XFEL- 3D-Coordinates, first phase design
(includes the LA-part)

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This document does not include absolute geographic coordinates. Here the reader is referred to G. Neubauer (MEA2) and the word-file "Hoehe der Strahlenebene_7.doc" in D:\XFEL_Archiv\XFEL_2006.
Due to the curvature of the surface noticable at the large extension of the XFEL, there are two Cartesian coordinate systems, namely the LA- and the PD-system.
They are defined as follows:
The z-axis of the LA-system coincides with the major part of the beam in the Linac-tunnel and is tangential to an earth potential face at 1000m. The y-axis is vertical, and consequently the x-axis is horizontal, forming a right-handed system. The origin lies in the intersection of the eastern inner wall of the first building, namely the XSIN, with the beam in the first part of the linac-tunnel XTL.
The z-axis of the PD-system coincides with the straight beam in the distribution fan, namely P4, but is tangential to an earth potential face at the end point, which is defined as the intersection of the eastern inner wall of the experimental hall with the straight beam. Thus a small angle of 0.02092 degrees lies inbetween both systems. The origin is a fictive point in the acceleration tunnel XLT at z=1994.492m. As this point must coincide with the beam which has already passed the S-shaped collimation section, it has the y-coordinate -2.4386m.

This document calculates the 3-dimensional locations of beam end points, pit start and end points, tunnel axis end points and undulator entrance and exit points.
To avoid confusion the name of all points ends with _LA when they are expressed in LA-coordinates. All dimensions are in meter.

Reference:C:\Users\tscheu\AppData\Local\Microsoft\Windows\Temporary Internet Files\Content.Outlook\7AROKEP7\Library3D.xmcd(R)

Remark:
Originally this document was intended to layout the distribution fan. In the meantime most of

the design is fixed, especially the buildings and minor changes are possible, only.
Consequently this document serves mainly as a verification of consistency.

General parameter definition:

radius of a sphere approximating the surface:	$R := 6390000$
z_origin:	$z0 := 1994.492$
y_origin:	$y0 := -2.4386$
z-coord. of the straight beam at the front side of the experimental hall	$PD\_Length := 1338.67$
tunnel element length	$tubbingLength := 1.5$

Parameter Definition for the linac region:

XSIN length:	$XSIN\_Length := 17$
XTIN length:	$XTIN\_Length := 50$
XSE length:	$XSE\_Length := 22.55$
vertical injector separation:	$inj\_sep := 5.5$
horizontal distance between beam and tunnel axis:	$horAxisLin := 0.2$

vertical distance between beam and tunnel axis:	$vertAxisLin := -0.9$
z-position of first dipole in the collimation (end):	$dipole1CollEnd := 1708.8444$

The angle between both coordinate systems (y- and z-axes):

$$\alpha_k := \frac{z0 + PD\_Length - 1000}{R} \qquad \frac{\alpha_k}{deg} = 0.02092$$

Transformation functions are governed by the matrix A

$$A := \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha_k) & -\sin(\alpha_k) \\ 0 & \sin(\alpha_k) & \cos(\alpha_k) \end{pmatrix} \qquad origin\_PD := \begin{pmatrix} 0 \\ y0 \\ z0 \end{pmatrix}$$

$$PDtoLA(p) := A \cdot p + origin\_PD \qquad LAtoPD(p) := A^{-1} \cdot (p - origin\_PD)$$

The first three buildings are treated as a single complex with parallel walls. As they are built strictly to the plumb, they form a small inclination angle to the beam:

building complex length: $L_c := XSIN\_Length + XTIN\_Length + XSE\_Length$

$$\delta_c := \frac{\frac{L_c}{2} - 1000}{R} \qquad \frac{\delta_c}{deg} = -0.008565$$

The rotation occurs about the BO of XSIN:

$$XTL\_start\_LA := \begin{pmatrix} horAxisLin \\ vertAxisLin \\ L_c \end{pmatrix} \qquad XTL\_start\_LA = \begin{pmatrix} 0.2000 \\ -0.9000 \\ 89.5500 \end{pmatrix}$$

$$XSIN\_start\_LA := \begin{pmatrix} horAxisLin \\ vertAxisLin \\ 0 \end{pmatrix}$$

The rotation of a point p around the point c and the angle α about the x-axis is described by this function:

$$X\_transform(p, c, \alpha) := \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) \\ 0 & \sin(\alpha) & \cos(\alpha) \end{pmatrix} \cdot (p - c) + c$$

As the tunnel axis of the injector is also rotated the BOs of XTIN and XSE in the Structure-assembly change whereas in the local assembly they are fixed.

$$X\_transform\left[\begin{pmatrix} horAxisLin \\ -2.15 \\ XSIN\_Length \end{pmatrix}, XSIN\_start\_LA, \delta_c\right] = \begin{pmatrix} 0.2000 \\ -2.1475 \\ 17.0002 \end{pmatrix}$$

$$\text{X\_transform}\left[\begin{pmatrix} \text{horAxisLin} \\ -2.15 \\ \text{XSIN\_Length} + \text{XTIN\_Length} \end{pmatrix}, \text{XSIN\_start\_LA}, \delta_c\right] = \begin{pmatrix} 0.2000 \\ -2.1400 \\ 67.0002 \end{pmatrix}$$

In the following the z-coordinates of the sections used by the beam dynamics group are listed:

z_L1_LA := 92

z_B1_LA := 169

z_B1D_LA := 227

z_L2_LA := 234

z_B2_LA := 383

z_B2D_LA := 460

z_L3_LA := 467

z_CL_LA := 1689

z_TL_LA := 1901

In contrast the Base Orphans (BO) are very close to these borders but end at a tubbing element

Collimation

straight lines between dipoles:

a := 5

b := 23

c := 41

Dipole length in the collimation 4m

as a vector

$$straight := \begin{pmatrix} dipole1CollEnd - 4 - z\_CL\_LA \\ b \\ a \\ b \\ c \\ b \\ a \\ b \\ 4.5 \end{pmatrix} \qquad straight = \begin{pmatrix} 15.8 \\ 23.0 \\ 5.0 \\ 23.0 \\ 41.0 \\ 23.0 \\ 5.0 \\ 23.0 \\ 4.5 \end{pmatrix}$$

bending angle of a dipole $\Delta\alpha := 0.31627 \cdot deg$

Lenght of a dipole $lenDip := 4$

BO XTL_CL_1

$$CL1\_LA := \begin{pmatrix} horAxisLin \\ vertAxisLin \\ dipole1CollEnd - straight_0 - lenDip \end{pmatrix}$$

Assuming that there is a tubbing border 14.5m shift already included

Always the midpoint of a dipole is taken

Mid 1. dipole $\quad \text{dipole1CollEnd} - \frac{\text{lenDip}}{2}\cdot\cos(\Delta\alpha) = 1706.844$

$$\text{CL1\_LA} = \begin{pmatrix} 0.2000 \\ -0.9000 \\ 1689.0000 \end{pmatrix}$$

$$\frac{\text{CL1\_LA} - \text{XTL\_start\_LA}}{\text{tubbingLength}} = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 1066.3000 \end{pmatrix}$$

$dipol_0$ und $dipol_9$ are additional points to construct the beams

vector of angles (at the exit of a dipole):

The kink angle between LA and PD
is smeared out over the second bend

$$\alpha := \begin{pmatrix} 0 \\ \Delta\alpha \\ 2\cdot\Delta\alpha \\ 3\cdot\Delta\alpha \\ 4\cdot\Delta\alpha \\ 3\cdot\Delta\alpha + \frac{1}{4}\cdot\alpha_k \\ 2\cdot\Delta\alpha + \frac{1}{2}\cdot\alpha_k \\ \Delta\alpha + \frac{3}{4}\cdot\alpha_k \\ \alpha_k \\ 0 \end{pmatrix}$$

running variable $\quad i := 1..8$

Initialisation

$$dipol_0 := \begin{pmatrix} 0 \\ 0 \\ \text{CL1\_LA}_2 - \frac{\text{lenDip}}{2} \end{pmatrix}$$

$$dipol_i := dipol_{i-1} + \left(straight_{i-1} + lenDip\right) \cdot \begin{pmatrix} 0 \\ -\sin\left(\alpha_{i-1}\right) \\ \cos\left(\alpha_{i-1}\right) \end{pmatrix}$$

$$dipolEnd_i := dipol_i + \frac{lenDip}{2} \cdot \begin{pmatrix} 0 \\ -\sin\left(\alpha_i\right) \\ \cos\left(\alpha_i\right) \end{pmatrix}$$

Midpoint of quadrupole after 8. dipole

$$quad := dipol_8 + 4.5 \cdot \begin{pmatrix} 0 \\ -\sin\left(\alpha_8\right) \\ \cos\left(\alpha_8\right) \end{pmatrix}$$

$$dipol_9 := quad$$

$$quad = \begin{pmatrix} 0 \\ -2.39764 \\ 1882.32401 \end{pmatrix}$$

$$dipol_1 = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 1706.8444 \end{pmatrix} \qquad dipolEnd_1 = \begin{pmatrix} 0.0000 \\ -0.0110 \\ 1708.8444 \end{pmatrix}$$

For comparison with the Excel-list

$$dipol_2 = \begin{pmatrix} 0.0000 \\ -0.1490 \\ 1733.8440 \end{pmatrix} \qquad dipolEnd_2 = \begin{pmatrix} 0.0000 \\ -0.1711 \\ 1735.8439 \end{pmatrix}$$

$$dipol_3 = \begin{pmatrix} 0.0000 \\ -0.2484 \\ 1742.8434 \end{pmatrix} \qquad dipolEnd_3 = \begin{pmatrix} 0.0000 \\ -0.2815 \\ 1744.8432 \end{pmatrix}$$

$$dipol_4 = \begin{pmatrix} 0.0000 \\ -0.6955 \\ 1769.8397 \end{pmatrix} \qquad dipolEnd_4 = \begin{pmatrix} 0.0000 \\ -0.7396 \\ 1771.8393 \end{pmatrix}$$

$$dipol_5 = \begin{pmatrix} 0.0000 \\ -1.6890 \\ 1814.8288 \end{pmatrix} \qquad dipolEnd_5 = \begin{pmatrix} 0.0000 \\ -1.7223 \\ 1816.8285 \end{pmatrix}$$

$$dipol_6 = \begin{pmatrix} 0.0000 \\ -2.1386 \\ 1841.8250 \end{pmatrix} \qquad dipolEnd_6 = \begin{pmatrix} 0.0000 \\ -2.1610 \\ 1843.8249 \end{pmatrix}$$

$$dipol_7 = \begin{pmatrix} 0.0000 \\ -2.2396 \\ 1850.8245 \end{pmatrix} \qquad dipolEnd_7 = \begin{pmatrix} 0.0000 \\ -2.2511 \\ 1852.8244 \end{pmatrix}$$

$$dipol_8 = \begin{pmatrix} 0.0000 \\ -2.3960 \\ 1877.8240 \end{pmatrix} \qquad dipolEnd_8 = \begin{pmatrix} 0.0000 \\ -2.3967 \\ 1879.8240 \end{pmatrix}$$

distances for IDEAS-assembly beam_LA

$$abst_i := (dipol_i)_2 - (dipol_1)_2$$

$abst_1 = 0.0000$ $abst_2 = 26.9996$

$abst_3 = 35.9990$ $abst_4 = 62.9953$

$abst_5 = 107.9844$ $abst_6 = 134.9806$

$abst_7 = 143.9801$ $abst_8 = 170.9796$

$\frac{\alpha}{deg} =$

	0
0	0
1	0.31627
2	0.63254
3	0.94881
4	1.26508
5	0.95404
6	0.643
7	0.33196
8	0.02092
9	0

$$\frac{\Delta\alpha - \frac{\alpha_k}{4}}{deg} = 0.31104$$

The beam must go through the origin of the PD-system

$$z0 = 1994.4920$$

$$dipol_8 + \left[z0 - (dipol_8)_2\right] \cdot \begin{pmatrix} 0 \\ -\sin(\alpha_8) \\ \cos(\alpha_8) \end{pmatrix} = \begin{pmatrix} 0.0000 \\ -2.4386 \\ 1994.4920 \end{pmatrix}$$

$$y0 = -2.4386$$

change $\Delta\alpha$!

$$mid := dipol_4 + \frac{c + lenDip}{2} \cdot \begin{pmatrix} 0 \\ -\sin(\alpha_4) \\ \cos(\alpha_4) \end{pmatrix}$$

$$mid = \begin{pmatrix} 0 \\ -1.192 \\ 1792.334 \end{pmatrix}$$

calculating the tunnel path in the range of collimation

angle of a special tubbing element $\Delta\beta := 0.1 \cdot deg$

radius of curvature $rc := \frac{tubbingLength}{\Delta\beta}$

9 elements $k := 0..8$

Beams between the dipoles: $beam_k := linePP(dipol_k, dipol_{k+1})$

construct the corresponding tunnel axis

A point on a parallel line to $beam_k$ $p_k := dipol_k + horAxisLin \cdot \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} + vertAxisLin \cdot \begin{pmatrix} 0 \\ \cos(\alpha_k) \\ \sin(\alpha_k) \end{pmatrix}$

$$ideal_k := \begin{bmatrix} p_k \\ (beam_k)_1 \end{bmatrix}$$

This is the ideal line but with a constant tubbing length not realistic (see below)

Between straight tunnel sections there are bent sections
but these are approximated by straights

$k := 1..8$

18 end points
of tunnel segments $idealAp_0 := CL1\_LA$

$$idealAp_{2k} := intersectLL(ideal_{k-1}, ideal_k)$$

$$idealAp_{17} := idealAp_{16} + \begin{pmatrix} 0 \\ 0 \\ 4.5 \end{pmatrix}$$

not an intersection just a point on the horizontal(!) tunnel section

$$\alpha_8 := 0$$

$$idealAp_{18} := \begin{bmatrix} (idealAp_{17})_0 \\ (idealAp_{17})_1 \\ z0 + 44.5676 \end{bmatrix}$$

the bending point in front of XS1

$$idealAp_0 = \begin{pmatrix} 0.2000 \\ -0.9000 \\ 1689.0000 \end{pmatrix} \qquad \left|idealAp_0 - dipol_0\right| = 2.2023$$

$$idealAp_2 = \begin{pmatrix} 0.2000 \\ -0.9000 \\ 1706.8419 \end{pmatrix} \qquad \left|idealAp_2 - dipol_1\right| = 0.9220$$

$$idealAp_4 = \begin{pmatrix} 0.2000 \\ -1.0490 \\ 1733.8365 \end{pmatrix} \qquad \left|idealAp_4 - dipol_2\right| = 0.9220$$

$$idealAp_6 = \begin{pmatrix} 0.2000 \\ -1.1483 \\ 1742.8310 \end{pmatrix} \qquad \left|idealAp_6 - dipol_3\right| = 0.9220$$

$$idealAp_8 = \begin{pmatrix} 0.2000 \\ -1.5953 \\ 1769.8224 \end{pmatrix} \qquad \left|idealAp_8 - dipol_4\right| = 0.9220$$

$$\text{idealAp}_{10} = \begin{pmatrix} 0.2000 \\ -2.5888 \\ 1814.8113 \end{pmatrix} \qquad \left|\text{idealAp}_{10} - \text{dipol}_5\right| = 0.9220$$

$$\text{idealAp}_{12} = \begin{pmatrix} 0.2000 \\ -3.0385 \\ 1841.8125 \end{pmatrix} \qquad \left|\text{idealAp}_{12} - \text{dipol}_6\right| = 0.9220$$

$$\text{idealAp}_{14} = \begin{pmatrix} 0.2000 \\ -3.1395 \\ 1850.8168 \end{pmatrix} \qquad \left|\text{idealAp}_{14} - \text{dipol}_7\right| = 0.9220$$

$$\text{idealAp}_{16} = \begin{pmatrix} 0.2000 \\ -3.2960 \\ 1877.8212 \end{pmatrix} \qquad \left|\text{idealAp}_{16} - \text{dipol}_8\right| = 0.9220$$

$$\text{idealAp}_{17} = \begin{pmatrix} 0.2000 \\ -3.2960 \\ 1882.3212 \end{pmatrix} \qquad \left|\text{idealAp}_{17} - \text{dipol}_9\right| = 0.9204$$

Length of bends
(8+1 dummy)

$$i := 1..8$$

$$\text{bend}_i := \left|\text{rc}\cdot\left(\alpha_i - \alpha_{i-1}\right)\right|$$

$$\text{bend} = \begin{pmatrix} 0.0000 \\ 4.7440 \\ 4.7440 \\ 4.7441 \\ 4.7440 \\ 4.6656 \\ 4.6656 \\ 4.6656 \\ 4.9794 \end{pmatrix}$$

$$\text{idealAp}_{2i-1} := \text{idealAp}_{2\cdot i} - \frac{\text{bend}_i}{2} \cdot \begin{pmatrix} 0 \\ -\sin(\alpha_{i-1}) \\ \cos(\alpha_{i-1}) \end{pmatrix}$$

$$\text{idealAp}_{2\cdot i} := \text{idealAp}_{2\cdot i} + \frac{\text{bend}_i}{2} \cdot \begin{pmatrix} 0 \\ -\sin(\alpha_i) \\ \cos(\alpha_i) \end{pmatrix}$$

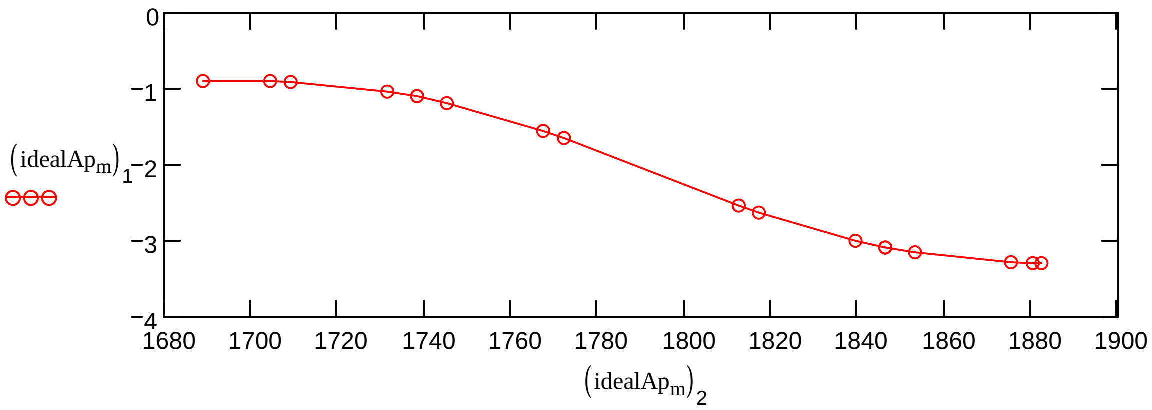
$$\text{idealAp}_4 = \begin{pmatrix} 0.2000 \\ -1.0752 \\ 1736.2084 \end{pmatrix} \qquad \text{idealAp}_5 = \begin{pmatrix} 0.2000 \\ -1.1221 \\ 1740.4591 \end{pmatrix}$$

If idealAp4 comes later than idealAp5, make one point

$$idealAp_4 := \frac{idealAp_4 + idealAp_5}{2} \qquad idealAp_{12} := \frac{idealAp_{12} + idealAp_{13}}{2}$$

$$idealAp_5 := idealAp_4 \qquad idealAp_{13} := idealAp_{12}$$

$$m := 0..17$$



$$ideal_m := linePP\left(idealAp_m, idealAp_{m+1}\right)$$

$$yAt(line, z) := \left[line_0 + \left[\frac{z - \left(line_0\right)_2}{\left(line_1\right)_2}\right] \cdot line_1\right]_1$$

$$\text{idealLine}(z) := \left|\begin{array}{l} \text{save} \leftarrow -1 \\ \text{for } i \in 0..17 \\ \quad \text{save} \leftarrow i \text{ if } z > \left(\text{idealAp}_i\right)_2 \\ \text{if save} < 0 \\ \quad \left|\begin{array}{l} f \leftarrow -0.9 \\ \text{return } f \end{array}\right. \\ \text{if save} > 16 \\ \quad \left|\begin{array}{l} f \leftarrow \left(\text{idealAp}_{17}\right)_1 \\ \text{return } f \end{array}\right. \\ f \leftarrow \text{yAt}\left(\text{ideal}_{\text{save}}, z\right) \\ \text{return } f \end{array}\right.$$

$$\text{idealAp}_4 = \begin{pmatrix} 0.2000 \\ -1.0987 \\ 1738.3338 \end{pmatrix}$$

$$\text{idealAp}_5 = \begin{pmatrix} 0.2000 \\ -1.0987 \\ 1738.3338 \end{pmatrix}$$

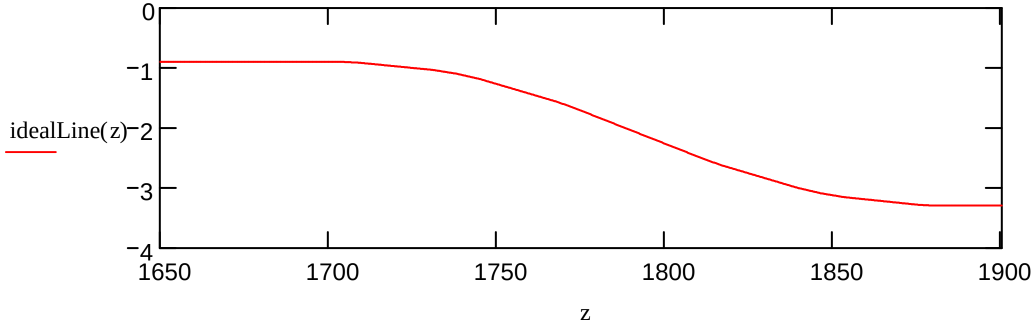
$$\text{idealLine}\left[\left(\text{idealAp}_4\right)_2\right] = -1.0987$$

$$\text{bend} = \begin{pmatrix} 0.0000 \\ 4.7440 \\ 4.7440 \\ 4.7441 \\ 4.7440 \\ 4.6656 \\ 4.6656 \\ 4.6656 \\ 4.9794 \end{pmatrix}$$

$$\text{eal}_4)_1 = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.0000 \end{pmatrix}$$

$$\text{straight} = \begin{pmatrix} 15.8444 \\ 23.0000 \\ 5.0000 \\ 23.0000 \\ 41.0000 \\ 23.0000 \\ 5.0000 \\ 23.0000 \\ 4.5000 \end{pmatrix}$$

$$\text{idealAp}_0 = \begin{pmatrix} 0.2000 \\ -0.9000 \\ 1689.0000 \end{pmatrix}$$



Bestimmung der Abschittsgrenzen

$$CL2\_LA := \begin{pmatrix} xAt(ideal_8, 1784.55) \\ yAt(ideal_8, 1784.55) \\ 1784.55 \end{pmatrix}$$

$$CL2\_LA = \begin{pmatrix} 0.2000 \\ -1.9206 \\ 1784.5500 \end{pmatrix}$$

$$mid = \begin{pmatrix} 0.0000 \\ -1.1922 \\ 1792.3343 \end{pmatrix}$$

$$teil1 := \left|CL2\_LA - idealAp_8\right| - \frac{bend_5}{2}$$

$teil1 = 10.0264$

$$\frac{CL2\_LA - CL1\_LA}{tubbingLength} = \begin{pmatrix} 0.0000 \\ -0.6804 \\ 63.7000 \end{pmatrix}$$

$$teil2 := \left|CL2\_LA - idealAp_9\right| - \frac{bend_6}{2}$$

$teil2 = 25.6031$

$$x := CL1\_LA_2 + 75 \cdot tubbingLength$$

$$TL := \begin{bmatrix} \left(idealAp_{16}\right)_0 \\ \left(idealAp_{16}\right)_1 \\ x \end{bmatrix}$$

Letzter Teil des XTL läuft parallel zu LA

$$TL = \begin{pmatrix} 0.2000 \\ -3.2960 \\ 1801.5000 \end{pmatrix}$$

$$teil1 := \left|TL - idealAp_{16}\right| - \frac{bend_7}{2}$$

$teil1 = 76.4781$

$$end := \begin{pmatrix} TL_0 \\ TL_1 \\ 1994.492 \end{pmatrix}$$

$$teil2 := \left|TL - end\right|$$

$teil2 = 192.9920$

With integer multiples of the tubbing length see
a Java project "collimation"

The straight between 2. and 3. dipole is so short that it will be treated in one bend, the same holds for dipole 6 and 7

With 13 sections the multiples are defined in a vector n

$$n := \begin{pmatrix} 15 \\ 7 \\ 11 \\ 12 \\ 14 \\ 6 \\ 22 \\ 5 \\ 12 \\ 12 \\ 9 \\ 8 \\ 15 \end{pmatrix}$$

15	from CL1_LA to 1.dipole
7	1. dipole
11	straight from 1. to 2. dipole
12	2. and 3. dipole
14	straight from 3. to 4. dipole
6	4. dipole
22	long straight from 4. to 5. dipole
5	5. dipole
12	straight from 5. to 6. dipole
12	6. and 7. dipole
9	straight from 7. to 8. dipole
8	8. dipole
15	straight after 8. dipole

$$\sum_{k=0}^{2} n_{2\cdot k+1} - \sum_{k=3}^{5} n_{2\cdot k+1} = 0.0000$$

$db := 0.05$ $\quad$ $realAp_0 := idealAp_0$

1. straight section 17 elements: $\quad i := 1 .. n_0 \quad n_0 = 15.0000$

$$realAp_i := realAp_{i-1} + \begin{pmatrix} 0 \\ 0 \\ 1.5 \end{pmatrix}$$

$$realAp_{n_0} = \begin{pmatrix} 0.2000 \\ -0.9000 \\ 1711.5000 \end{pmatrix} \qquad idealAp_1 = \begin{pmatrix} 0.2000 \\ -0.9000 \\ 1704.4699 \end{pmatrix}$$

7 wedge shaped segments

$$i := n_0 + 1 .. n_0 + n_1 \qquad n_1 = 7.0000$$

$$realAp_i := realAp_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left(i - n_0 - 0.5\right) \cdot db \cdot deg\right] \\ \cos\left[\left(i - n_0 - 0.5\right) \cdot db \cdot deg\right] \end{bmatrix}$$

$$realAp_{20} = \begin{pmatrix} 0.2000 \\ -0.9164 \\ 1719.0000 \end{pmatrix}$$

$$realAp_{n_0+n_1} = \begin{pmatrix} 0.2000 \\ -0.9321 \\ 1721.9999 \end{pmatrix} \qquad idealAp_2 = \begin{pmatrix} 0.2000 \\ -0.9131 \\ 1709.2139 \end{pmatrix}$$

15 straight segments

$$i := \sum_{k=0}^{1} n_k + 1 .. \sum_{k=0}^{2} n_k \qquad n_2 = 11.0000$$

$$realAp_i := realAp_{i-1} + 1.5 \cdot \begin{pmatrix} 0 \\ -\sin\left(n_1 \cdot db \cdot deg\right) \\ \cos\left(n_1 \cdot db \cdot deg\right) \end{pmatrix}$$

$$\text{realAp}_{\sum_{k=0}^{2} n_k} = \begin{pmatrix} 0.2000 \\ -1.0329 \\ 1738.4996 \end{pmatrix} \qquad \text{idealAp}_3 = \begin{pmatrix} 0.2000 \\ -1.0359 \\ 1731.4645 \end{pmatrix}$$

12 wedge shaped segments

$$i := \sum_{k=0}^{2} n_k + 1 .. \sum_{k=0}^{3} n_k \qquad n_3 = 12.0000$$

$$\text{realAp}_i := \text{realAp}_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left(i - \sum_{k=0}^{1} n_{2\cdot k} - 0.5\right)\cdot db\cdot deg\right] \\ \cos\left[\left(i - \sum_{k=0}^{1} n_{2\cdot k} - 0.5\right)\cdot db\cdot deg\right] \end{bmatrix}$$

14 straight segments

$$i := \sum_{k=0}^{3} n_k + 1 .. \sum_{k=0}^{4} n_k \qquad n_4 = 14.0000$$

$$\text{realAp}_i := \text{realAp}_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left(\sum_{k=0}^{1} n_{2\cdot k+1}\right)\cdot db\cdot deg\right] \\ \cos\left[\left(\sum_{k=0}^{1} n_{2\cdot k+1}\right)\cdot db\cdot deg\right] \end{bmatrix}$$

6 wedge shaped segments

$$i := \sum_{k=0}^{4} n_k + 1 .. \sum_{k=0}^{5} n_k \qquad n_5 = 6.0000$$

$$realAp_i := realAp_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left(i - \sum_{k=0}^{2} n_{2\cdot k} - 0.5\right)\cdot db\cdot deg\right] \\ \cos\left[\left(i - \sum_{k=0}^{2} n_{2\cdot k} - 0.5\right)\cdot db\cdot deg\right] \end{bmatrix}$$

22 straight segments $$i := \sum_{k=0}^{5} n_k + 1 .. \sum_{k=0}^{6} n_k \qquad n_6 = 22.0000$$

$$realAp_i := realAp_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left(\sum_{k=0}^{2} n_{2\cdot k+1}\right)\cdot db\cdot deg\right] \\ \cos\left[\left(\sum_{k=0}^{2} n_{2\cdot k+1}\right)\cdot db\cdot deg\right] \end{bmatrix}$$

5 wedge shaped segments back $$i := \sum_{k=0}^{6} n_k + 1 .. \sum_{k=0}^{7} n_k \qquad n_7 = 5.0000$$

$$realAp_i := realAp_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left(\sum_{k=0}^{6} n_k + \sum_{k=0}^{2} n_{2\cdot k+1} - i + 0.5\right)\cdot db\cdot deg\right] \\ \cos\left[\left(\sum_{k=0}^{6} n_k + \sum_{k=0}^{2} n_{2\cdot k+1} - i + 0.5\right)\cdot db\cdot deg\right] \end{bmatrix}$$

12 straight segments

$$i := \sum_{k=0}^{7} n_k + 1 .. \sum_{k=0}^{8} n_k \qquad n_8 = 12.0000$$

$$realAp_i := realAp_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left(\sum_{k=0}^{2} n_{2\cdot k+1} - n_7\right)\cdot db\cdot deg\right] \\ \cos\left[\left(\sum_{k=0}^{2} n_{2\cdot k+1} - n_7\right)\cdot db\cdot deg\right] \end{bmatrix}$$

12 wedge shaped segments back

$$i := \sum_{k=0}^{8} n_k + 1 .. \sum_{k=0}^{9} n_k \qquad n_9 = 12.0000$$

$$realAp_i := realAp_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left[\left[\sum_{k=0}^{8} n_k - i + \left(\sum_{k=0}^{2} n_{2\cdot k+1} - n_7\right)\right] + 0.5\right] \cdot db \cdot deg\right] \\ \cos\left[\left[\left[\sum_{k=0}^{8} n_k - i + \left(\sum_{k=0}^{2} n_{2\cdot k+1} - n_7\right)\right] + 0.5\right] \cdot db \cdot deg\right] \end{bmatrix}$$

11 straight segments $\quad i := \sum_{k=0}^{9} n_k + 1 .. \sum_{k=0}^{10} n_k \qquad n_{10} = 9.0000$

$$realAp_i := realAp_{i-1} + 1.5 \cdot \begin{bmatrix} 0 \\ -\sin\left[\left(\sum_{k=0}^{2} n_{2\cdot k+1} - \sum_{k=3}^{4} n_{2\cdot k+1}\right) \cdot db \cdot deg\right] \\ \cos\left[\left(\sum_{k=0}^{2} n_{2\cdot k+1} - \sum_{k=3}^{4} n_{2\cdot k+1}\right) \cdot db \cdot deg\right] \end{bmatrix}$$

8 wedge shaped segments back $\quad i := \sum_{k=0}^{10} n_k + 1 .. \sum_{k=0}^{11} n_k \qquad n_{11} = 8.0000$

$$realAp_i := realAp_{i-1} + 1.5\cdot\begin{bmatrix} 0 \\ -\sin\left[\left[\left[\sum_{k=0}^{10} n_k - i + \left(\sum_{k=0}^{2} n_{2\cdot k+1} - \sum_{k=3}^{4} n_{2\cdot k+1}\right)\right] + 0.5\right]\cdot db\cdot deg\right] \\ \cos\left[\left[\left[\sum_{k=0}^{10} n_k - i + \left(\sum_{k=0}^{2} n_{2\cdot k+1} - \sum_{k=3}^{4} n_{2\cdot k+1}\right)\right] + 0.5\right]\cdot db\cdot deg\right] \end{bmatrix}$$

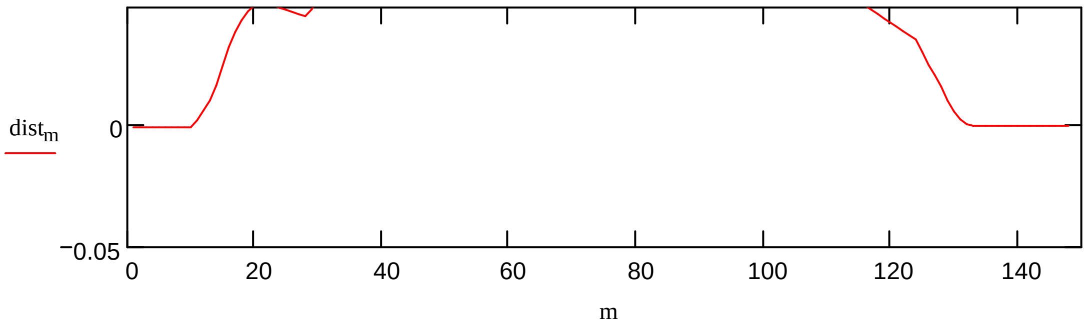
15 straight segments

$$i := \sum_{k=0}^{11} n_k + 1 .. \sum_{k=0}^{12} n_k \qquad n_{12} = 15.0000$$

$$realAp_i := realAp_{i-1} + 1.5\cdot\begin{bmatrix} 0 \\ -\sin\left[\left(\sum_{k=0}^{2} n_{2\cdot k+1} - \sum_{k=3}^{5} n_{2\cdot k+1}\right)\cdot db\cdot deg\right] \\ \cos\left[\left(\sum_{k=0}^{2} n_{2\cdot k+1} - \sum_{k=3}^{5} n_{2\cdot k+1}\right)\cdot db\cdot deg\right] \end{bmatrix}$$

$$m := 1 .. \sum_{k=0}^{12} n_k$$

$$dist_m := \left(realAp_m\right)_1 - idealLine\left[\left(realAp_m\right)_2\right]$$



$$\left(\sum_{k=0}^{5} n_k + \frac{n_6}{2}\right) = 76.0000 \qquad dist_{76} = 0.2098 \qquad \frac{CL2\_LA_2 - CL1\_LA_2}{1.5} = 63.7000$$

$$\sum_{k=1}^{11} n_k = 118.0000 \qquad \frac{(dipol_8)_2 - (dipol_1)_2 + bend_5}{1.5} = 117.0968$$

TOL := 0.0000001

Parameter Definition for the fan distribution:

CAUTION: changing the values of the parameters requires a careful check of all positions, as the handling of some conditions is not automated.

according to W. Decking (June 2005)

length of bend between undulators: B_D2 := 58.4

undulator length:

sase1Length := 201.3

sase2Length := 256.2

sase3Length := 134.2

spontLength := 59.9

tunnel radius

radiusLTunnel := 2.7

radiusETunnel := 2.25

shaft side lengths

	rw_XS1 := 11.5	lw_XS1 := 9.5
	rw_XS2 := 8.7	lw_XS2 := 8.95
	rw_XS3 := 9.09	lw_XS3 := 8.26
	rw_XS4 := 9.05	lw_XS4 := 8.45
L_XS5 := 38	rw_XS5 := 9	lw_XS5 := 8

minimum separation between tunnels	$\text{separat} := 1$
tunnel wall thickness	$\text{tunnelWall} := 0.3$
shaft wall thickness (including excavation wall)	$\text{shaft\_wall} := 2$
angular increment (in some cases it is doubled)	$\Delta\alpha := 0.05 \cdot \text{deg}$
minimum radius of tunnel curvature	$\frac{\text{tubbingLength}}{\Delta\alpha} = 1718.8734$
distance between beam in the undulator and the tunnel axis	$\text{smallHorAxisUnd} := 1.25$
	$\text{largeHorAxisUnd} := 1.6$
distance between photonbeam and the tunnel axis	$\text{horAxisPhotEnd} := 0.5$
safety margin shaft rear wall - undulator start	$\text{safeDist} := 10$
minimal separation between electron beam and tunnel	$\text{gapElectron} := 0.5$
minimal separation between photon beam and tunnel	$\text{gapPhoton} := 0.3$
standard beam height	$\text{vertAxis} := -0.11$
length of dump hall:	$\text{dumpLength} := 23.5$
distance between the last undulator and the entrance wall of the dump hall	$\text{driftDump} := 39.5$

The angles of the beams are fixed, according to the design for the PFV

angle between P1 and P4 $\text{p1\_}\alpha := 2.28586 \cdot \text{deg}$

angle between P2 and P4 $p2\_\alpha := 1.720855 \cdot deg$

angle between P3 and P4 $p3\_\alpha := -0.221355 \cdot deg$

angle between P5 and P4 $p5\_\alpha := -1.318245 \cdot deg$

angle between P6 and P4 $p6\_\alpha := -4.10082 \cdot deg$

angle between P9 and P4 $p9\_\alpha := -6.58553 \cdot deg$

$$rt := \frac{tubbingLength}{\Delta\alpha}$$

transport way width: $tw := 0.1 + 1.4 + 0.1$

General remarks

The nomenclature is standardized and follows the corresponding Java-code:
Beams are denoted by pn. Their starting point is pn_start, their angle to z is pn_α etc.
For all tunnels we assume three or more sections: xtn_s1, xtn_s2, xtn_s3 etc.
All shafts (except XS1) are oriented parallel to the axis of the incoming tunnel. The outgoing tunnels start in such a way that they are parallel to the corresponding beam and the undulator can start immediately (after a certain safety distance from the shaft). The end of a shaft is defined by the requirement that the outgoing tunnels are perpendicular to the wall and are separated by 1.7m to install the shielding wall. So the circumference of a shaft is a polygon.

Due to the small angles between the beams the bending is assumed to be a sharp kink and the length of the bending is taken on straight rather than on bent lines

The end of the LINAC tunnel (XLT) houses switches for SASE2, the commissioning dump and the second phase.
Here we are interested in the projection to the s,t-plane, only.

After the PFU are finished the layout of the beams is fixed and the shaft buildings are elaborated to a detail that changes should be kept to a minimum.

Beam Layout:

P4:

$$p4\_start := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \qquad p4\_end := \begin{pmatrix} 0 \\ 0 \\ PD\_Length \end{pmatrix} \qquad p4\_\alpha := 0$$

$$p4\_dir := dirHor(p4\_\alpha) \qquad p4\_normal := normHor(p4\_\alpha) \qquad p4\_line := linePP(p4\_start, p4\_end)$$

for a consistent design we have to fix the inclination of the experimental hall by the angles α1 and α5

$$hall\_\alpha := \frac{p1\_\alpha + p5\_\alpha}{2} \qquad \frac{hall\_\alpha}{deg} = 0.483808$$

$$hall\_dir := dirHor(hall\_\alpha)$$

$$hall\_frontPlane := planePR(p4\_end, hall\_dir)$$

$$hall\_normal := normHor(hall\_\alpha)$$

P1:

$$p1\_end := p4\_end + 3 \cdot 17 \cdot hall\_normal \qquad p1\_dir := dirHor(p1\_\alpha) \qquad p1\_normal := normHor(p1\_\alpha)$$

$$p1\_line := linePR(p1\_end, p1\_dir)$$

$$p1\_start := intersectLL(p4\_line, p1\_line)$$

P5:

$$p5\_end := p4\_end - 17 \cdot hall\_normal \qquad p5\_dir := dirHor(p5\_\alpha) \qquad p5\_normal := normHor(p5\_\alpha)$$

$$p5\_line := linePR(p5\_end, p5\_dir)$$

$$p5\_start := intersectLL(p4\_line, p5\_line)$$

P3:

$$p3\_end := p4\_end + 17 \cdot hall\_normal \qquad p3\_dir := dirHor(p3\_\alpha) \qquad p3\_normal := normHor(p3\_\alpha)$$

$$p3\_line := linePR(p3\_end, p3\_dir)$$

$$p3\_start := intersectLL(p1\_line, p3\_line)$$

P2: $p2\_end := p4\_end + 2 \cdot 17 \cdot hall\_normal$ $p2\_dir := dirHor(p2\_\alpha)$ $p2\_normal := normHor(p2\_\alpha)$

$p2\_line := linePR(p2\_end, p2\_dir)$

$p2\_start := intersectLL(p3\_line, p2\_line)$

P9 is defined by a point on P9 from W.Decking's list:

$$p\_LA := \begin{pmatrix} -3.0994 \\ -2.4872 \\ 2112.7402 \end{pmatrix} \qquad p9\_dir := dirHor(p9\_\alpha)$$

$p9\_line := linePR(LAtoPD(p\_LA), p9\_dir)$

$p9\_start := intersectLL(p4\_line, p9\_line)$

All beams are fixed now

Each tunnel axis starts at the same height $axisBegin := \begin{pmatrix} 0 \\ vertAxis \\ 0 \end{pmatrix}$

The position of each shaft is fixed, the separation of each beam to the tunnel wall is checked

shaft XS1:

The tunnel XTL is parallel to the z-axis of the LA-system, so that the fan plane intersects the end of

XTL a few cm below 90cm

We ignore the small horizontal inclination of XTL (0.3º -> 3.0cm/5.8m) and orientate XS1 parallel to P4

orientation of the shaft parallel to P4:

$xs1\_dir := p4\_dir$ $\quad xs1\_normal := p4\_normal$

$xs1\_\alpha := p4\_\alpha$

frontwall of XS1

$$xs1\_start := \begin{pmatrix} -0.0967 \\ -0.8210 \\ 105.732 \end{pmatrix}$$

$$xs1\_frontplane := planePR(xs1\_start, p4\_dir)$$

The deviation towards P9 is not yet finished, we have to consider an intermediate beam

Fehler y=0!

$$dipol2\_LA := \begin{pmatrix} -0.6320 \\ -2.4774 \\ 2085.8552 \end{pmatrix} \quad LAtoPD(dipol2\_LA) = \begin{pmatrix} -0.6320 \\ -0.0054 \\ 91.3632 \end{pmatrix}$$

$$dipol3\_LA := \begin{pmatrix} -2.8795 \\ -2.4864 \\ 2110.7523 \end{pmatrix} \quad LAtoPD(dipol3\_LA) = \begin{pmatrix} -2.8795 \\ -0.0054 \\ 116.2603 \end{pmatrix}$$

$$intermediate := linePP(LAtoPD(dipol2\_LA), LAtoPD(dipol3\_LA))$$

$$radiusLTunnel - \left|intersectPL(xs1\_frontplane, intermediate) - xs1\_start\right| = 0.6943$$

$$radiusLTunnel - \left|intersectPL(xs1\_frontplane, p1\_line) - xs1\_start\right| = 0.6330$$

all three tunnels (XTD1, XTD2 and XTD20) leave perpendicularly to the backside of XS1 (polygon)

The shaft XS1 should end, when the separation between the outside of XTD1 and XTD2 have the value 1.7m to start the shielding wall

$$line\_t1\_right := parallelHor(p1\_line, largeHorAxisUnd - radiusLTunnel - tunnelWall)$$

$$line\_t2\_left := parallelHor(p4\_line, radiusLTunnel - largeHorAxisUnd + tunnelWall)$$

$$xs1\_shield\_start\_12 := ShaftEnd(line\_t1\_right, line\_t2\_left, 1.7)$$

$$xs1\_shield\_start\_12 = \begin{pmatrix} 2.2502 \\ 0.0000 \\ 173.4115 \end{pmatrix}$$

Correct for the wall thickness

$$xs1\_shield\_start\_12_2 - xs1\_start_2 - 1.5 = 66.1795$$

$$xs1\_t2\_plane := parallelHorP\left(xs1\_frontplane, xs1\_shield\_start\_12_2 - xs1\_start_2 - 1.5\right)$$

We can calculate the length of the external shielding wall

$$d := 3$$

$$xs1\_shield\_end\_12 := ShaftEnd(line\_t1\_right, line\_t2\_left, d)$$

$$xs1\_shield\_end\_12 = \begin{pmatrix} 2.9003 \\ 0.0000 \\ 205.9921 \end{pmatrix}$$

$$\left|xs1\_shield\_end\_12 - xs1\_shield\_start\_12\right| = 32.5871$$

construct the corner between XTD1 and XTD2 on the bisecting line

$$c12 := xs1\_shield\_start\_12 - 1.5 \cdot dirHor\left(\frac{p1\_\alpha + p4\_\alpha}{2}\right)$$

$$xs1\_t1\_plane := planePR(c12, p1\_dir) \qquad c12 = \begin{pmatrix} 2.2202 \\ 0.0000 \\ 171.9118 \end{pmatrix}$$

position of XS5 and XTD20

$$xs5\_start := \begin{pmatrix} -14.7842 \\ -0.35 \\ 227.4739 \end{pmatrix} \qquad xt20\_end := xs5\_start$$ fixed by IG, taken from drawing

$$xs5\_c3 := \begin{pmatrix} -8.706 \\ -0.35 \\ 227.996 \end{pmatrix} \qquad xs5\_c2 := \begin{pmatrix} -23.153 \\ -0.35 \\ 226.753 \end{pmatrix}$$

orientation of XS5 perpendicular to xs5_c3 and xs5_c2

$$line\_f\_xs5 := linePP(xs5\_c3, xs5\_c2)$$

$$xs5\_\alpha := -\left[\frac{\pi}{2} - atan\left[\frac{\left(line\_f\_xs5_1\right)_0}{\left(line\_f\_xs5_1\right)_2}\right]\right] \qquad \frac{xs5\_\alpha}{deg} = -4.9175$$

$$xt20\_dir := dirHor(xs5\_\alpha) \qquad xt20\_s1\_line := linePR(xt20\_end, xt20\_dir) \qquad xt20\_\alpha := xs5\_\alpha$$

backside for XTD20

$line\_t2\_right := parallelHor(p4\_line, -radiusLTunnel - largeHorAxisUnd - tunnelWall)$

$line\_t20\_left := parallelHor(xt20\_s1\_line, radiusETunnel + tunnelWall)$

bisecting line

$line\_bs := linePR(intersectLL(line\_t2\_right, line\_t20\_left), bidirHor(0, xt20\_\alpha))$

$c220 := intersectPL(xs1\_t2\_plane, line\_bs)$ $\quad c220 = \begin{pmatrix} -6.0195 \\ 0.0000 \\ 171.9115 \end{pmatrix}$

$xs1\_t20\_plane := planePR(c220, dirHor(xs5\_\alpha))$

$plane\_s1\_t2\_out := parallelHorP(xs1\_t2\_plane, 1.5)$

$plane\_s1\_t20\_out := parallelHorP(xs1\_t20\_plane, 1.5)$

$xs1\_shield\_start\_220 := intersectPP(plane\_s1\_t2\_out, plane\_s1\_t20\_out, 0)$

$xs1\_shield\_start\_220 = \begin{pmatrix} -6.0839 \\ 0.0000 \\ 173.4115 \end{pmatrix}$

$xs1\_shield\_end\_220 := ShaftEnd(line\_t2\_right, line\_t20\_left, 3)$ $\quad xs1\_shield\_end\_220 = \begin{pmatrix} -6.0986 \\ 0.0000 \\ 173.7860 \end{pmatrix}$

$xs1\_shield\_220 := |xs1\_shield\_start\_220 - xs1\_shield\_end\_220|$ $\quad xs1\_shield\_220 = 0.3747$

incoming tunnel XTL

horizontal bending of the end of the LINAC tunnel (assuming the electron beam arrives 81cm above the axis and 20cm to the right) :

$$xt0\_start := \begin{pmatrix} 0.2 \\ xs1\_start_1 - xs1\_start_2 \cdot \sin(\alpha_k) \\ 0 \end{pmatrix} \qquad xt0\_end := xs1\_start \quad b\_t0 := \begin{pmatrix} 0.2 \\ xt0\_start_1 + 50 \cdot \sin(\alpha_k) \\ 50 \end{pmatrix}$$

$$xt0\_s1\_line := linePP(xt0\_start, b\_t0) \qquad xt0\_s3\_line := linePP(b\_t0, xt0\_end)$$

outgoing tunnels XDT1, XDT2 and XTD20

$$xt2\_start := intersectPL(xs1\_t2\_plane, parallelHor(p4\_line, -largeHorAxisUnd)) + axisBegin$$

$$xt2\_s1\_line := linePR(xt2\_start, p4\_dir)$$

$$xt2\_\alpha := p4\_\alpha$$

$$xt2\_start = \begin{pmatrix} -1.6000 \\ -0.1100 \\ 171.9115 \end{pmatrix}$$

$$xt1\_start := intersectPL(xs1\_t1\_plane, parallelHor(p1\_line, largeHorAxisUnd)) + axisBegin$$

$$xt1\_s1\_line := linePR(xt1\_start, p1\_dir)$$

$$xt1\_\alpha := p1\_\alpha$$

$$xt1\_start = \begin{pmatrix} 6.0371 \\ -0.1100 \\ 171.7595 \end{pmatrix}$$

$$xt20\_start := intersectPL(xs1\_t20\_plane, xt20\_s1\_line) \qquad xt20\_start = \begin{pmatrix} -9.9744 \\ -0.3500 \\ 171.5713 \end{pmatrix}$$

The position of **SASE1** can also be calculated

$$s1\_start := intersectPL(parallelHorP(xs1\_t2\_plane, safeDist), p4\_line) \quad s1\_start = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 181.9115 \end{pmatrix}$$

$s1\_end := s1\_start + sase1Length \cdot p4\_dir$

$$s1\_end = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 383.2115 \end{pmatrix}$$

$L1\_opt := p5\_start \cdot p4\_dir - s1\_end \cdot p4\_dir - \frac{B\_D2}{2}$

$s1\_opt := s1\_end + L1\_opt \cdot p4\_dir$

$L1\_opt = 187.6762$

The position of **SASE2** can also be calculated

$s2\_start := intersectPL(parallelHorP(xs1\_t1\_plane, safeDist), p1\_line)$ $\quad s2\_start = \begin{pmatrix} 4.8372 \\ 0.0000 \\ 181.8153 \end{pmatrix}$

$s2\_end := s2\_start + sase2Length \cdot p1\_dir$

$$s2\_end = \begin{pmatrix} 15.0558 \\ 0.0000 \\ 437.8115 \end{pmatrix}$$

$L2\_opt := (p3\_start - s2\_end) \cdot p1\_dir - \frac{B\_D2}{2}$

$s2\_opt := s2\_end + L2\_opt \cdot p1\_dir$ $\quad L2\_opt = 94.7756$

crossing at the end of XTD1: transportation way 1.6m crossing photon beam

$xt1\_cross := intersectLL[parallelHor[p3\_line, (tw + gapElectron + gapPhoton)], p1\_line]$

$$xt1\_cross = \begin{pmatrix} 22.1889 \\ 0.0000 \\ 616.5079 \end{pmatrix}$$

horizontal deviation $\quad distancePL(xt1\_cross, xt1\_s1\_line) = 1.6038$

vertical deviation $\quad \sqrt{2.6^2 - tw^2} - 2.3 + 0.01 = -0.2406$

crossing at the end of XTD2: transportation way 1.6m crossing electron beam

$$xt2\_cross := intersectLL[parallelHor[p4\_line, -(tw + gapElectron + gapPhoton)], p5\_line]$$

$$xt2\_cross = \begin{pmatrix} -2.4000 \\ 0.0000 \\ 704.3821 \end{pmatrix}$$

horizontal deviation $distancePL(xt1\_cross, xt1\_s1\_line) = 1.6038$

vertical deviation $\sqrt{2.6^2 - tw^2} - 2.3 + 0.01 = -0.2406$

shaft XS2:

$$xs2\_dir := p3\_dir \qquad xs2\_\alpha := p3\_\alpha \qquad \frac{xs2\_\alpha}{deg} = -0.2214$$

$$xs2\_start := \begin{pmatrix} 21.7742 \\ -0.11 \\ 646.183 \end{pmatrix}$$

Plane for front side $xs2\_frontPlane := planePR(xs2\_start, xs2\_dir)$

$$xs2\_c3 := \begin{pmatrix} 21.2496 \\ -0.156 \\ 678.4340 \end{pmatrix}$$ from IG

$$xs2\_t6\_plane := planePR(xs2\_c3, p1\_dir)$$

$$xs2\_t3\_plane := planePR(xs2\_c3, p3\_dir)$$

incoming tunnel XDT1

$$xs2hor := horCompP(xs2\_start) - \begin{pmatrix} 0. \\ 0.11 \\ 0. \end{pmatrix}$$

$$xt1\_end := xs2\_start$$

$$xt1\_s3\_line := linePP(p3\_start + largeHorAxisUnd \cdot p1\_normal + axisBegin, xs2hor)$$

outgoing tunnels XDT3 and XDT6

$$xt3\_start := intersectPL(xs2\_t3\_plane, parallelHor(p3\_line, -smallHorAxisUnd)) + axisBegin$$

$$xt3\_s1\_line := linePR(xt3\_start, p3\_dir)$$

$$xt3\_start = \begin{pmatrix} 18.2996 \\ -0.1100 \\ 678.4226 \end{pmatrix}$$

$$xt3\_\alpha := p3\_\alpha$$

first section of XDT6

$$xt6\_start := intersectPL(xs2\_t6\_plane, parallelHor(p1\_line, smallHorAxisUnd)) + axisBegin$$

$$xt6\_\alpha := p1\_\alpha$$

$$xt6\_start = \begin{pmatrix} 25.9043 \\ -0.1100 \\ 678.2482 \end{pmatrix}$$

$$xt6\_s1\_line := linePR(xt6\_start, p1\_dir)$$

finishing XTD6 , back to horAxisPhotEnd at the experimental hall, bend 100m before the hall:

$$xt6\_end := p1\_end + horAxisPhotEnd \cdot hall\_normal + axisBegin$$

$$xt6\_s3\_line := linePP(p1\_end - 100 \cdot p1\_dir + smallHorAxisUnd \cdot p1\_normal, xt6\_end)$$

$$b\_t6 := intersectLL(xt6\_s1\_line, xt6\_s3\_line)$$

$$b\_t6 = \begin{pmatrix} 48.3426 \\ -0.1100 \\ 1240.3722 \end{pmatrix}$$

The position of **U1** can also be calculated

$$u1\_start := intersectPL(parallelHorP(xs2\_t3\_plane, safeDist), p3\_line)$$

$$u1\_end := u1\_start + p3\_dir \cdot spontLength$$

$$u1\_start = \begin{pmatrix} 19.5110 \\ 0.0000 \\ 688.4274 \end{pmatrix}$$

$$LU1\_opt := (p2\_start - u1\_end) \cdot p3\_dir - \frac{B\_D2}{2} \qquad LU1\_opt = 59.5197$$

$$u1\_end = \begin{pmatrix} 19.2796 \\ 0.0000 \\ 748.3269 \end{pmatrix}$$

$$u1\_opt := u1\_end + LU1\_opt \cdot p1\_dir$$

Finding the position of shaft XS4:

A point on the axis of the incoming tunnel XTD3

$b\_t3 := p2\_start - smallHorAxisUnd \cdot p3\_normal + axisBegin$

$b\_t3 = \begin{pmatrix} 17.6868 \\ -0.1100 \\ 837.0411 \end{pmatrix}$

orientation of the shaft (old value):

$xs4\_\alpha := 1.4576 \cdot deg$

$xs4\_dir := dirHor(xs4\_\alpha)$

The start of shaft XS4 is

$xs4\_start := \begin{pmatrix} 20.4074 \\ -0.11 \\ 941.3923 \end{pmatrix}$

$xAt(p3\_line, 941.3923) = 18.5337$

$xs4\_start - p2\_start = \begin{pmatrix} 1.4706 \\ -0.1100 \\ 104.3464 \end{pmatrix}$

Plane for front side

$plane\_s4\_f := planePR(xs1\_start, dirHor(p3\_\alpha))$

Given is the corner in the fan-system

$xs4\_c3 := \begin{pmatrix} 20.4112 \\ -0.54 \\ 973.8952 \end{pmatrix}$

$xs4\_t5\_plane := planePR(xs4\_c3, p2\_dir)$

$xs4\_t8\_plane := planePR(xs4\_c3, p3\_dir)$

incoming tunnel XDT3

$xt3\_s3\_line := linePP(b\_t3, xs4\_start)$

$xt3\_end := xs4\_start$

outgoing tunnels XDT5 and XDT8

first section of XDT5

$xt5\_s1\_line := fSLine(p2\_line, smallHorAxisUnd, -.11)$

$xt5\_start := intersectPL(xs4\_t5\_plane, xt5\_s1\_line)$

$xt5\_\alpha := p2\_\alpha$

$$xt5\_start = \begin{pmatrix} 24.2953 \\ -0.1100 \\ 973.7785 \end{pmatrix}$$

first section of XDT8

$xt8\_s1\_line := fSLine(p3\_line, -smallHorAxisUnd, vertAxis)$

$xt8\_\alpha := p3\_\alpha$

$xt8\_start := intersectPL(xs4\_t8\_plane, xt8\_s1\_line)$

$$xt8\_start = \begin{pmatrix} 17.1581 \\ -0.1100 \\ 973.8826 \end{pmatrix}$$

finish **XTD8**

$xt8\_end := p3\_end - horAxisPhotEnd \cdot p3\_normal + axisBegin$

$xt8\_s3\_line := linePP(p3\_end - 100 \cdot p3\_dir - smallHorAxisUnd \cdot p3\_normal, xt8\_end)$

$b\_t8 := intersectLL(xt8\_s1\_line, xt8\_s3\_line)$

$$b\_t8 = \begin{pmatrix} 16.1276 \\ -0.1100 \\ 1240.6282 \end{pmatrix}$$

The position of **U2** can also be calculated

$u2\_start := intersectPL(parallelHorP(xs4\_t5\_plane, safeDist), p2\_line)$

$$u2\_start = \begin{pmatrix} 23.3462 \\ 0.0000 \\ 983.8115 \end{pmatrix}$$

$u2\_end := u2\_start + p2\_dir \cdot spontLength$

$LU2\_opt := 90$

$u2\_opt := u2\_end + LU2\_opt \cdot p2\_dir$

The position of the dump **XHDU1** should be fixed to avoid the HEW-Trasse
CAUTION: the dump doesn't start on the beam!

$corrhor := 0.2869$

$p2\_spec := parallelHor(p2\_line, corrhor)$

$xd1\_beam := u2\_opt + (driftDump + 4.77) \cdot p2\_dir$ $\qquad xd1\_beam = \begin{pmatrix} 29.1771 \\ 0.0000 \\ 1177.8940 \end{pmatrix}$

$xd1\_frontPlane := planePR(xd1\_beam, p2\_dir)$

$$xd1\_start := intersectPL(xd1\_frontPlane, p2\_spec) - 0.396 \cdot \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

$xd1\_end := xd1\_start + dumpLength \cdot p2\_dir$

$xd1\_end\_beam := xd1\_beam + dumpLength \cdot p2\_dir$ $\qquad xd1\_start = \begin{pmatrix} 29.4639 \\ -0.3960 \\ 1177.8853 \end{pmatrix}$

$|xd1\_start - u2\_opt| = 44.2727$

dumped beam: $\quad sben\_end := LAtoPD\left(\begin{pmatrix} 29.1559 \\ -4.7696 \\ 3171.6737 \end{pmatrix}\right) \qquad quad\_end := LAtoPD\left(\begin{pmatrix} 29.3038 \\ -5.6397 \\ 3176.5952 \end{pmatrix}\right)$

$dump\_line := linePP(sben\_end, quad\_end) \qquad yAt(dump\_line, xd1\_start_2) = -2.0252$

The incoming tunnel **XDT5** is curved (vertical bend see below)

$xt5\_s3\_line := linePP(u2\_opt + smallHorAxisUnd \cdot p2\_normal, xd1\_start)$ $\qquad xt5\_end := xd1\_start$

$b\_t5 := intersectLL(xt5\_s1\_line, xt5\_s3\_line)$ $\qquad b\_t5 = \begin{pmatrix} 29.1505 \\ -0.1100 \\ 1135.3839 \end{pmatrix}$

$$xt7\_start := (xd1\_end\_beam + horAxisPhotEnd \cdot p2\_normal) + vertAxis \cdot \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \quad xt7\_start = \begin{pmatrix} 30.3826 \\ -0.1100 \\ 1201.3683 \end{pmatrix}$$

$$xt7\_\alpha := p2\_\alpha$$

$$xt7\_end := intersectPL(hall\_frontPlane, parallelHor(p2\_line, horAxisPhotEnd)) + vertAxis \cdot \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

Back to the other branch

Finding the position of shaft XS3:

$xs3\_dir := p4\_dir$ $xs3\_\alpha := p4\_\alpha$

orientation of the shaft
parallel to P4

The start of shaft XS3 is

$$xs3\_start := \begin{pmatrix} -1.6 \\ -0.11 \\ 760.8692 \end{pmatrix}$$

Plane for front side

$$xs3\_frontPlane := planePR(xs3\_start, p4\_dir)$$

Given is the corner in the shaft-system

$$c3\_txs3 := \begin{pmatrix} -0.399 \\ 0 \\ 32.45 \end{pmatrix}$$

Transformation into fan-system

$$xs3\_c3 := c3\_txs3 + xs3\_start \qquad xs3\_c3 = \begin{pmatrix} -1.9990 \\ -0.1100 \\ 793.3192 \end{pmatrix}$$

$$xs3\_t9\_plane := planePR(xs3\_c3, p4\_dir)$$

$$xs3\_t4\_plane := planePR(xs3\_c3, p5\_dir)$$

Now we can complete **XDT2**

$xt2\_end := xs3\_start$

Outgoing tunnels **XDT4** and **XDT9**

first section of XDT4

$xt4\_s1\_line := fSLine(p5\_line, -smallHorAxisUnd, vertAxis)$

$xt4\_start := intersectPL(xs3\_t4\_plane, xt4\_s1\_line)$

$xt4\_start = \begin{pmatrix} -5.6950 \\ -0.1100 \\ 793.2341 \end{pmatrix}$

$xt4\_\alpha := p5\_\alpha$

we can complete **XDT9**

$xt9\_start := intersectPL(xs3\_t9\_plane, parallelHor(p4\_line, smallHorAxisUnd)) + axisBegin$

$xt9\_s1\_line := linePR(xt9\_start, p4\_dir)$

$xt9\_\alpha := p4\_\alpha$

finishing XTD9 , back to horAxisPhotEnd at the experimental hall, bend 100m before the hall:

$xt9\_end := intersectPL(hall\_frontPlane, parallelHor(p4\_line, horAxisPhotEnd)) + axisBegin$

$xt9\_s3\_line := linePP(p4\_end - 100 \cdot p4\_dir + smallHorAxisUnd \cdot p4\_normal + axisBegin, xt9\_end)$

$b\_t9 := intersectLL(xt9\_s1\_line, xt9\_s3\_line)$

$b\_t9 = \begin{pmatrix} 1.2500 \\ -0.1100 \\ 1238.6700 \end{pmatrix}$

The position of **SASE3** is

$$s3\_start := intersectPL(parallelHorP(xs3\_t4\_plane, safeDist), p5\_line)$$

$$s3\_end := s3\_start + sase3Length \cdot p5\_dir \qquad s3\_start = \begin{pmatrix} -4.6754 \\ 0.0000 \\ 803.2603 \end{pmatrix}$$

$$L3\_opt := 117.5$$

$$s3\_opt := s3\_end + L3\_opt \cdot p5\_dir \qquad s3\_opt = \begin{pmatrix} -10.4659 \\ 0.0000 \\ 1054.8936 \end{pmatrix}$$

The entrance of beam P5 in the dump **XHDU2** is at

The separation between beam and tunnel axis makes a parallel line to the beam necessary

$$p5\_spec := parallelHor(p5\_line, -corrhor)$$

$$xd2\_beam := s3\_opt + driftDump \cdot p5\_dir \qquad xd2\_beam = \begin{pmatrix} -11.3746 \\ 0.0000 \\ 1094.3832 \end{pmatrix}$$

$$xd2\_frontPlane := planePR(xd2\_beam, p5\_dir)$$

$$xd2\_start := intersectPL(xd2\_frontPlane, p5\_spec) - 0.396 \cdot \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

$$xd2\_end := xd2\_start + dumpLength \cdot p5\_dir \qquad xd2\_start = \begin{pmatrix} -11.6614 \\ -0.3960 \\ 1094.3766 \end{pmatrix}$$

$$xd2\_end\_beam := xd2\_beam + dumpLength \cdot p5\_dir$$

The incoming tunnel **XDT4**

$$xd2\_beam = \begin{pmatrix} -11.3746 \\ 0.0000 \\ 1094.3832 \end{pmatrix}$$

$$xt4\_end := xd2\_start$$

$$xt4\_s3\_line := linePP(s3\_opt - smallHorAxisUnd \cdot p5\_normal + axisBegin, xt4\_end)$$

$b\_t4 := intersectLL(xt4\_s1\_line, xt4\_s3\_line)$

$$b\_t4 = \begin{pmatrix} -11.7156 \\ -0.1100 \\ 1054.8649 \end{pmatrix}$$

The outgoing tunnel **XDT10**

$xt10\_start := xd2\_end\_beam - p5\_normal \cdot horAxisPhotEnd$

$xt10\_\alpha := p5\_\alpha$

$xt10\_end := intersectPL(hall\_frontPlane, parallelHor(p5\_line, -horAxisPhotEnd)) + axisBegin$

$$xt10\_end = \begin{pmatrix} -17.4996 \\ -0.1100 \\ 1338.8178 \end{pmatrix}$$

Tunnel bending

XTL

$bent := CurveHor(xt0\_s1\_line, xt0\_s3\_line, xs1\_start, \Delta\alpha, rt)$

$$xt0\_s2\_start := \begin{pmatrix} bent_0 \\ xt0\_start_1 + bent_1 \cdot \alpha_k \\ bent_1 \end{pmatrix} \quad xt0\_s3\_start := \begin{pmatrix} bent_2 \\ xt0\_start_1 + bent_3 \cdot \alpha_k \\ bent_3 \end{pmatrix} \quad bent = \begin{pmatrix} 0.2000 \\ 44.5670 \\ 0.1764 \\ 53.5669 \\ -0.0052 \end{pmatrix}$$

$xt0\_s2\_\alpha := bent_4$

XTD1

$bent := CurveHor(xt1\_s1\_line, xt1\_s3\_line, horCompP(xs2\_start), \Delta\alpha, rt)$

$$xt1\_s2\_start := \begin{pmatrix} bent_0 \\ xt1\_start_1 \\ bent_1 \end{pmatrix} \qquad xt1\_s3\_start := \begin{pmatrix} bent_2 \\ xt1\_start_1 \\ bent_3 \end{pmatrix} \qquad bent = \begin{pmatrix} 20.2856 \\ 528.7131 \\ 21.6486 \\ 593.1949 \\ -0.0375 \end{pmatrix}$$

$$xt1\_s2\_\alpha := bent_4$$

Querung P1

$$intersectLL(xt1\_s3\_line, p1\_line) = \begin{pmatrix} 21.6868 \\ -0.1100 \\ 603.9313 \end{pmatrix}$$

XTD2

Querung P5

$$intersectLL(xt2\_s1\_line, p5\_line) = \begin{pmatrix} -1.6000 \\ -0.1100 \\ 669.6173 \end{pmatrix}$$

XTD3

$$bent := CurveHor(xt3\_s1\_line, xt3\_s3\_line, horCompP(xs4\_start), \Delta\alpha, rt)$$

$$xt3\_s2\_start := \begin{pmatrix} bent_0 \\ xt3\_start_1 \\ bent_1 \end{pmatrix} \qquad xt3\_s3\_start := \begin{pmatrix} bent_2 \\ xt3\_start_1 \\ bent_3 \end{pmatrix} \qquad bent = \begin{pmatrix} 17.7889 \\ 810.6307 \\ 18.3484 \\ 861.6258 \\ 0.0297 \end{pmatrix}$$

$$xt3\_s2\_\alpha := bent_4$$

Querung P3

$$\frac{xt3\_s2\_\alpha}{deg} = 1.7000$$

$$intersectLL(xt3\_s3\_line, p3\_line) = \begin{pmatrix} 18.7755 \\ -0.1100 \\ 878.7989 \end{pmatrix}$$

XTD4 (in front of a dump)

$$xt4\_s2\_\alpha := 1.8 \cdot deg \qquad sa := \sin(xt4\_s2\_\alpha) \qquad ca := \cos(xt4\_s2\_\alpha)$$

$$ve := 0.286 \qquad he := 1.25 - corrhor$$

$$re := \sqrt{ve^2 + he^2} \qquad re = 1.0047 \qquad he = 0.9631$$

$$\beta t4 := -\operatorname{atan}\left(\frac{ve}{he}\right) \qquad \frac{\beta t4}{deg} = -16.5392$$

$$L2\_4 := \frac{re - \frac{rt}{2} \cdot (1 - ca)}{sa} \qquad L2\_4 = 18.4837$$

$$L1\_4 := 301.20 - \frac{rt}{2} \cdot sa - L2\_4 \cdot ca \qquad L1\_4 = 255.7298$$

$$anf1 := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \qquad end1 := \begin{pmatrix} 0 \\ 0 \\ L1\_4 \end{pmatrix}$$

$$anf2 := \begin{bmatrix} \frac{rt}{2}\cdot(1 - ca) \\ 0 \\ L1\_4 + \frac{rt}{2}\cdot sa \end{bmatrix} \qquad end2 := anf2 + L2\_4\cdot\begin{pmatrix} sa \\ 0 \\ ca \end{pmatrix}$$

$$anf2 = \begin{pmatrix} 0.4241 \\ 0.0000 \\ 282.7254 \end{pmatrix} \qquad end2 = \begin{pmatrix} 1.0047 \\ 0.0000 \\ 301.2000 \end{pmatrix}$$

$$\frac{\beta t4}{deg} = -16.5392 \qquad B := \begin{pmatrix} \cos(\beta t4) & -\sin(\beta t4) & 0 \\ \sin(\beta t4) & \cos(\beta t4) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\gamma := p5\_\alpha$$

$$A := \begin{pmatrix} \cos(\gamma) & 0 & \sin(\gamma) \\ 0 & 1 & 0 \\ -\sin(\gamma) & 0 & \cos(\gamma) \end{pmatrix} \qquad xs3\_start = \begin{pmatrix} -1.6000 \\ -0.1100 \\ 760.8692 \end{pmatrix}$$

$$A \cdot B \cdot anf1 + xt4\_start = \begin{pmatrix} -5.6950 \\ -0.1100 \\ 793.2341 \end{pmatrix}$$ $$abog := A \cdot B \cdot end1 + xt4\_start$$ $$xt4\_s2\_start := abog$$

$$ebog := A \cdot B \cdot anf2 + xt4\_start$$ $$ziel := A \cdot B \cdot end2 + xt4\_start$$

$$xt4\_s3\_start := ebog$$

minimize the difference $\left|ziel - xd2\_start\right| = 0.0000$

$$xd2\_start = \begin{pmatrix} -11.6614 \\ -0.3960 \\ 1094.3766 \end{pmatrix} \qquad ziel = \begin{pmatrix} -11.6614 \\ -0.3960 \\ 1094.3766 \end{pmatrix}$$

$$\frac{ebog_2 + abog_2}{2} - xt4\_start_2 = 269.1610$$

XTD5 (in front of a dump, mirror image of XTD4)

$$xt5\_s2\_\alpha := -xt4\_s2\_\alpha \qquad \beta t5 := -\beta t4 \qquad \left|xt5\_end - xt5\_start\right| = 204.1725$$

$$L2\_5 := L2\_4 \qquad L1\_5 := \left|xt5\_end - xt5\_start\right| - \frac{rt}{2} \cdot sa - L2\_4 \cdot ca - 0.0025 \qquad L1\_5 = 158.6998$$

$$anf1 := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \qquad end1 := \begin{pmatrix} 0 \\ 0 \\ L1\_5 \end{pmatrix}$$

$$anf2 := \begin{bmatrix} \frac{-rt}{2}\cdot(1 - ca) \\ 0 \\ L1\_5 + \frac{rt}{2}\cdot sa \end{bmatrix} \qquad end2 := anf2 + L2\_5\cdot\begin{pmatrix} -sa \\ 0 \\ ca \end{pmatrix} \qquad anf2 = \begin{pmatrix} -0.4241 \\ 0.0000 \\ 185.6954 \end{pmatrix}$$

$$end2 = \begin{pmatrix} -1.0047 \\ 0.0000 \\ 204.1700 \end{pmatrix}$$

$$\frac{\beta t5}{deg} = 16.5392 \qquad B := \begin{pmatrix} \cos(\beta t5) & -\sin(\beta t5) & 0 \\ \sin(\beta t5) & \cos(\beta t5) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\gamma := p2\_\alpha$$

$$A := \begin{pmatrix} \cos(\gamma) & 0 & \sin(\gamma) \\ 0 & 1 & 0 \\ -\sin(\gamma) & 0 & \cos(\gamma) \end{pmatrix}$$

$$A\cdot B\cdot anf1 + xt5\_start = \begin{pmatrix} 24.2953 \\ -0.1100 \\ 973.7785 \end{pmatrix} \qquad abog := A\cdot B\cdot end1 + xt5\_start \qquad xt5\_s2\_start := abog$$

$$ebog := A\cdot B\cdot anf2 + xt5\_start \qquad ziel := (A\cdot B\cdot end2 + xt5\_start)$$

$xt5\_s3\_start := ebog$

$$abog = \begin{pmatrix} 29.0611 \\ -0.1100 \\ 1132.4067 \end{pmatrix} \qquad ebog = \begin{pmatrix} 29.4654 \\ -0.2307 \\ 1159.4023 \end{pmatrix}$$

minimize the difference $\quad \left| ziel - xd1\_start \right| = 0.0000$

$$xd1\_start = \begin{pmatrix} 29.4639 \\ -0.3960 \\ 1177.8853 \end{pmatrix} \qquad ziel = \begin{pmatrix} 29.4639 \\ -0.3960 \\ 1177.8853 \end{pmatrix}$$

$$\frac{ebog_2 + abog_2}{2} - xt5\_start_2 = 172.1260$$

XTD6

$$bent := CurveHor(xt6\_s1\_line, xt6\_s3\_line, horCompP(xt6\_end), \Delta\alpha, rt)$$

$$xt6\_s2\_start := \begin{pmatrix} bent_0 \\ xt6\_start_1 \\ bent_1 \end{pmatrix} \qquad xt6\_s3\_start := \begin{pmatrix} bent_2 \\ xt6\_start_1 \\ bent_3 \end{pmatrix} \qquad bent = \begin{pmatrix} 48.1687 \\ 1236.0141 \\ 48.6541 \\ 1249.5053 \\ -0.0079 \end{pmatrix}$$

$$xt6\_s2\_\alpha := bent_4$$

XTD7 is not curved

XTD8

$$bent := CurveHor\left(xt8\_s1\_line, horCompL(xt8\_s3\_line), horCompP(xt8\_end), \Delta\alpha, rt\right)$$

$$xt8\_s2\_start := \begin{pmatrix} bent_0 \\ xt8\_start_1 \\ bent_1 \end{pmatrix} \quad xt8\_s3\_start := \begin{pmatrix} bent_2 \\ xt8\_start_1 \\ bent_3 \end{pmatrix} \quad bent = \begin{pmatrix} 16.1444 \\ 1236.2813 \\ 16.1453 \\ 1249.7813 \\ 0.0079 \end{pmatrix}$$

$$xt8\_s2\_\alpha := bent_4$$

XTD9

$$bent := CurveHor\left(xt9\_s1\_line, xt9\_s3\_line, horCompP(xt9\_end), \Delta\alpha, rt\right)$$

$$xt9\_s2\_start := \begin{pmatrix} bent_0 \\ xt9\_start_1 \\ bent_1 \end{pmatrix} \quad xt9\_s3\_start := \begin{pmatrix} bent_2 \\ xt9\_start_1 \\ bent_3 \end{pmatrix} \quad bent = \begin{pmatrix} 1.2500 \\ 1236.4247 \\ 1.1970 \\ 1249.9246 \\ -0.0079 \end{pmatrix}$$

$$xt9\_s2\_\alpha := bent_4$$

$$\alpha_K := 0.0003651$$

$$PDtoLA(xs1\_start) = \begin{pmatrix} -0.0967 \\ -3.2982 \\ 2100.2237 \end{pmatrix}$$

Summary:

undulators:

$$s1\_start = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 181.9115 \end{pmatrix} \quad s1\_end = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 383.2115 \end{pmatrix} \quad L1\_opt = 187.6762 \quad PDtoLA(s1\_start) = \begin{pmatrix} 0.0000 \\ -2.5050 \\ 2176.4035 \end{pmatrix}$$

$$s2\_start = \begin{pmatrix} 4.8372 \\ 0.0000 \\ 181.8153 \end{pmatrix} \quad s2\_end = \begin{pmatrix} 15.0558 \\ 0.0000 \\ 437.8115 \end{pmatrix} \quad L2\_opt = 94.7756 \quad PDtoLA(s2\_start) = \begin{pmatrix} 4.8372 \\ -2.5050 \\ 2176.3073 \end{pmatrix}$$

$$s3\_start = \begin{pmatrix} -4.6754 \\ 0.0000 \\ 803.2603 \end{pmatrix} \quad s3\_end = \begin{pmatrix} -7.7627 \\ 0.0000 \\ 937.4247 \end{pmatrix} \quad L3\_opt = 117.5000 \quad PDtoLA(s3\_end) = \begin{pmatrix} -7.7627 \\ -2.7809 \\ 2931.9167 \end{pmatrix}$$

$$u1\_start = \begin{pmatrix} 19.5110 \\ 0.0000 \\ 688.4274 \end{pmatrix} \quad u1\_end = \begin{pmatrix} 19.280 \\ 0.000 \\ 748.327 \end{pmatrix} \quad LU1\_opt = 59.5197 \quad PDtoLA(u1\_start) = \begin{pmatrix} 19.5110 \\ -2.6900 \\ 2682.9193 \end{pmatrix}$$

$$u2\_start = \begin{pmatrix} 23.3462 \\ 0.0000 \\ 983.8115 \end{pmatrix} \quad u2\_end = \begin{pmatrix} 25.1450 \\ 0.0000 \\ 1043.6845 \end{pmatrix} \quad LU2\_opt = 90.0000$$

$$PDtoLA(u2\_start) = \begin{pmatrix} 23.3462 \\ -2.7978 \\ 2978.3035 \end{pmatrix}$$

tunnels:

XLT (part belonging to XFEL fan, 3 segments)

!!!

$$xt0\_start = \begin{pmatrix} 0.2000 \\ -0.8596 \\ 0.0000 \end{pmatrix} \quad xt0\_s2\_start = \begin{pmatrix} 0.2000 \\ -0.8433 \\ 44.5670 \end{pmatrix} \quad xt0\_s3\_start = \begin{pmatrix} 0.1764 \\ -0.8400 \\ 53.5669 \end{pmatrix}$$

$$xt0\_end = \begin{pmatrix} -0.0967 \\ -0.8210 \\ 105.7320 \end{pmatrix}$$

$$|xt0\_start - xt0\_s2\_start| = 44.5670$$

$$|xt0\_start - xt0\_s2\_start| + 1994.492 - 1900.05 = 139.0090$$

$$\frac{xt0\_s2\_\alpha}{deg} = -0.3000 \quad |xt0\_end - xt0\_s3\_start| = 52.1658$$

XDT1 3 segments

$$|xt1\_start - xt1\_end| = 474.6845$$

$$xt1\_start = \begin{pmatrix} 6.0371 \\ -0.1100 \\ 171.7595 \end{pmatrix} \quad xt1\_s2\_start = \begin{pmatrix} 20.2856 \\ -0.1100 \\ 528.7131 \end{pmatrix} \quad xt1\_s3\_start = \begin{pmatrix} 21.6486 \\ -0.1100 \\ 593.1949 \end{pmatrix}$$

$\frac{xt1\_\alpha}{deg} = 2.2859$

$|xt1\_start - xt1\_s2\_start| = 357.2379$

$\frac{xt1\_s2\_\alpha}{deg} = -2.1500$

$xt1\_end = \begin{pmatrix} 21.7742 \\ -0.1100 \\ 646.1830 \end{pmatrix}$

XDT2 1 segment

$xt2\_start = \begin{pmatrix} -1.6000 \\ -0.1100 \\ 171.9115 \end{pmatrix}$

$\frac{xt2\_\alpha}{deg} = 0.0000$

$xt2\_end = \begin{pmatrix} -1.6000 \\ -0.1100 \\ 760.8692 \end{pmatrix}$

$|xt2\_end - xt2\_start| = 588.9577$

XTD3 3 segments

$xt3\_start = \begin{pmatrix} 18.2996 \\ -0.1100 \\ 678.4226 \end{pmatrix}$

$$xt3\_s2\_start = \begin{pmatrix} 17.7889 \\ -0.1100 \\ 810.6307 \end{pmatrix} \qquad xt3\_s3\_start = \begin{pmatrix} 18.3484 \\ -0.1100 \\ 861.6258 \end{pmatrix}$$

$$\frac{xt3\_\alpha}{deg} = -0.2214 \qquad \frac{xt3\_s2\_\alpha}{deg} = 1.7000$$

XDT4 3 segments $\frac{\beta t4}{deg} = -16.5392$ rotated about z $\frac{rt}{2} = 859.4367$

$$L_1 := \left|xt4\_s2\_start - xt4\_start\right| \qquad L_2 := \left|xt4\_end - xt4\_s3\_start\right|$$

$$e1t4 := \begin{pmatrix} 0 \\ 0 \\ L_1 \end{pmatrix} \quad e1t4 = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 255.7298 \end{pmatrix} \quad a2t4 := \begin{bmatrix} \frac{rt}{2}\cdot(1 - \cos(xt4\_s2\_\alpha))\cdot\cos(\beta t4) \\ \frac{rt}{2}\cdot(1 - \cos(xt4\_s2\_\alpha))\cdot\sin(\beta t4) \\ L_1 + \frac{rt}{2}\cdot\sin(xt4\_s2\_\alpha) \end{bmatrix} \quad a2t4 = \begin{pmatrix} 0.4065 \\ -0.1207 \\ 282.7254 \end{pmatrix}$$

$$e2t4 := \begin{bmatrix} \left[\frac{rt}{2}\cdot(1 - \cos(xt4\_s2\_\alpha)) + L_2\cdot\sin(xt4\_s2\_\alpha)\right]\cdot\cos(\beta t4) \\ \left[\frac{rt}{2}\cdot(1 - \cos(xt4\_s2\_\alpha)) + L_2\cdot\sin(xt4\_s2\_\alpha)\right]\cdot\sin(\beta t4) \\ L_1 + \frac{rt}{2}\cdot\sin(xt4\_s2\_\alpha) + L_2\cdot\cos(xt4\_s2\_\alpha) \end{bmatrix} \qquad e2t4 = \begin{pmatrix} 0.9631 \\ -0.2860 \\ 301.2000 \end{pmatrix}$$

$$\frac{rt}{2\cdot\cos(\beta t4)} = 896.5304 \qquad \frac{rt}{2\cdot\sin(\beta t4)} = -3019.0506$$

$$|xt4\_start - xt4\_end| = 301.2017$$

$$xt4\_start = \begin{pmatrix} -5.6950 \\ -0.1100 \\ 793.2341 \end{pmatrix}$$

$$L_1 = 255.7298$$

$$\frac{xt4\_s2\_\alpha}{deg} = 1.8000$$

$$\frac{xt4\_\alpha}{deg} = -1.3182$$

$$L_2 = 18.4837$$

XDT5 3 segments $\frac{\beta t5}{deg} = 16.5392$ rotated about z $\frac{rt}{2} = 859.4367$

$$L_1 := |xt5\_s2\_start - xt5\_start| \qquad L_2 := |xt5\_end - xt5\_s3\_start|$$

$$e1t5 := \begin{pmatrix} 0 \\ 0 \\ L_1 \end{pmatrix} \quad e1t5 = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 158.6998 \end{pmatrix} \quad a2t5 := \begin{bmatrix} \frac{-rt}{2} \cdot (1 - \cos(xt5\_s2\_\alpha)) \cdot \cos(\beta t5) \\ \frac{-rt}{2} \cdot (1 - \cos(xt5\_s2\_\alpha)) \cdot \sin(\beta t5) \\ L_1 - \frac{rt}{2} \cdot \sin(xt5\_s2\_\alpha) \end{bmatrix} \quad a2t5 = \begin{pmatrix} -0.4065 \\ -0.1207 \\ 185.6954 \end{pmatrix}$$

$$e2t5 := \begin{bmatrix} \left[\frac{-rt}{2}\cdot(1-\cos(xt5\_s2\_\alpha)) + L_2\cdot\sin(xt5\_s2\_\alpha)\right]\cdot\cos(\beta t5) \\ \left[\frac{-rt}{2}\cdot(1-\cos(xt5\_s2\_\alpha)) + L_2\cdot\sin(xt5\_s2\_\alpha)\right]\cdot\sin(\beta t5) \\ L_1 - \frac{rt}{2}\cdot\sin(xt5\_s2\_\alpha) + L_2\cdot\cos(xt5\_s2\_\alpha) \end{bmatrix} \qquad e2t5 = \begin{pmatrix} -0.9631 \\ -0.2860 \\ 204.1700 \end{pmatrix}$$

$$\frac{rt}{2\cdot\cos(\beta t5)} = 896.5304 \qquad \frac{rt}{2\cdot\sin(\beta t5)} = 3019.0506$$

$$xt5\_s2\_start = \begin{pmatrix} 29.0611 \\ -0.1100 \\ 1132.4067 \end{pmatrix} \qquad xt5\_s3\_start = \begin{pmatrix} 29.4654 \\ -0.2307 \\ 1159.4023 \end{pmatrix}$$

$$|xt5\_start - xt5\_end| = 204.1725$$

$$xt5\_start = \begin{pmatrix} 24.2953 \\ -0.1100 \\ 973.7785 \end{pmatrix} \qquad |xt5\_s2\_start - xt5\_start| = 158.6998$$

$$\frac{xt5\_s2\_\alpha}{deg} = -1.8000$$

$$\frac{xt5\_\alpha}{deg} = 1.7209 \qquad |xt5\_end - xt5\_s3\_start| = 18.4838$$

XDT6 3 segments

$$|xt6\_start - xt6\_end| = 660.4830$$

$$xt6\_start = \begin{pmatrix} 25.9043 \\ -0.1100 \\ 678.2482 \end{pmatrix} \qquad xt6\_s2\_start = \begin{pmatrix} 48.1687 \\ -0.1100 \\ 1236.0141 \end{pmatrix} \qquad xt6\_s3\_start = \begin{pmatrix} 48.6541 \\ -0.1100 \\ 1249.5053 \end{pmatrix}$$

$$xt6\_end = \begin{pmatrix} 51.4982 \\ -0.1100 \\ 1338.2351 \end{pmatrix}$$

$$\frac{xt6\_\alpha}{deg} = 2.2859$$

$$\left| xt6\_start - xt6\_s2\_start \right| = 558.2101$$ $$\frac{xt6\_s2\_\alpha}{deg} = -0.4500$$ $$\left| xt6\_s3\_start - xt6\_end \right| = 88.7754$$

XDT7 1 segment

$$xt7\_start = \begin{pmatrix} 30.3826 \\ -0.1100 \\ 1201.3683 \end{pmatrix}$$ $$xt7\_end = \begin{pmatrix} 34.4989 \\ -0.1100 \\ 1338.3787 \end{pmatrix}$$ $$\left| xt7\_start - xt7\_end \right| = 137.0722$$

$$\frac{xt7\_\alpha}{deg} = 1.7209$$

$$\left| xt8\_start - xt8\_end \right| = 364.6425$$

XDT8 3 segments

$$xt8\_start = \begin{pmatrix} 17.1581 \\ -0.1100 \\ 973.8826 \end{pmatrix}$$ $$xt8\_s2\_start = \begin{pmatrix} 16.1444 \\ -0.1100 \\ 1236.2813 \end{pmatrix}$$ $$xt8\_s3\_start = \begin{pmatrix} 16.1453 \\ -0.1100 \\ 1249.7813 \end{pmatrix}$$

$$\frac{xt8\_\alpha}{deg} = -0.2214$$ $$xt8\_end = \begin{pmatrix} 16.4994 \\ -0.1100 \\ 1338.5245 \end{pmatrix}$$

$|xt8\_start - xt8\_s2\_start| = 262.4007$

$|xt8\_s3\_start - xt8\_end| = 88.7439$

$\frac{xt8\_s2\_\alpha}{deg} = 0.4500$

XDT9 3 segment

$|xt9\_start - xt9\_end| = 545.3471$

$xt9\_start = \begin{pmatrix} 1.2500 \\ -0.1100 \\ 793.3192 \end{pmatrix}$ $xt9\_s2\_start = \begin{pmatrix} 1.2500 \\ -0.1100 \\ 1236.4247 \end{pmatrix}$ $xt9\_s3\_start = \begin{pmatrix} 1.1970 \\ -0.1100 \\ 1249.9246 \end{pmatrix}$

$\frac{xt9\_\alpha}{deg} = 0.0000$

$xt9\_end = \begin{pmatrix} 0.5000 \\ -0.1100 \\ 1338.6658 \end{pmatrix}$

$|xt9\_start - xt9\_s2\_start| = 443.1055$

$\frac{xt9\_s2\_\alpha}{deg} = -0.4500$

$|xt9\_s3\_start - xt9\_end| = 88.7439$

XDT10 1 segment

$xt10\_start = \begin{pmatrix} -12.4151 \\ 0.0000 \\ 1117.8655 \end{pmatrix}$ $xt10\_end = \begin{pmatrix} -17.4996 \\ -0.1100 \\ 1338.8178 \end{pmatrix}$

$|xt10\_start - xt10\_end| = 221.0108$

$\frac{xt10\_\alpha}{deg} = -1.3182$

XDT20 1 segment

$$xt20\_start = \begin{pmatrix} -9.9744 \\ -0.3500 \\ 171.5713 \end{pmatrix}$$

$$\frac{xt20\_\alpha}{deg} = -4.9175$$

$$\left| xt20\_end - xt20\_start \right| = 56.1092$$

Dump halls:

$$xd1\_start = \begin{pmatrix} 29.4639 \\ -0.3960 \\ 1177.8853 \end{pmatrix} \qquad xd1\_end = \begin{pmatrix} 30.1696 \\ -0.3960 \\ 1201.3747 \end{pmatrix}$$

$$xd2\_start = \begin{pmatrix} -11.6614 \\ -0.3960 \\ 1094.3766 \end{pmatrix} \qquad xd2\_end = \begin{pmatrix} -12.2021 \\ -0.3960 \\ 1117.8704 \end{pmatrix}$$

$$LAtoPD\left(\begin{pmatrix} -11.358 \\ -4.739 \\ 3088.164 \end{pmatrix}\right) = \begin{pmatrix} -11.3580 \\ -1.9011 \\ 1093.6728 \end{pmatrix} \qquad xAt(p5\_line, 1094.3766) = -11.3745$$

Dump windows:

$$PDtoLA(xd1\_beam + 15.5 \cdot p2\_dir) = \begin{pmatrix} 29.6426 \\ -2.8743 \\ 3187.8789 \end{pmatrix}$$

$$PDtoLA(xd2\_beam + 15.5 \cdot p5\_dir) = \begin{pmatrix} -11.7312 \\ -2.8438 \\ 3104.3710 \end{pmatrix}$$

ramps

XTD1, 1 ramp

crossing: $li := parallelHor(p3\_line, 1.8)$

$$crossing := intersectLL(li, p1\_line) + \begin{pmatrix} 0 \\ -0.11 \\ 0 \end{pmatrix} \qquad crossing = \begin{pmatrix} 21.6418 \\ -0.1100 \\ 602.8030 \end{pmatrix}$$

$$xt1\_r1\_z := \frac{2566.9283 + 2571.4022 - 0.5}{2} - 1994.492$$

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$$xt1\_r1 := \begin{pmatrix} xAt(p1\_line, xt1\_r1\_z) \\ -1.4 \\ xt1\_r1\_z \end{pmatrix} \qquad xt1\_r1 = \begin{pmatrix} 20.5090 \\ -1.4000 \\ 574.4233 \end{pmatrix}$$

$DistPL(crossing, xt1\_s1\_line) =$ ▮

$$\left| xt1\_r1 - p3\_start \right| = 12.8217$$

XTD2, 1ramp

crossing: $li := parallelHor(p4\_line, -1.8)$

$$crossing := intersectLL(li, p5\_line) + \begin{pmatrix} 0 \\ -0.11 \end{pmatrix} \qquad crossing = \begin{pmatrix} -1.8000 \\ -0.1100 \\ 678.3085 \end{pmatrix}$$

$$xt2\_r1\_z := \frac{2605.319 + 2614.2617 - 0.5}{2} - 1994.492$$

$$xt2\_r1 := \begin{pmatrix} xAt(p4\_line, xt2\_r1\_z) \\ -1.4 \\ xt2\_r1\_z \end{pmatrix} \qquad xt2\_r1 = \begin{pmatrix} 0.0000 \\ -1.4000 \\ 615.0484 \end{pmatrix} \qquad |xt2\_r1 - p5\_start| = 15.0260$$

DistPL(crossing, xt2_s1_line) = ▮

XTD3, 1ramp

crossing: $li := parallelHor(p2\_line, -1.8)$

$$crossing := intersectLL(li, p3\_line) + \begin{pmatrix} 0 \\ -0.11 \\ 0 \end{pmatrix} \qquad crossing = \begin{pmatrix} 18.7316 \\ -0.1100 \\ 890.1562 \end{pmatrix}$$

$$xt3\_r1\_z := \left(\frac{2842.2823 + 2846.1625 - 0.5}{2}\right) - 1994.492$$

$$xt3\_r1 := \begin{pmatrix} xAt(xt3\_s1\_line, xt3\_r1\_z) \\ -1.4 \\ xt3\_r1\_z \end{pmatrix} \qquad xt3\_r1 = \begin{pmatrix} 17.6388 \\ -1.4000 \\ 849.4804 \end{pmatrix}$$

$|xt3\_r1 - p2\_start| = 12.5802$

$DistPL(crossing, xt3\_s1\_line) = ▮$

photon beams:

$p1\_start = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 60.6326 \end{pmatrix}$ $|p1\_start - p1\_end| = 1278.6242$ $\frac{p1\_\alpha}{deg} = 2.285860$

$|p1\_end - s2\_end| = 901.1450$

$p1\_end = \begin{pmatrix} 50.9982 \\ 0.0000 \\ 1338.2394 \end{pmatrix}$ $|p1\_start - p3\_start| = 501.4548$

$p2\_start = \begin{pmatrix} 18.9368 \\ 0.0000 \\ 837.0459 \end{pmatrix}$ $|p2\_start - p2\_end| = 501.5632$ $\frac{p2\_\alpha}{deg} = 1.720855$

$|p2\_end - u2\_end| = 294.8314$

$p2\_end = \begin{pmatrix} 33.9988 \\ 0.0000 \\ 1338.3829 \end{pmatrix}$ $|p2\_start - u2\_opt| = 296.7318$

$p3\_start = \begin{pmatrix} 20.0006 \\ 0.0000 \\ 561.6884 \end{pmatrix}$ $|p3\_start - p3\_end| = 776.8439$ $\frac{p3\_\alpha}{deg} = -0.221355$

$$p3\_end = \begin{pmatrix} 16.9994 \\ 0.0000 \\ 1338.5265 \end{pmatrix}$$

$$|p3\_end - u1\_end| = 590.2039$$

$$|p3\_start - p2\_start| = 275.3596$$

$$p4\_start = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.0000 \end{pmatrix}$$

$$|p4\_start - p4\_end| = 1338.6700$$

$$\frac{p4\_\alpha}{deg} = 0.000000$$

$$|p4\_end - s1\_end| = 955.4585$$

$$p4\_end = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 1338.6700 \end{pmatrix}$$

$$|p4\_start - p5\_start| = 600.0877$$

$$p5\_start = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 600.0877 \end{pmatrix}$$

$$|p5\_start - p5\_end| = 738.921$$

$$\frac{p5\_\alpha}{deg} = -1.318245$$

$$|p5\_end - s3\_end| = 401.4951$$

$$p5\_end = \begin{pmatrix} -16.9994 \\ 0.0000 \\ 1338.8135 \end{pmatrix}$$

$$|p5\_start - u1\_opt| = 208.8372$$

$$PDtoLA(p5\_start) = \begin{pmatrix} 0.0000 \\ -2.6577 \\ 2594.5797 \end{pmatrix}$$

shafts:

$$R := 6390000 \cdot deg$$

$$xs1\_start = \begin{pmatrix} -0.0967 \\ -0.8210 \\ 105.7320 \end{pmatrix}$$

$$xs1\_\alpha = 0.000000$$

$$\frac{PD\_Length - xs1\_start_2 - 25}{R} = 0.010831$$

$$xs2\_start = \begin{pmatrix} 21.7742 \\ -0.1100 \\ 646.1830 \end{pmatrix}$$

$$\frac{xs2\_\alpha}{deg} = -0.221355$$

$$\frac{PD\_Length - xs2\_start_2 - 16.1}{R} = 0.006065$$

$$xs3\_start = \begin{pmatrix} -1.6000 \\ -0.1100 \\ 760.8692 \end{pmatrix}$$

$$\frac{xs3\_\alpha}{deg} = 0.000000$$

$$\frac{PD\_Length - xs3\_start_2 - 16.2}{R} = 0.005036$$

$$intersectPL(xs2\_frontPlane, p1\_line) - intersectPL(xs2\_frontPlane, xt1\_s3\_line) = \begin{pmatrix} 1.5994 \\ 0.1100 \\ 0.0062 \end{pmatrix}$$

$$xs4\_start = \begin{pmatrix} 20.4074 \\ -0.1100 \\ 941.3923 \end{pmatrix}$$

$$\frac{xs4\_\alpha}{deg} = 1.457600$$

$$\frac{PD\_Length - xs4\_start_2 - 16.2}{R} = 0.003417$$

$$xs5\_start = \begin{pmatrix} -14.7842 \\ -0.3500 \\ 227.4739 \end{pmatrix}$$

$$\frac{xs5\_\alpha}{deg} = -4.917540$$

$$\frac{PD\_Length - xs5\_start_2 - 18}{R} = 0.009802$$

Vergleich mit W.Deckings Liste vom 26.11.2007

$$xdu1\_LA := \begin{pmatrix} 29.70 \\ -7.98 \\ 3187.8775 \end{pmatrix}$$

$$xsdu1\_dump := LAtoPD(xdu1\_LA) \qquad xsdu1\_dump = \begin{pmatrix} 29.7000 \\ -5.1057 \\ 1193.3874 \end{pmatrix}$$

$$xd1\_beam + 15.5 \cdot p2\_dir = \begin{pmatrix} 29.6426 \\ 0.0000 \\ 1193.3870 \end{pmatrix}$$

$$xdu2\_LA := \begin{pmatrix} -11.7764 \\ -7.9494 \\ 3106.3398 \end{pmatrix}$$

$$xsdu2\_dump := LAtoPD(xdu2\_LA)$$

$$xsdu2\_dump = \begin{pmatrix} -11.7764 \\ -5.1048 \\ 1111.8497 \end{pmatrix}$$

$$xd2\_beam + 15.5 \cdot p5\_dir = \begin{pmatrix} -11.7312 \\ 0.0000 \\ 1109.8791 \end{pmatrix}$$