G. L. Orlandi

Longitudinal Beam Diagnostics at SwissFEL

11^{th} Workshop on Longitudinal electron Bunch Diagnostics, Lille, June 29-July 01, 2022

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- ➢Overview of the Bunch Compression Monitor (BCM) at SwissFEL
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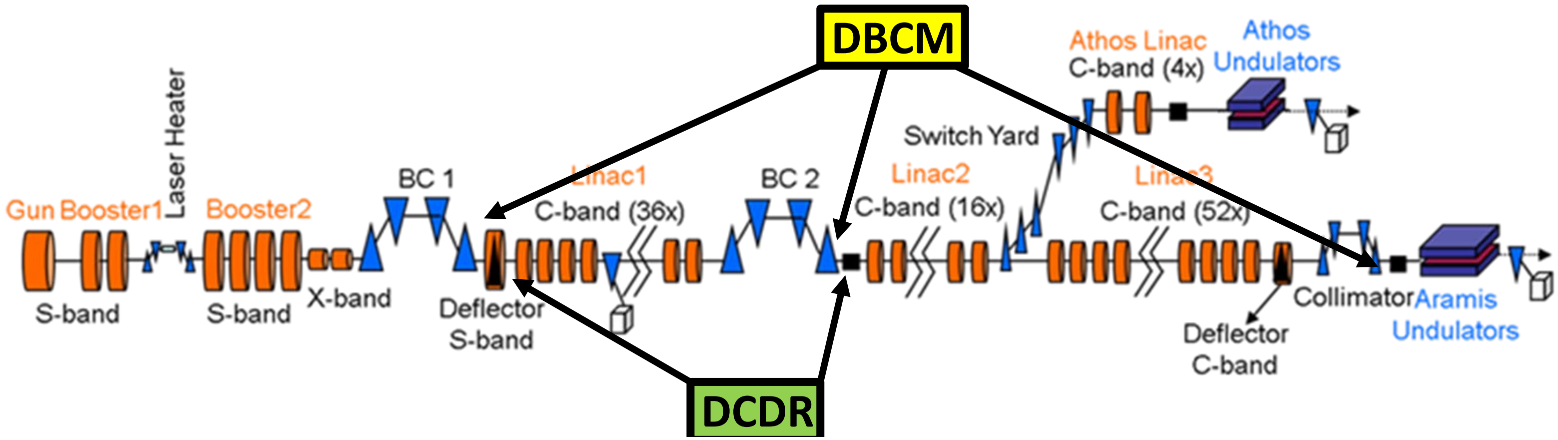
Bunch Compressor Monitors (BCM) at SwissFEL



Gun:
σ_z(10 pC, rms) = 334 μm
σ_z(200 pC, rms) = 871 μm

→

BC1:
σ_z(10 pC, rms) = 66.8 μm (C.F.=5)
σ_z(200 pC, rms) = 87.1 μm (C.F.=10)

→

BC2:
σ_z(10 pC, rms) = 1.0 μm (C.F.=300)
σ_z(200 pC, rms) = 5.7 μm(C.F.=150)

- **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 down 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

FEL experimental stations at SwissFEL

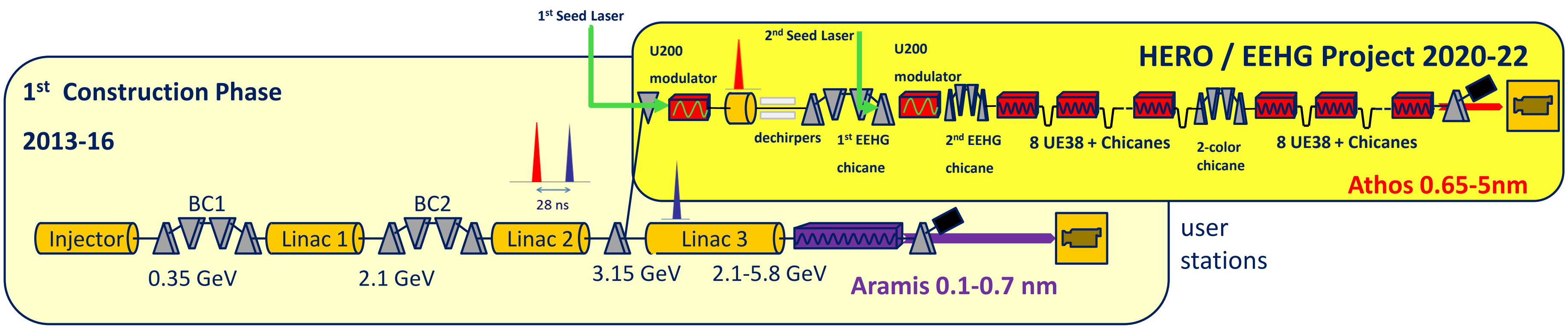
- **6 FEL experimental stations fed by the two linac branches (ARAMIS and ATHOS)**

- **ARAMIS:**
  - **ALVRA: Op. Jan. 2019, ultrafast photon biology (protein) and photo-chemistry (solar cell, catalizator),100fs resolution**
  - **BERNINA: Op.2019, solid state matter (superconductor, material for memory storage)**
  - **CRISTALLINA: Comm. 2022, users 2024, protein photo-biology, quantum-material -technology**

- **ATHOS:**
  - **MALOJA: Op. 2022, Atomic et Molecular Optical Physics (AMO), gas phase spectroscopy, single particle imaging**
  - **FURKA: Comm. 2022,users 2023, solid state matter, HERO**
  - **DIAVOLEZZA: under design and construction**

SwissFEL – HERO / EEHG Project

HERO seed laser: λ=793nm



ERC Grant - HERO: Hidden, Entangled and Resonating Orders

First Phase: 1st slicing in Summer 2022

=> increase temporal coherence

=> generation of train of mode-locked attosecond pulses

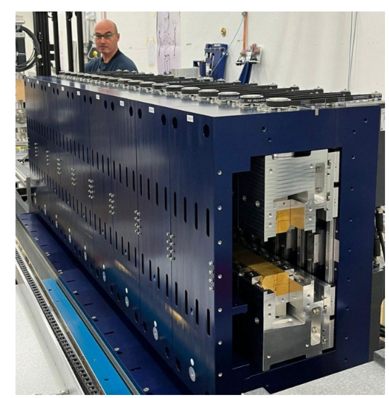
Second Phase: 1st Echo Enabled Harmonic Generation in Spring 2023

=> higher spectral brightness

=> X ray pulses synchronized with external source

HERO modulator:

- 8 periods
- 20 cm period length
- Resonant up to 1600 nm
- Each pole can be controlled individually



Goal:
Fully coherent x-ray laser

Single pulse or pulse train:

- 1uJ / pulse
- < 1 fs / pulse
- 0.1-0.4 % BW rms

- Courtesy R. Ganter, S. Reiche, A. Trisorio, M. Calvi

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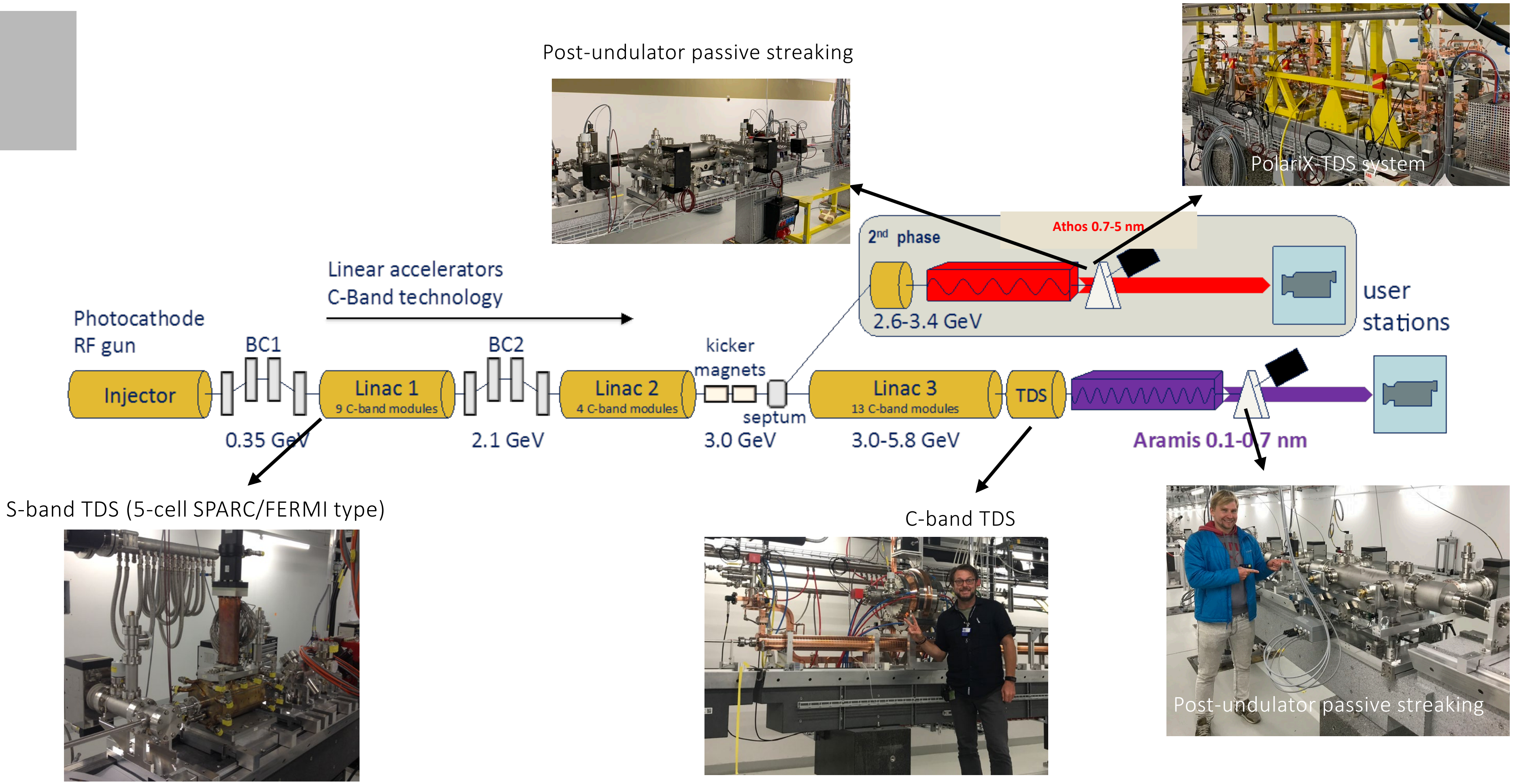
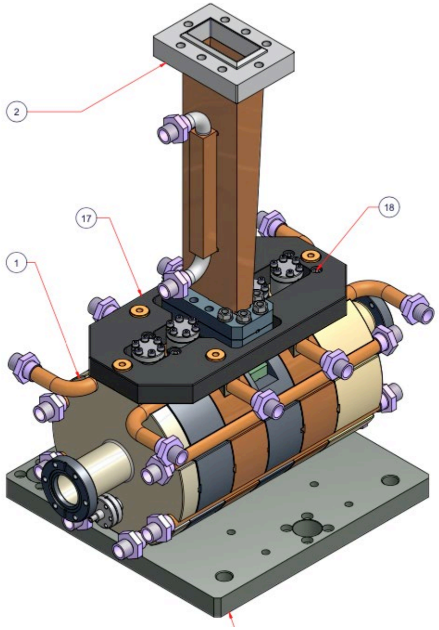
Overview of the bunch length and LPS measurements

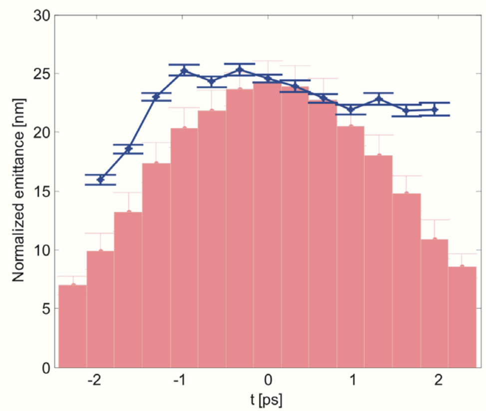


Courtesy P. Craievich

S-band TDS after BC1



- RF system: Small scandinova modulator + 7 MW Klystron, 5-cell SW SPARC/FERMI type
- Max integrated Deflecting voltage 5 MV, beam energy 300 MeV, Resolution ~10 fs
- Essentially used for injector setup after shutdown, slice and energy spread measurements
- A deep maintainance will be done in the next shutdown



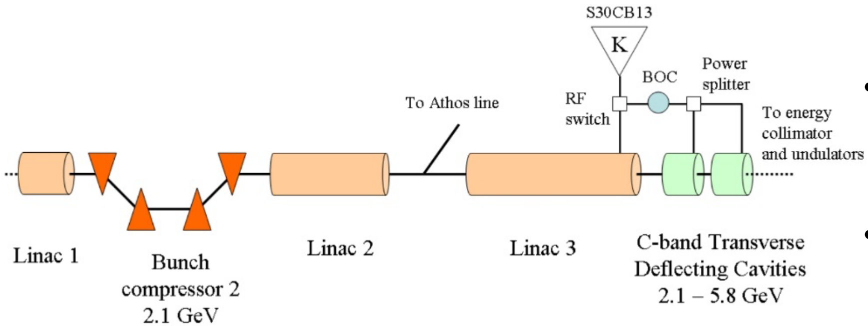
- Measurement done for a total bunch charge of about **30 fC**
- Measurement done with low gradient (E=3.7 MeV) and smallest laser aperture (rms laser beam size around 50 μm)
- Core slice emittance **< 25 nm**

Smallest measured emittance

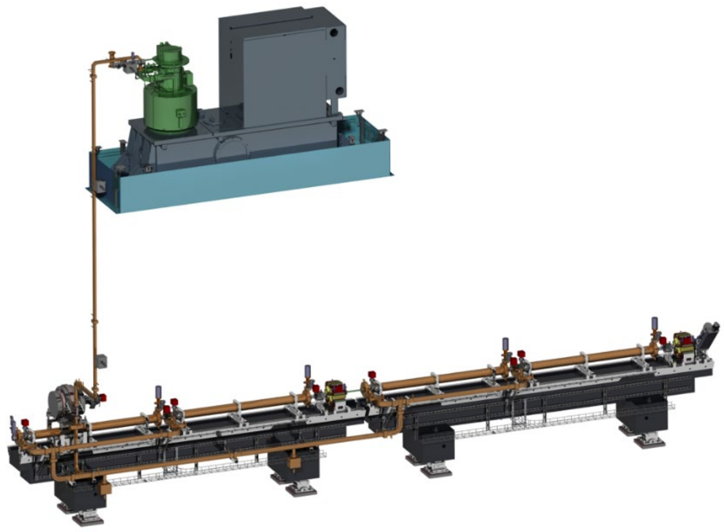
Courtesy of E. Prat

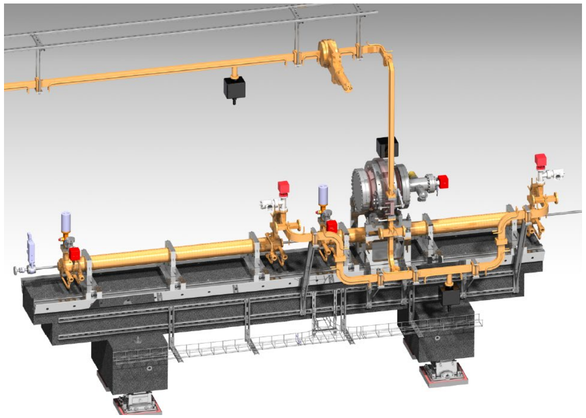
Courtesy P. Craievich

C-band TDS – end Linac 3 (before Aramis line)



- ScandiNova modulator with 50 MW Canon klystron shared with the last module in linac 3 using a high power switch (by Nihon Koshua)
- 2 deflecting structures bought at Mitsubishi Heavy Industries (RF-Deflector developed for SACLA XFEL, H. Ego et al.)
- Nominal integrated deflecting voltage 60 MV, beam energy 6 GeV
- Characterization of the electron bunch before the undulator chain

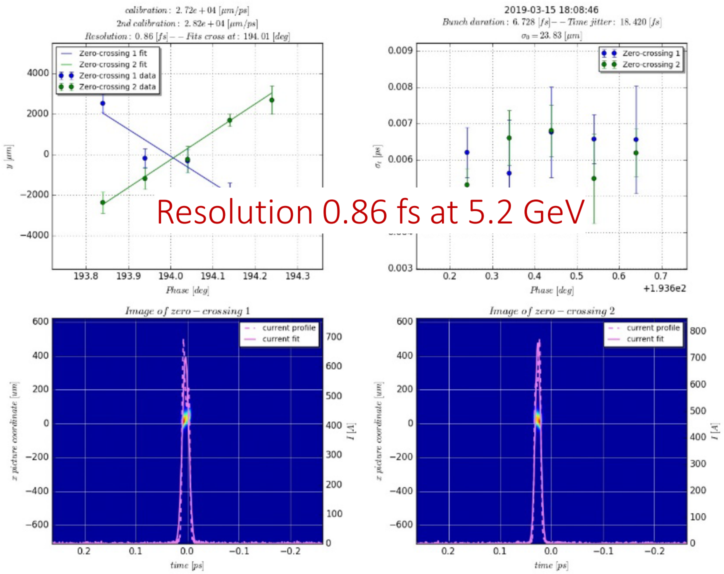


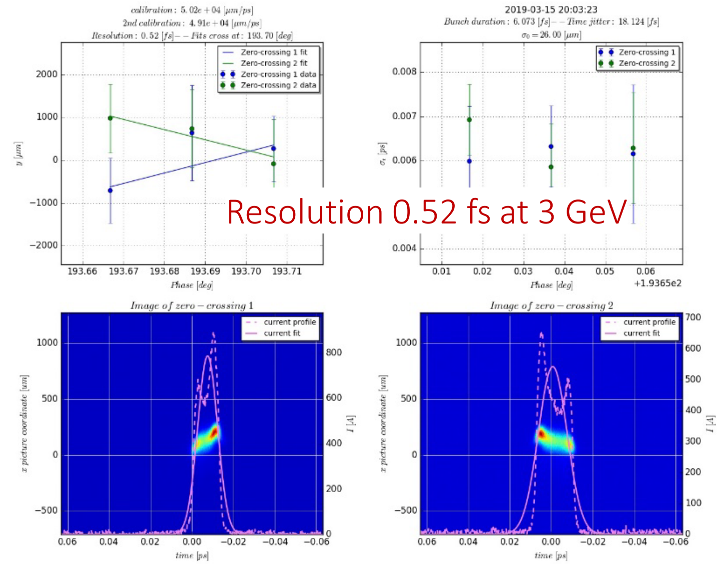


Courtesy P. Craievich

C-band TDS, short pulse and best resolution

- *Integrated deflecting voltage 83 MV* (phase jitter seems to be the limiting factor at this voltage)
- Pulse duration at 5.2 GeV: 6.7 fs rms, resolution: 0.86 fs
- Pulse duration at reduced beam energy of 3 GeV: 6.1 fs rms, resolution 0.52 fs.
- Beam jitter was quite high but after averaging enough we got an acceptable measurement



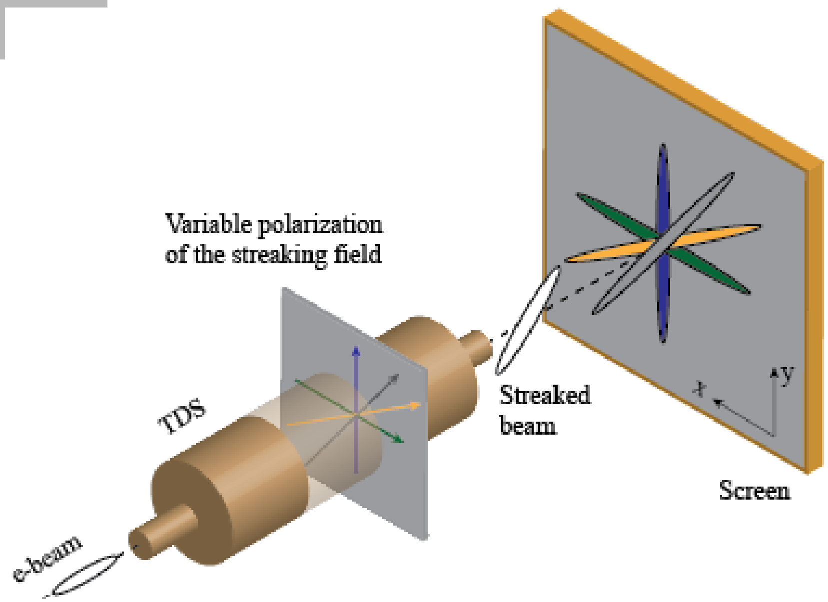


link to ELOG

Courtesy P. Craievich

Next generation TDS – ATHOS post undulator

POLARIzable X-band Transverse Deflection Structure – POLARIX TDS



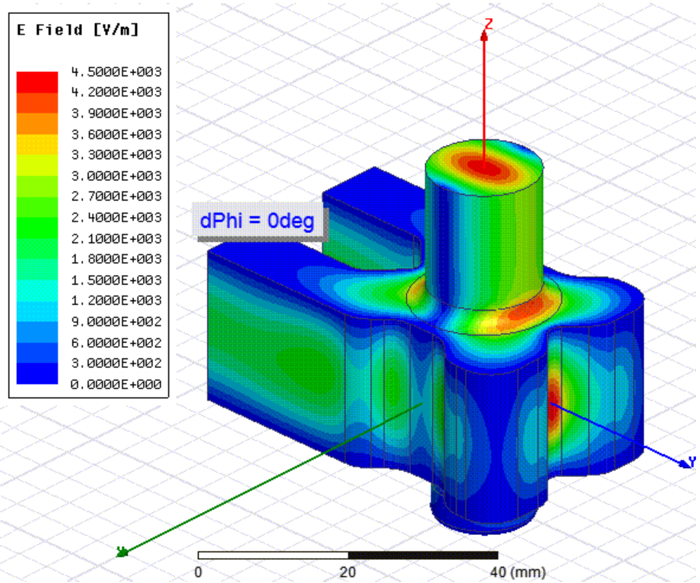
- The possibility of changing the orientation of the streaking field of the TDS to an arbitrary azimuthal angle opens new opportunities for extended beam characterization which makes particular use of the variable streaking direction
- Measurement of slice emittance on different transverse planes
- For example, a five/six dimensional (5/6D) phase-space characterization becomes possible by streaking the beam horizontally and vertically
- These types of measurements may reveal possible cross correlations between the different phase spaces that cannot be detected with the present measurements using a conventional TDS.
- Another important application is to retrieve the three dimensional (3D) charge distribution (will see later the results of the first experiments at DESY)

Collaboration PSI-DESY-CERN

Courtesy P. Craievich

Novel Concept with Variable Polarization

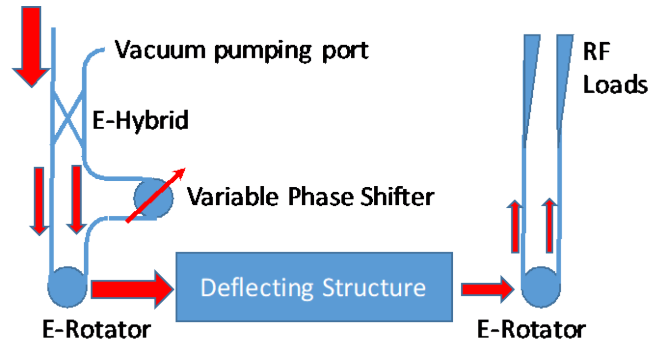
Variable polarization circular TE11 mode launcher: E-rotator

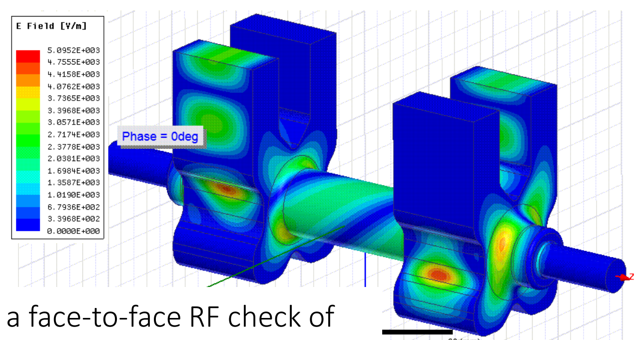


A. Grudiev, CLIC-note-1067 (2016)

Phase difference between port 1 and port 2:

- 0 degree -> vertical polarization
- 180 degree -> horizontal polarization

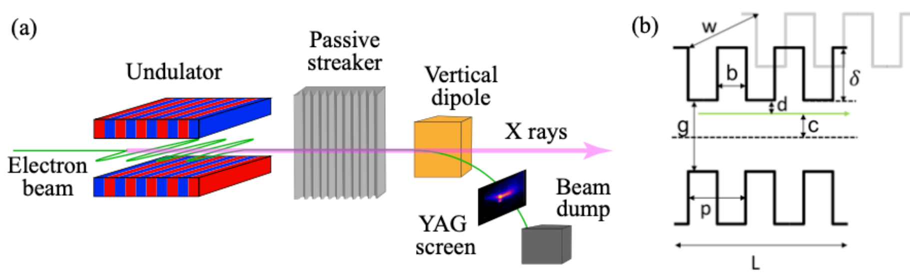


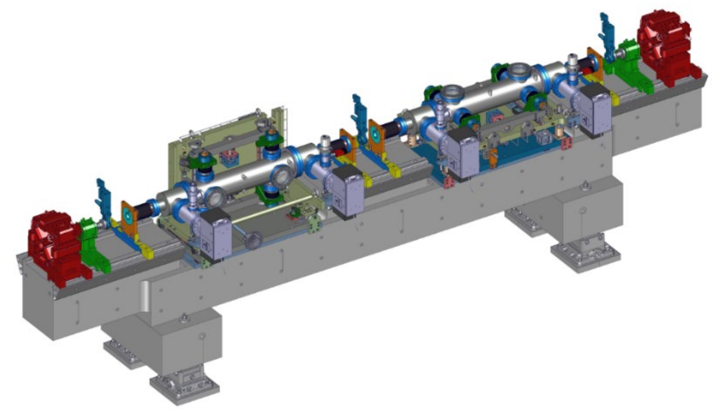


Full geometry for a face-to-face RF check of two E-rotators

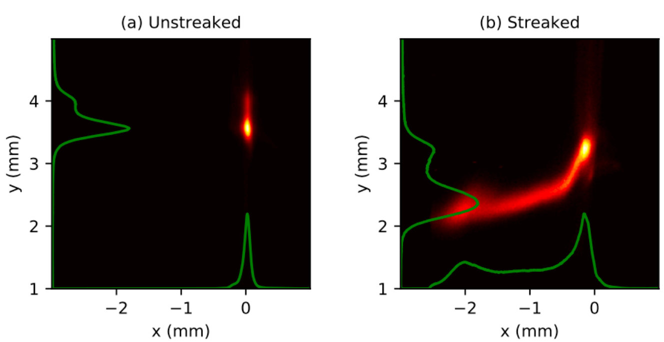
Courtesy P. Craievich

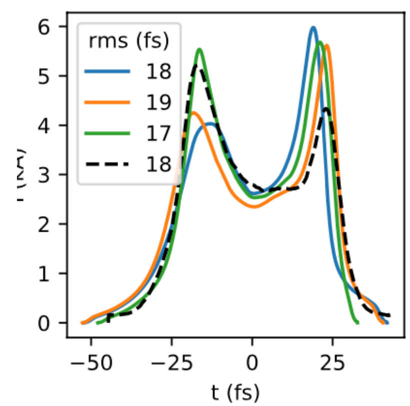
Post-undulator passive streaking (Aramis)

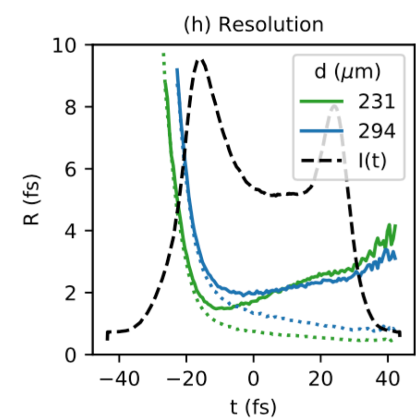




An electron beam traveling off-axis through such a device excites transverse wakefields, resulting in a time-dependent kick that streaks the electron beam.







Self-synchronized and cost-effective time-resolved measurements at X-ray free-electron lasers with femtosecond resolution

Philipp Dijkstal[1,2], Alexander Malyzhenkov[1], Paolo Craievich[1], Eugenio Ferrari[1], Romain Ganter [1], Sven Reiche[1], Pavle Juranić[1], and Eduard Prat[1]*
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(Dated: August 23, 2021)

submitted

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Bunch-Compressor-Monitor (BCM) at SwissFEL

- Bunch Compression Monitor (BCM) at SwissFEL:
  - DBCM: Coherent Edge Synchrotron Radiation (SR) from the entrance edge of the 4^{th} dipole of a chicane
  - DCDR: Coherent Diffraction Radiation (DR) from a 45 deg tilted metallic screen with a hole (4mm and 6 mm) in a straight section
- BCM main functionality and machine operation applications:
  - BCM signal:
    - No absolute measurement of the bunch length
    - Bunch length variation sensitive: detector signal integrate the coherent radiation threshold over the full transmission bandwidth of the monitor
    - Input to the machine feedback to stabilize the compression phase

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BCM in SwissFEL

➢ **Bunch Compression Monitors (BCM) for machine operations**:

- BC1-DBCM, SINBC02-DBCM410: compression phase stabilization (machine feedback)
- BC2-DCDR, S10MA01-DCDR080: compression phase stabilization (machine feedback)
- EC-DBCM (Aramis Energy Collimator), SARMA01-DBCM030: full compression monitor after the EC chicane and before the injection into the Aramis undulators

➢ **BCMs for special applications**:

- BC1-DCDR (SINDI02-DCDR065): used as test-bench of detectors
- BC2-DBCM (S10BC02-DBCM410): equipped with an FIR spectrometers and MCT detector array (liquid nitrogen cooled,100Hz acquisition, not so fast to resolve the 2-bunch 28 ns time structure)

➢ **BCMs under construction**:

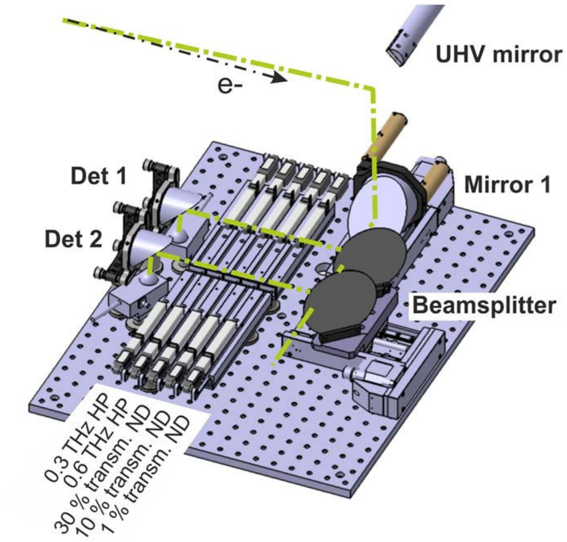
- DCDR in the Athos switchyard (dispersion closed region):
  - in-vacuum hardware (pneumatic feedthrough+DR screen)+optical hardware+detector aligned and installed; MPS interface ready
  - Controls Electronics: installation to be completed
  - Beckhoff electronics for Motion Control and signal ADC to be installed (under development)

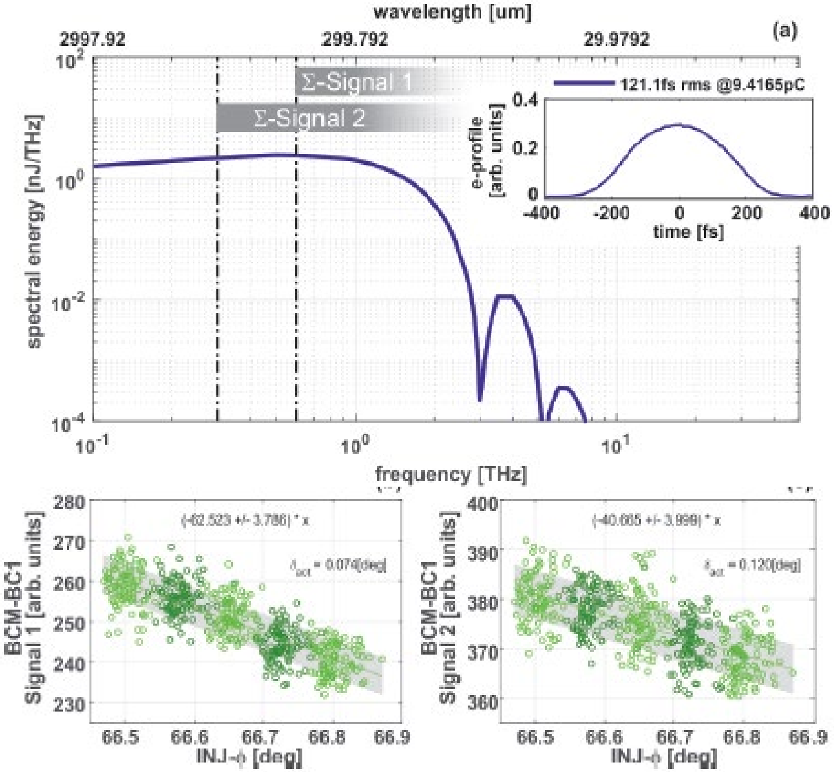
- DCDR in Aramis before the chicane of the Energy Collimator (complementary to EC-DBCM):
  - in-vacuum hardware (pneumatic feedthrough+DR screen)+optical hardware+detector aligned and installed; MPS interface ready
  - installation: second priority w.r.t. the Athos DCDR

BCM for machine operations

- **BC1-DBCM (SINBC02-DBCM410):**
  - BC1: bending-angle 0➔4.6deg, operation setting: 300MeV and 4.1 deg
  - Design optimized for bunch lengths of 223 fs (10pC) and 290 fs (200 pC) and to discriminate the 28ns 2-bunch time structure
  - Extracted radiation (HRFZ-Si window) split into 2 optical paths equipped with 2 different high-pass filters (0.3 and 0.6 THz, to increase the detection sensitivity) and 2 broadband Schottky diodes (0.3-2THz)
  - Monitor sensitivity: from 0.03 deg to 0.07 deg of the off-crest phase of the last 2 S-band structures of the injector (bunch length from 600 fs (rms,200 pC) to 120 fs (rms, 10pC)

Expected spectral distribution for a measured (TDS S-band) bunch length of 120fs (@10pC) and plot BCM signals (0.6THz left, 0.3THz right) vs off-crest phase injector RF structure





F.Frei, R. Ischebeck, *Electron Bunch Compression Monitors for short Bunches-Commissioning Results from SwissFEL*, Proceeding IBIC2019, Malmoe, Sweden

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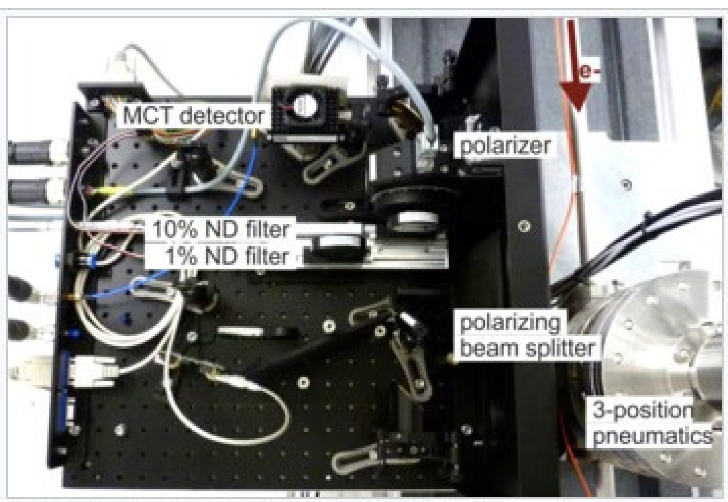
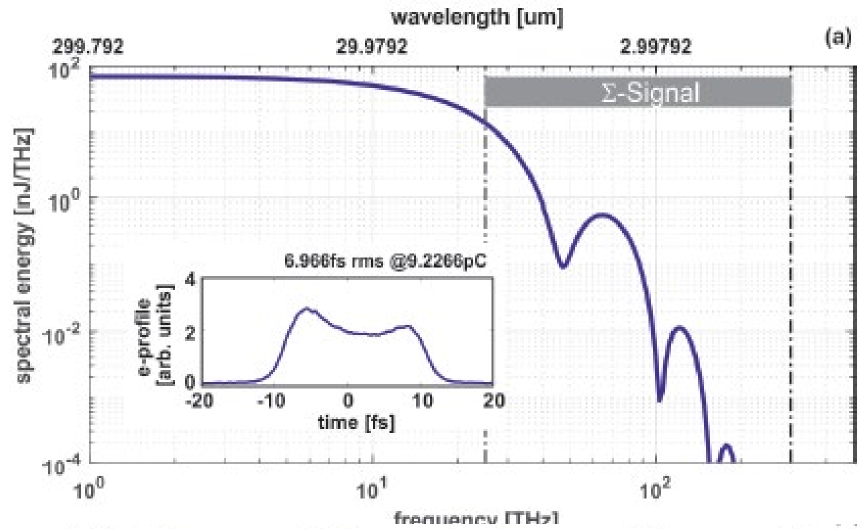
BCM for machine operations

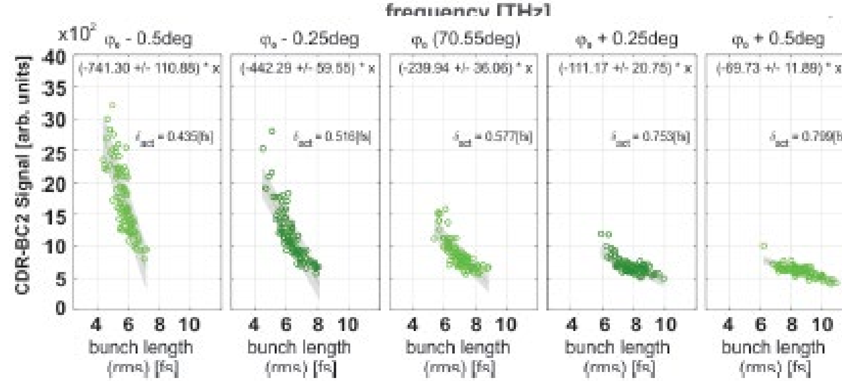
- **BC2-DCDR (S10MA01-DCDR080):**
  - Installed in a straight section after BC1 (Energy 2.1 GeV)
  - DCDR screen: 1 mm thick titanium foil with hole diameter 4 mm (6 mm hole also available)
  - Design optimized for electron bunch length 3-25 fs (rms) and sensitivity to bunch length variation of 8%
  - Diamond window + wire grid polarizer+ motorized polarizer for signal attenuation
  - Detector: fast Mercury Cadmium Telluride (MCT) for 2-bunch detection and sensitivity for wavelength 2-12 μm

Expected spectral distribution for a measured (TDS C-band) bunch length of 7fs (@10pC) and correlation DCDR signal vs bunch length (TDS) for +/-0.5deg phase variation of LINAC1



S10MA01-DCDR080 - im Tunnel installierte Hardware



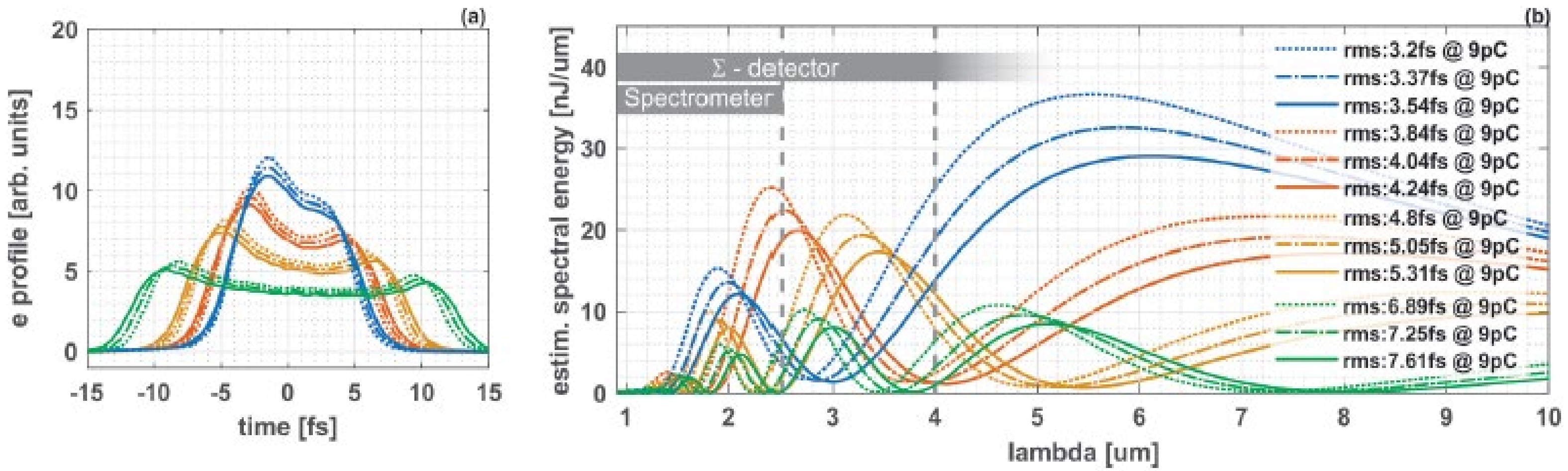


F.Frei, R. Ischebeck, *Electron Bunch Compression Monitors for short Bunches-Commissioning Results from SwissFEL*, Proceeding IBIC2019, Malmoe, Sweden

BCM for machine operations

➢ **EC-BCM (SARMA01-DBCM030), Aramis Energy Collimator (EC):**

- EC: single bunch @100 Hz, 6.1 GeV, fixed bending angle 1 deg,
- vacuum chamber cutoff of the radiation (<4μm)
- Design optimized for bunch length 0.7-3 fs (10 pC), resolution: 5% of the bunch length
- Detectors:
  - Pyroelectric sensor for integrated signal readout
  - Spectrometer (Ocean Optics) covering the range 0.9-2.5 μm (bunch-length <3fs)



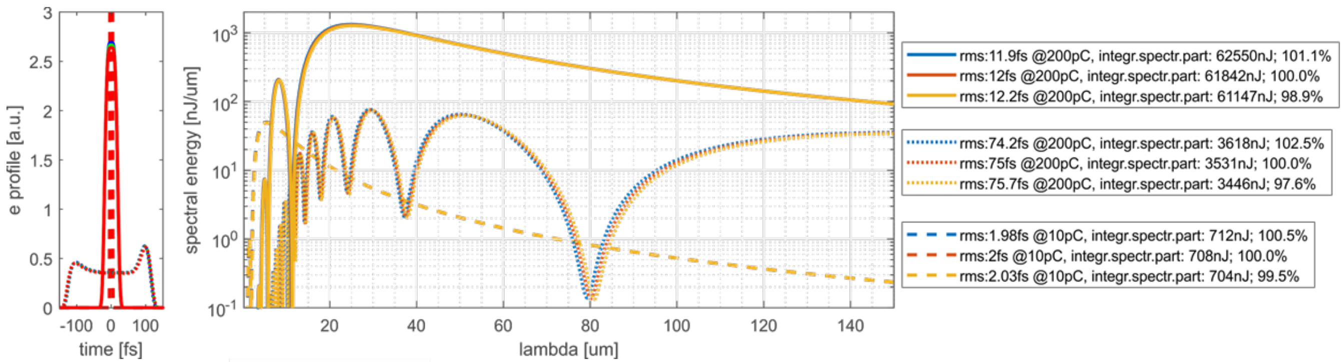
For bunch length >4fs the spectral region 0.9-4 μm exclusively contains side maxima of the coherent spectrum ➔monitor sensitivity to the shape but not to bunch length change.

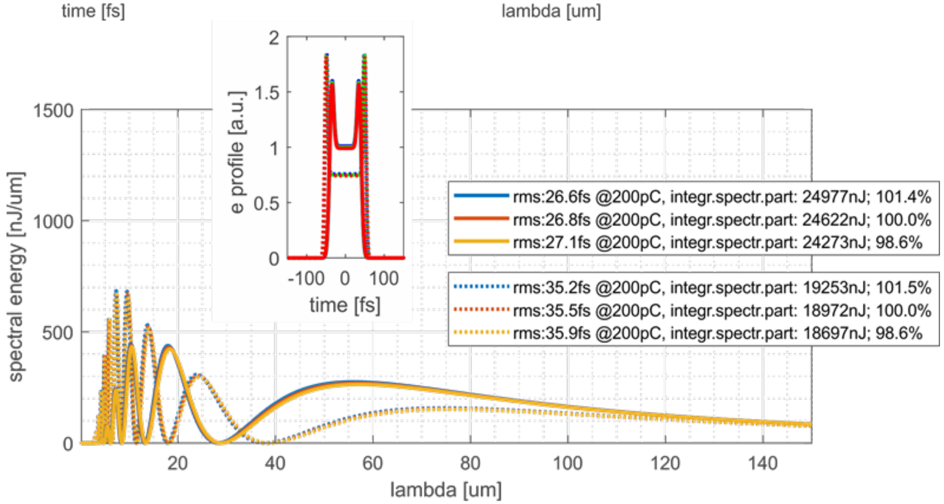
Only for bunch length <4 fs the main part of the coherent spectrum is detectable in the spectral region 0.9-4 mm

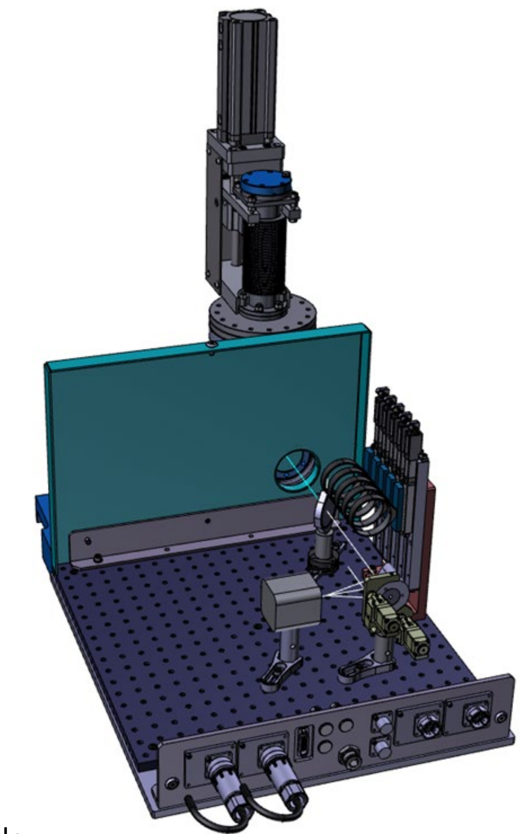
F.Frei, R. Ischebeck, *Electron Bunch Compression Monitors for short Bunches-Commissioning Results from SwissFEL*, Proceeding IBIC2019, Malmoe, Sweden

BCM under construction in SwissFEL

- **Athos switchyard (SATSY03-DCDR050) and Aramis (SARCL01-DCDR105)**
  - Monitor installed in a region of the switchyard where the dispersion is closed
  - Monitor intended to be used not for shot-to-shot feedback but for slow feedback to compensate for drifts
  - Designed for bunch length 12-75fs rms @200pC (resolution 1%) and ~2fs rms @10pC (single bunch @100Hz)
  - Transmission and detection covering 2-100 μm: diamond window, pyroelectric sensor (Phluxi Pyro) and ND filters (no spectrally flat)
  - Aramis DCDR is a replica of the Athos one (to be installed before the Aramis Energy Collimator)



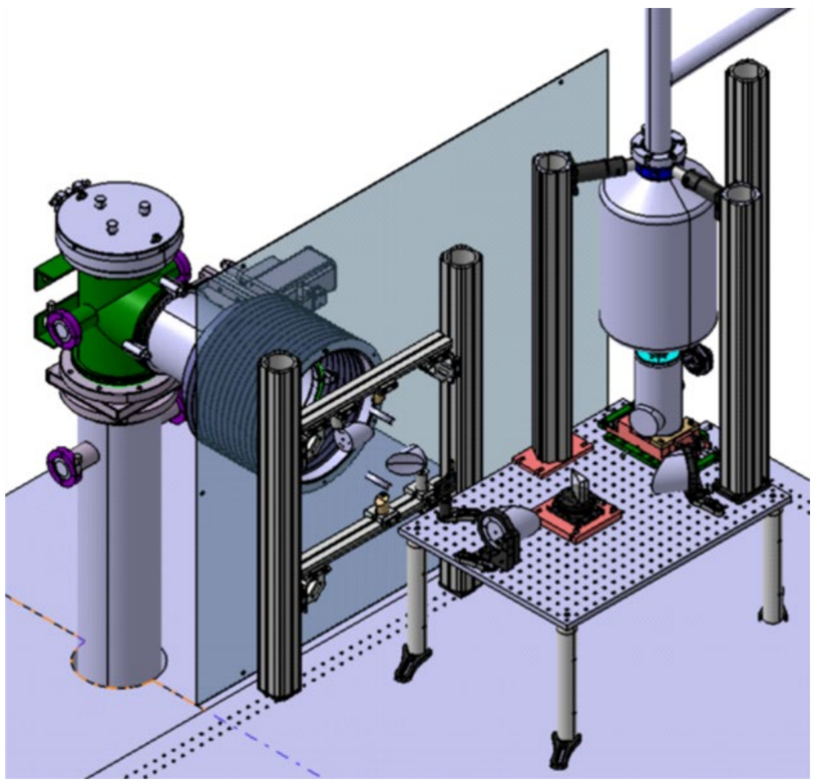


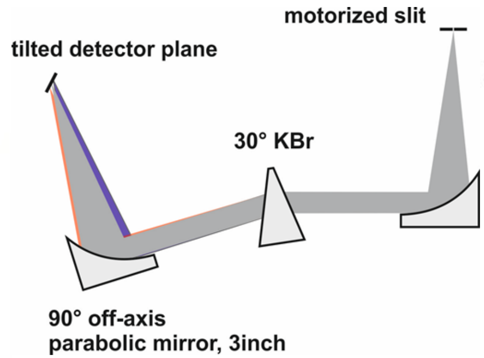


Courtesy F.Frei and G. Kotrle

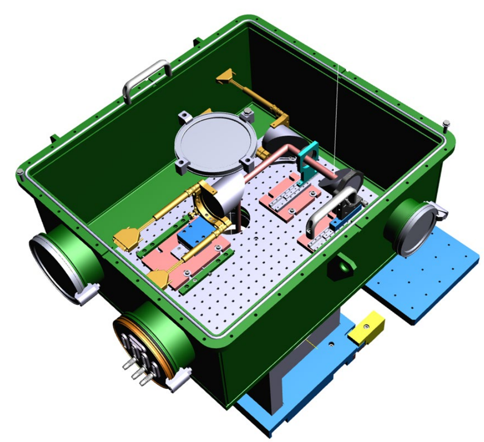
BCM for special applications

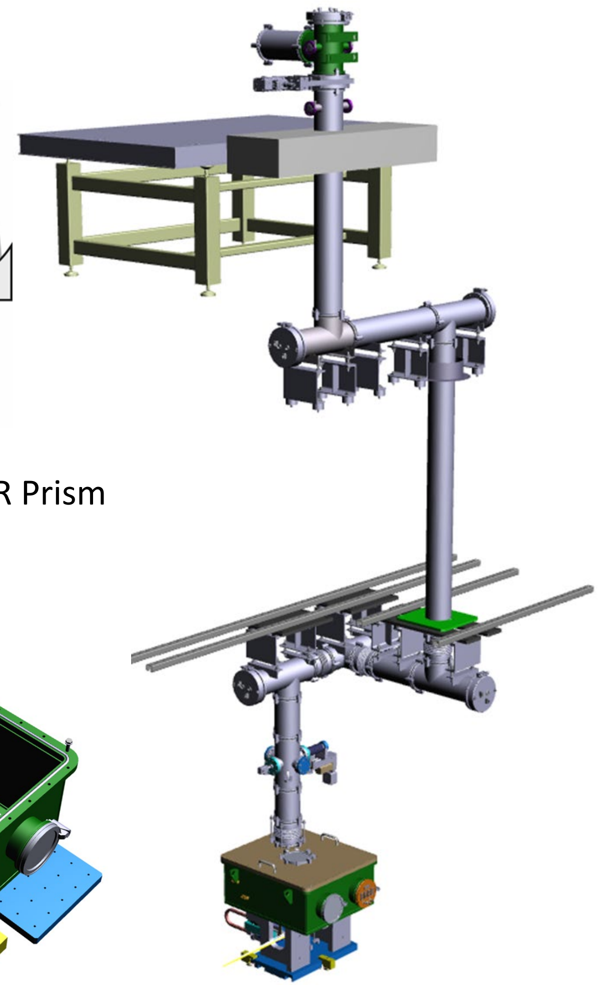
- **BC2-DBCM (S10BC02-DBCM410)**
  - BC2: bending angle 0→3.8-deg, operation settings: 2.2GeV and 2.1 deg
  - Detector MCT detector array (liquid nitrogen cooled,100Hz, no 2-bunch resolution)
  - Complex optical transfer line for the Edge SR from the linac tunnel to the service gallery
  - IR spectrometer





Conceptual Design of an IR Prism





Courtesy of F.Frei,

Conclusions and Outlook

- **BC1-DBCM (SINBC02-DBCM410) and BC2-DCDR (S10MA01-DCDR080):**
  - cover the requested dynamic range (charge and bunch length) and resolve the 2-bunch time structure
  - fully integrated in the machine feedback and used for the phase stabilization of the compression
  - very stable and reliable, controlled by state-machine code

- **EC-DBCM (SARMA01-DBCM030):**
  - Designed to be a full compression monitor before the Aramis undulator line
  - Design optimized for bunch length <3fs (10 pC)
  - Monitor operational and equipped with:
    - Pyroelectric sensor (signal integration over a large spectral bandwidth)
    - Optical fiber spectrometer (operational for bunch length <3fs)

- **Athos switchyard (SATSY03-DCDR050) and Aramis (SARCL01-DCDR105) (under construction):**
  - Designed to cover the full dynamic range (charge and bunch length) of the machine
  - Intended to be integrated in the machine feedback (slow drift corrections of the compression phase)
  - Aramis SARCL01-DCDR105, placed before the Energy Collimator, as a complement to SARMA01-DBCM030

- **BCM equipped with spectrometers:**
  - BC2-DBCM (S10BC02-DBCM410): IR spectrometer, detector not discriminating the 2-bunch time structure
  - EC-BCM (SARMA01-DBCM030): NIR spectrometer (operational for bunch length <3fs, 10 pC)

- **Pending Questions**:
  - How the spectrometer signal analysis can be usefully exploited for routine machine operations?
  - For what special machine operations are spectrometers particularly eligible and/or essential?

Many thanks to:
F.Frei
A. Alarcon
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W.Koprek
G.Kotrle
E. Prat
S. Reiche
S.Schnabel
V.Schlott
D.Trayer
…and many other colleagues…

Thank you for your attention