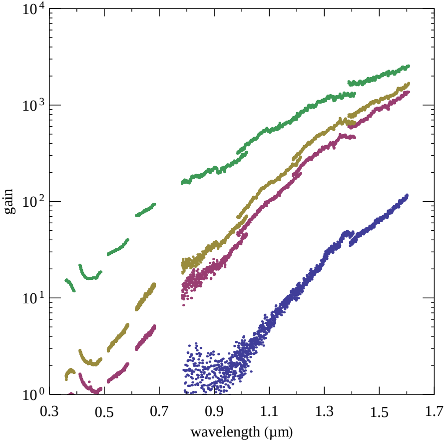
→ FEL mode in VIS regime follows λ^{-2} + cut-off (optics)

→ extension to longer wavelength defines incoherent level in NIR regime

→ NIR spectra adjusted by ONE factor to VIS spectra

Data analysis II

VIS + NIR gain



- FEL mode
  $r_{56,\mathrm{BC2}} = -185$ mm / $r_{56,\mathrm{BC3}} = -55$ mm
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- oncrest phases
  $r_{56,\mathrm{BC2}} = -130$ mm / $r_{56,\mathrm{BC3}} = -20$ mm

→ $\mathrm{gain}(\lambda) \equiv I_{\mathrm{total}}(\lambda) \,/\, I_{\mathrm{incoh.}}(\lambda)$

→ exponential grow of gain (over 3 orders of magnitude)!

→ different influence of BC2 and BC3 on intensity

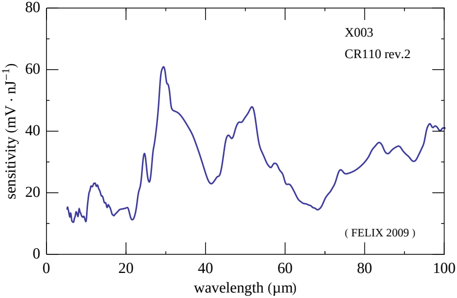
→ for smallest r_{56}'s COTR exeeds into the ultraviolet

Analysis procedure II

FIR regime

Absolute adjustment:

- polarizer efficiency
- grating efficiency
  (simulations with *PCGrate6.1* and *GSolver4.2* agree)
- response of pyroelectric elements
  (calibration at FELIX)



response of detector + electronics

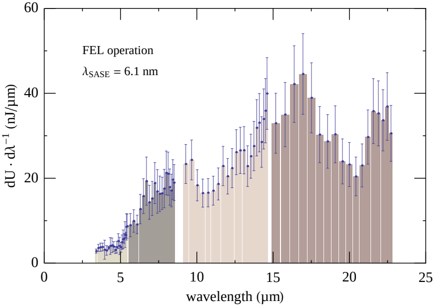
Gain calculation:

- Calculation of emitted TR through beamline to the external lab
  (*THzTransport*: flattop bunch, diamond window, finite mirror size, gold coating of mirrors)

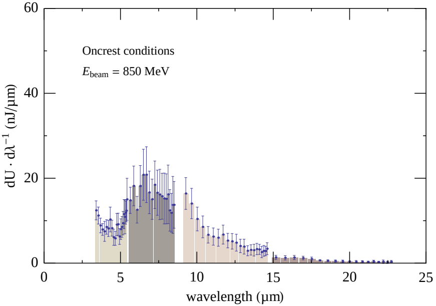
→ measured spectra normalized to simulated spectra for incoherent emission

Data analysis III

FIR spectra



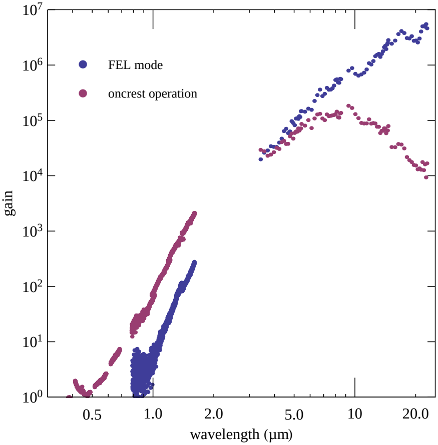
FEL mode CTR spectrum



oncrest CTR spectrum

Data analysis IV

Gain level



combination of data sets:

→ same compressor seetings

- mixing of microbunching signal and gain signature of compressed bunch (no separation)

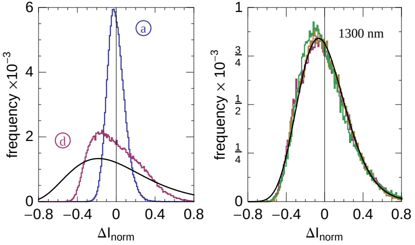
- pure microbunching signal due to few ps long uncompressed bunch
- maximum gain of ~ 100.000
- $\lambda_{opt} \sim 9$ µm

→ good agreement between different analysis procedures

Fluctuations

- fluctuation strength δ is given by number of modes m: $\delta^2 = 1/m \quad (m \gg 1)$
- fluctuation is discribed by Γ distribution with m modes

$$m = \sqrt{1 + 4\,\sigma_\omega^2 \sigma_t^2} \cdot \left(1 + 4\,k^2 \sigma_\theta^2 \sigma_\perp^2\right) \qquad \text{Sannibale et al., PRST032801(2009)}$$



FEL mode (550 nm):

- fluctuation described by Γ dist. with $m \sim 80$
- rough estimation: $\sigma_\omega = \text{spec.res.}$, $\sigma_t = 4\,\text{ps}$, $\sigma_\theta = 1/\gamma$, $\sigma_\perp = 150\,\mu\text{m}$

$\longrightarrow$ $m = 70$

Oncrest mode (1300 nm):

- fluctuation described by Γ dist. with $m = 15$
- number is only given by longitudinal term, transverse mode has to be 1

$\longrightarrow$ bunch seems to be fully coherent in transverse plane!

Results

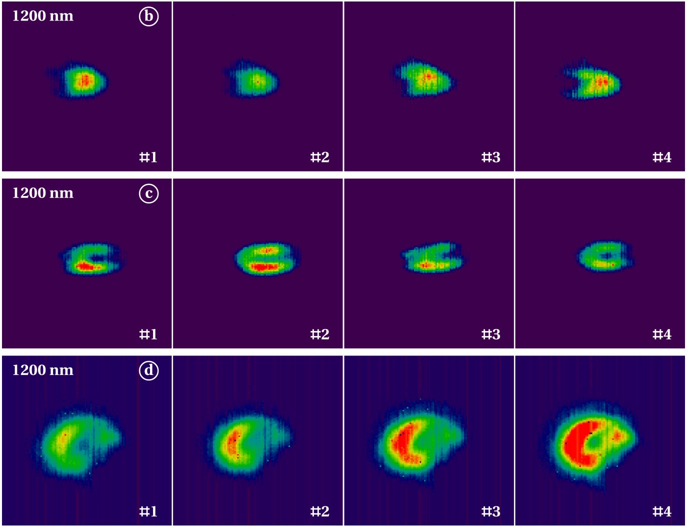
- transition radiation spectra from 350 nm to 23 µm for different machine settings were measured
- good understanding of used devices enables reasonable connection of gain spectra
- fluctuation analysis show fully transverse coherence
- data can be used to test analytical and numerical microbunching models

Outlook

Questions:

- Is the linearization of longitudinal phase space a problem for FLASH?
- Is it possible to model the instability quantitatively?
- What are the critical machine parameters to distinguish between models?

Closing



OTR screen images with InGaAs camera and $1200\,\mathrm{nm}$ bandpass filter ($\sigma = 10\,\mathrm{nm}$)