Longitudinal bunch profile reconstruction using CRISP4 spectrometer

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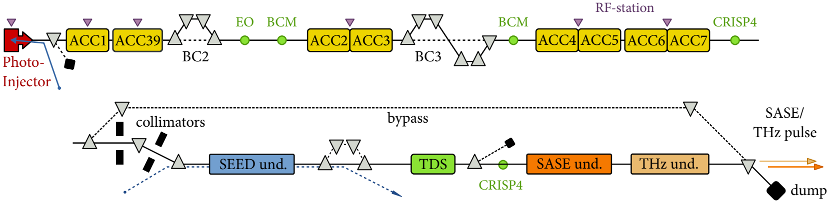
FEL seminar 2013

Outline

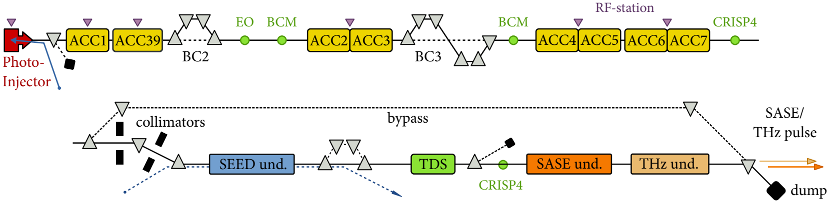
Longitudinal diagnostic stations at FLASH



Longitudinal diagnostic stations at FLASH

Introduction

Coherent
Radiation
Intensity
Spectrometer
with 4 stages



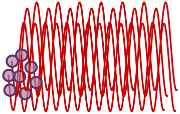
Coherent radiation

Introduction

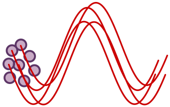
- Charged particle emits electromagnetic radiation
  - Transition radiation, diffraction radiation, synchrotron radiation etc.
- A bunch of N charged particles emits radiation with Intensity $U(\lambda, \Omega)$
  - Superposition of the fields $\vec{E}$ from the individual electrons

- Emission characteristics

$\lambda \ll \sigma_{long}$: incoherent emission
$\vec{E} \propto \sqrt{N} \rightarrow U \propto N$



$\lambda \gg \sigma_{long}$: coherent emission
$\vec{E} \propto N \rightarrow U \propto N^2$



- Strong increase in intensity ($N \approx 10^9$)

Coherent radiation of relativistic electron bunches

- Spectral-angular distribution of coherent radiation

$$\frac{\mathrm{d}^2 U}{\mathrm{d}\lambda\,\mathrm{d}\Omega} \approx \frac{\mathrm{d}^2 U_1}{\mathrm{d}\lambda\,\mathrm{d}\Omega} N^2 \, |F_{3D}(\lambda,\Omega)|^2 \qquad \text{with} \qquad F_{3D}(\lambda,\Omega) = \int_{-\infty}^{\infty} \rho_{3D}(\vec{\mathbf{r}})\, \exp(-i\,\vec{\mathbf{k}}\,\vec{\mathbf{r}})\, d\vec{\mathbf{r}}$$

- Approximations
  - No longitudinal and transversal correlation: $F_{3D}(\lambda,\Omega) = F_{long}(\lambda,\Omega)\, F_{trans}(\lambda,\Omega)$
  - Small observation angle: $F_{long}(\lambda,\Omega) \approx F_{long}(\lambda)$

- Coherent spectral intensity becomes

$$\frac{\mathrm{d}U}{\mathrm{d}\lambda} \approx \left[\int_{\Omega_{det}} \frac{\mathrm{d}^2 U_1}{\mathrm{d}\lambda\,\mathrm{d}\Omega} F_{trans}(\lambda,\Omega)\mathrm{d}\Omega\right] N^2 \left|F_{long}(\lambda)\right|^2$$

- Longitudinal formfactor

$$F_{long}(\lambda) = \int_{-\infty}^{\infty} \rho_{long}(z)\exp(-2\pi i z/\lambda)\,\mathrm{d}z$$

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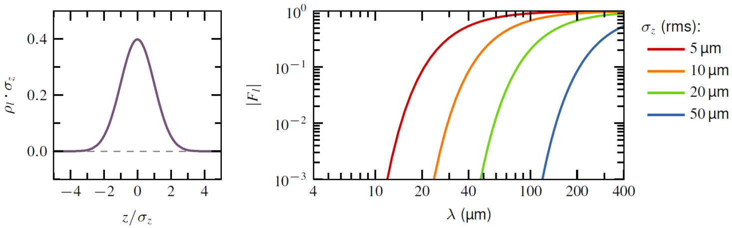
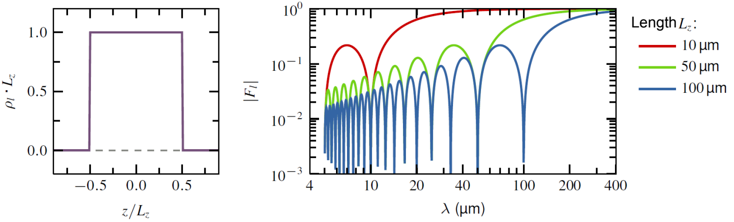
Measurement of absolute intensity of coherent radiation allows determination of absolute value of the formfactor

Formfactor examples

- Gaussian profile



- Rectangle profile

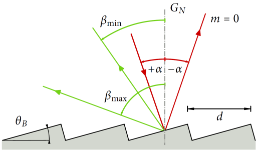


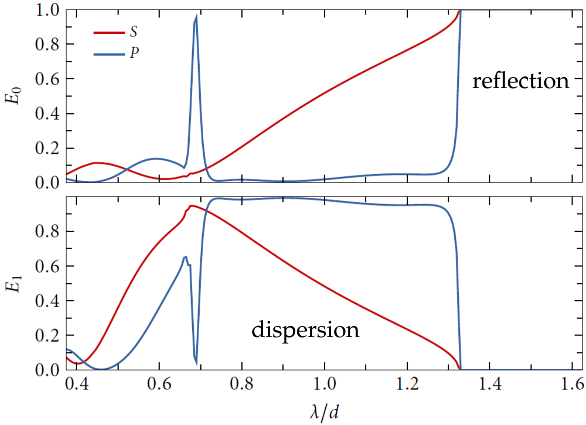
Principle

Coherent Radiation Intensity Spectrometer with four gratings (CRISP4)

- bandpass filter for:
  $\lambda/d > 1.33$ in zero order

- high transmission for:
  $0.78 < \lambda/d < 1.31$
  in first order

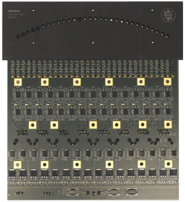




Courtesy of S.Wesch

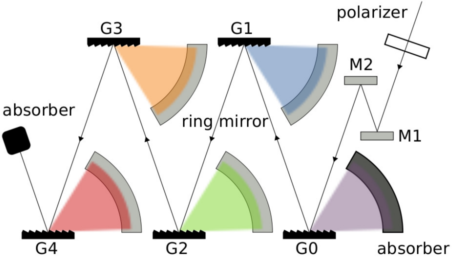
Setup

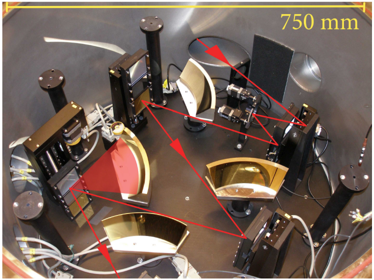
CRISP4



Courtesy of S.Wesch

- Five consecutive gratings as prefilter and dispersive devices
- Wavelength coverage from 5.5 to $440\mu m$ with two sets of gratings
  - MIR configuration: 5.5 to $44\mu m$
  - FIR configuration: 44 to $440\mu m$
- One order of magnitude in λ for four gratings
- Parallel readout of 120 channels for one set of gratings





Spectrometer model

CRISP4

$$S_{SP4}(\lambda) = Q^2\, R_\delta(\lambda)\, \left|F_{long}(\lambda)\right|^2 \rightarrow \left|F_{long}(\lambda)\right| = \sqrt{\frac{S_{SP4}(\lambda)}{Q^2\, R_\delta(\lambda)}}$$

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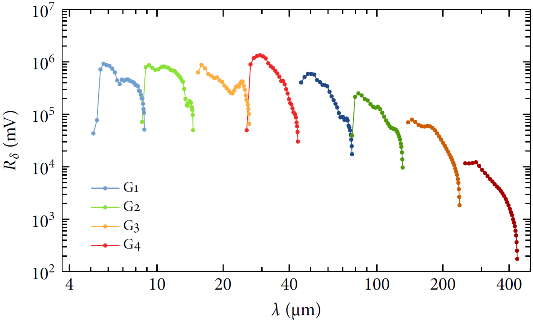
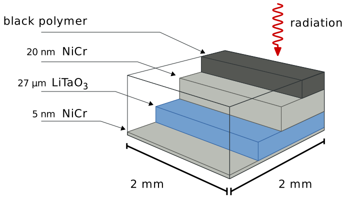


$$Q = 1nC, \sigma_t = 200\mu m$$

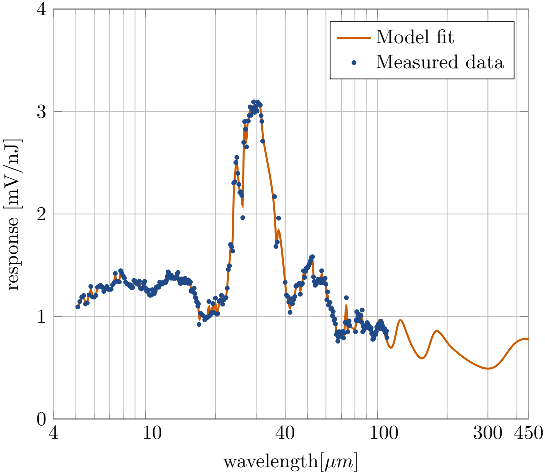
- Response function includes
  - CTR source
  - Diamond window
  - Beamline transmission
  - Transmission of the polarizer
  - Spectrometer transmission
  - Focus profile
  - Detector size
  - Grating efficiency
  - Detector sensitivity
  - Electronic amplifiers

Pyro response

CRISP4

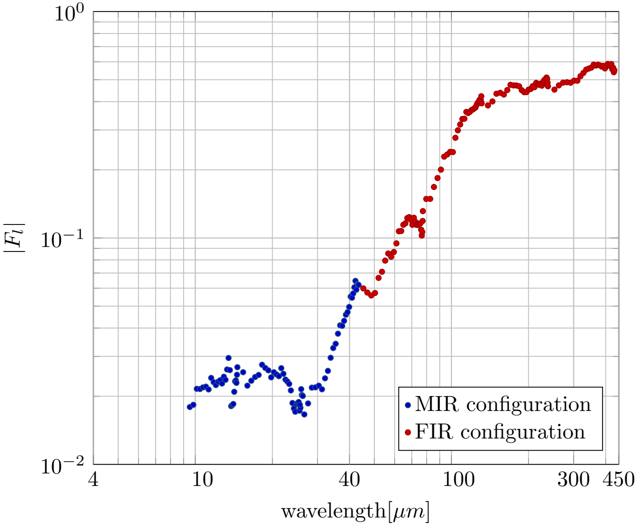


- Measured for $5\,\mu$m $< \lambda < 110\,\mu$m
- Modelled for $\lambda > 110\,\mu$m



Measurements

CRISP4



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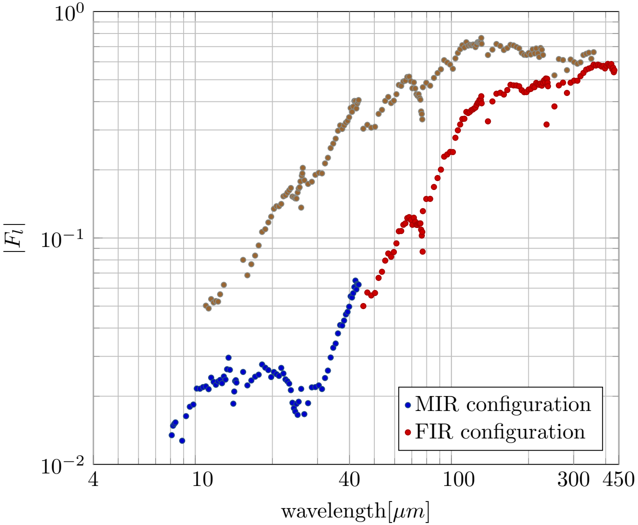

Reconstruction of temporal profile

CRISP4

- Complex Formfactor

$$F_{long}(\lambda) = \left|F_{long}(\lambda)\right| \exp(i\,\phi(\lambda))$$

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- Reconstructed phase

$$\phi_{min}(\lambda) = -\frac{2\,\lambda}{\pi}\int_0^\infty \frac{\ln(\left|F_{long}(\lambda')\right|) - \ln(\left|F_{long}(\lambda)\right|)}{(\lambda'^2 - \lambda^2)}\,\mathrm{d}\lambda'$$

- Reconstruction

$$\rho_{long,min}(z) = -\frac{2}{\lambda^2}\int_0^\infty \left|F_{long}(\lambda)\right| \cos(\frac{2\,\pi\,z}{\lambda} - \phi_{min}(\lambda))\,\mathrm{d}\lambda$$

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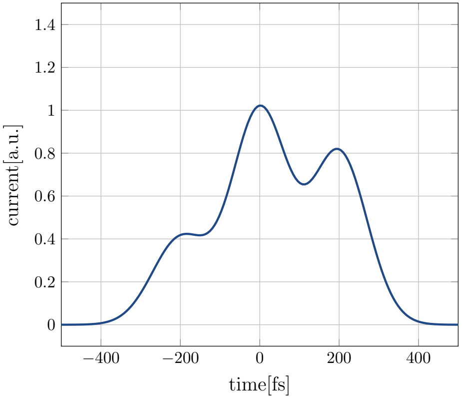
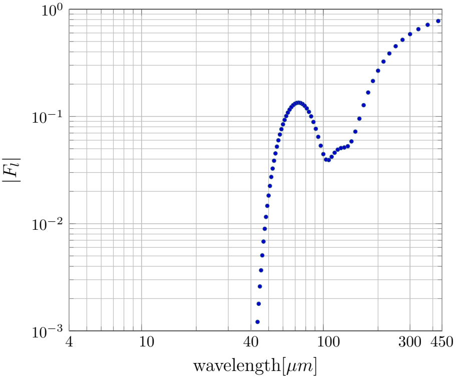
  - **Reconstructed profile is not unique**
  - **Needs a wide range of $\left|F_{long}(\lambda)\right| \rightarrow$ extrapolation needed**

Reconstruction of known profiles

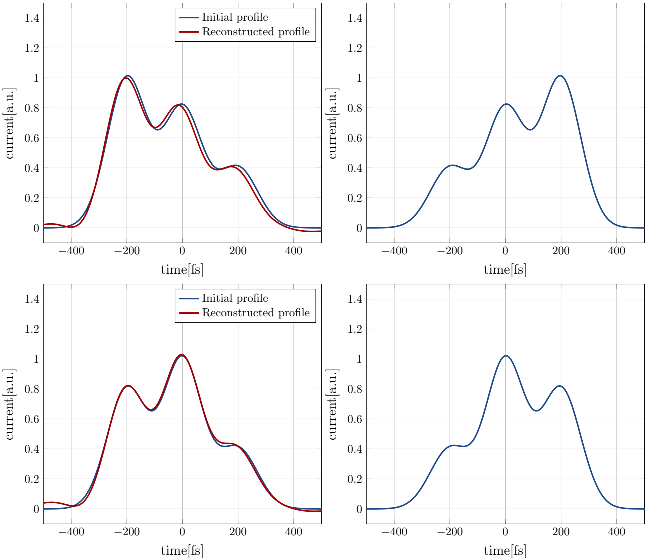
CRISP4





Reconstruction examples

CRISP4



Reconstruction examples

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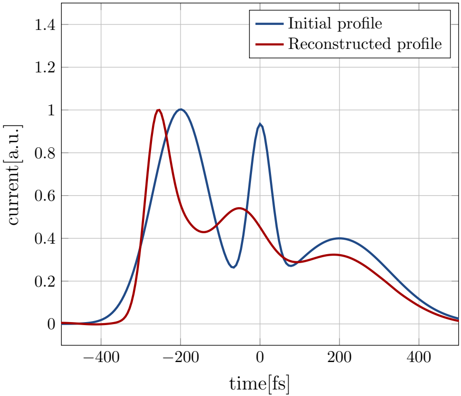
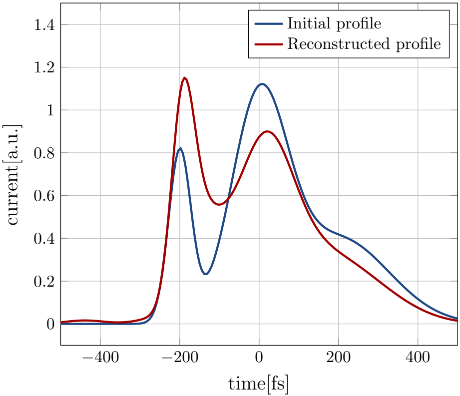
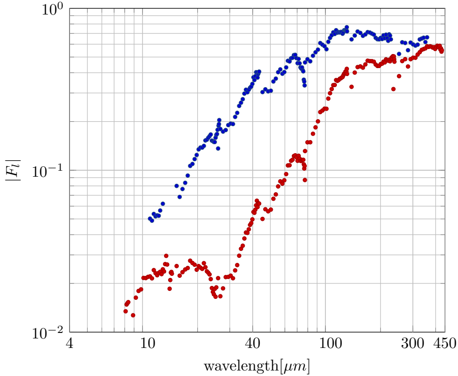
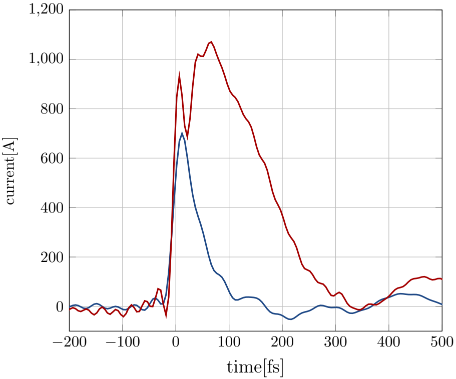




Reconstruction from measurements

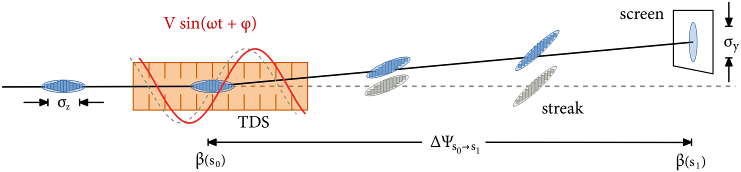
CRISP4

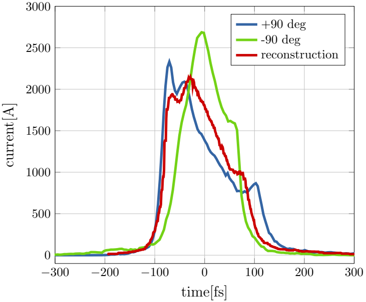




Comparison with measurements in time domain

TDS setup

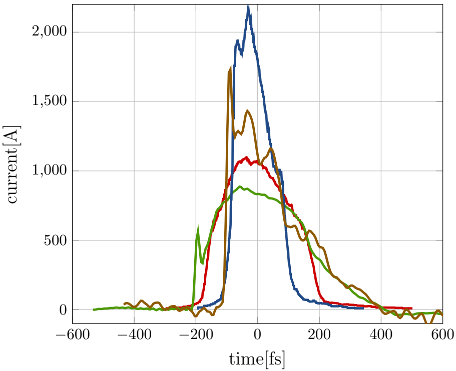


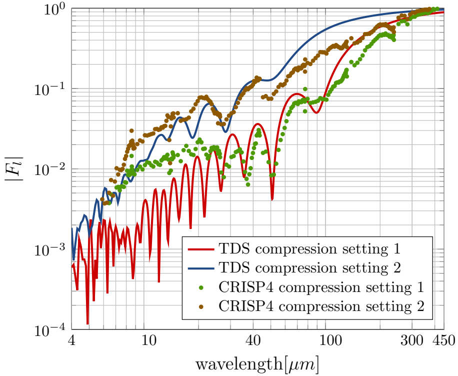


- direct temporal single shot measurement
- resolution depends on streak power and machine optics
- reliable measurements needs measurement with both streak directions

Status: February 2013

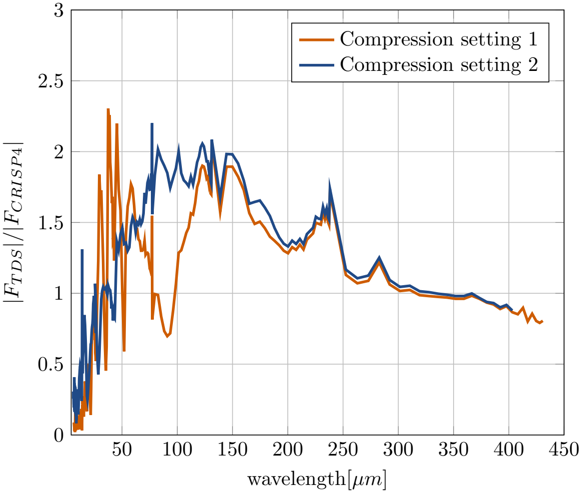
CRISP4





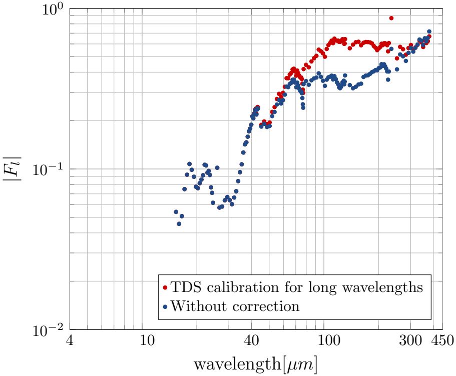
Long wavelengths response

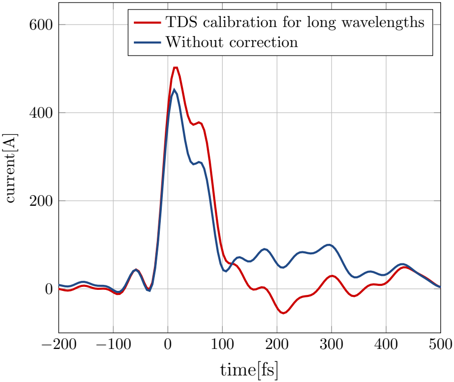
CRISP4



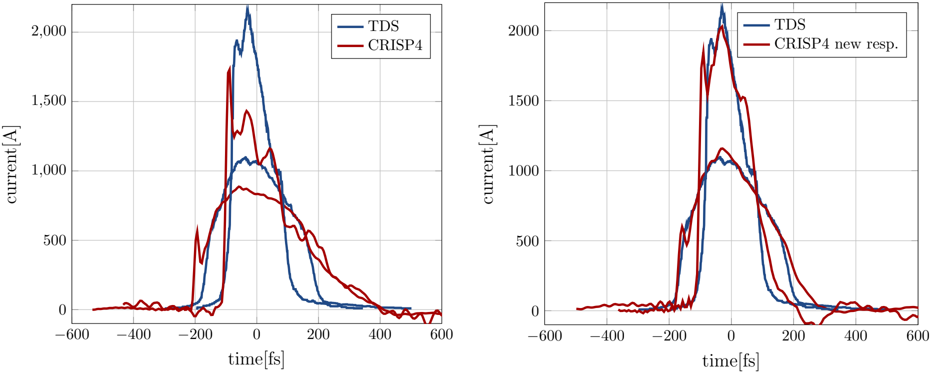
Influence on reconstructed profiles

CRISP4



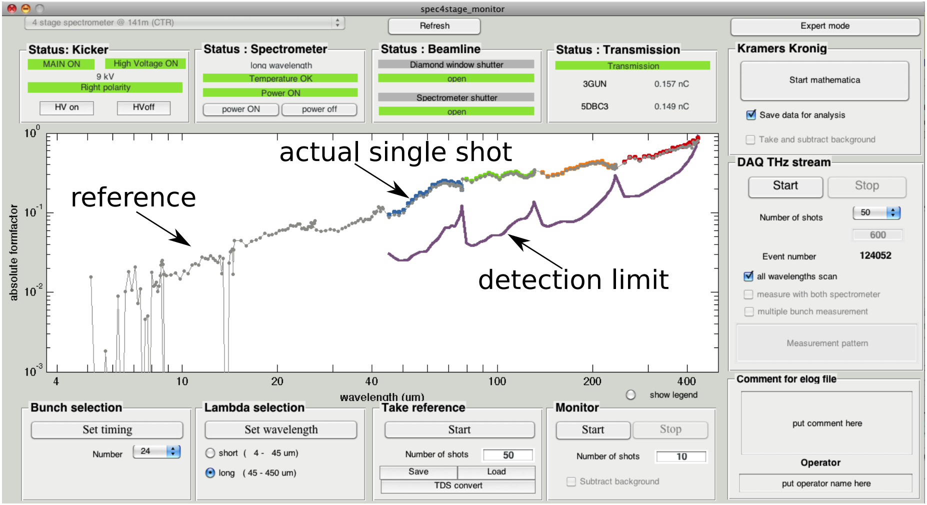


Comparison with TDS in time domain
CRISP4



CRISP4 as a STANDARD!!! diagnostic tool in control room

Control panel



Summary

- CRISP 4 can measure $\left|F_{long}(\lambda)\right|$ from 5.5 to $440\ \mu m$
- Measurements down to 50 pC are possible for sufficiently short bunches
- Calibration above 110μm using TDS in progress
- CRISP4 can be used as an online diagnostic and monitoring tool in control room
- A good agreement between reconstructed temporal profiles and direct temporal measurement with TDS is found

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Thank You