Non-invasive Longitudinal Profile Measurements of Electron Bunches Simultaneously to FEL Operation at MHz Rates

IBIC 2020 – 9th International Beam Instrumentation Conference

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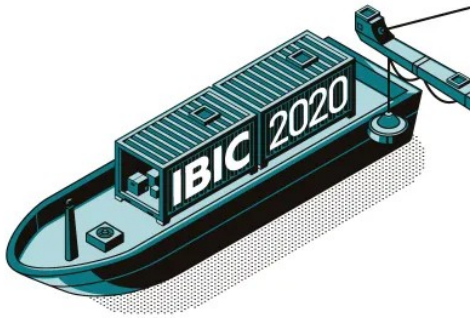
Brazil, 14-18.9.2020



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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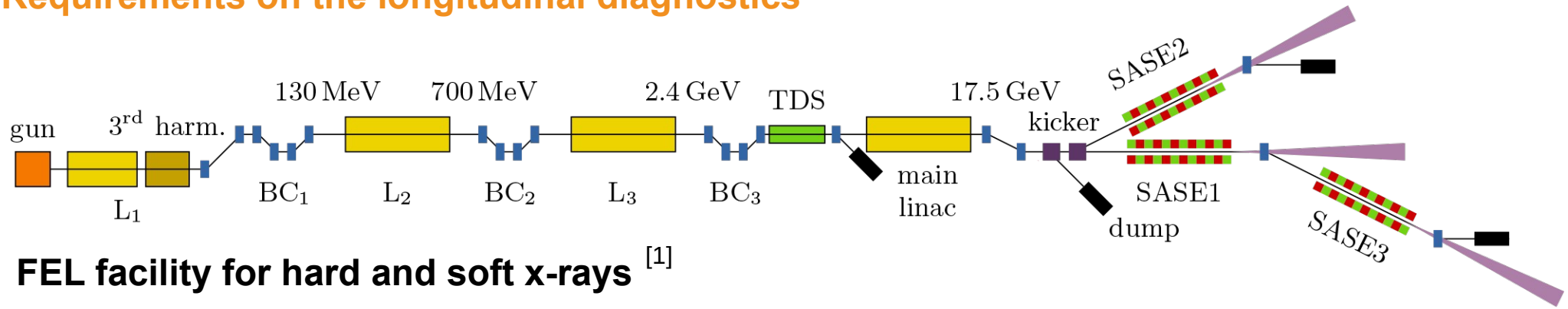
DESY.

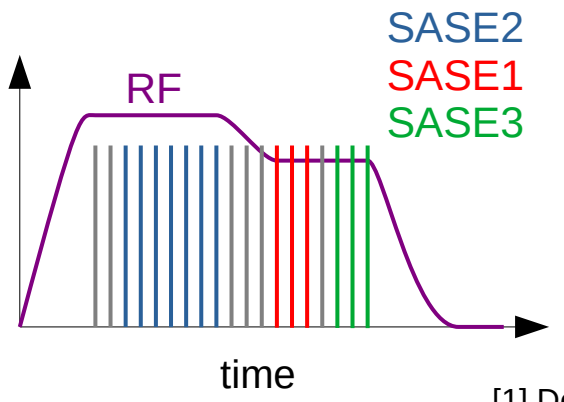
European XFEL

Requirements on the longitudinal diagnostics



FEL facility for hard and soft x-rays [1]

- Requires kA peak currents ↔ few ten fs bunch lengths
- Current profile subject to highly nonlinear effects
  - CSR, space-charge
- Bunch trains with MHz repetition rates
- Different RF settings for SASE1/3 and SASE2



Diagnostics requirements

- Few femtosecond resolution
- Every bunch
  - Non-invasive
  - MHz readout rates

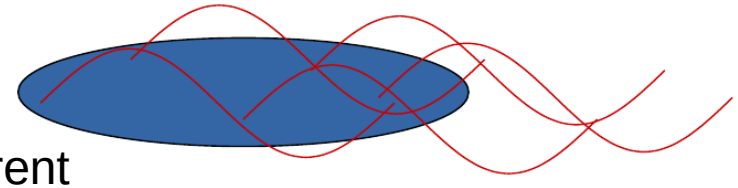
[1] Decking, W. et al., Nat. Photonics 14, 391–397 (2020)

Coherent Radiation Diagnostics

Longitudinal diagnostics based on spectral measurements

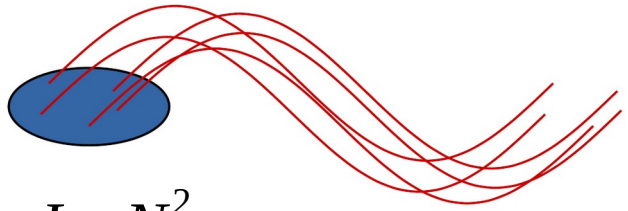
Coherent emission

incoherent



$$I \sim N_e$$

coherent



$$I \sim N_e^2$$

$$I_{coh}(f) = I_1 N_e^2 |F(f)|^2$$

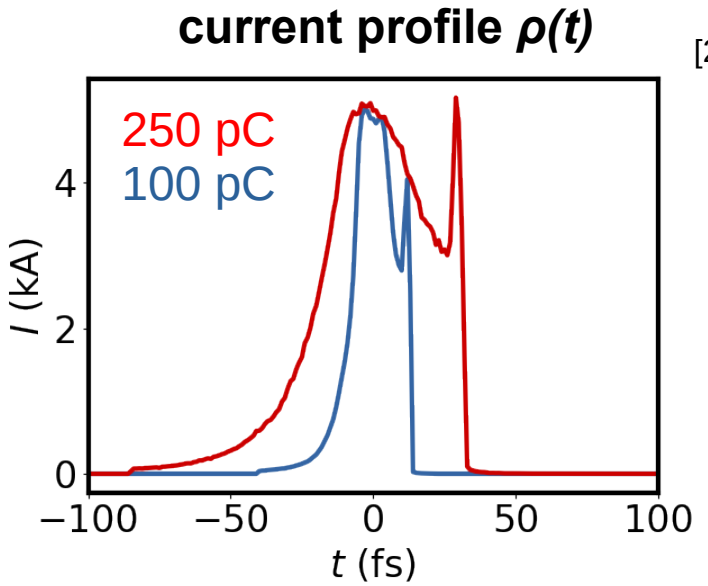
Form factor *F(f)* is the Fourier transform of the current profile *ρ(t)*

$$F(f) = \int_{-\infty}^{\infty} \rho(t) \exp(-i 2\pi f t)\, dt$$

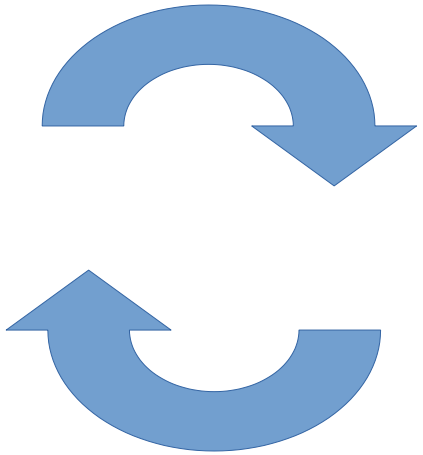
Coherent Radiation Diagnostics

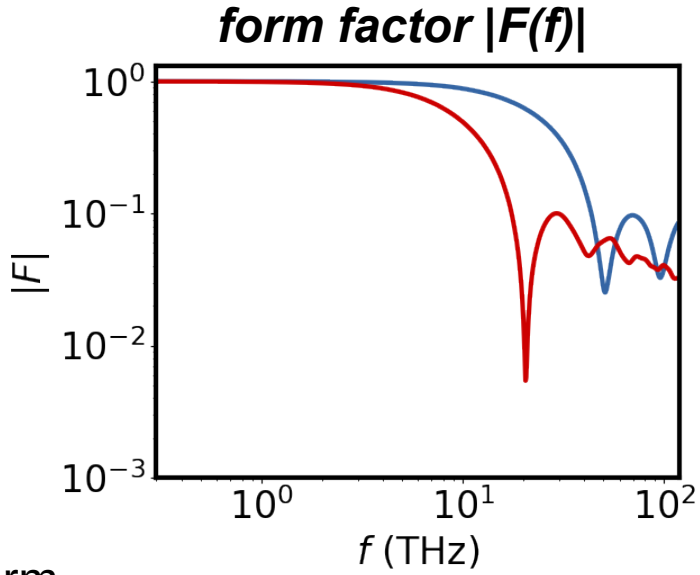
Form factor

- Spectral measurement
- Required frequency range
  - IR – THz



[2]





- Inverse Fourier transform

$$F(f) = |F|(f)\exp(i\,\phi(f))$$

- **Phase *Φ (f) ?***

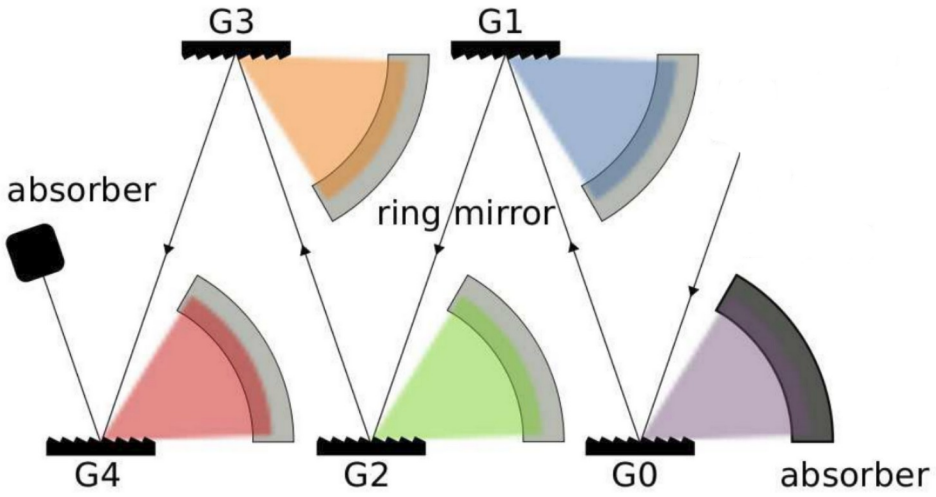
[2] https://www.desy.de/xfel-beam/s2e/xfel.html

CRISP Spectrometer

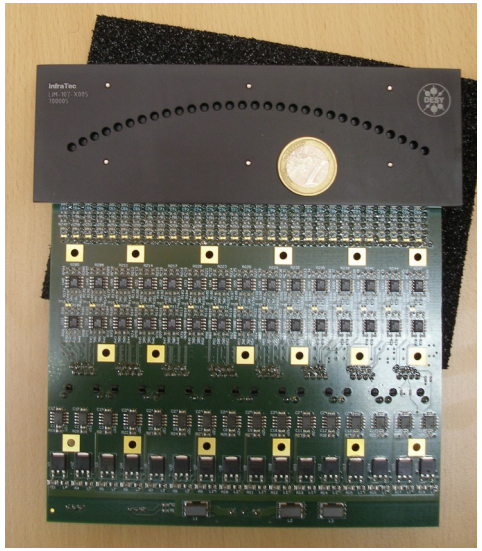
Covering a wide frequency range

Coherent Radiation Intensity SPectrometer [3]

- 4 cascaded gratings
  - Each grating is a low-pass
- Two operation modes / grating sets
  - IR(6-60 THz) and THz (0.6-6 THz)



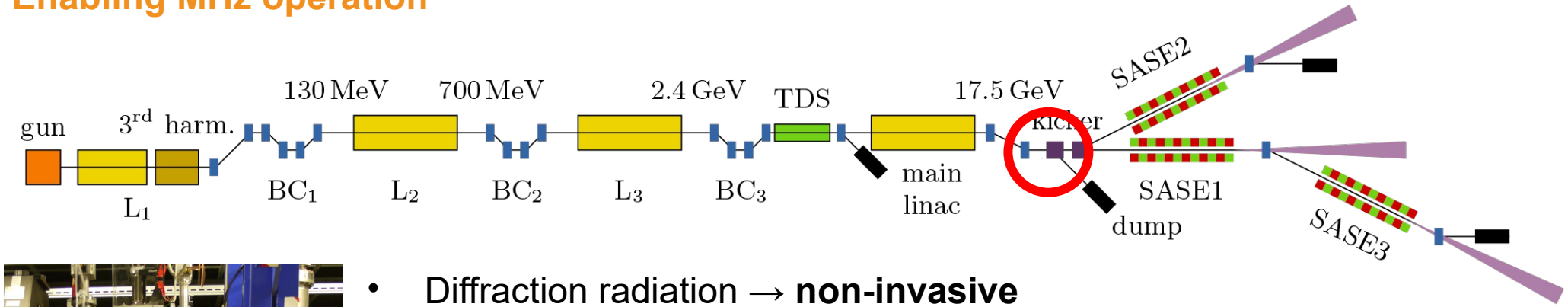
- Single-shot
- Pyroelectric detector arrays with 30 channels
- Total of 240 channels

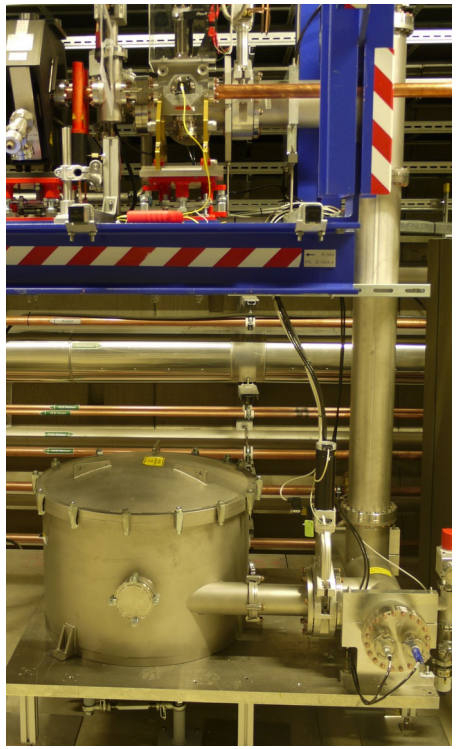


[3] Wesch, S. et al., NIM A 665 40-47 (2011)

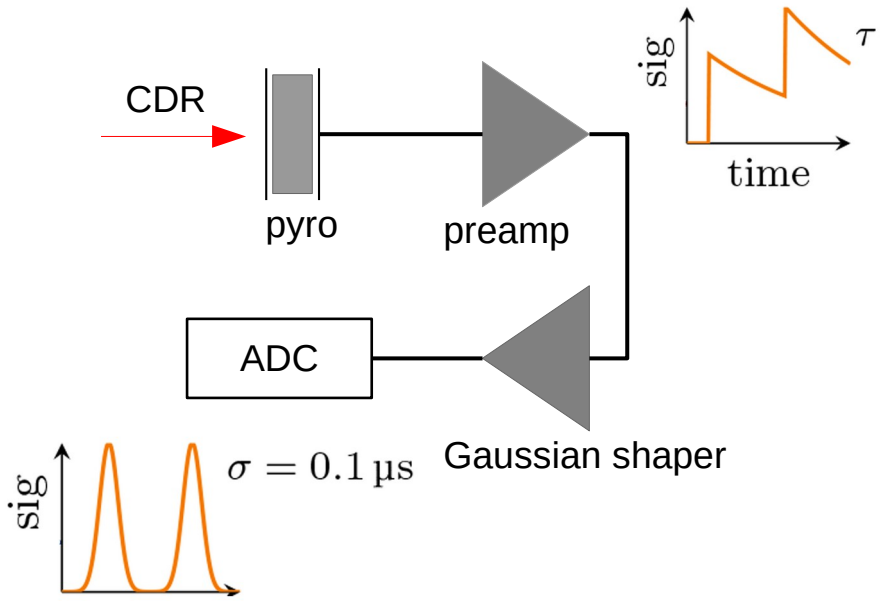
CRISP at European XFEL

Enabling MHz operation

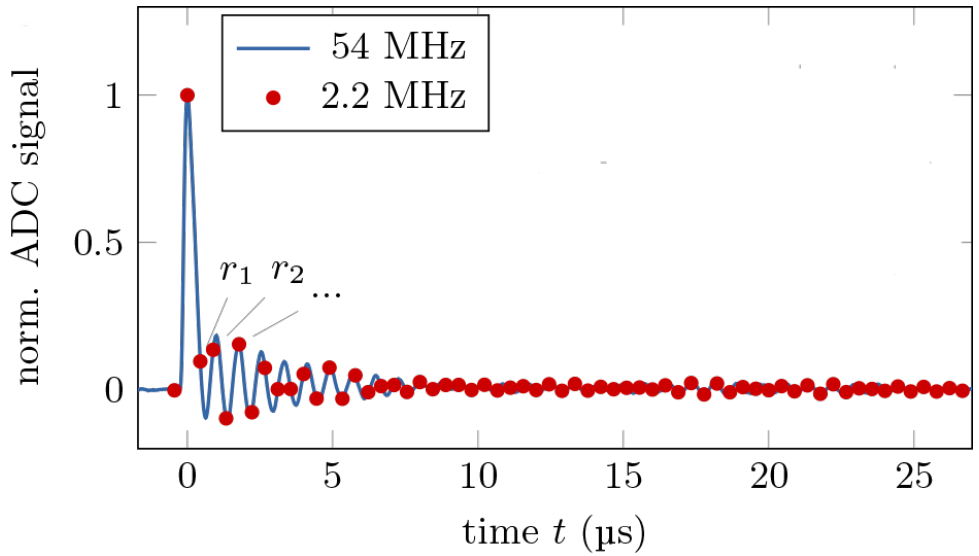




- Diffraction radiation → **non-invasive**
- Fast pulse shaping electronics



- Mechanical crystal oscillations
  - **Pileup ?**

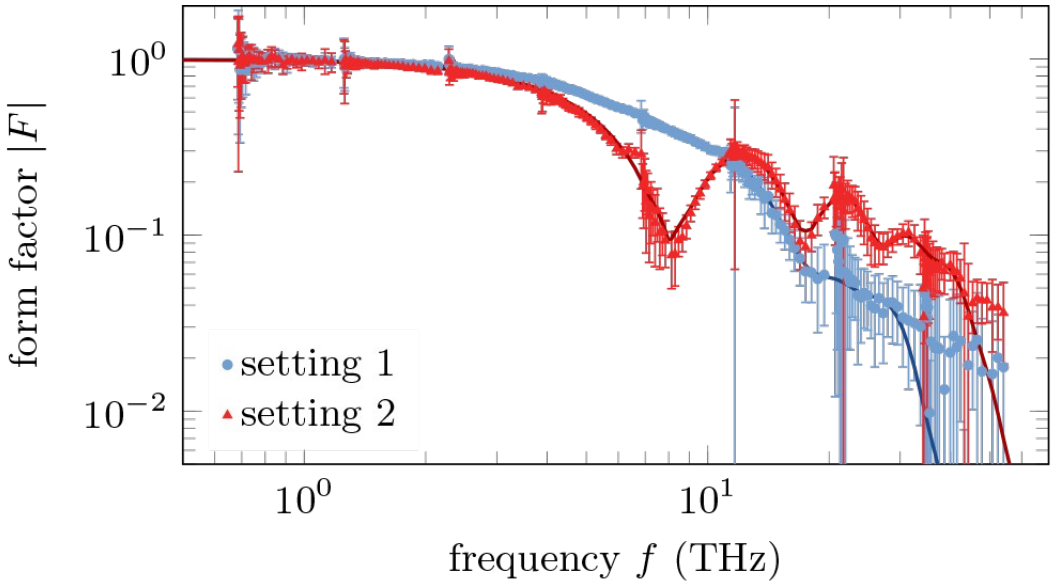


Form factor and current profile

Retrieving the phase information

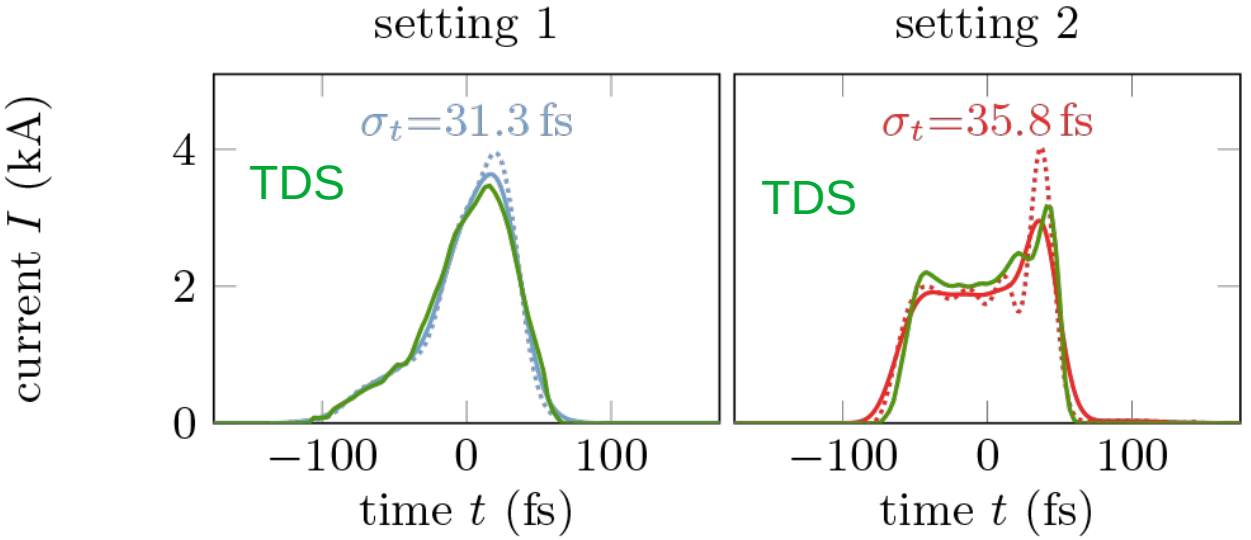
Measured form factors of single bunches

- Sufficient signal along wide frequency range
- Changes in bunch compression clearly detectable



Current profiles

- Intensively studied [4]
- Gerchberg-Saxton algorithm starting from Kramers-Kronig phase → Fast, well-defined solution



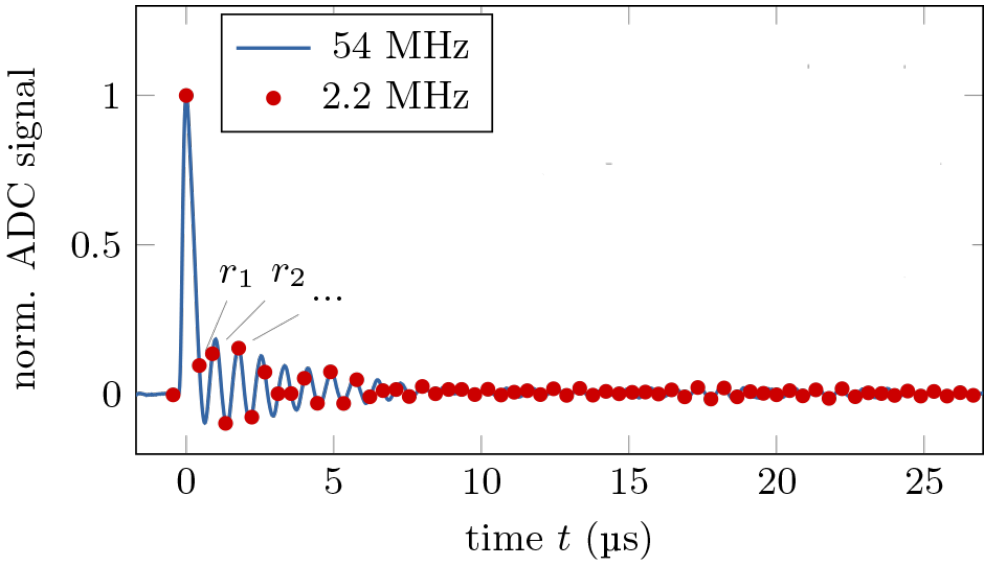
[4] Schmidt, B. et al., PRAB 23, 062801 (2020))

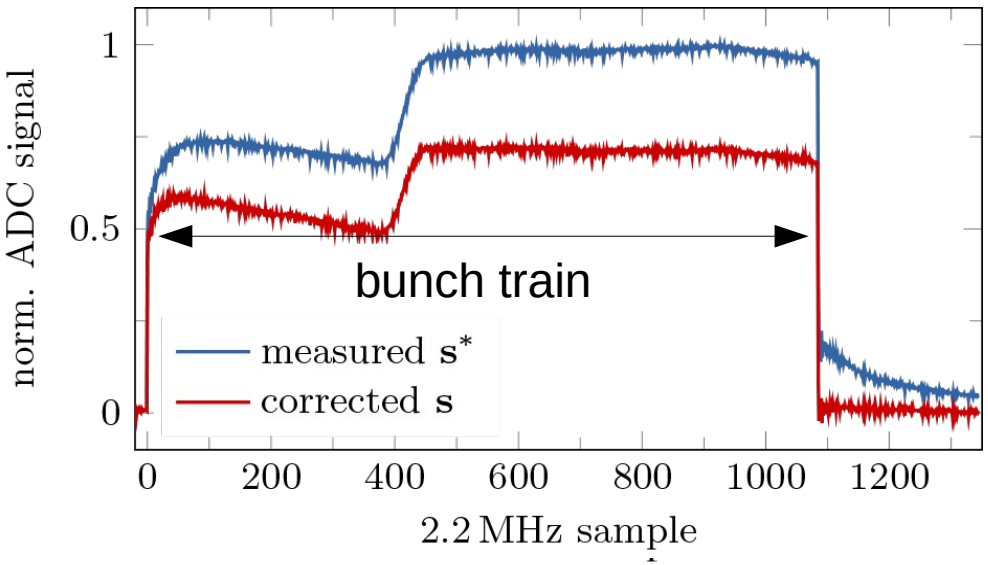
MHz operation

Pileup issue

Pileup properties

- Leads to signal after bunch train
- Ringing is phase stable, e.g. same for every bunch: $s_n^* = s_n + r_1 s_{n-1} + r_2 s_{n-2} + \ldots + r_n s_0$
- Linear superposition → inversion → pileup removal



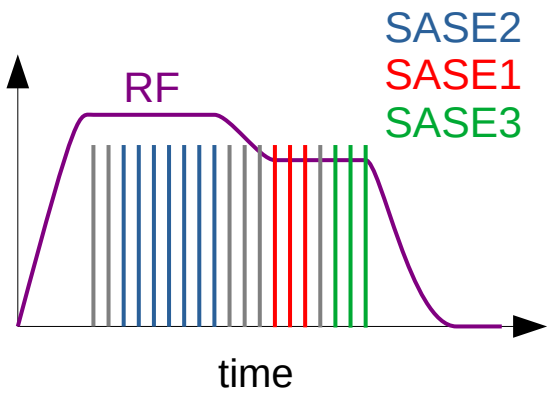


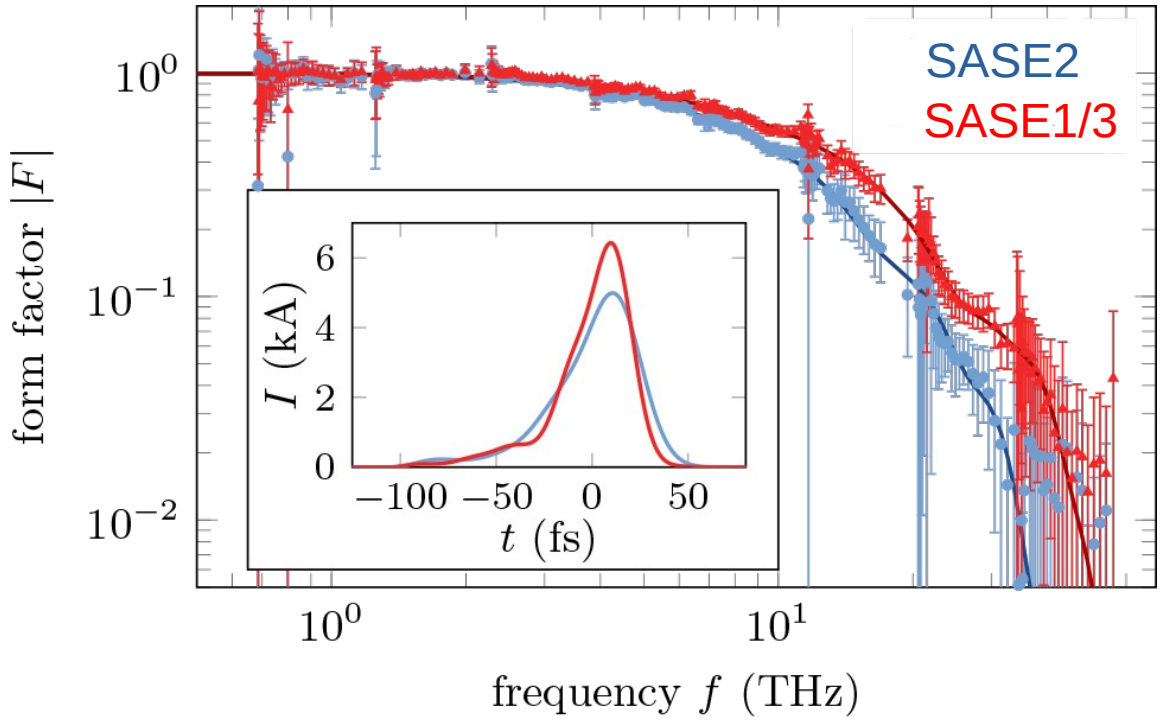
MHz operation

Current profile examples

Current profile measurements parallel to FEL operation

- Different compression settings for SASE1/3 and SASE2
- Selected bunch from each destination



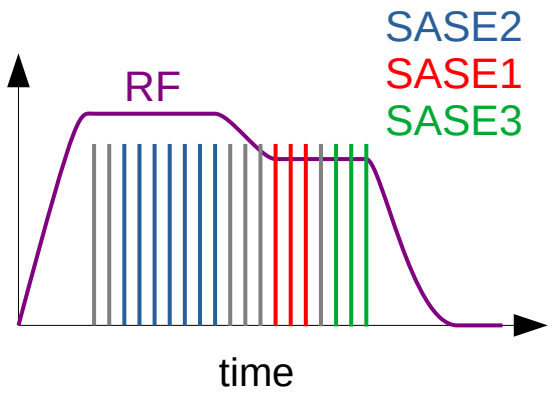


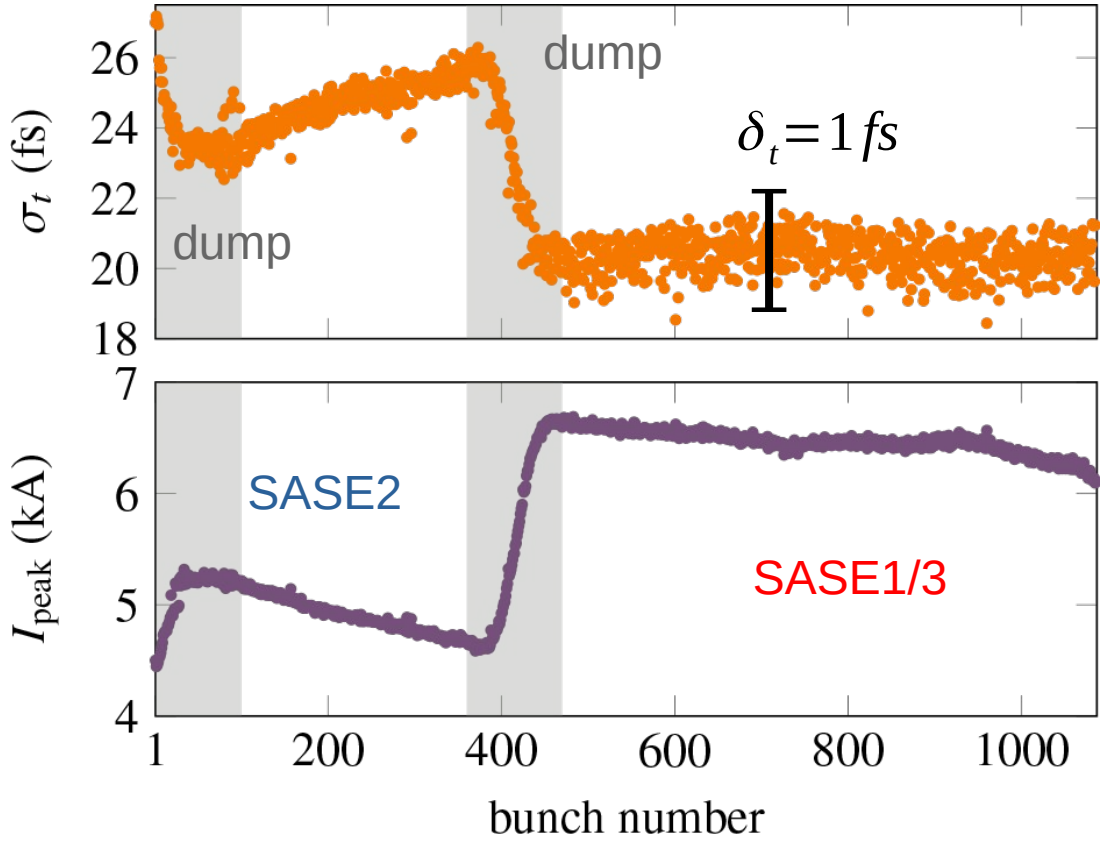
MHz operation

Continuous current profile monitoring

Every bunch along the train

- 2.2 MHz repetition rate
- Variations along flattops visible
- Transition regions
- ~ fs relative uncertainty



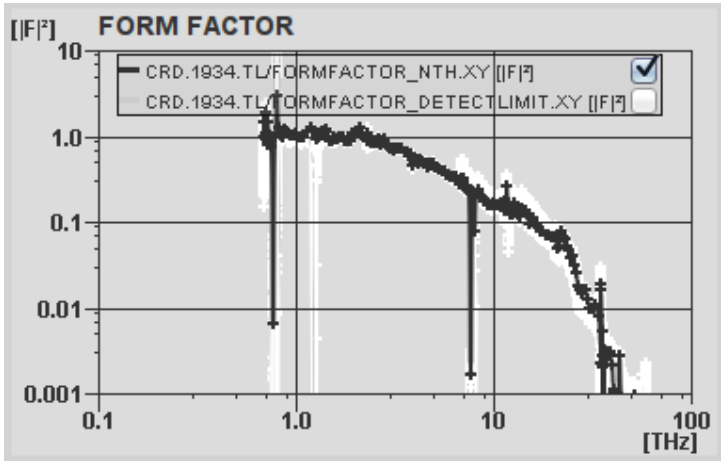


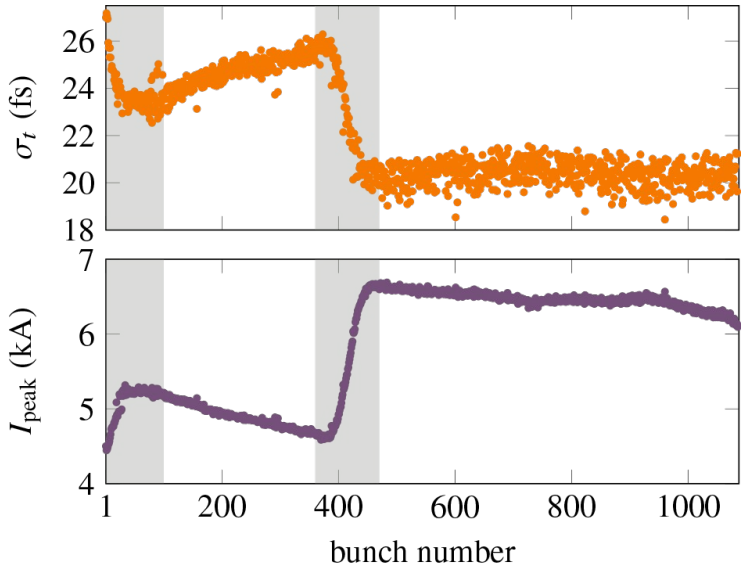
Conclusion

A potent diagnostic for hard x-ray FELs with MHz rep rates

Summary

- Few femtosecond resolution → broadband spectrometer, fast and robust phase retrieval
- Every bunch
  - Non-invasive → diffraction radiation
  - MHz operation → pyroelectric detectors with fast pulse shaping and pileup correction

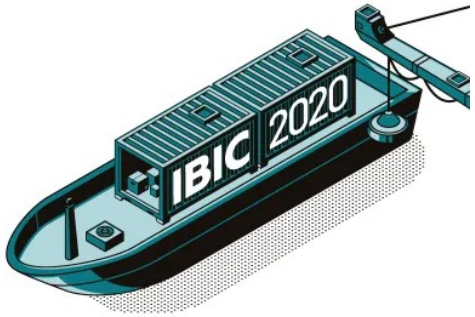




Outlook

- Online operator tool
  - Form factor and current profiles
- Slow and fast feedback:
  - Stabilize compression along bunch train
- Applicable for future CW XFELs

Thank you



… looking forward to IBIC20 and to answer your questions in the live session

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