



Advanced Beam Diagnostics with PolariX TDS: Experimental 5D Reconstruction at SwissFEL

Contribution ID: 611 (24th September Session)



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1. PolariX transverse deflection structure

- A transverse deflecting structure is an RF cavity where the Lorentz force is directed in the transverse plane, particles in different points along the beam will feel a different field so that a correlation is imprinted between the transverse coordinate at the screen and particle's longitudinal position
- The **PolariX** is an X-band Transverse Deflecting Structure with the feature of changing the beam streaking direction

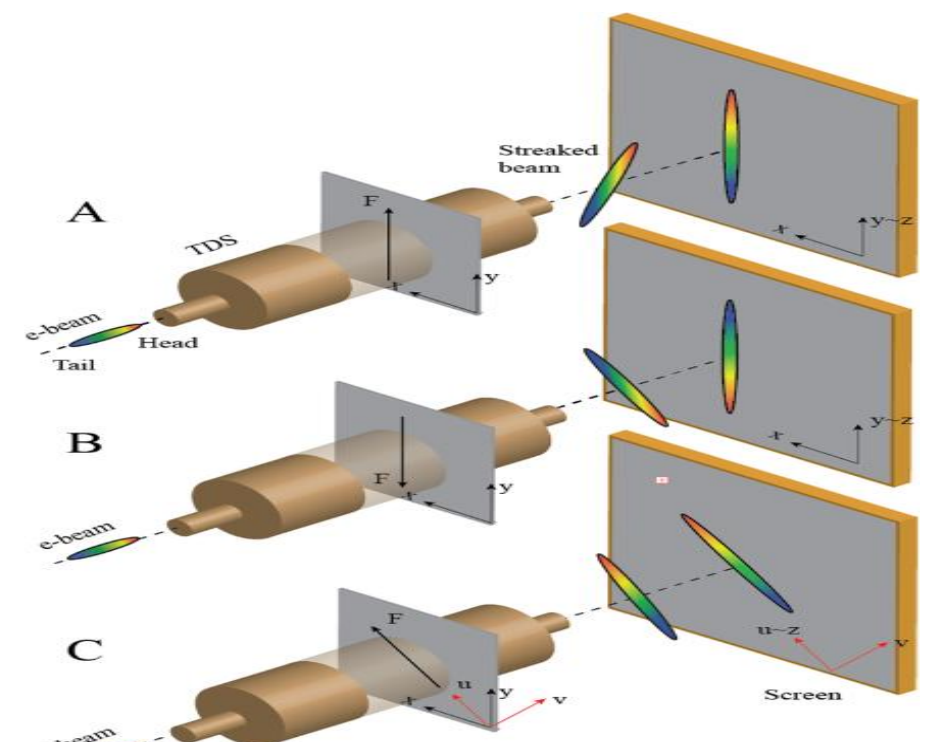


FIG 1: PolariX TDS working principle [1]

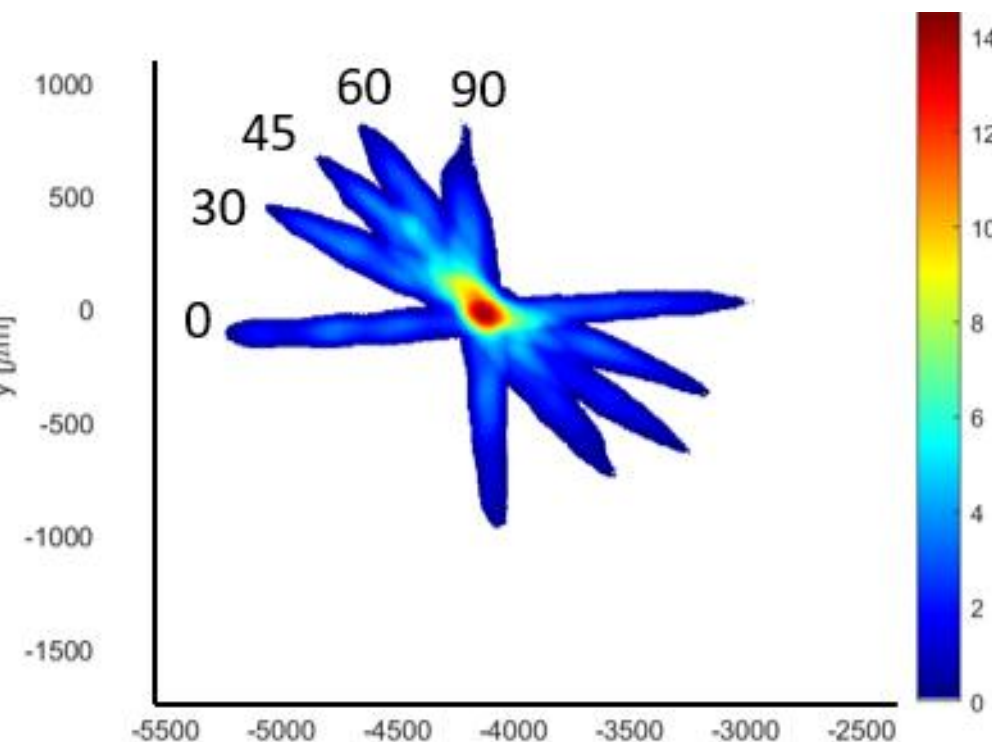


FIG 2: Multiple polarizations

2. 3D and 5D Reconstruction methodology

- Combination of **two scans**:
 - Quadrupole scan** → change optics, vary transverse phase advance
 - PolariX TDS scan** → streaking at 10 polarization angles (~180° coverage)
- For each **quadrupole settings**:
 - Acquire 10 streaked images**
 - Each image is divided into longitudinal slices**
- 3D Reconstruction**
 - Each slice (1D in time) + 10 projections → tomographic 2D reconstruction (x-y) with SART algorithm
 - Stacking slices → 3D charge distribution (x, y, t)

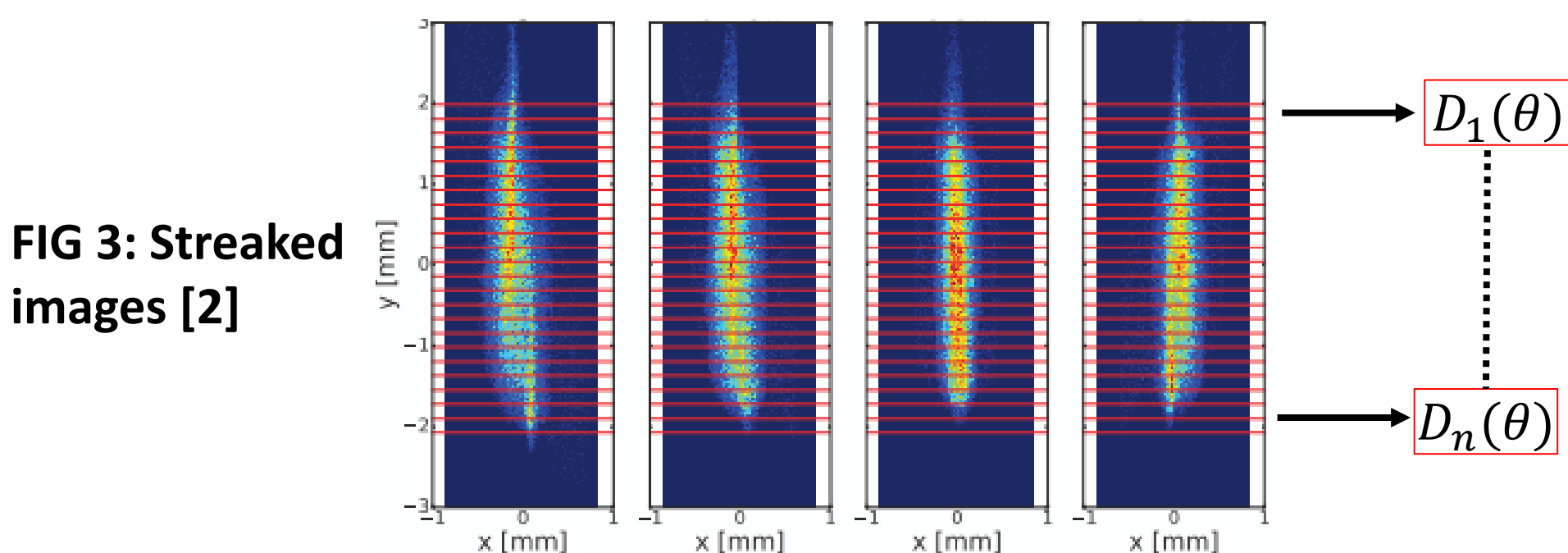


FIG 3: Streaked images [2]

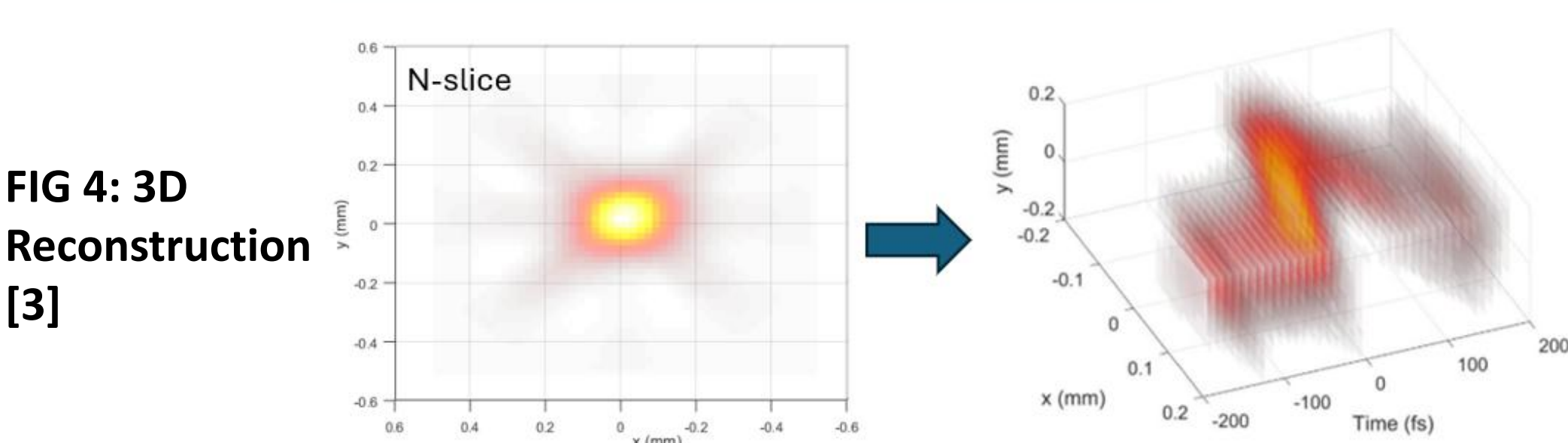


FIG 4: 3D Reconstruction [3]

- 4D Reconstruction**
 - 2D slice images interpreted as projections of full 4D phase space (x, x', y, y') rotated by an angle depending on the phase advance
$$I(x, y) = \int \int f_b(x, x', y, y') dx' dy'$$
$$\begin{pmatrix} x_1 \\ x'_1 \end{pmatrix} = \begin{pmatrix} \cos(\theta_x) & -\sin(\theta_x) \\ \sin(\theta_x) & \cos(\theta_x) \end{pmatrix} \begin{pmatrix} x \\ x' \end{pmatrix}$$
 - $I_y(x_1, \theta_x)$ is the projection along the θ_x direction in the horizontal phase space
 - Back-projection algorithm recovers transverse momenta x', y'

$$I_{y, \theta_x}(x) \xrightarrow{1^{\text{st}} \text{ iteration}} f_y(x, x') \xrightarrow{2^{\text{nd}} \text{ iteration}} f(x, x', y, y')$$

- 5D Reconstruction**
 - Combine transverse phase space (4D) with longitudinal coordinate (t)
 - Result: full 5D beam distribution

3. ATHOS diagnostics beamline at SwissFEL

- ATHOS is the soft X-rays beamline at SwissFEL at 3 GeV, **two PolariX TDS** are installed to measure the longitudinal properties of the beam

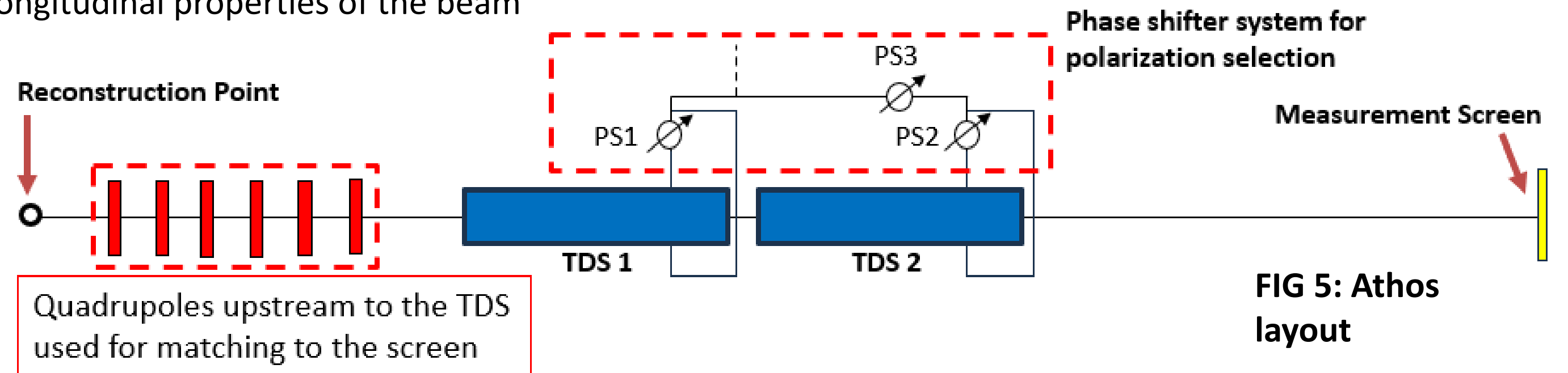


FIG 5: Athos layout

TDS Parameters	
TDS Length	1.2 m
TDS Voltage	70 MV
Klystron Power	28 MW

Measurement Parameters	
Charge	200 pC
Energy	3.4 GeV
TDS Calibration	16.5 $\mu\text{m}/fs$

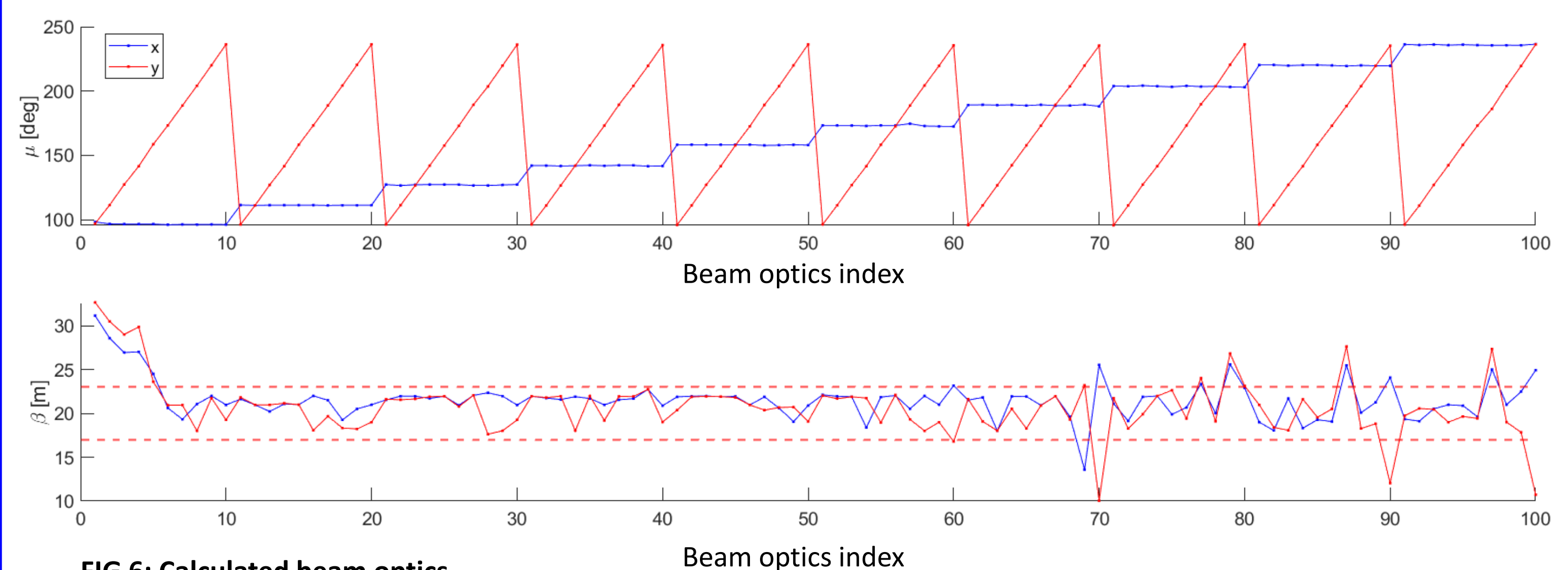


FIG 6: Calculated beam optics

4. Results

Courtesy: S. Jaster-Merz (DESY)

FIG 7: Beam 1: High compression ~19 fs (σ_t)

Fig 8: Beam 2: Moderate compression ~40 fs (σ_t)

FIG 9: Beam 1: 5D Tomography

Final results removed for publication

FIG 10: Beam 2: 5D Tomography

Courtesy: S. Jaster-Merz (DESY)

- The measurement has been done in **two settings**: a **short bunch** (~ 19 fs) and a **less compressed** (~ 40 fs) to **mitigate collective effects** in the compressor and **reduce the beam tilt**, as confirmed by the reconstruction.

References

- [1] Craievich, Paolo, et al. "Novel X-band transverse deflection structure with variable polarization." *Physical review accelerators and beams* 23.11 (2020): 112001.
- [2] Marx, Daniel, et al. "Reconstruction of the 3D charge distribution of an electron bunch using a novel variable-polarization transverse deflecting structure (TDS)." *Journal of Physics: Conference Series*. Vol. 874. No. 1. IOP Publishing, 2017.
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Acknowledgement: " This poster presentation has received support from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730."

Acknowledgement: " PACRI – Grant Agreement n. 101188004."