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PSI

G. L. Orlandi on behalf (*)

Bunch Length and Energy Characterization with the Synchrotron Radiation Monitor of the SwissFEL Bunch Compressor

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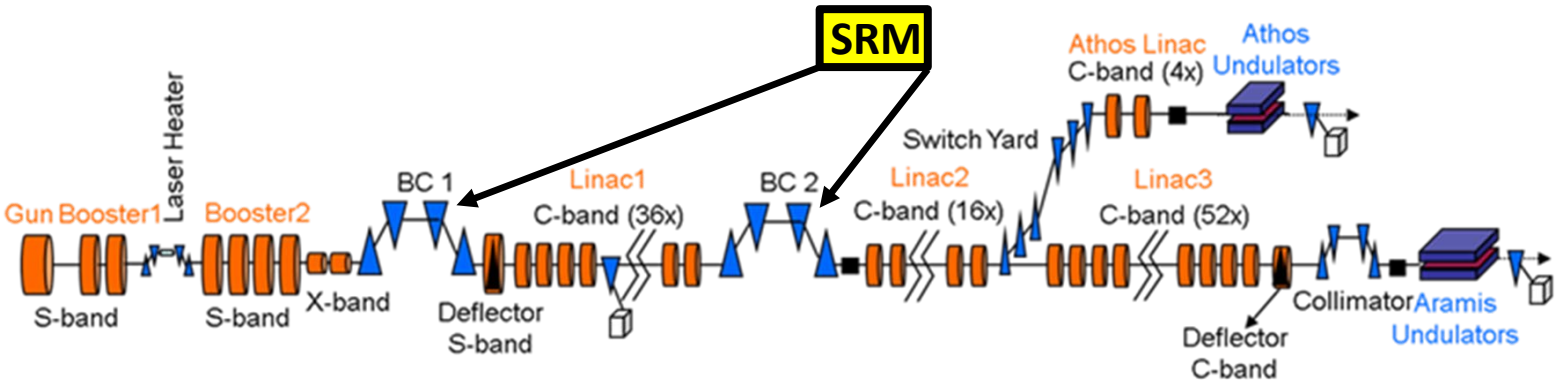
(*) G. L. Orlandi, R. Xue, H. Brands, F. Frei, Z. Geng, V. Thominet, S. Bettoni, *bunch length and energy measurements in the bunch compressor of a free-electron laser*, Phys. Rev. Accel. Beams 22, 072803 (2019)

Synchrotron Radiation Monitor (SRM) in SwissFEL



- Beam energy: 6.2 GeV and 3.3 GeV
- Beam charge: 10-200 pC @100Hz, 28 ns 2-bunch time structure
- Emittance: 0.4/0.2 mm mrad
- Bunch length: from a 3 ps up to a few fs
- Bunch Compression factors (BC1+BC2): ~150 (@200pC) and ~300 (@10pC)
- Photon wavelength: 0.1-0.7 nm and 0.7-7.0 nm

SRM in SwissFEL

➢ **SRM set-up in the Aramis phase (single bunch operations)**:

- BC1: bending-angle 0➔4.6deg, operation setting: 300MeV and 4.1 deg (η=-448mm)
- sCMOS PCO.Edge camera (100fps, Optical Fiber Camera Link)+300 mm lens+BW UV/IR cut filter
- Visible Edge Synchrotron Radiation from the entrance edge of the 3rd dipole of the chicane
- Charge sensitivity range 10-200 pC, beam size 6.0mm (rms, @BC1)
- Monitor the beam transverse profile over the entire range of the bunch-compressor bending angle to determine the beam energy and relative energy spread
- Relative energy spread resolution BC1= 1.4x10^-4
- Real time (100Hz) processing of the images with C/C++ analysis algorithm running on the camera server and interfacing the IOC/EPICS channels

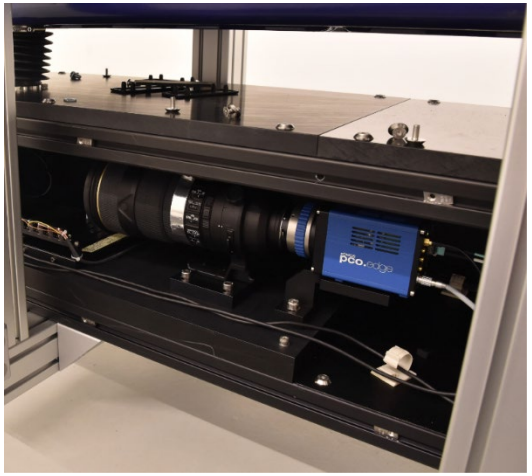
➢ **SRM operations in the Aramis+Athos phase (2 bunch operations):**

- BC1 SRM: sCMOS camera replaced with PCO.Dicam C1, fast gated MCP camera to resolve Bunch-1 or Bunch-2

BC1 SRM set-up at SwissFEL

2-bunch camera set-up: PCO.Dicam C1

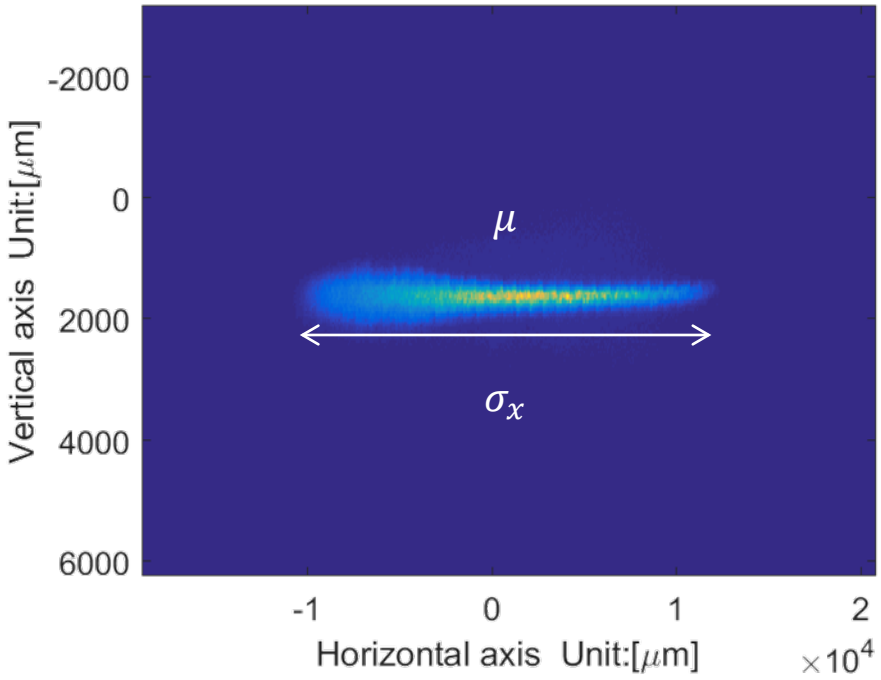
Single bunch camera set-up: sCMOS PCO.Edge



SRM BC1: mean energy and energy spread characterization

- shot to shot and not invasive monitor of the beam transverse profile.
- Mean energy (E_0)➔ centroid of the SR light distribution
- Energy spread ($\Delta E/E_0$) ➔ sigma (rms) of the horizontal distribution of the SR light
- beam synchronous acquisition of the camera images at SwissFEL (time stamp and ID number)
- Centroid and sigma (rms) (➔➔ mean energy and spread) can be processed in real time @100Hz by means of a C/C++ analysis algorithm running on the camera server and interfacing the IOC/EPICS (function developed and tested for single bunch camera but not yet implemented in the 2-bunch camera)
- Possibility to use the shot-to-shot processed SR light centroid and sigma (rms) for feedback of the RF

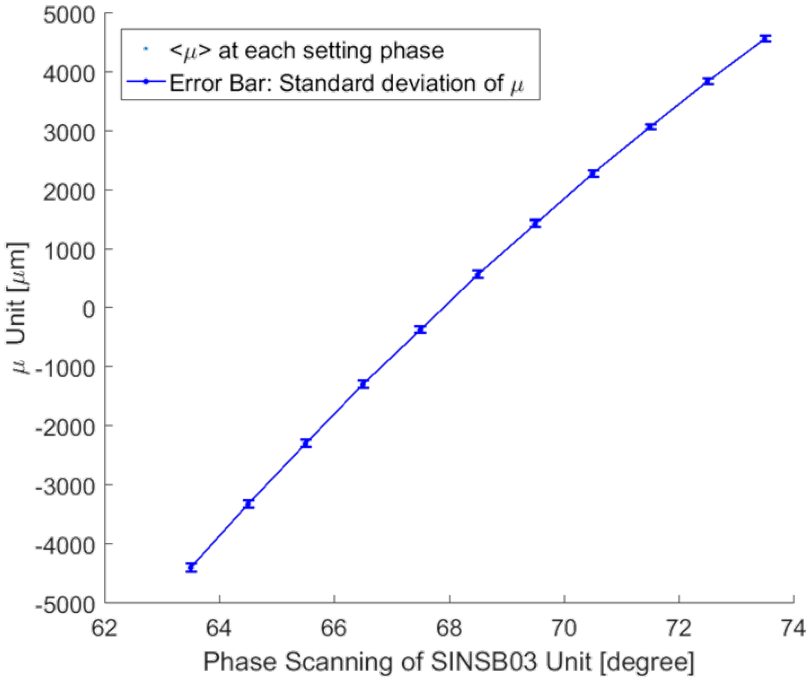
$$\frac{\Delta E}{E_0} = \frac{\Delta x}{\eta}$$

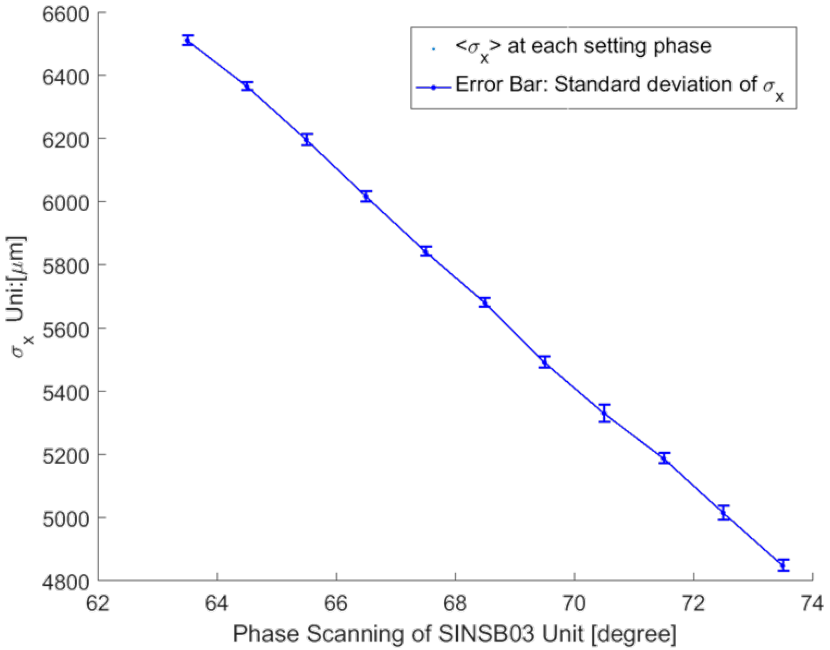


SwissFEL SRM BC1: Mean energy and spread characterization vs compression

- BC1-SRM measurements vs S-Bands Phase (SINSB03/04) at SwissFEL:

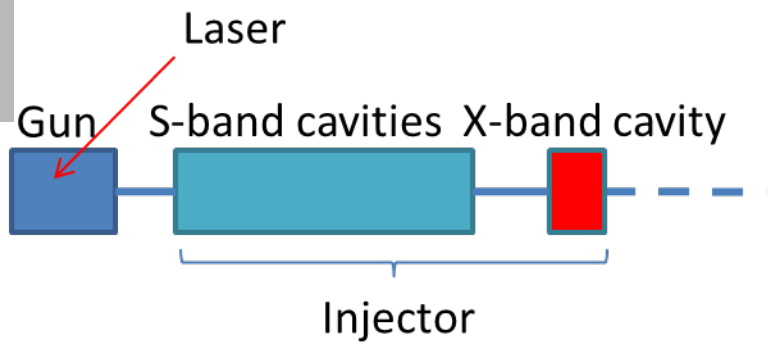
  - single bunch camera (July,2018)
  - Energy feedback – OFF
  - Compression feedback – OFF
  - SINSB03/04: off-crest nominal phase setting 69.7 deg





BC1 SRM:non-invasive and shot-to shot monitoring of the electron bunch-length (*)

Modelling of the RF Chirp: Linear Approximation



Nominal Settings:

Setup	Frequency (GHz)	Phase (deg)	Amplitude (MV)
SINEG01	3	90	7.5
SINSB01	3	90	65.5
SINSB02	3	90	68.5
SINSB03	3	69.7	96.2
SINSB04	3	69.7	96.2
SINXB01	12	269.7	19.3

Energy gain in the SwissFEL injector:

$$E(\Delta z) = \sum_{j=1}^{6} A_j \sin(\varphi_j + k_j \Delta z)$$

Taylor Expansion

$$E(\Delta z) = \sum_{j=1}^{6} [A_j \sin\varphi_j + A_j \cos\varphi_j \, k_j \Delta z + \mathcal{O}(\Delta z^2)]$$

$$= E_0 + T_1 \Delta z + \cdots$$

Linear approx.: $\Delta E = T_1 \Delta z$

$$T_1 = \sum_{j=1}^{6} A_j k_j \cos\varphi_j$$

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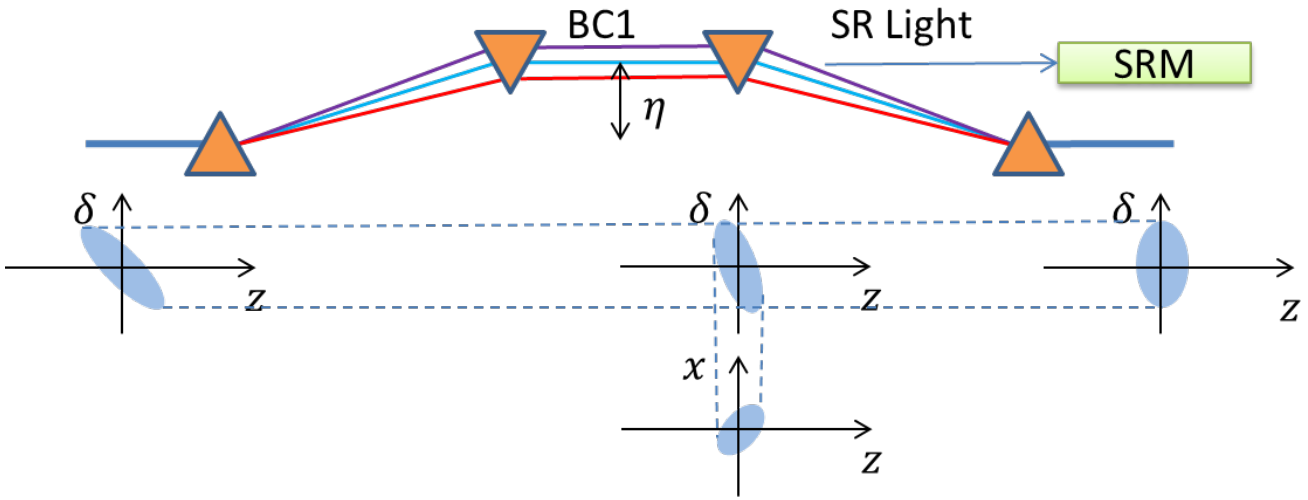
BC1 SRM:bunch length monitoring…



Relative energy spread @Injector:

$$\delta = \frac{\Delta E}{E_0} = \frac{T_1}{E_0}\Delta z$$

Relative energy spread @BC1-SRM:

$$\delta = \frac{\Delta E}{E_0} = \frac{\Delta x}{\eta}$$

$$\Delta z = \frac{E_0}{T_1}\frac{\Delta x}{\eta}$$

$$\sigma_{zi}(@Injector) = \frac{E_0}{T_1}\frac{\sigma_x(@SRM)}{\eta}$$

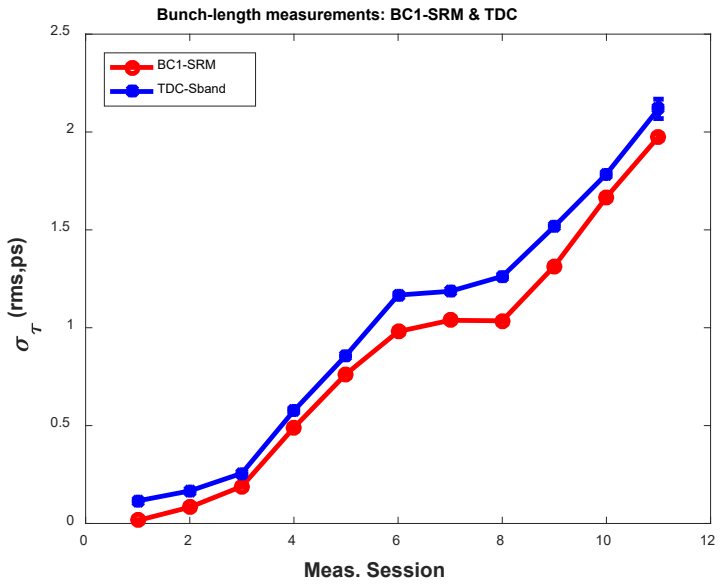
BC1 SRM: bunch length monitoring…

Energy chirp (lin. approx.): $\frac{\Delta E}{E_0} = \frac{\Delta x}{\eta} = \frac{T_1}{E_0}\Delta z$

$\Delta z = \frac{E_0}{T_1}\frac{\Delta x}{\eta}$ @ injector: $\sigma_{zi} = \frac{E_0}{T_1}\frac{\sigma_x(@SRM)}{\eta}$

@ exit of BC1: $\sigma_{zf} = |1 + AR_{56}|\sigma_{zi} = \left|1 + \frac{T_1 R_{56}}{E_0}\right|\sigma_{zi}$

$\sigma_t = \frac{1}{c}\left|1 + \frac{T_1 R_{56}}{E_0}\right|\frac{E_0}{T_1}\frac{\sigma_x}{\eta}$



BC1-SRM measurements:

- **mean energy and energy spread of the beam**, from the knowledge of the dispersion η;
- **absolute measurement of the bunch-length** from R_{56} and BS-READ of RF parameters of the injector ("energy chirp"T_1/E_0) and the camera images.
- **Comparison with TDS bunch length measurements at injector**

Conclusions and Outlook

➢ **BC1-SRM @ SwissFEL**:

- Basic operation application of the BC1-SRM:
  - Energy distribution characterization: mean value and spreading of the beam energy distribution (shot-to-shot @100Hz and fully non-invasive measurement)
- Further operation capability of the BC1-SRM, determine the electron bunch length:
  - beam synchronous acquisition of the BC1-SRM images and RF parameters (phase and amplitudes) of the injector
  - processing of the BC1-SRM images to determine the sigma(rms) of the horizontal distribution of the SR light spot and of the injector RF parameters to calculate the energy chirp (linear approximation)
  - shot-to-shot (100 Hz) and fully non-invasive determination of the bunch length by means of an algorithm depending on the known parameters of the magnetic chicane (dispersion η and R_{56}) and the processed values of the linear energy chirp (T_1) and the sigma(rms) of the horizontal distribution of the SR light spot

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