

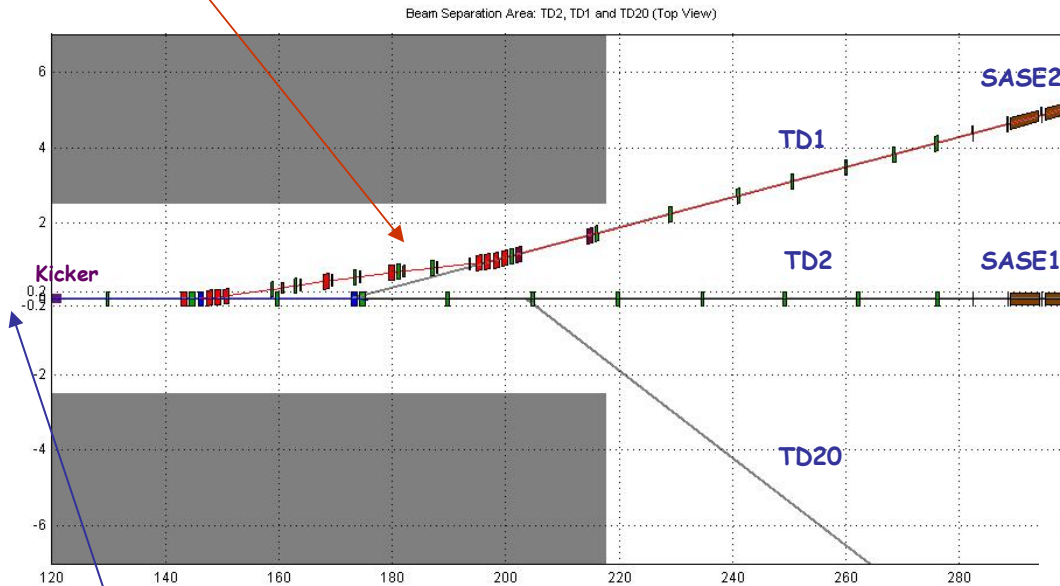
Optics Solution for Deflection Arc of the Beam Switchyard at the European XFEL

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Beam Switchyard

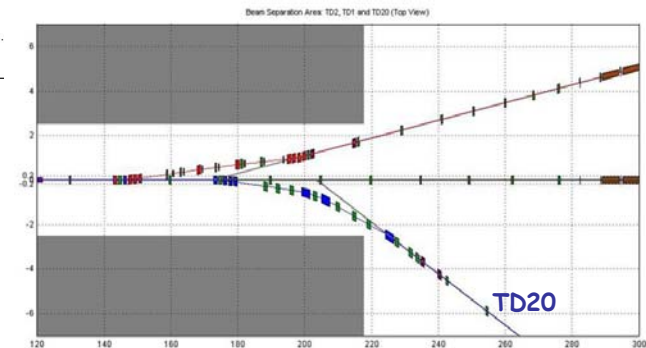
Deflection arc TD1



Four beam lines:

- TD0, dump line (not shown)
- TD2, straight to SASE1
- TD1, deflection to SASE2
- TD20, future beam line

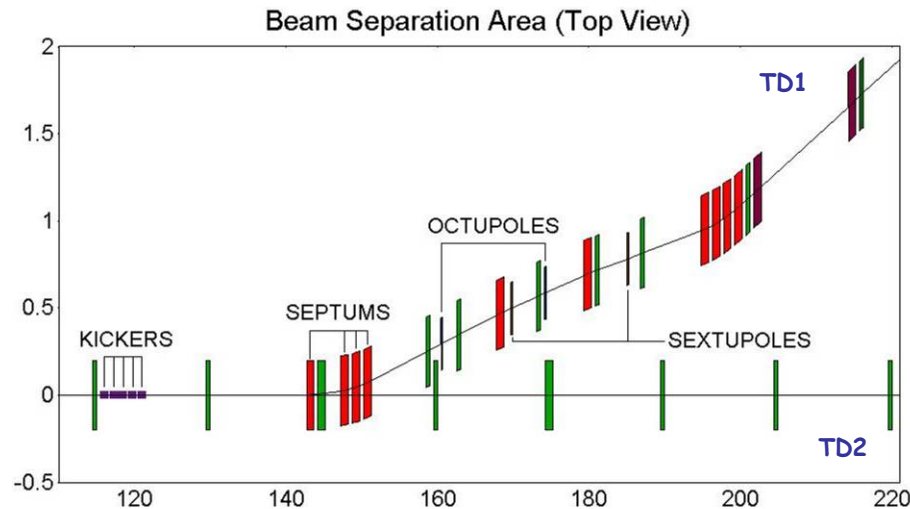
Extraction to the dump line (TD0 line): Kicker kicks the beam horizontally into Lambertson type septum that deflects the beam upward to the dump line.



TD1 Arc: Main Constraints for Design

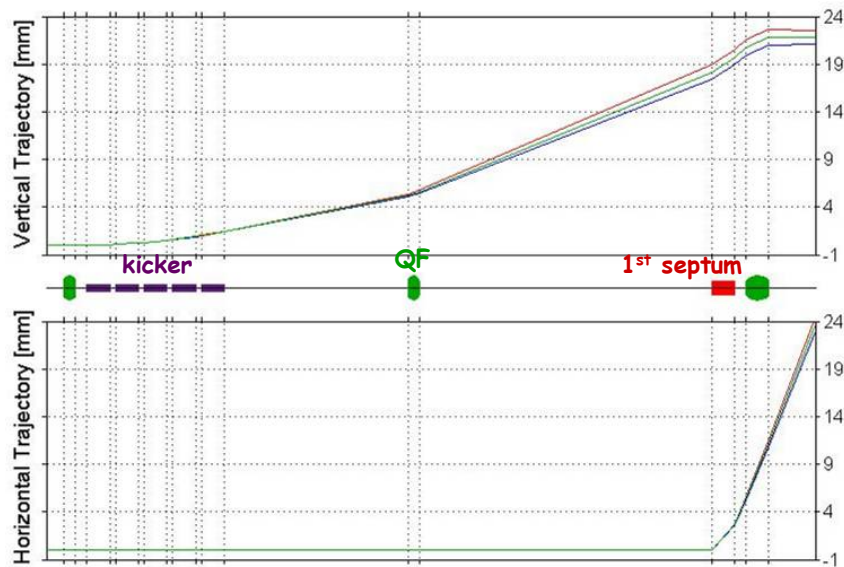
- ▶ **Geometry:**
 - Deflection angle is 2.2859 degree (fixed).
 - Z-coordinate of TD1 and TD2 crossing is fixed.
- ▶ Initial betatron functions are defined by the magnet lattice of the straight beam line TD2.
- ▶ Optimization of placement of kicker and septum to minimize the required kicker strength while having the needed separation (20 mm) of two beams at the septum entrance (Lambertson type septum).
- ▶ Beam optics must be
 - sufficiently achromatic (unperturbed transport of beams for the energy deviation of up to $\pm 1.5\%$ to the undulator)
 - sufficiently isochronous ($R_{56} = 0$)

TD1 Deflection Arc: Kicker-Septum scheme



- ▶ **Kicker-septum scheme:**
 - kicker deflects the beam in vertical plane, upward
 - Lambertson type septum magnet bends the beam horizontally
 - => beam line with two dispersions
- ▶ **Special constraints on the design:**
 - no overlapped elements in beam lines
 - bring the beam back in the horizontal plane with $y=0$
 - taking into account the possible addition of 3d beam line (TD20)

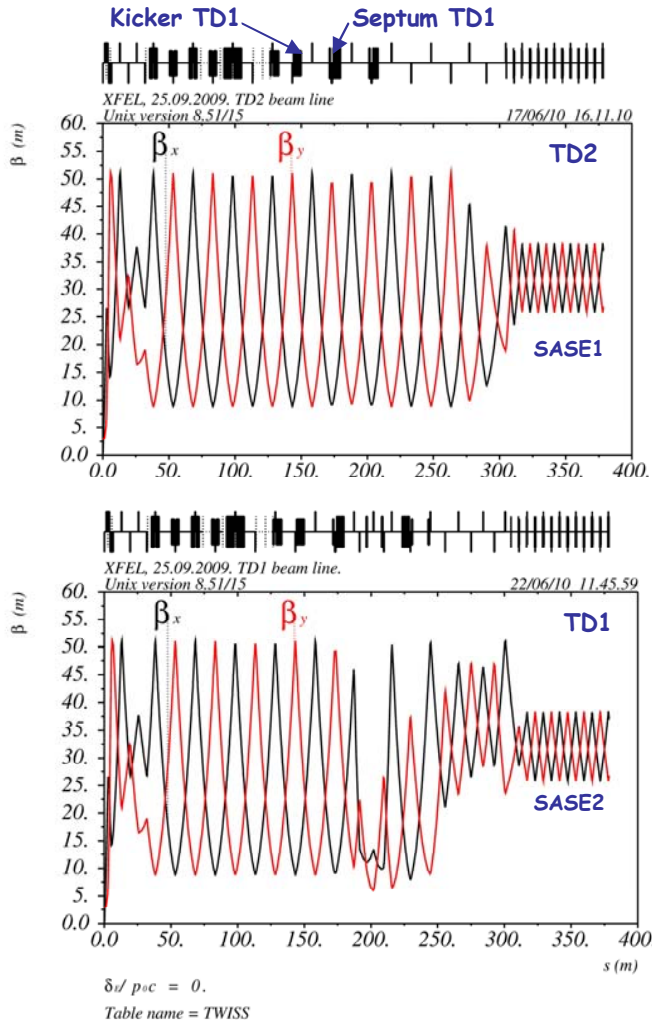
Trajectory of Kicked Beam



Trajectories of the kicked particles in the first part of the separation area TD1. The relative energy deviations are **-3%**, **0%** and **+3%**.

- ▶ Optimized placement of kicker and septum:
 - kicker and 1st septum in one 30 m FODO cell
 - horizontally focusing quadrupole between kicker and septum
 - vertical separation is about 18 mm at the entrance of 1st septum
- ▶ From the entrance of 2^d septum the beam is traveling in parallel to the horizontal plane at $y \approx 22$ mm:
 - 1st septum is tilted by $\sim 11^\circ$, it bends particles horizontally and slightly upward.

Constraints on Linear Optics

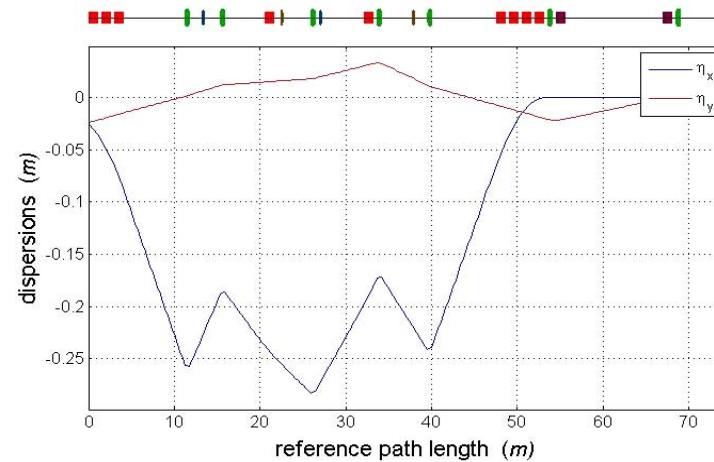
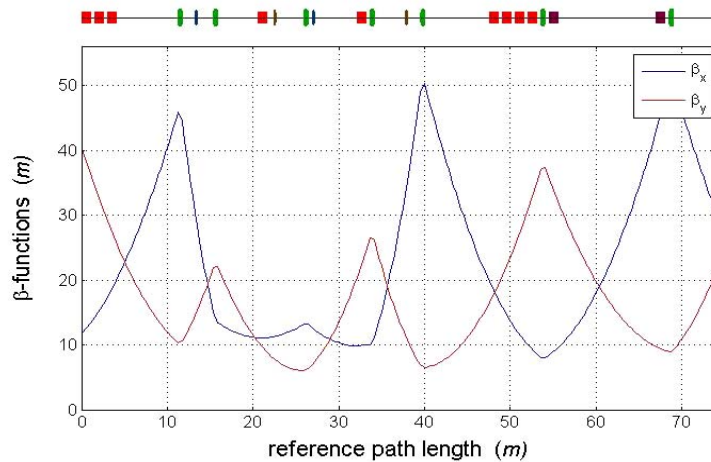


- ▶ Twiss parameters at the entrance of the deflection arc are defined by 30 m FODO lattice in the straight line TD2.
- ▶ Exit Twiss functions have to allow the easy matching to the downstream periodic transport.
- ▶ Deflection arc TD1 has to be a first-order isochronous ($R_{56} = 0$).

Betatron functions along the straight line TD2 and the line TD1 starting from the end of collimation arc.

Linear Optical Functions

Betatron and dispersion functions shown starting from the entrance of 2d non-tilted septum.

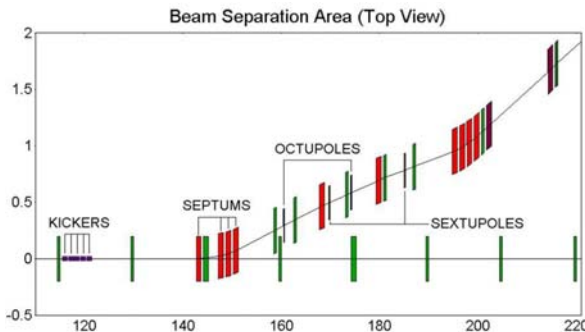
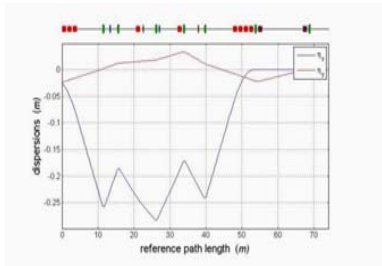


- ▶ Starting from the entrance of 2d septum (non-tilted) the arc is constructed from normally oriented (non-tilted) dipoles and quadrupoles.
- ▶ From the entrance of 2d septum the beam is traveling in parallel to the horizontal plane $y \approx 22$ mm.
- ▶ Deflection arc ends by a dogleg in vertical plane to bring the beam back to horizontal plane $y=0$ and to close the linear vertical dispersion.
- ▶ Deflection arc is a first-order isochronous beam line ($R56=0$). Two reverse bend dipoles are placed close to the arc center.

Chromatic Properties of Deflection Arc

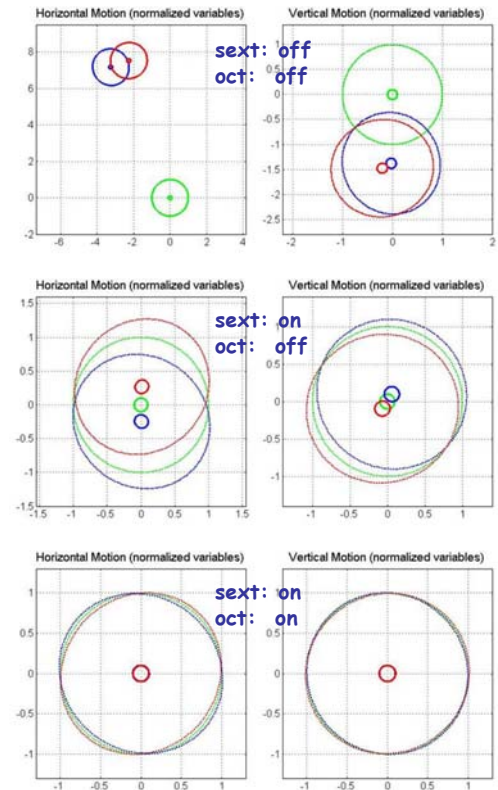
Design specification: Optics should be able to accept bunches with different energies (up to $\pm 1.5\%$ from nominal energy) and transport them without noticeable deterioration of transverse beam parameters.

Deflection arc has nonzero horizontal and vertical dispersions simultaneously, and there is vertical dispersion in horizontal dipoles. In such beamline the linear betatron motion is still transversely uncoupled, but the vertical and horizontal oscillations become chromatically coupled, and non-linear dispersions are generated in both transverse planes.



Two tilted sextupoles and two tilted octupoles are used for correction of chromatic aberrations.

The optimization of the number of sextupoles and octupoles, their positions, strengths, and tilt angles was not a separate task after the design of the linear optics, but both, linear and nonlinear, optics were designed together.



$\Delta E/E = -1.5\%, 0\%, +1.5\%$

Summary

The optics solution for TD1 deflection arc meets the design specification from the point of view of single beam dynamics.

The impact of collective effects on the beam quality requires additional investigations.