BUNCH COMPRESSION MONITOR BASED ON COHERENT DIFFRACTION RADIATION AT EUROPEAN XFEL AND FLASH.

Christopher Gerth* and Nils Maris Lockmann
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany.

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Bunch Compression Monitor (BCM).

1) Screen Station and CDR screen:

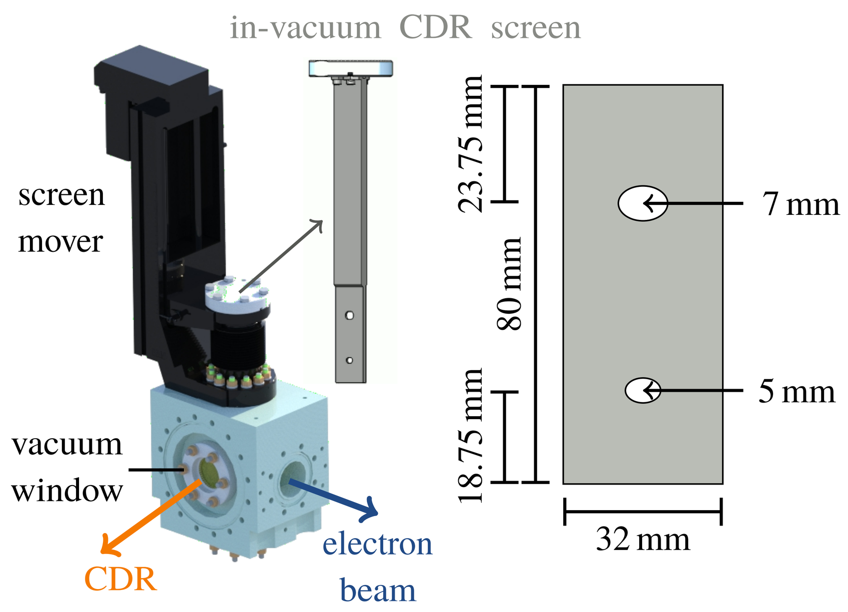


Figure 2: CAD model of screen station and CDR screen and radiator area enlarged with dimension.

- Screen station in e-beamline for generation of coherent diffraction radiation (CDR)
- In-vacuum CDR screen remotely controllable
- Screen normal 45° w.r.t. to e-beam axis
- 2 apertures: 5 mm and 7 mm diameter
- Backward CDR emitted at 90° to e-beam
- BCM1/2 : fused silica vacuum window
- BCM3 : diamond vacuum window
- Optics and detector unit directly mounted to screen station

2) Optics and Detector Unit:

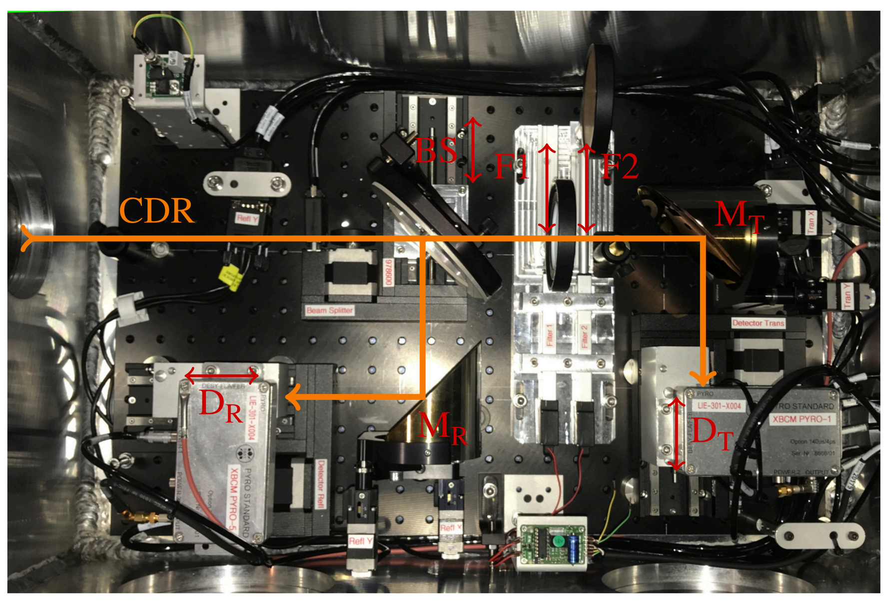


Figure 4: Top view of the optics and detector unit. CDR beam path from screen station is illustrated.

- BS: Beamsplitter
  - Thin film Polarizer (movable)
  - T : transmitted beam path
  - R : reflected beam path
- F1 / F2 : 2 movable filter holders
- M_R / M_T : motorized focusing mirrors
  - gold-coated toroids (f = 101.6 mm)
- D_R / D_T : Detectors
  - BCM1: zero-biased Schottky diodes
  - BCM2/3: pyro-electric detectors

3) Spectral energy density of CDR:

$$\left[\frac{dU}{df}\right]_{CDR} = \left[\frac{dU}{df}\right]_1 \cdot \left(\frac{Q}{e}\right)^2 \cdot |F(f)|^2 , \qquad (1)$$

Bunch charge

Emission by 1 electron

Form factor given by 3D particle distribution - can be approximated by longitudinal form factor
<=> Fourier transform of current profile

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

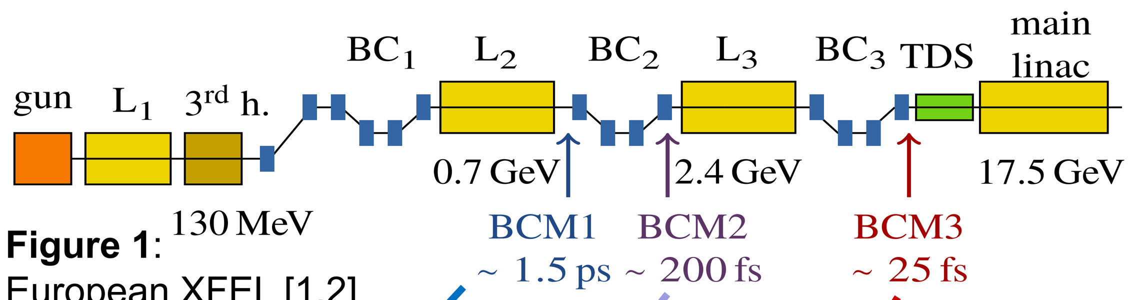


Figure 1: European XFEL [1,2]

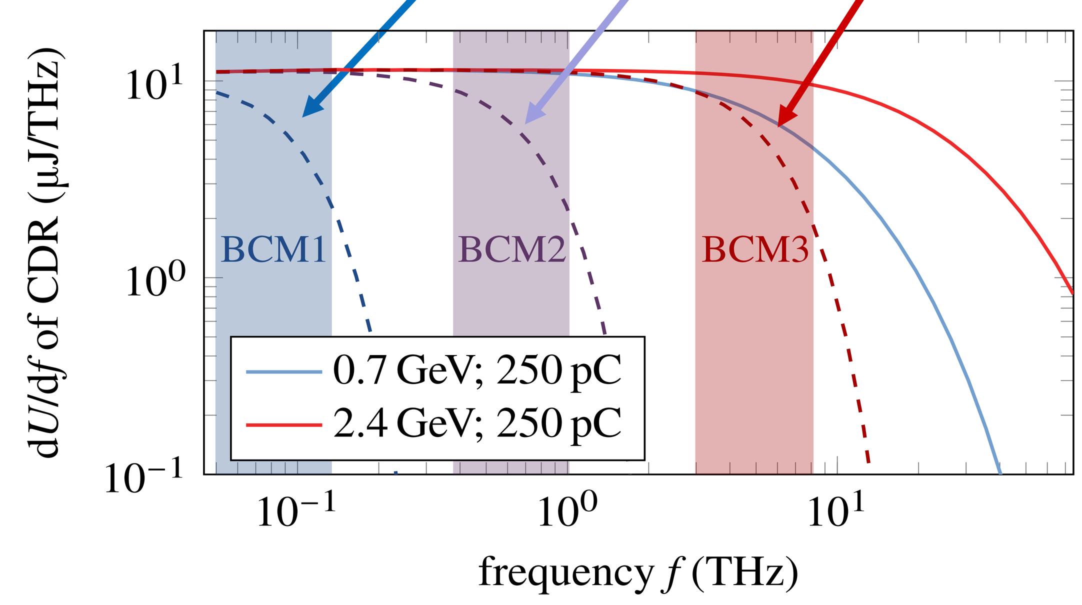


Figure 3: Spectral energy density of CDR [3]. Dashed lines include the form factor term of Eq. 1 for rms bunch lengths given above. Coloured areas are of interest for BCM as correlated to bunch length.

BCM3 Calibration with TDS.

- At BCM3, the bunches are fully compressed
- Ref. [5]: the particular shape of the longitudinal profiles of electron bunches with the same rms bunch length leads to differences in the form factor only at high frequencies
- Use low-pass filter: 6 THz cut-off frequency
- Use the charge-normalised BCM signal as intensity scales quadratically (see Eq. 1):

$$S_{norm} = S_{BCM}/Q^2$$

- Use TDS [4] for cross calibration (see Fig. 1)
- Subtract TDS resolution for rms bunch length:

$$\sigma_{TDS} = \sqrt{\sigma^2_{mess} - R^2_{TDS}}$$

1) BCM signal vs. TDS rms bunch length:

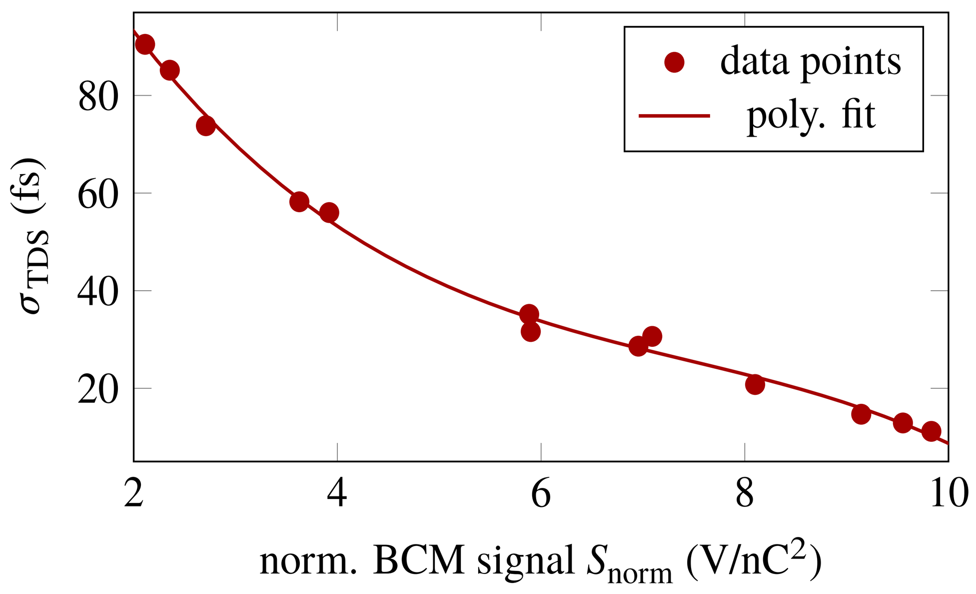


Figure 5: Third-order polynomial fit as a cross-calibration of the charge-normalised BCM signal S_{norm} to the rms bunch lengths measured with a TDS.

2) Compression scan from 6 fs to 90 fs:

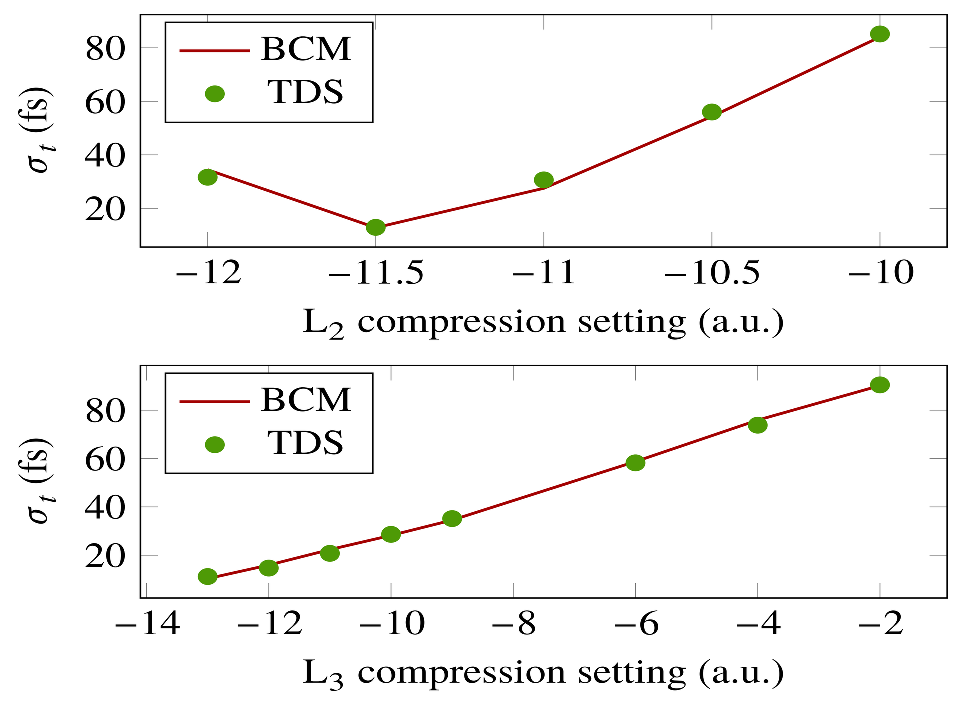
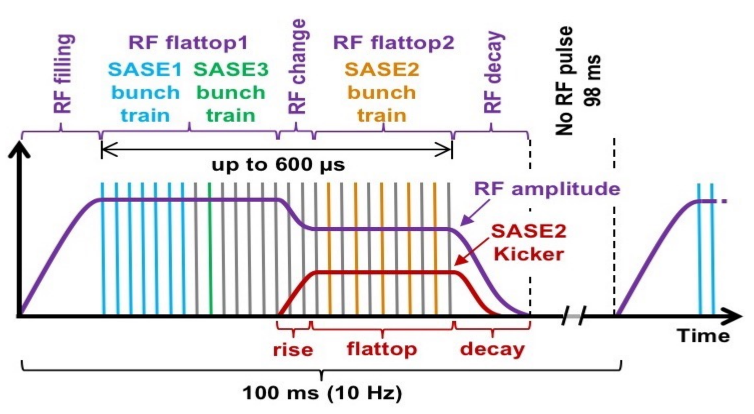


Figure 6: Comparison of rms bunch lengths. Rel. difference between TDS and BCM smaller than 10%.

MHz Operation.

1) European XFEL Bunch Pattern:



- Superconducting Accelerator
  - Bunch trains at 10 Hz
  - Bunch rep rate up to 4.5 MHz
- 2 RF flattops in bunch train
  - Bunch train split for 2 FEL branches
  - Optimize compression independently

2) Signal Pileup Correction:

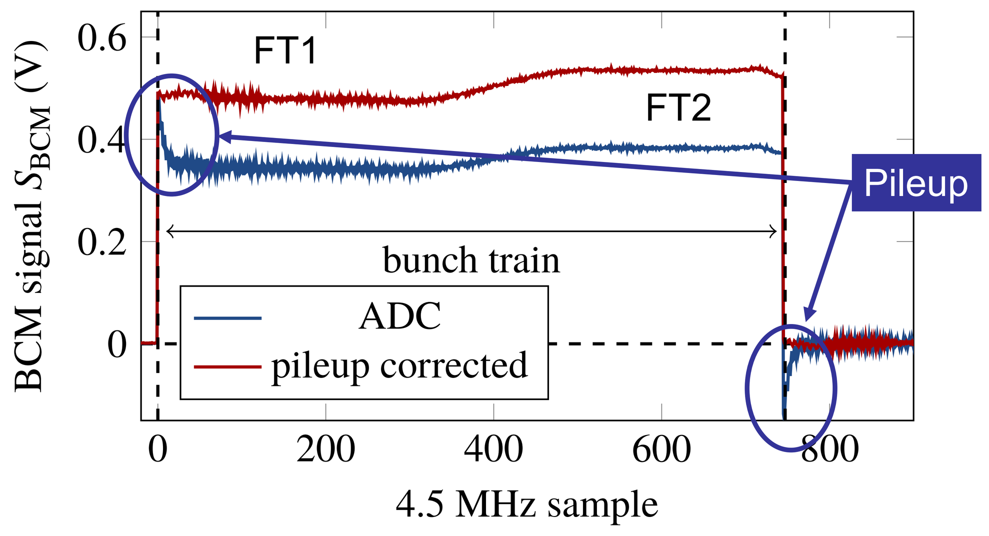


Figure 7: Signal pileup correction at 4.5 MHz

- Mechanical oscillations of pyro-electric detector lead to signal pileup (blue curve)
- Pileup can be corrected: see Appendix of Ref. [6]
- Indication of successful pileup correction: Baseline after bunch train within noise level (red curve)

3) Comparative measurements with TDS:

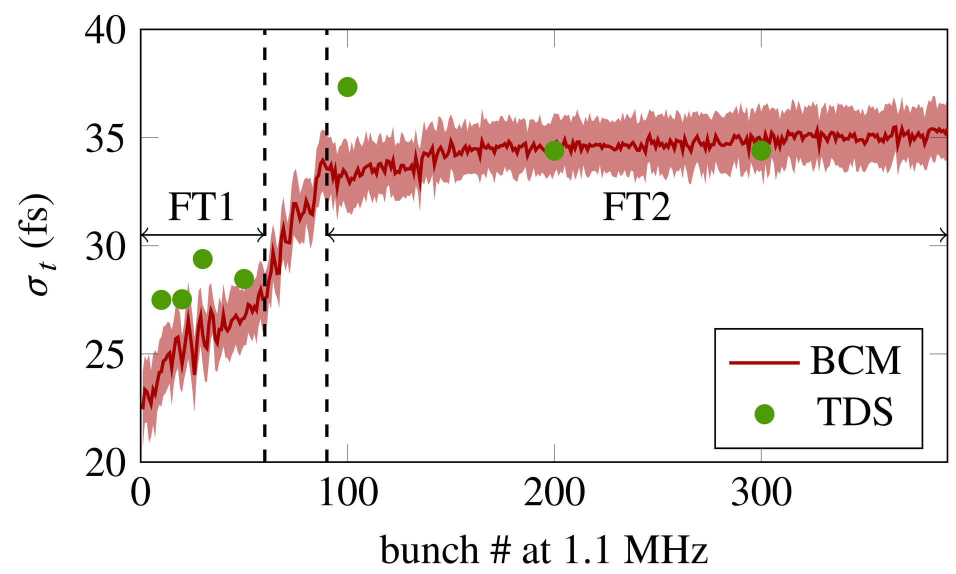


Figure 8: Comparison of rms bunch lengths

- **Red curve**: all bunches in the bunch train with BCM3 by applying the calibration presented in Fig. 5.
- **Red line**: mean of 30 consecutive bunch trains.
- **Green dots**: few selected bunch numbers with TDS.

Summary.

- BCMs were installed after each bunch compressor at European XFEL
  - Measure bunch compression non-invasively with CDR
- Signal pileup correction for pyro-electric detectors
  - Enables bunch-resolved measurements at rep rates of up to 4.5 MHz
- Cross-calibration of BCM3 with TDS:
  - Signal converted to rms bunch lengths
  - Monitoring of entire bunch trains
- FLASH:
  - Same BCMs will be installed within FLASH2020+ Upgrade Project [7]

References.

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[3] S. Casalbuoni, B. Schmidt, and P. Schmüser, "Far-infrared transition and diffraction radiation, part I: Production, diffraction effects and optical propagation," DESY, Hamburg Germany, Report 2005-15, 2005.

[4] C. Gerth, B. Beutner, O. Hensler, F. Obier, M. Scholz, and M. Yan, "Online longitudinal bunch profile and slice emittance diagnostics at the European XFEL," 2017, pp. 153–156. DOI: 10.18429/JACoW-IBIC2017-TUPCC03.

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*christopher.gerth@desy.de