PAUL SCHERRER INSTITUT

PSI

Thomas Geoffrey Lucas on behalf of the PolariX team :: Paul Scherrer Institute

The PolariX TDS system at SwissFEL

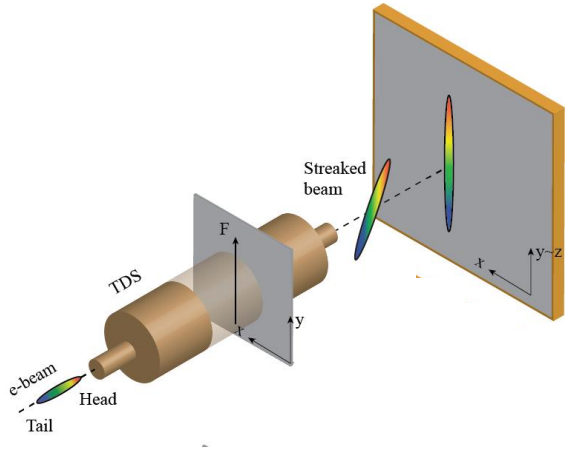
CLIC Mini Week 2023

Contents

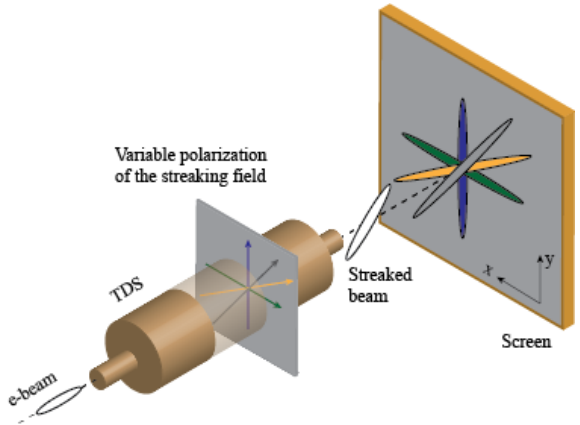
Transverse Deflecting Structures – What's next?

TDS are RF-based devices used for the manipulation and/or the diagnostics of charged particle beams to retrieve longitudinal/temporal proprieties

Conventional TDS: streaking in a fixed polarization (i. e. vertical or horizontal)



POLARIzable X-band Transverse Deflection Structure – POLARIX TDS



The longitudinal distribution of the e-bunch is mapped into the transverse one thanks to the time dependent transversely deflecting field

$$\sigma_{t,R} \geq \frac{\sigma_{y0}}{S} = \sqrt{\frac{\varepsilon_{N,y}}{\gamma\beta_d}} \frac{pc}{eV_\perp} \frac{1}{ck_{rf}\sin(\Delta\psi_{ds})}$$

DESY-CERN-PSI Collaboration

The PolariX TDS has been developed in the framework of a collaboration among CERN, DESY and PSI.

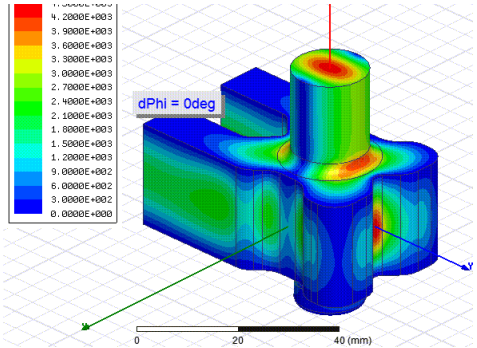
As a result, 7 TDS have been produced:

- 1 TDS in FLASHForward
- 2x TDSs installed in FLASH II
- 2x TDS installed in SINBAD-ARES (DESY)
- 2x TDSs installed in Athos, the Soft X-rays beamline in SwissFEL

Novel Concept with Variable Polarization – X band

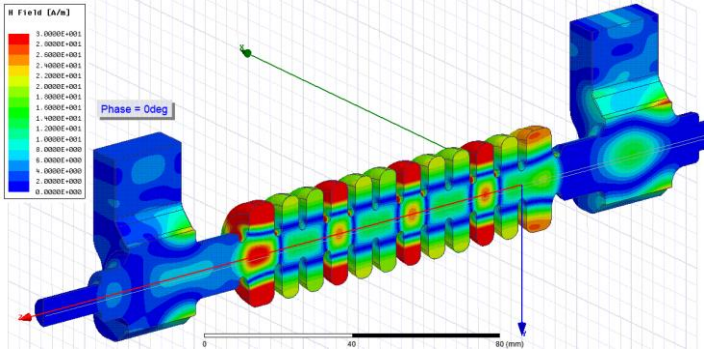
Key Component

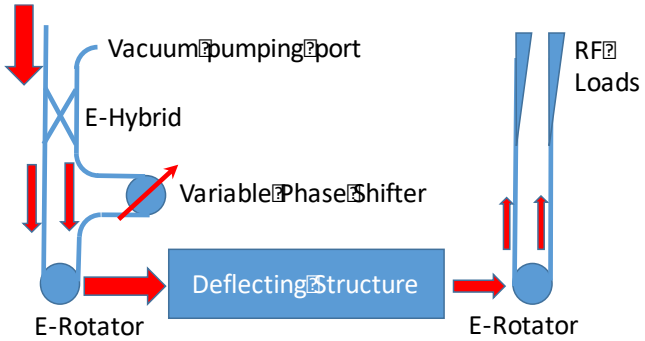
E- Rotator: E-plane TE11 rotating mode launcher



Key Technology:

PSI high-precision tuning-free assembly procedure

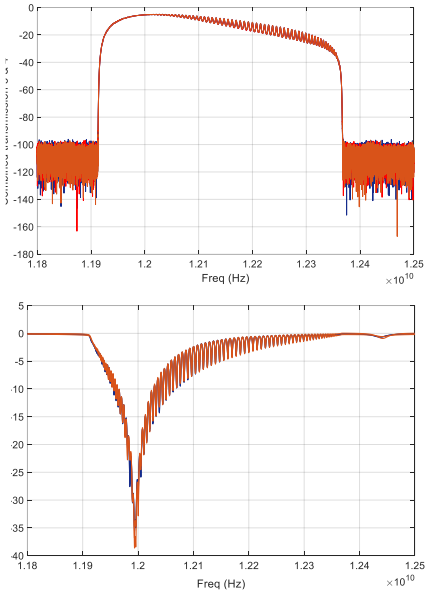




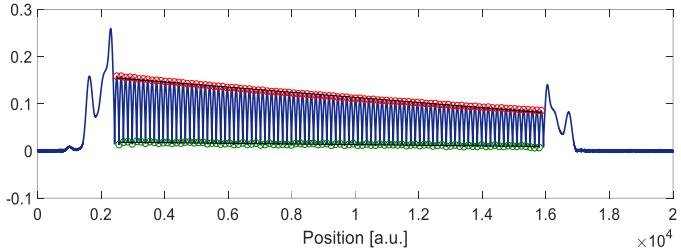
Polarization of deflecting field in the structure depends on the relative phase difference at the two TDS input ports.

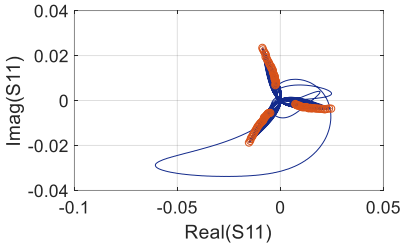
References:
Grudiev, CLIC-Note-1067, 2016
P. Craievich et al., Phys. Rev. Accel. Beams, 2020
B. Marchetti et al., Sci. Rep., 2021

TDS RF measurements

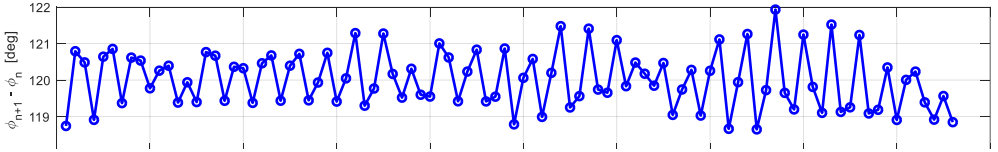


Insertion and return loss measured for different polarizations

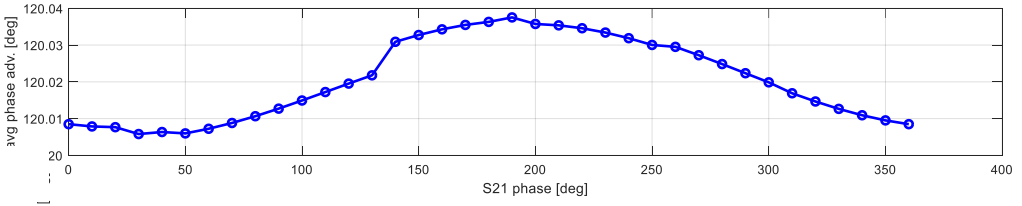




On axis bead pulling, phase difference between input ports 0°

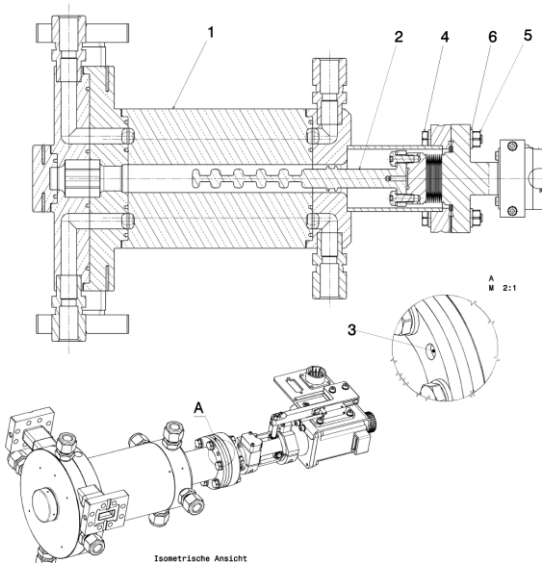


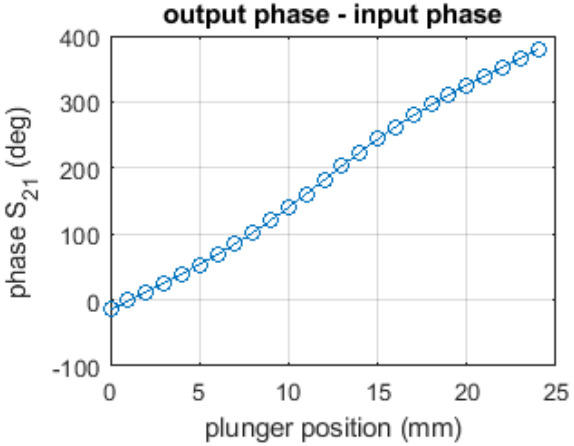
Cell to cell phase advance, phase difference between input ports 0°

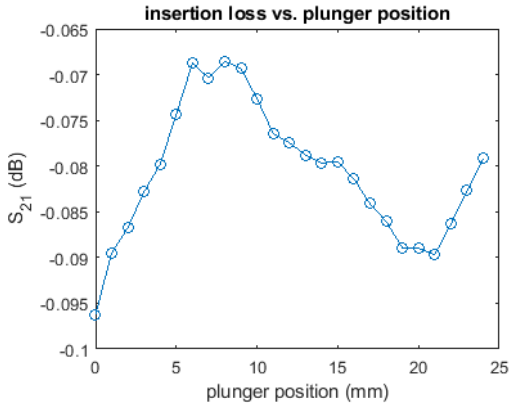


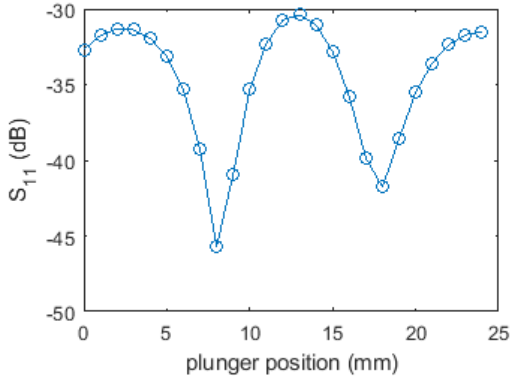
Average cell to cell phase advance measured at different polarization.
Peak to peak phase adv. 0.03°.→ very good cell rotational symmetry.

X-band phase shifter measurements

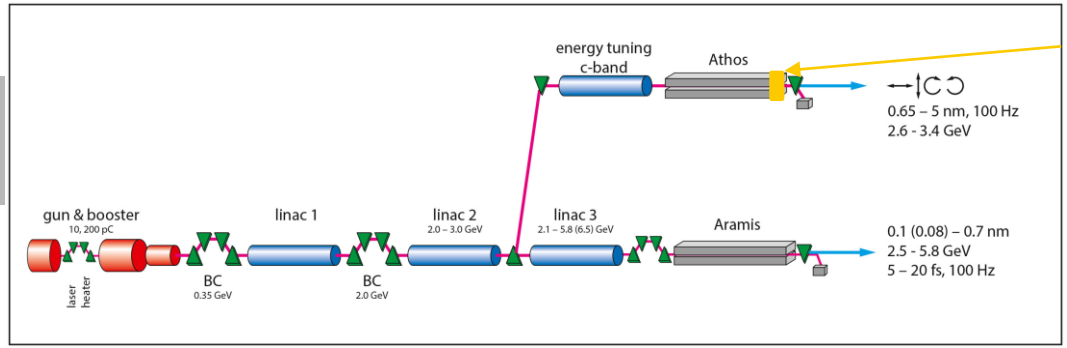








PolariX in ATHOS



PSI HV modulator: develop and built in-house (400 kV, 3 us)

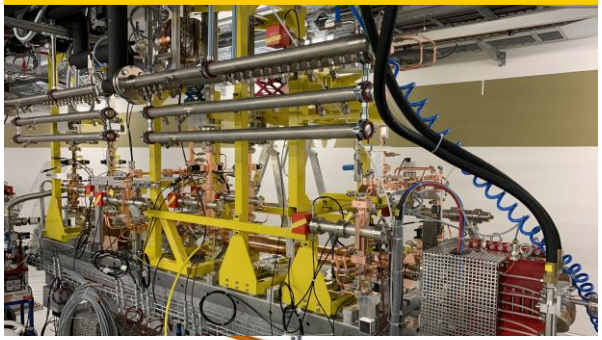
- based on the Linac 1 and 2 design (Ampegon)
- Investment for future renewal of the injector modulators (S-band and X-band)

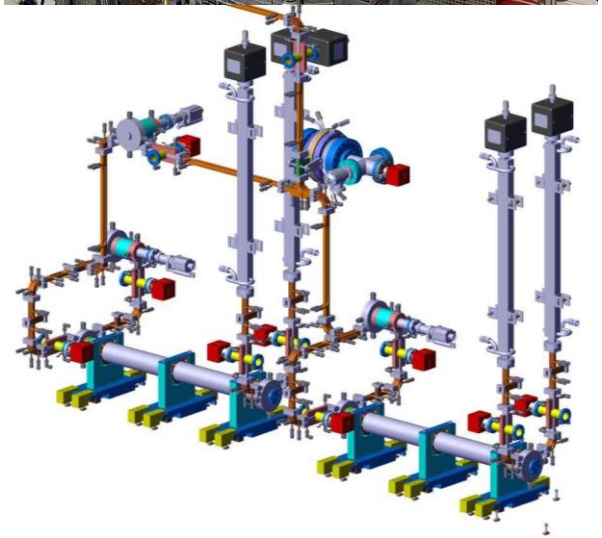
Klystron: CPI VKK-8311 50 MW X-band.

Waveguide RF components including the XBOC, phase shifters and directional couplers designed and built at PSI.

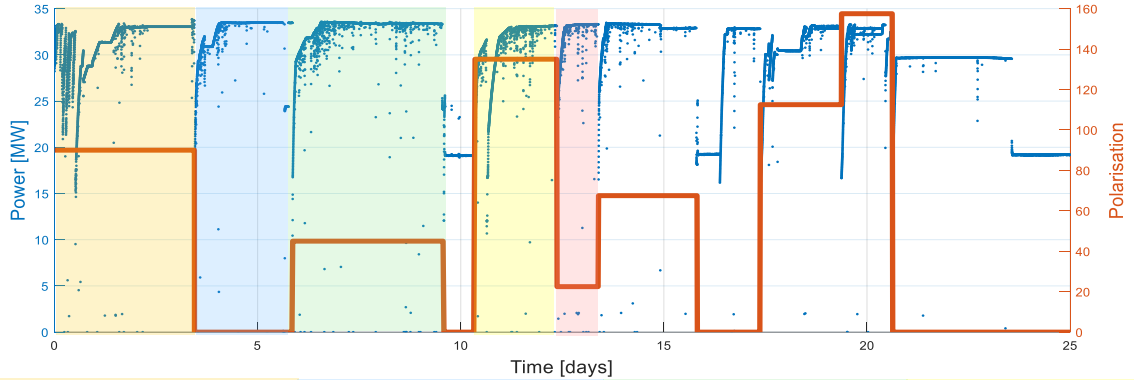
Two TDSs (120 cells version) built at PSI.

PolariX TDS placed downstream the ATHOS undulators

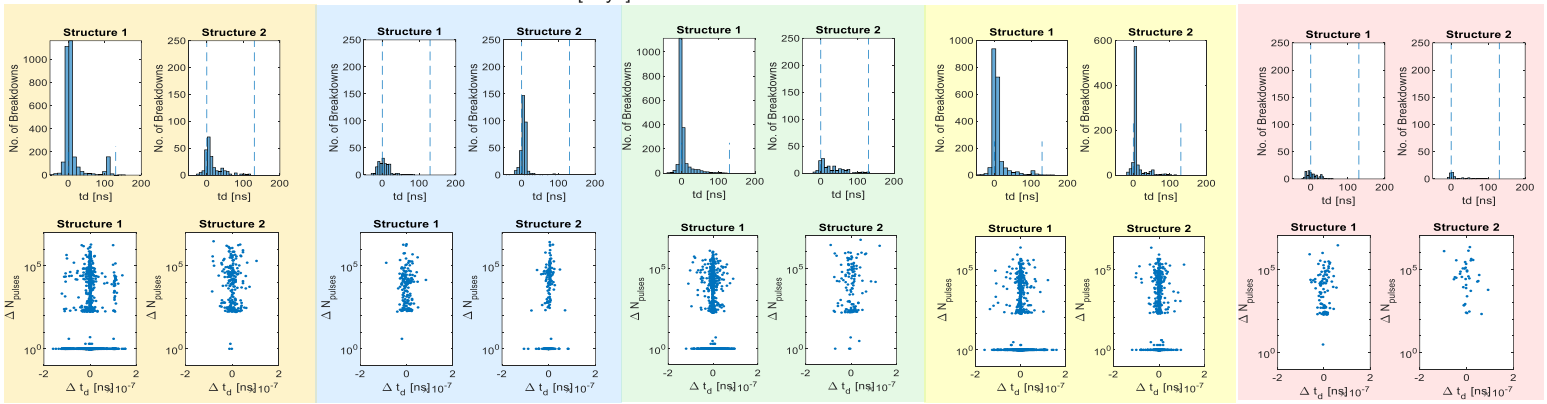




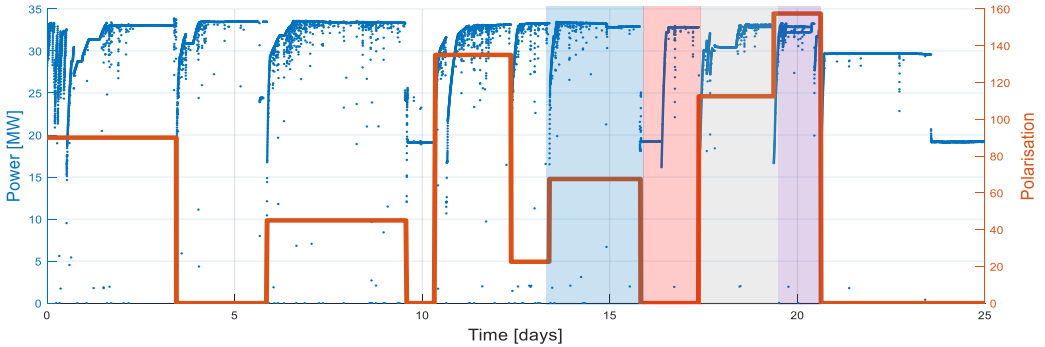
Conditioning and breakdown analysis

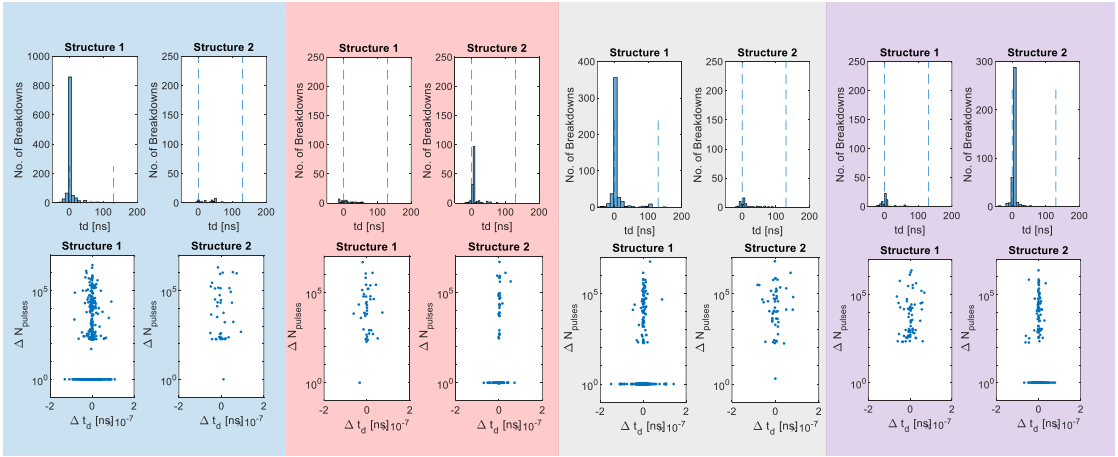


Results of the first systematic conditioning performed in July ’23. Target klystron output power: 34MW



Conditioning and breakdown analysis



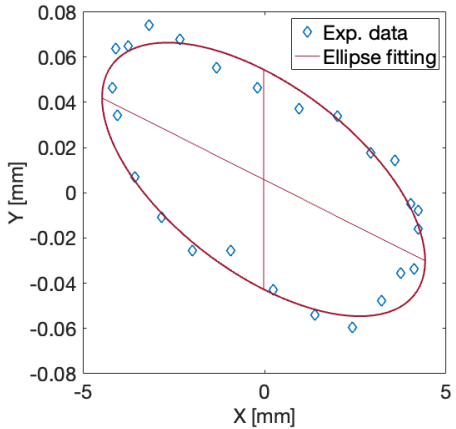


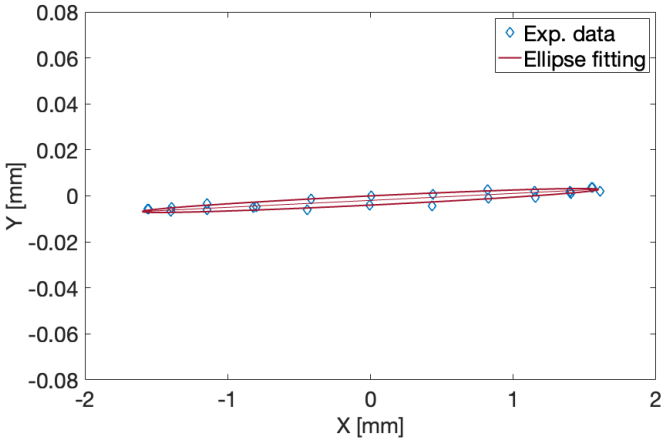
RF setup and commissioning with beam

$$\vec{V}_+ = L\cos(\varphi_{\mathrm{RF}} + \varphi_L + \varphi_{\mathrm{PS}})\hat{x} + L\sin(\varphi_{\mathrm{RF}} + \varphi_L + \varphi_{\mathrm{PS}})\hat{y},$$
$$\vec{V}_- = R\cos(\varphi_{\mathrm{RF}} + \varphi_R)\hat{x} - R\sin(\varphi_{\mathrm{RF}} + \varphi_R)\hat{y}$$

Deflecting field is the sum of two rotating modes, one clockwise and the other counter clockwise

Wrong setting of the PSs and/or the amplitudes are unbalanced then the superposition of the two rotating modes results in an elliptically polarized mode, whose effect is to provide a kick in the plane orthogonal to the streaking plane (we will call this effect a *residual kick*).

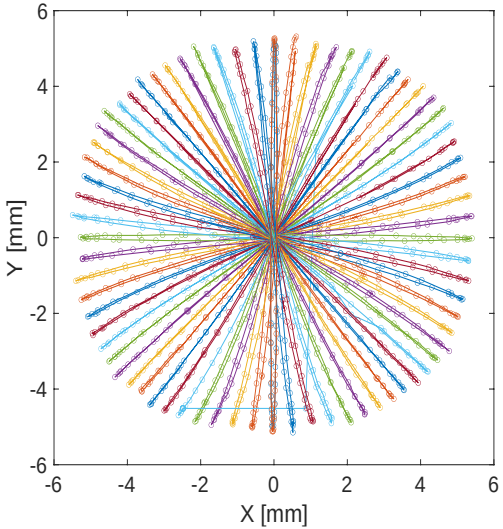


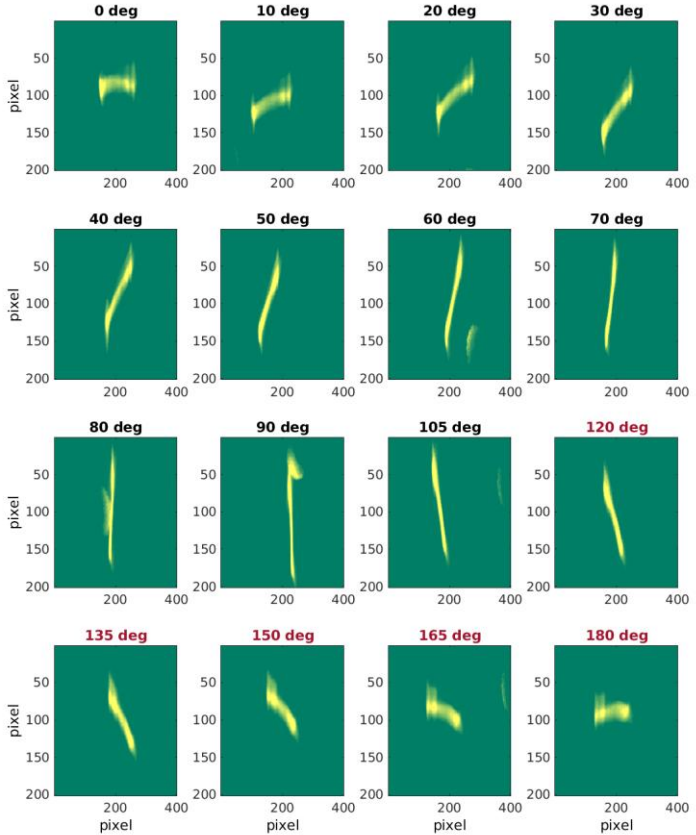


F. Marcellini et al.

Variable polarization – first measurements

Bunch centroid on a BPM after TDSs as a function of the global RF phase. Polarisation variation of 5 deg.

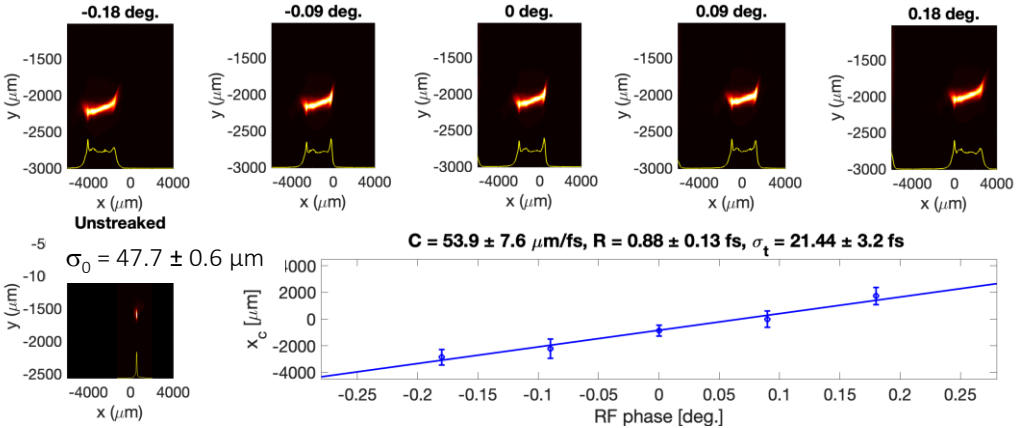




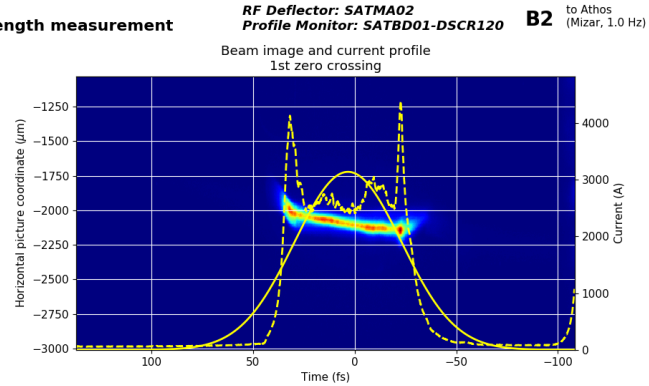
Right plots: Images on screen before dipole as a function of polarization angle. Dark polarization angles: 85 MW, red polarization angles: 72.8 MV.

Calibration, resolution and bunch length

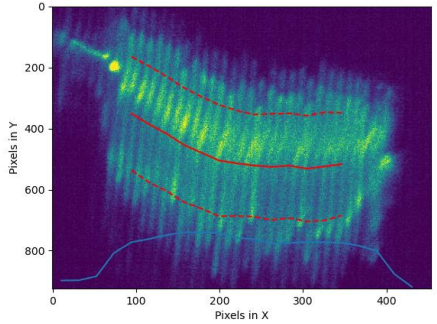
- The absolute calibration factor C between the transverse coordinate on a screen and the time coordinates within the electron bunch is obtained by measuring the dependence of the transverse position of the centroid of the streaked beam on the RF phase
- Time coordinates are obtained by dividing the transverse coordinates on the screen by the calibration
- Bunch length is simply obtained as the streaked beam size divided by the calibration factor C
- Resolution R= s_0/C < 1fs



Deflecting voltage 85 MV, s_0 = 47.7 ± 0.6 µm



Courtesy of Paolo Craievich



ESASE: the periodicity of the modulation is 800 nm, corresponding to 2.66 fs. It shows that we have a resolution well be 1 fs

Courtesy of S. Reiche's

Conclusions

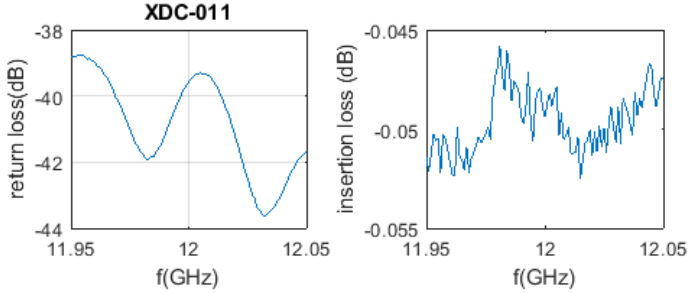
- Seven PolariX transverse deflecting structures have been realised as part of collaboration between PSI, DESY and CERN.
- Fabricated through PSI brazed structure technology, the low power measurements illustrate that these are extremely well-tuned structure.
- Two TDSs have been installed in the Athos line of SwissFEL and conditioned to high power across all polarisation. The conditioning found evidence of a reduction in conditioning time when changing polarisation between angles where peak fields overlap.
- Measurements found a residual kick on the beam resulted in an ellipsoidal behaviour for streaking.
- After calibration, the first measurements of the bunch length found a value of 21.44 ± 3.2 fs with a measurement resolution of 0.88 ± 0.13 fs.

Thank you to everyone that has contributed.

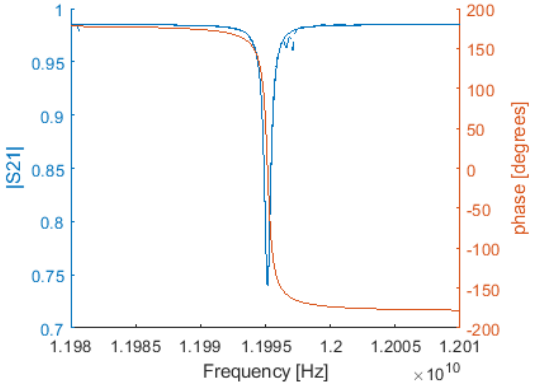
- We thank all the technical groups at PSI involved in the installation and commissioning of the PolariX TDS system
- To prepare my slides, I have especially used material from: E. Prat, F. Marcellini, S. Reiche
- Thanks also go to our colleagues at CERN and DESY involved in this collaboration for the useful discussions.

Thank you for your attention!

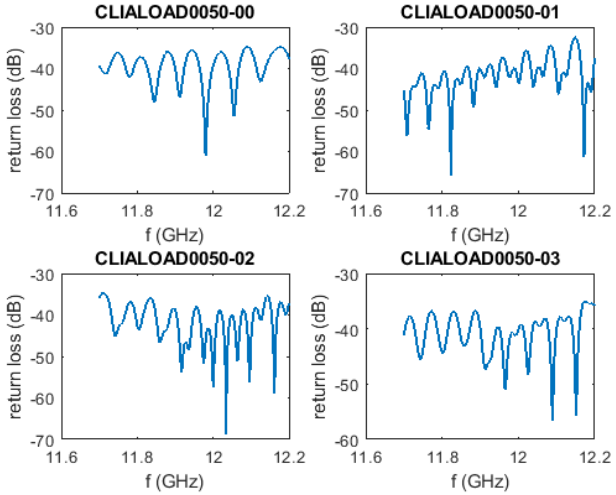
Other X-band components



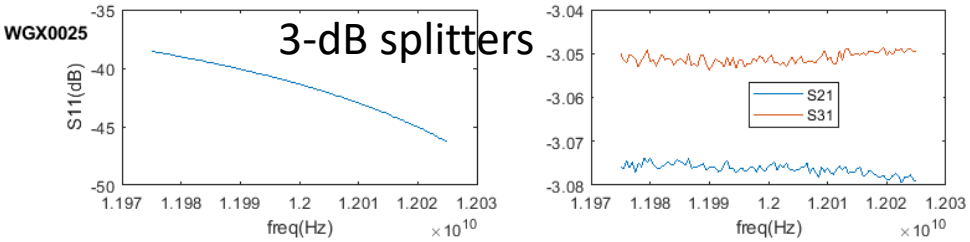
Directional couplers



BOC



Loads



3-dB splitters