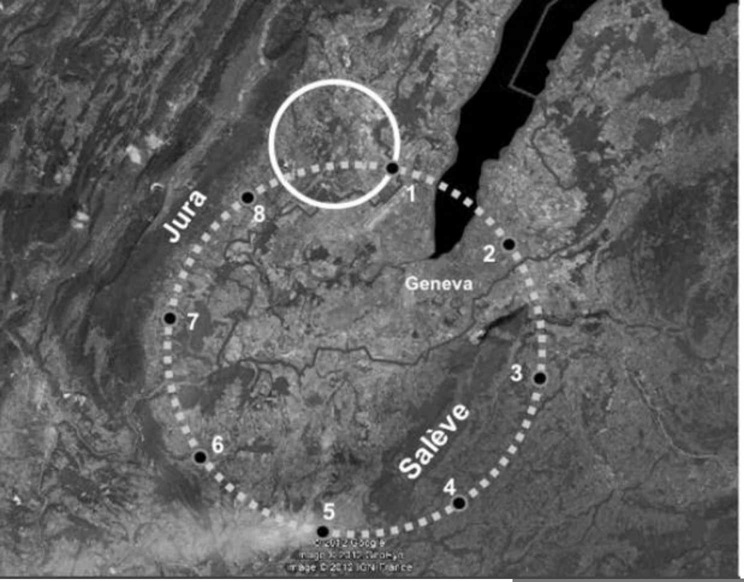
TLEP ... Lattice Design & Beam Optics

Parameter-List on TKLEP-WEB Page

!! emittance !!

	TLEP Z	TLEP W	TLEP H	TLEP t
E_{beam} [GeV]	45	80	120	175
I_{total} [mA]	1180	124	24	5.4
#bunches/beam	4400	600	80	12
#e−/beam [10^{12}]	*1960*	*200*	*40.8*	*9.0*
horiz. emit. [nm]	30.8	9.4	9.4	10
vert. emit. [nm]	0.07	0.02	0.02	0.01
β^*_x [m]	*0.5*	*0.5*	*0.5*	*1*
β^*_y [mm]	*0.1*	*0.1*	*0.1*	*1*
σ^*_x [µm]	*124*	*78*	*68*	*100*
σ^*_y [µm]	*0.27*	*0.14*	*0.14*	*0.10*
L/IP[10^{32}cm^{-2}*s^{-1}*]	*5600*	*1600*	*480*	*130*



Reminder:

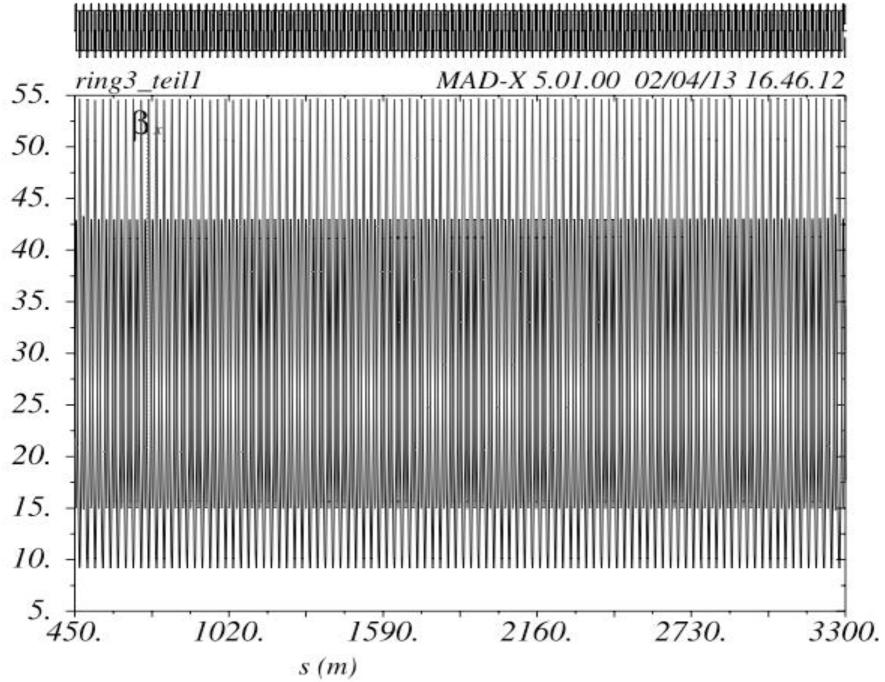
TLEP ... the very first steps

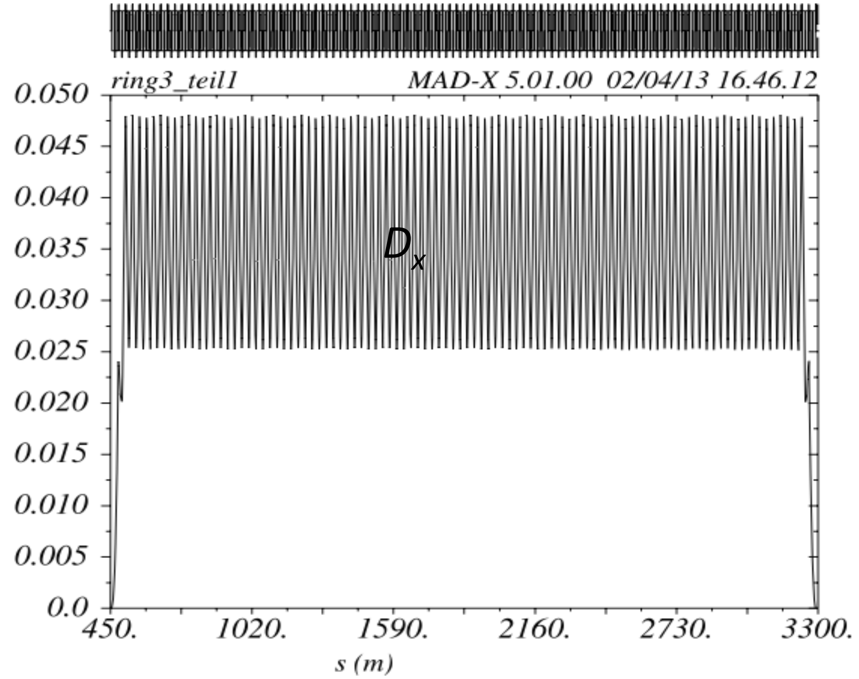
	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
beam energy E_b [GeV]	104.5	60	120	45.5	120	175
circumference [km]	26.7	26.7	26.7	80	80	80
beam current [mA]	4	100	7.2	1180	24.3	5.4
#bunches/beam	4	2808	4	2625	80	12
#e-/beam [10^{12}]	2.3	56	4.0	2000	40.5	9.0
horizontal emittance [nm]	48	5	25	30.8	9.4	20
vertical emittance [nm]	0.25	2.5	0.10	0.15	0.05	0.1
bending radius [km]	3.1	2.6	2.6	9.0	9.0	9.0
partition number J_ε	1.1	1.5	1.5	1.0	1.0	1.0
momentum comp. α_c [10^{-5}]	18.5	8.1	8.1	9.0	1.0	1.0
SR power/beam [MW]	11	44	50	50	50	50
β^*_x [m]	1.5	0.18	0.2	0.2	0.2	0.2
β^*_y [cm]	5	10	0.1	0.1	0.1	0.1
σ^*_x [μm]	270	30	71	78	43	63
σ^*_y [μm]	3.5	16	0.32	0.39	0.22	0.32
hourglass F_{hg}	0.98	0.99	0.59	0.71	0.75	0.65
ΔE^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99	0.04	2.1	9.3

SuperKEKB: $\varepsilon_y/\varepsilon_x$=0.25%

TLEP ... Lattice Design ... Version 1...2

Arc: 96 standard FoDo cells & 2 half bend cells at beginning and end
length of arc: 2.8km
length of straight section: 0.45 km





TLEP ... Lattice Design

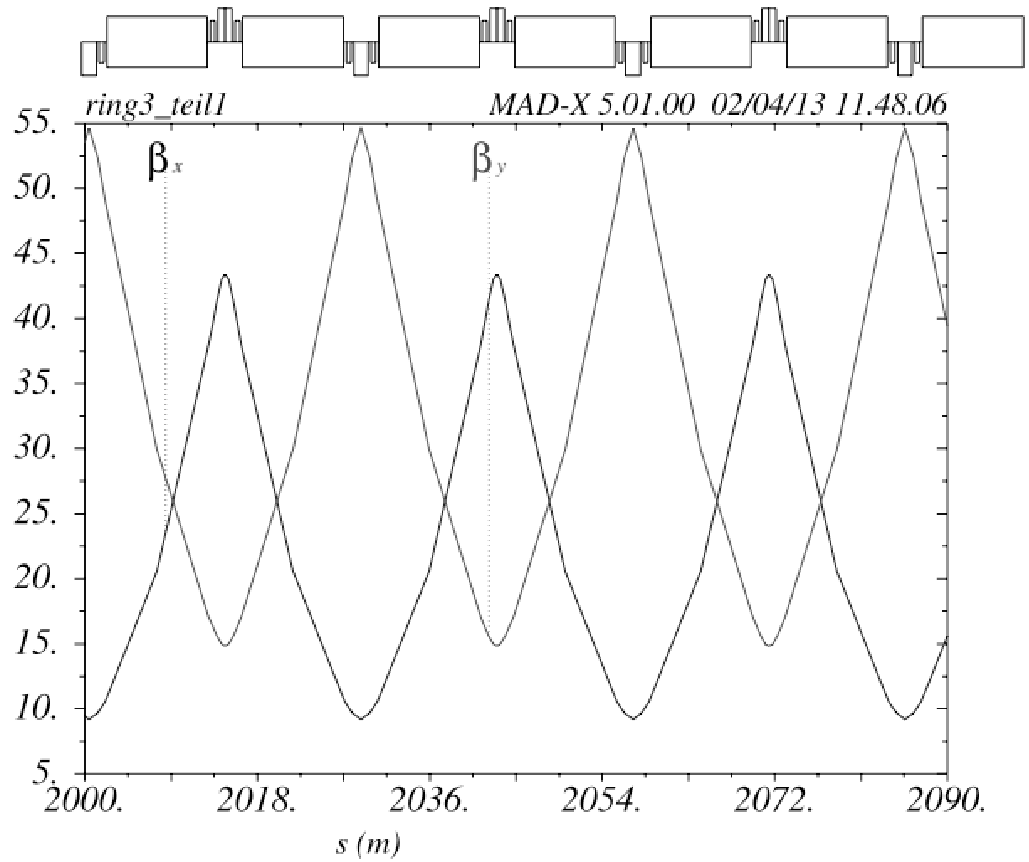
Arc: the single FoDo cell

until now ... 2 dipoles / 2 quadrupoles
to be optimised according to hardware engineering

short cell length: ≈ 30 m

advantage: small betas
small dispersion
small emittance

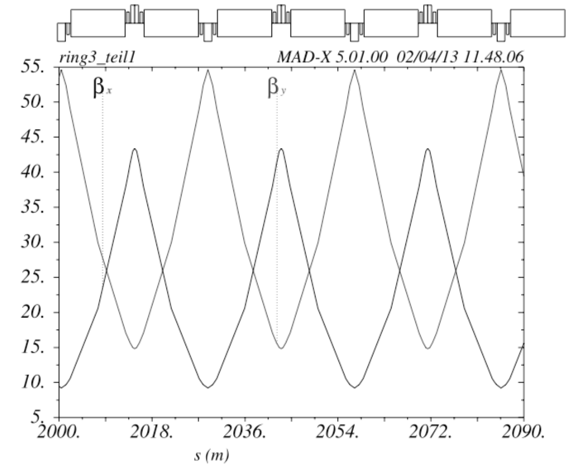
but: realistic hardware design ?



TLEP ... Lattice Design

Arc: the single FoDo cell

phase advance: 90^0 / 60^0

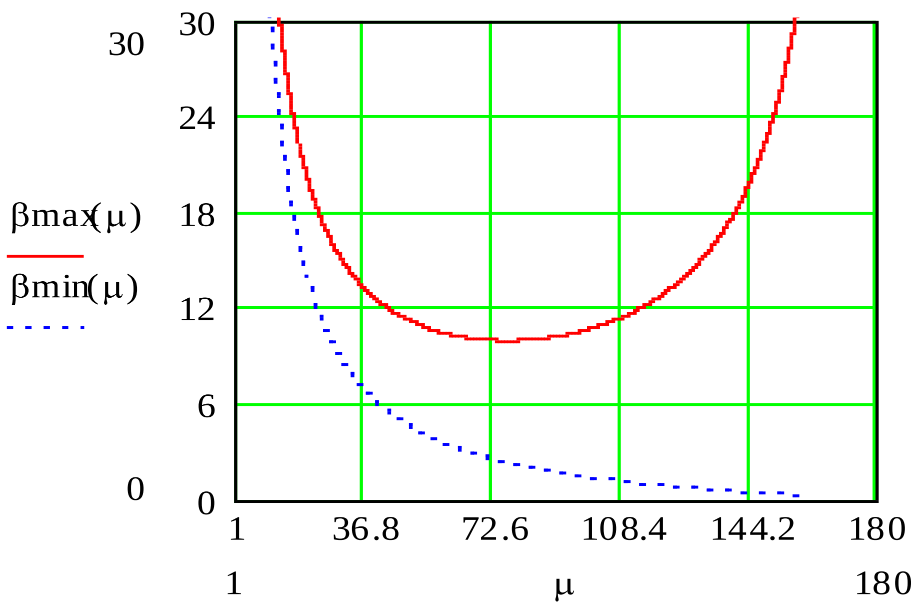


to be discussed ...

90^0 horizontally: small dispersion & emittance

60^0 vertically: small beam size (β_y)

and better orbit correction tolerance (LEP experience)



TLEP ... Lattice Design (175 GeV)

not the very first steps anymore (... V9.e)

Main modifications wrt. previous versions:

longer cells to achieve higher dispersion values

Text-Book like approach

still 80 km, standard FoDo structure

fill factor, robustness, easy to handle & modify

easy to understand & optimise analytically

Choice of single cell: compared to V.3 ...V.6

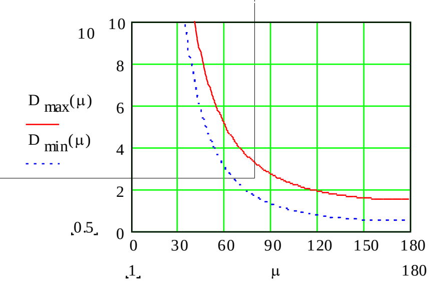
cell length increased to L_{cell} = 50m

equilibrium emittance

$$\varepsilon = \left(\frac{\delta p}{p}\right)^2 \left(\gamma D^2 + 2\alpha D D' + \beta D'^2\right)$$

scaling of dispersion in a FoDo

$$\hat{D} = \frac{l^2}{\rho} * \frac{\left(1 + \frac{1}{2}\sin\frac{\psi_{cell}}{2}\right)}{\sin^2\frac{\psi_{cell}}{2}}$$



TLEP ... single cell

L_{cell}=50m

Dipole: N_{dipole} = 2932

L_{dipole} = 21.3 m

*due to techn. reasons: 2 * 11 m*

bending angle = 2.14 mrad

B_0 = 580 Γ

Quadrupole (arc):

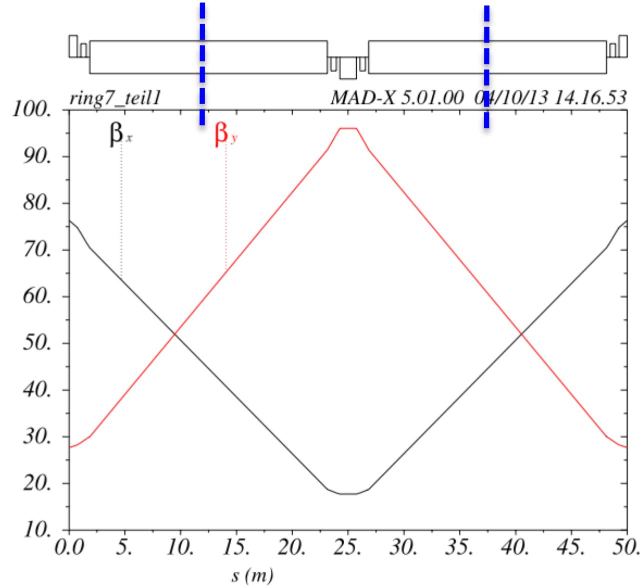
$L_{quadrupole}$ = 1.5 m

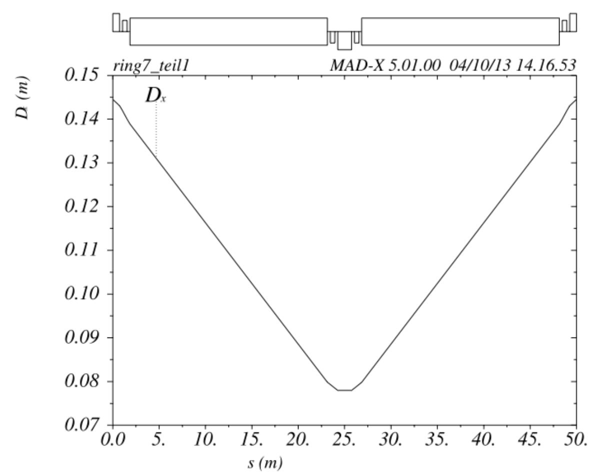
$k=3.55*10^{-2}\ m^{-2}$

g=20.7 T/m

aperture: $r_0=30\sigma=11mm$

B_{tip}= 0.23 T





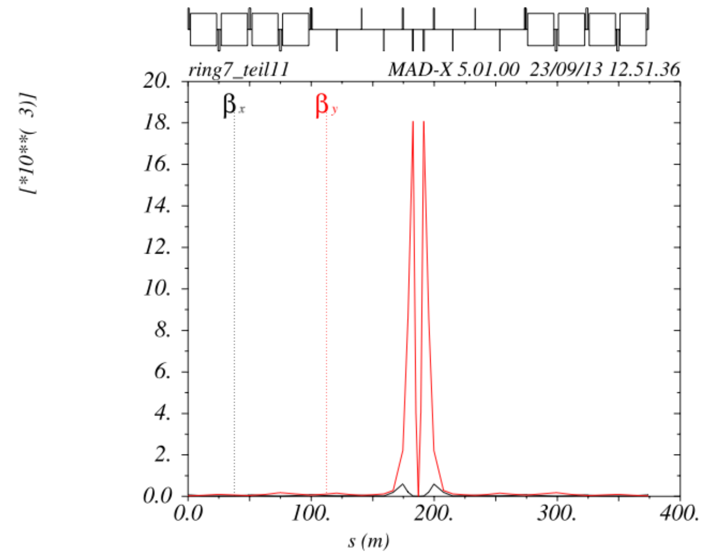
$\beta \approx 100m$, D_x= 15.3 cm

FoDo Cell

At present the dipole length is “symbolic”. Due to technical reasons we think of putting 2 dipoles of 11m length each between the quads

TLEP ... mini beta hardware

$L^* = 4m$



Quadrupole (mini-β):

$L_{quadrupole} = 0.75\ m$

$k = 0.43\ m^{-2}$

$g = k * B\rho \approx 250\ T/m$

aperture assumption:

$r_0 = 30\sigma$

$$\sigma_x = \sqrt{\varepsilon_x \beta_x} = \sqrt{2nm * 600m} = 1.1mm$$

$$\sigma_y = \sqrt{\varepsilon_y \beta_y} = \sqrt{0.002nm * 18000m} = 0.19mm$$

pole tip field:

$$B_0 \approx 30mm * 250T/m = 7.5T$$

-> scale mini-β quad length to 7.5m

$B_0 = 0.75\ T$

**** beam separation / crossing angle / synchrotron radiation / beam-beam interaction in the vicinity of strong quadrupole gradients***

TLEP ... Lattice Design

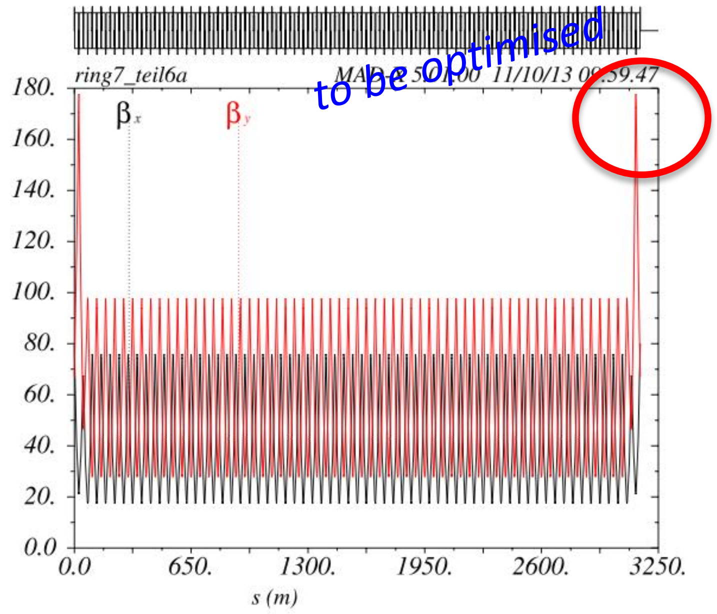
24 Arcs : built out of 56 standard FoDo cells & 2 half bend cells at beginning and end

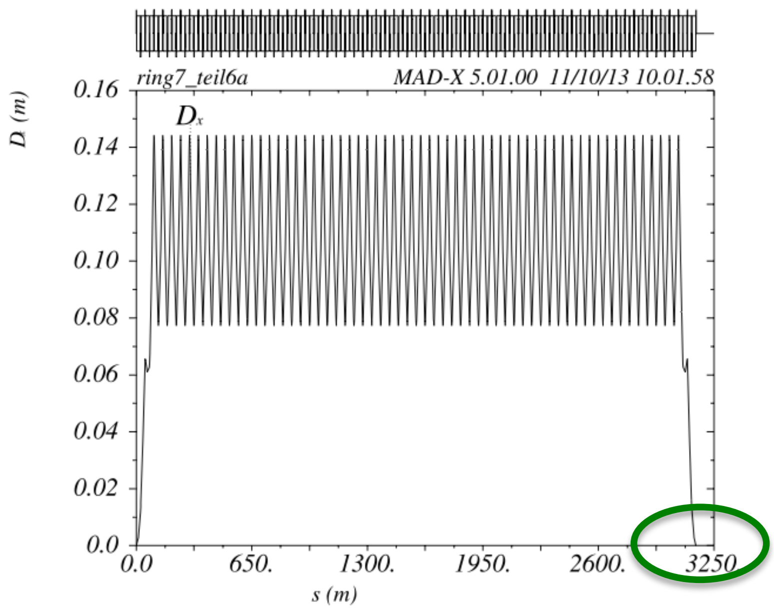
length of arc: ≈ 3.0km

each arc is embedded in dispersion free regions ...

arcs are connected by straight. sections ... 12 long (mini β and RF)

... 12 ultra shorties tbc



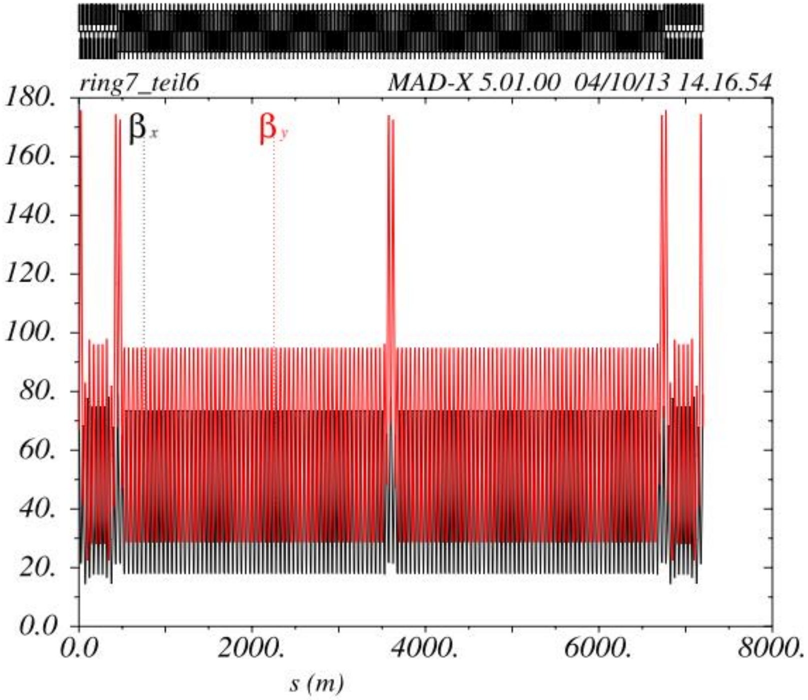


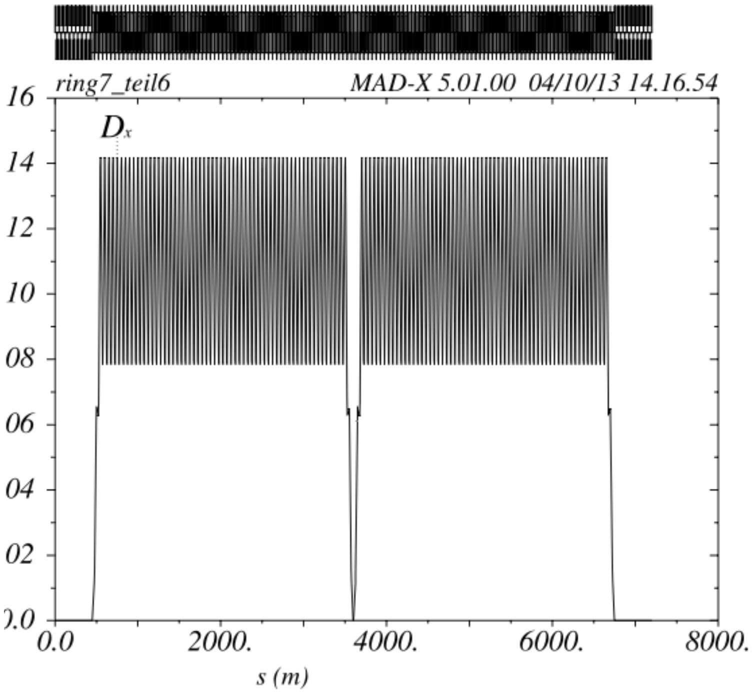
TLEP Octant

Straight – Arc – Arc – Straight

arcs are connected in pairs via a disp-free-empty cell

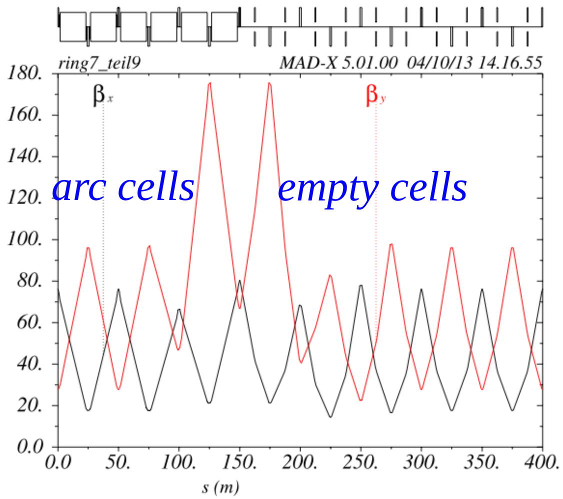
-> only reason: in case of additional insertions we get the boundary conditions for free.

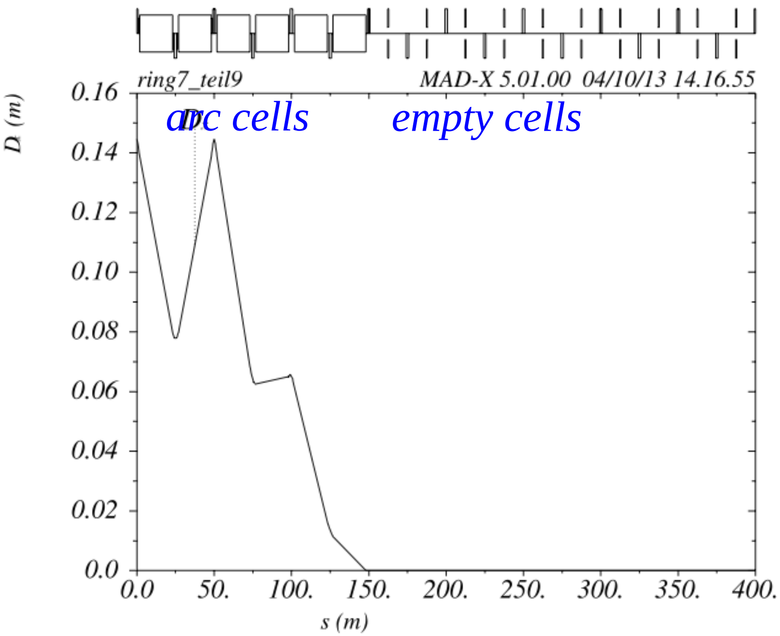




TLEP Arc-Straights

8 Straights : 9 empty (i.e. dispersion free) FoDo cells including matching sections
arc-straight, l = 450m





to be optimised: β_y at matching section,
needs an additional quadrupole lens → already built in but not used yet.
and / or optimisation of the lens positions

TLEP   Mini-Betas

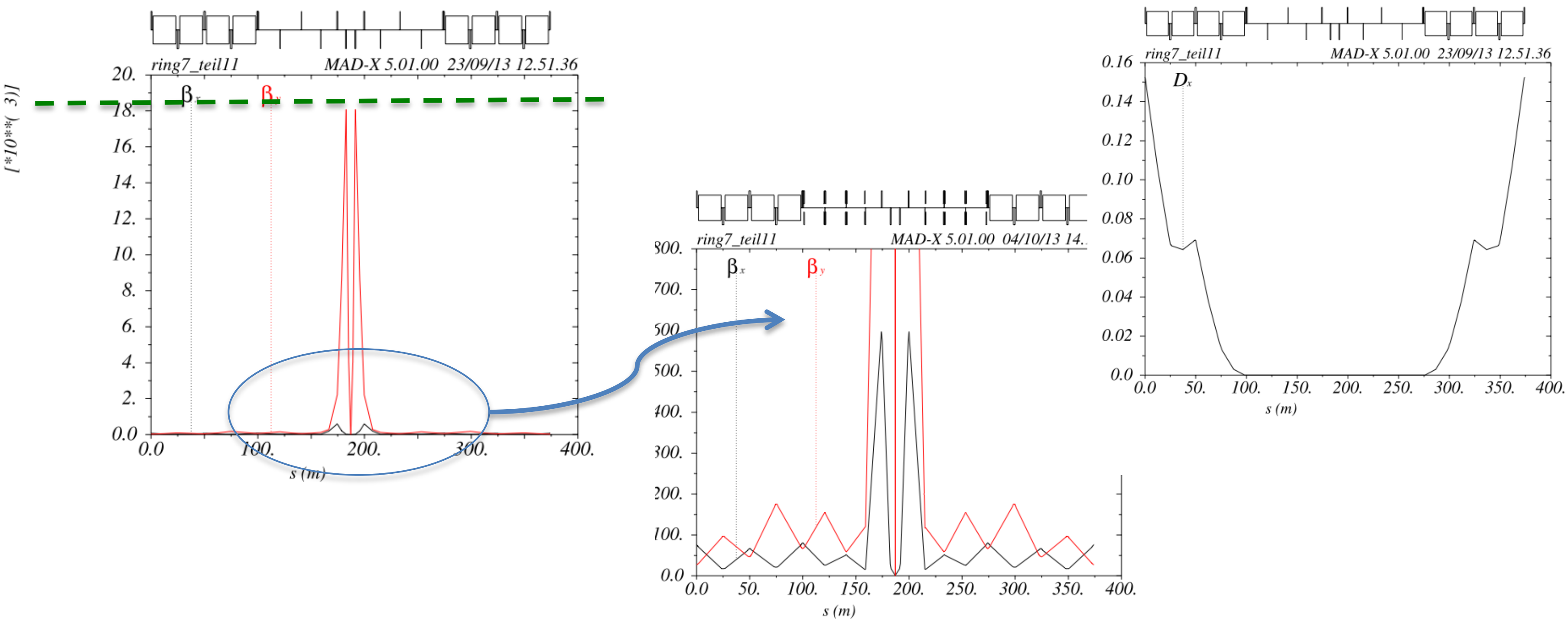
4 Mini-beta-Insertions : ***based on empty (i.e. dispersion free) FoDo cells***

L*=4m

β^*_x =1m, β^*_y =1mm

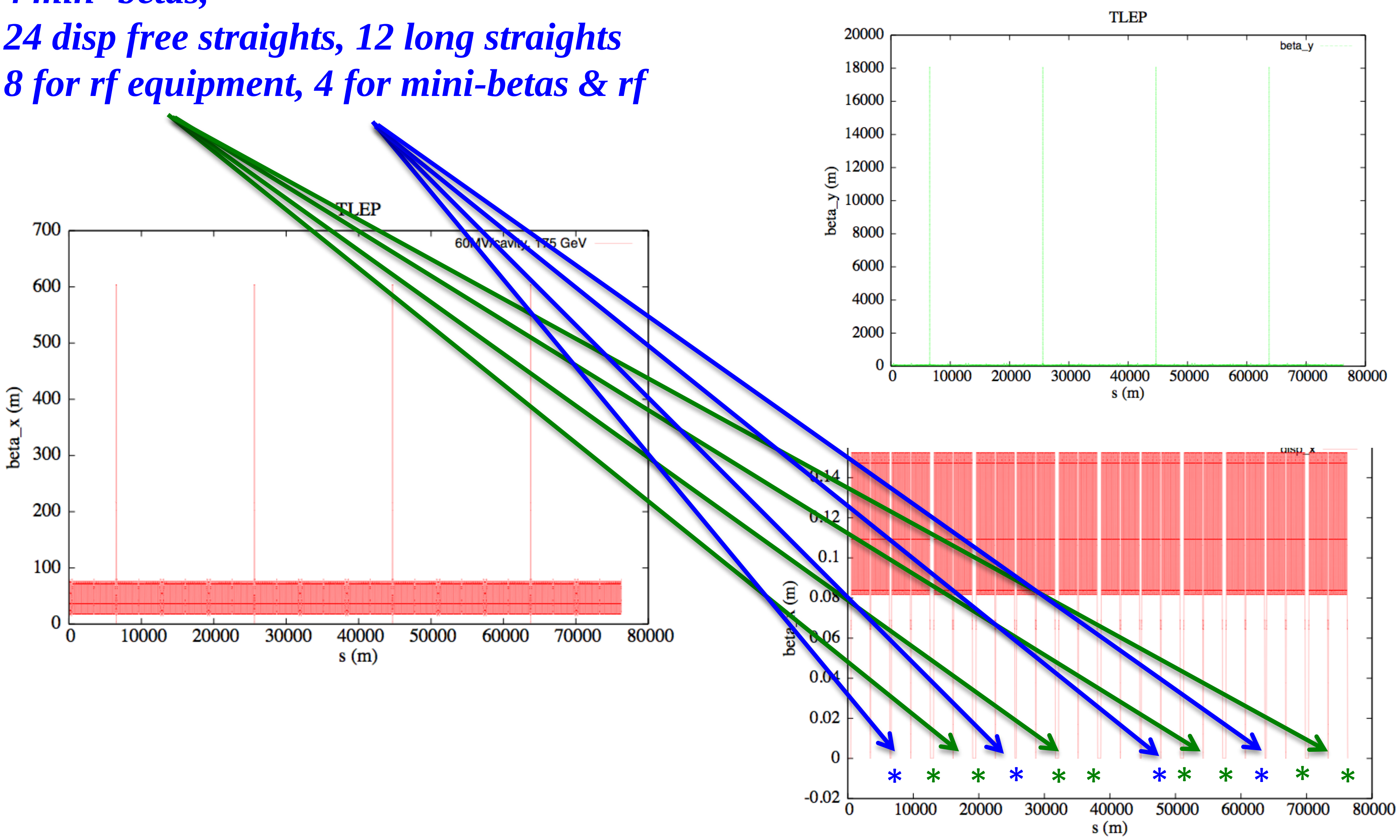
standard doublet structure & matching section

$\beta_{m,ax}$ =18 km



TLEP The Ring
rf-sections

L_{ring} = 79.9km
4 min- betas,
24 disp free straights, 12 long straights
8 for rf equipment, 4 for mini-betas & rf



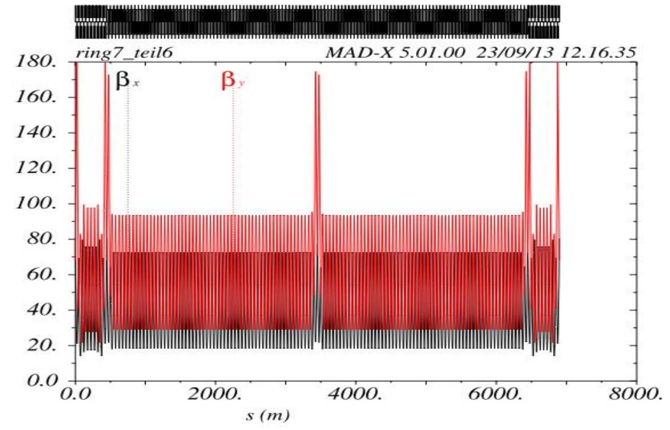
TLEP

... new parameter list

	TLEP Z	TLEP W	TLEP H	TLEP t		TLEP ttH & ZHH
E_{beam} [GeV]	45	80	120	175		250
circumf. [km]	**100**	**100**	**100**	**100**		**100**
beam current [mA]	1440	154	29.8	6.7		1.6
#bunches/beam	**7500**	**3200**	**167**	**160**	**20**	**10**
#e−/bunch [10^{11}]	4.0	1.0	3.7	0.88	7.0	3.3
# arc cells in units of base cell	6	2	2	1	2	1
horiz. emit. [nm]	**29.2**	**3.3**	**7.5**	**2.0**	**16.0**	**4.0**
vert. emit. [nm]	**0.06**	**0.017**	**0.015**	**0.002**	**0.016**	**0.004**
bending rad. [km]	11.0	11.0	11.0	11.0		11.0
κ_ε	**500**	**200**	**500**	**1000**		**1000**
mom. c. α_c [10^{-5}]	3.6	0.4	0.4	0.1	0.4	0.1
$P_{loss,SR}$/beam [MW]	50	50	50	50		50
β^*_x [m]	0.5	0.2	0.5	1.0		1.0
β^*_y [mm]	1.0	1.0	1.0	1.0		1.0
σ^*_x [μm]	121	26	61	45	126	63
σ^*_y [μm]	0.25	0.13	0.12	0.045	0.126	0.063
δ^{SR}_{rms} [%]	0.05	0.09	0.14	0.20		0.29
$\sigma^{SR}_{z,rms}$ [mm]	1.16	0.91	0.98	0.68	1.35	1.56
δ^{tot}_{rms} **[%]**	**0.13**	**0.20**	**0.30**	**0.23**	**0.29**	**0.34**
$\sigma^{tot}_{z,rms}$ **[mm]**	**2.93**	**1.98**	**2.11**	**0.77**	**1.95**	**1.81**
hourglass F_{hg}	0.61	0.71	0.69	0.90	0.71	0.73
E^{SR}_{loss}/turn [GeV]	0.03	0.3	1.7	7.5		31.4
V_{RF},tot [GV]	2	2	6	12		35
$\tau_{\parallel}$ (turns)	1319	242	72	23		8
$\delta_{max,RF}$ [%]	5.3	10.6	13.4	19.0	9.5	5.9
ξ_x**/IP**	**0.068**	**0.086**	**0.094**	**0.057**		**0.075**
ξ_y**/IP**	**0.068**	**0.086**	**0.094**	**0.057**		**0.075**
f_s [kHz]	0.77	0.19	0.27	0.14	0.29	0.266
E_{acc} [MV/m]	3	3	10	20		20
eff. RF length [m]	600	600	600	600		1750
f_{RF} [MHz]	800	800	800	800		800
$\mathcal{L}$ **/IP[10^{32}cm^{-2}s^{-1}]**	**5860**	**1640**	**508**	**132**	**104**	**48**
number of IPs	4	4	4	4		4
beam lifetime [min] (rad. Bhabha)	**99**	**38**	**24**	**21**	**26**	**13**
beam lifetime [min] (beamstrahlung Telnov with η=2%)	>10^{25}	>10^{6}	38	14	2.1 [11.6 with	0.3 [2.8 with η=3%]

TLEP ... Lattice Design V9.e

beam dynamics of the ring



Main Parameters:

momentum compaction

$$\alpha_{cp} \approx \frac{\langle D \rangle}{R} = \frac{11 * 10^{-2} m}{L_0 /(2\pi)} \approx 8.64 * 10^{-6}$$

MADX: α_{cp} =8.94*10^{-6}

$$\eta \approx \frac{1}{\gamma^2} - \alpha_{cp} \approx -\alpha_{cp} \qquad \gamma = \frac{175000}{0.511} = 342466$$

energy loss per turn:

$$\Delta U_0(keV) \approx \frac{89 * E^4(GeV)}{\rho}$$

$$\Delta U_0 \approx 8.4\ GeV$$

MADX: ΔU_0=8.2 GeV

$$N_{dipoles} = 2932$$

$$\theta = \frac{2\pi}{2932} = 2.14\,mrad$$

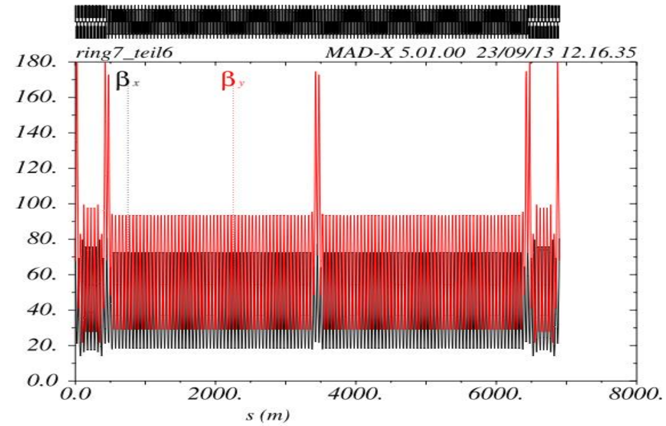
$$E = 175 GeV, \qquad B\rho = 583.33$$

$$\rho = \frac{L_B}{\theta} \approx 9.95 km$$

TLEP ... V 9.e

Main Parameters:

Damping & Beam Emittance

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Global parameters for electrons, radiate = T:

C                 79896.4 m        f0          0.003752264908 MHz
T0                  266.5 musecs   alfa        8.937464662e-06
eta        8.937456136e-06         gamma(tr)       334.4974653
Bcurrent   5.410611548e-05 A/bunch Kbunch                    1
Npart               9e+10 /bunch   Energy              175 GeV
gamma         342466.4839          beta                      1
U0         8201.979536 [MeV/turn]

Damping partition numbers          1.00447477      0.99999615      1.99552171
Damping constants [1/s]            0.88324891E+02  0.87931079E+02  0.17546905E+03
Damping times [s]                  0.11321837E-01  0.11372543E-01  0.56990106E-02
Emittances [pi micro m]            0.16335327E-02  0.83929190E-28  0.19355070E+01

RF system:
Cavity              length[m]     voltage[MV]        lag      freq[MHz]      harmon
cav                         1              70        0.4    754.2052465      201000
```

***Nota bene:** Emittance is as before nicely small .. still smaller than the design value (2nm).*
however for a theoretical, ideal lattice without coupling, beam-beam, solenoid fields, tolerances → error tolerances to be considered,
→ how realistic is 2nm and 1 permille for $\varepsilon_y / \varepsilon_x$

Synchrotron Radiation Power
175 GeV, 80km

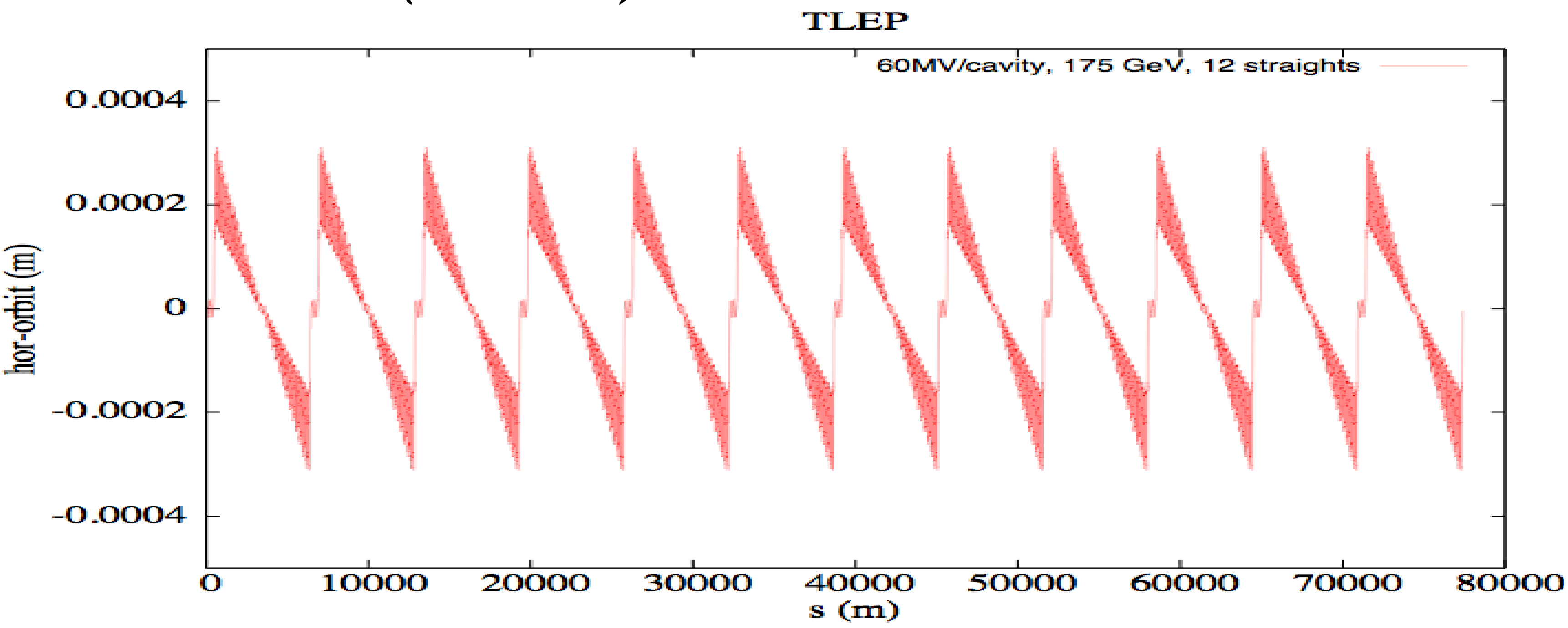
N_p = $9*10^{12}$
ΔU_0 = 8.2 GeV
T_0 = 266 µs

$$\Delta P_{sy} \approx \frac{\Delta U_0}{T_0} * N_p = \frac{8.2*10^6 eV * 1.6*10^{-19} Cb}{266*10^{-6} s} * 9*10^{12}$$

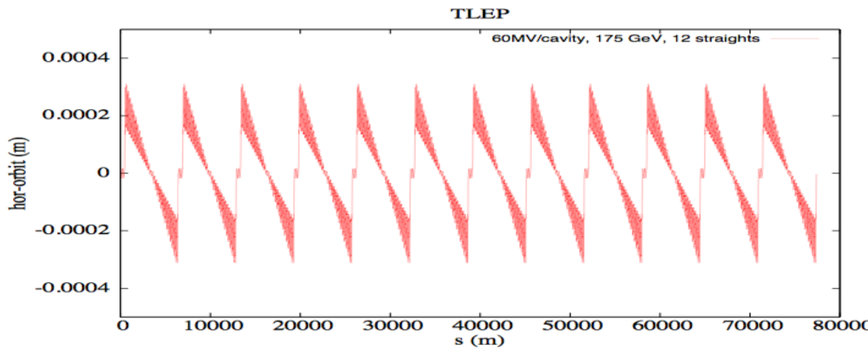
$$\Delta P_{sy} \approx 44\ MW$$

... and Saw-Tooth effect (still without mini-beta)

rf distributed over 12 straights
and 216 cavities (60MV each)



Next steps:



*** Optics fine tuning: including radiation effects***

*** Do we really need D_x= 15 cm or should we relax ??***

*** Establish complete versions for different Mini Beta Options***
local / global Q' correction

*** Optimise RF distribution***
how many straights do we really need ???

*** Lattice for lower energies***
beam separation ???

*** 80 km / 100 km ??? tbd***

*** start with the Ph.D. topics:***
what about the momentum acceptance ???

****** define a mid term parameter table (t >> 2 days)***