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Laboratori Nazionali di Frascati

WP4 report
High Energy Damping Ring

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O. Etisken, (LNF-INFN, Italy and Kirikalle University, Turkey)

FCC-ee Injector Design Coordination meeting 20, December 5th 2024

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Management and Manpower

A new collaboration agreement between INFN and CERN is in preparation:

- it will replace the Addendum FCC-GOV-CC-0205 (KE 4907) expired on past October,
- It must be compliant with the CHART 2025 – 2028 also under definition.

Simone Spampinati concluded his work contract at LNF we are preparing for him an associate contract similar to the one we gave to Ozgur Etisken.

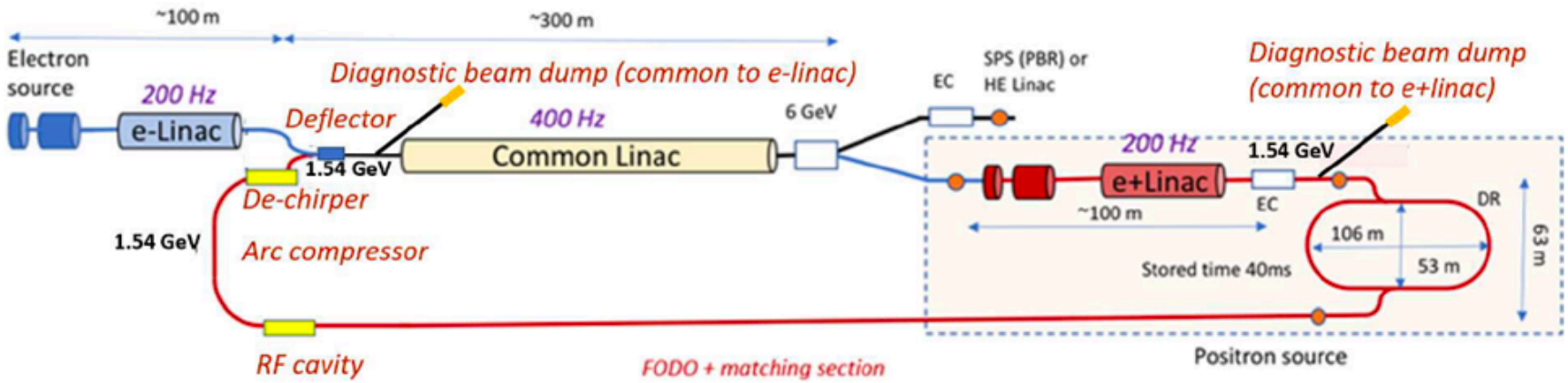
Selection to hire two new collaborators have been completed and winner have been appointed:

- Yongke Zhao
- Shalva Bilanishvili

They should be operative by the beginning of 2025.

March 2024
Design mature
Cost evaluation done

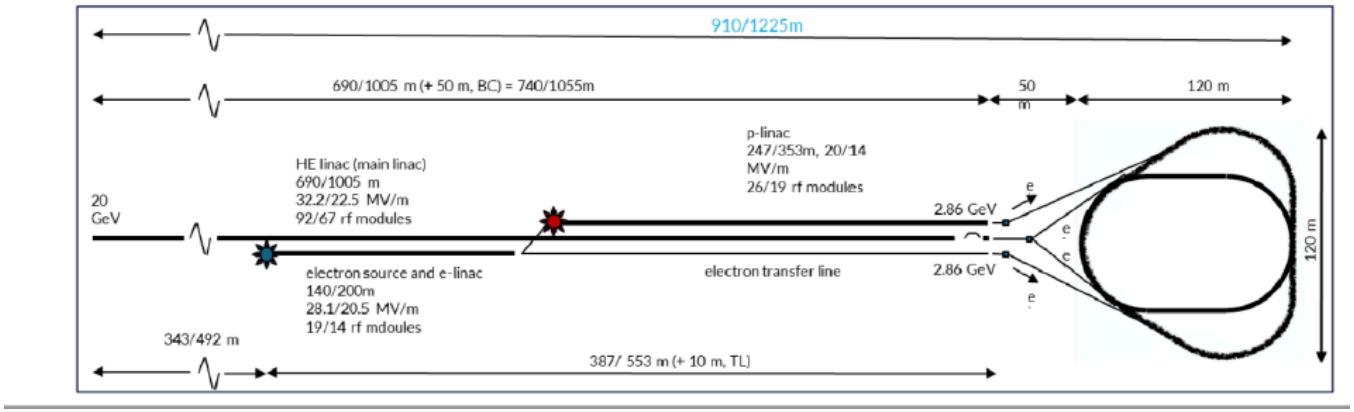
FCC-ee Injector



New layout

Sketched layout becomes

P. Craievich / M. Benedikt



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e+/e- Damping Ring at 2.86 GeV Conceptual Design

Basic design criteria

Six-fold symmetry layout in order to provide:

- best use of allocated space;
- flexible dedicated injection/extraction sections;
- dedicated Rf section;
- wide flexibility in independently tuning the ring working point, and in general operations;
- overall dimension 122m x 122m.

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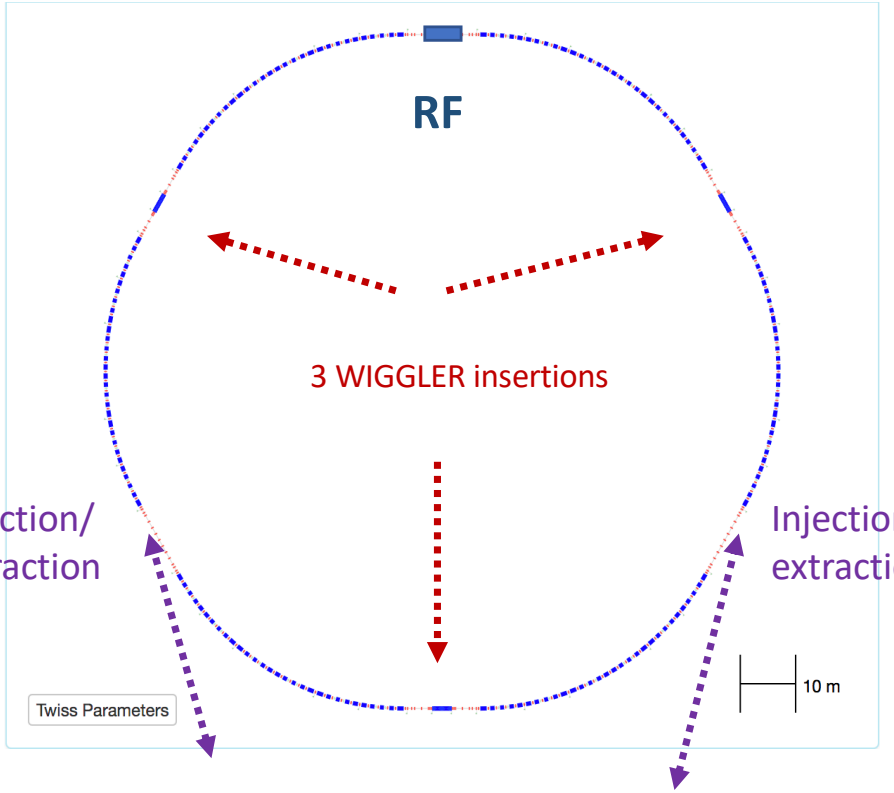
Damping Ring Layout

Six arc cells (60 deg. each) providing, low emittance, damping time, and low non-linear contributions aiming at large beam acceptance.

3 WIGGLER insertion $\eta = \eta' = 0$ in the arcs to enhance damping

3 straight sections based on FODO cells, each of them devoted to:
injection/extraction
RF cavity



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Damping Ring Optics Options

Several options have been considered for the arc cell based on :

- *FODO*
- *Multi-bend*
- *Multi-bend achromat*

Multi-bend lattice is more effective in providing
Low H5 function
Lower betatron oscillation amplitude
Flexibility for chromaticity correction

Final decision requires DA, and beam acceptance studies.

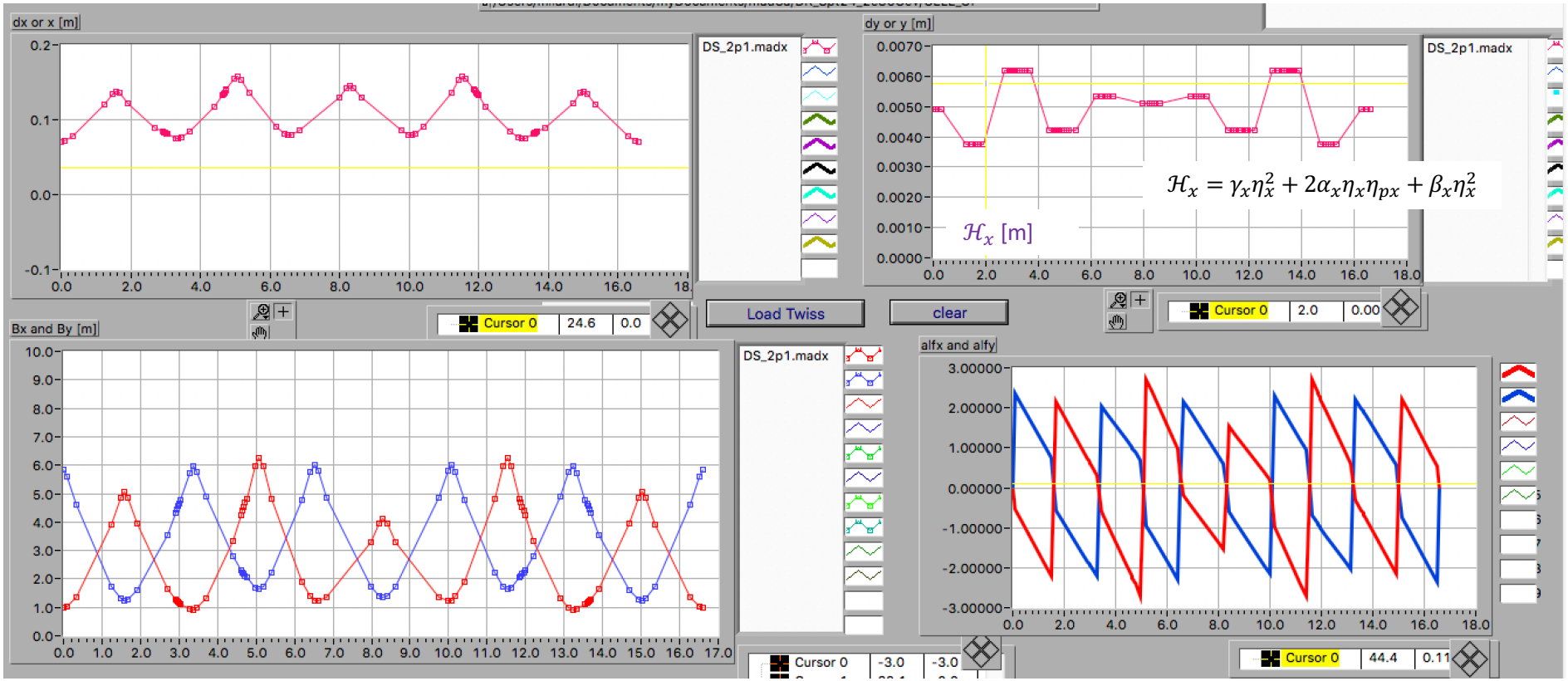
Multibend Arc Cell

Each arc cell includes 10 dipoles of 5 different type

adl1a*180/pi = 1.904562835e+00 deflection angle degree
adl2a*180/pi = 2.187680194e+00
adl0a*180/pi = 1.815531878e+00
adl3a*180/pi = 2.187680194e+00
adl4a*180/pi = 1.904562835e+00

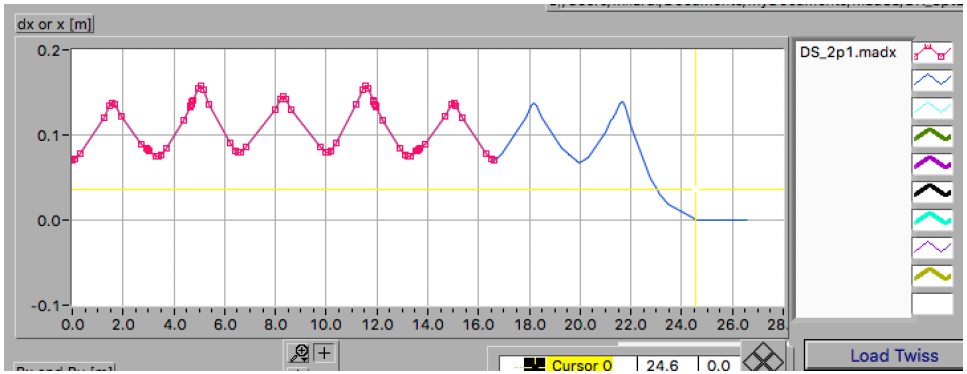
(adl1a+adl2a+adl0a+adl3a+adl4a)*2*180/pi = 2.000003587e+01 ;

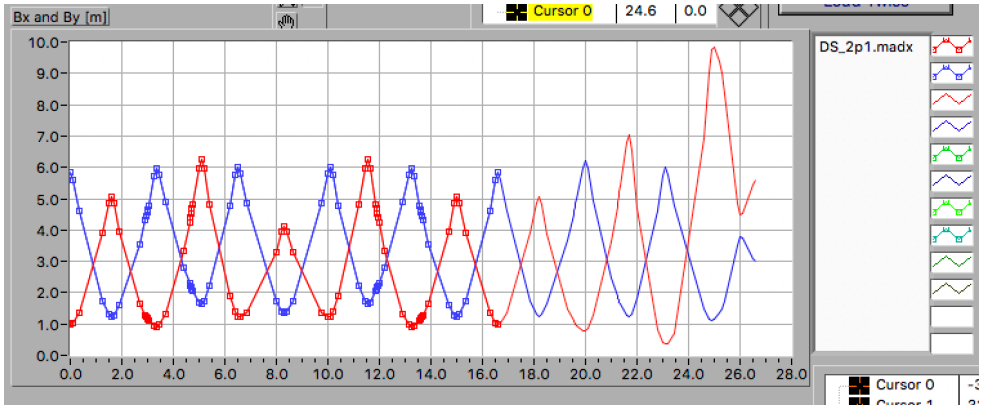
ldl1a = 9.313160749e-01 length m
ldl2a = 7.921526987e-01
ldl0a = 7.012254558e-01
ldl3a = 7.921526987e-01
ldl4a = 1.132217066e+00
adl1a*br/ldl1a = 3.405029699e-01 magnetic field T
adl2a*br/ldl1a = 3.911194682e-01
adl0a*br/ldl1a = 3.245857709e-01
adl3a*br/ldl1a = 3.911194682e-01



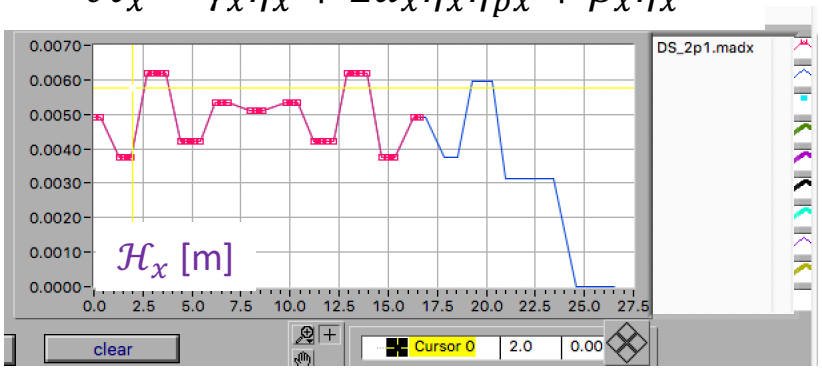
10 Bends, 11 Quads, 4 SXTs

Arc Cell + η_x suppressor

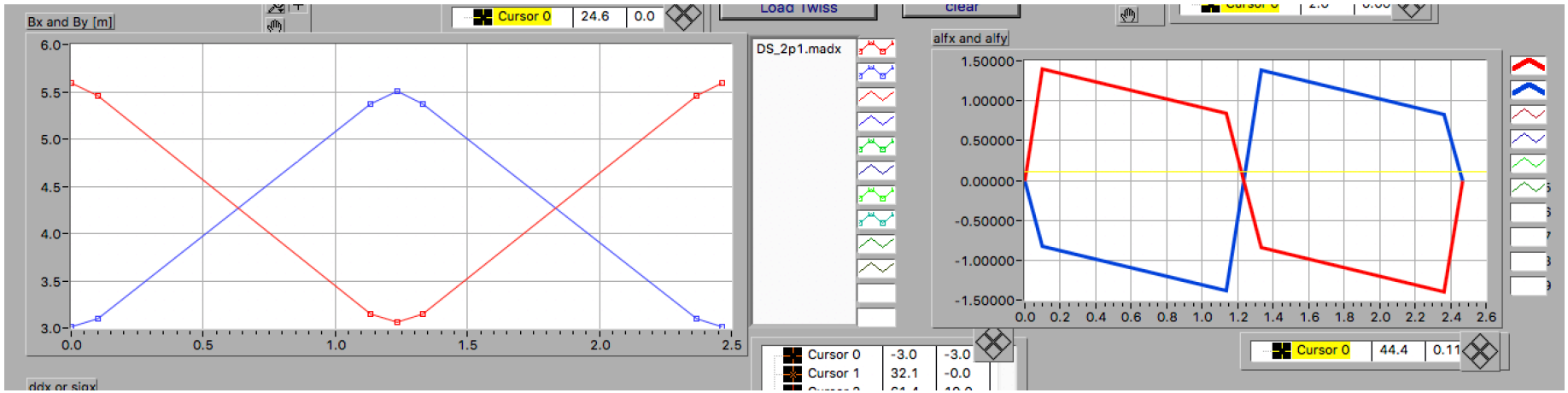




$$\mathcal{H}_x = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_{px} + \beta_x \eta_x^2$$



FODO Cell


Bx and By [m]
Cursor 0
24.6
0.0
Load Twiss
Clear
DS_2p1.madx
alfx and alfy
Cursor 0
-3.0
-3.0
Cursor 1
32.1
-0.0
Cursor 0
44.4
0.11
ddx or sigx

Wiggler Parameters

$$U_0 = 2E_0 \frac{T_0}{t_y}$$

$$U_0 = 2E_0 \frac{T_0}{t_y}$$

Achieving $t_y = 10$ msec requires $U_0 = 726.24$ keV

$U_0^{dip} = 246.7$ KeV

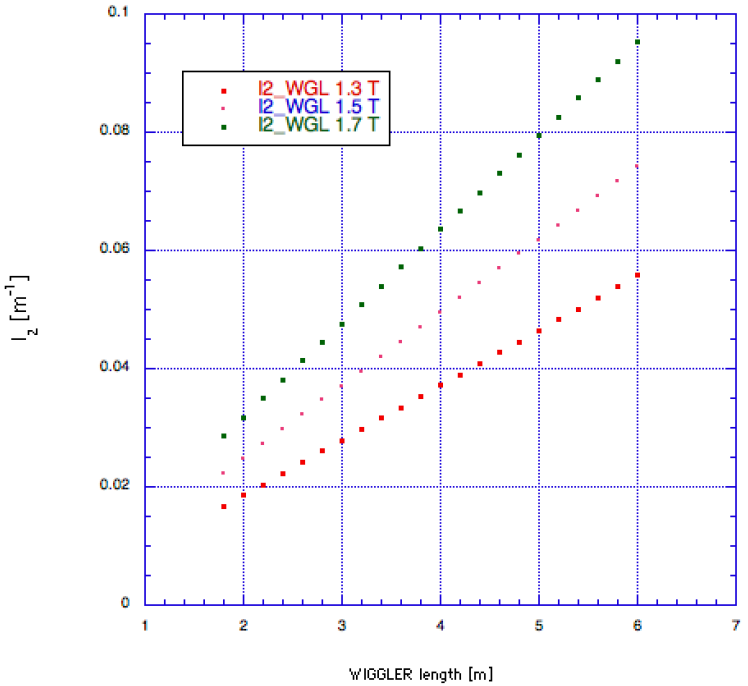
$U_0^{wgl} = 479.54$ keV assuming 3 WGLs 159.85 keV per WGL

Wiggler Parameters

$$I_2^{wgl} = \frac{B_{wgl}^2 L_{wgl}}{2(B\rho)^2}$$

$$U_0 = \frac{1}{2\pi} c_\gamma I_2 E_0^4$$

$$U_0^{wgl} = \frac{c_\gamma E_0^4 \, B_{wgl}^2 L_{wgl}}{4\pi(B\rho)^2}$$



$$B_{wgl}^2 L_{wgl} = fact * U_0^{wgl}$$

fact = 1.403378 [T^2 m sec]

In the present DR version:

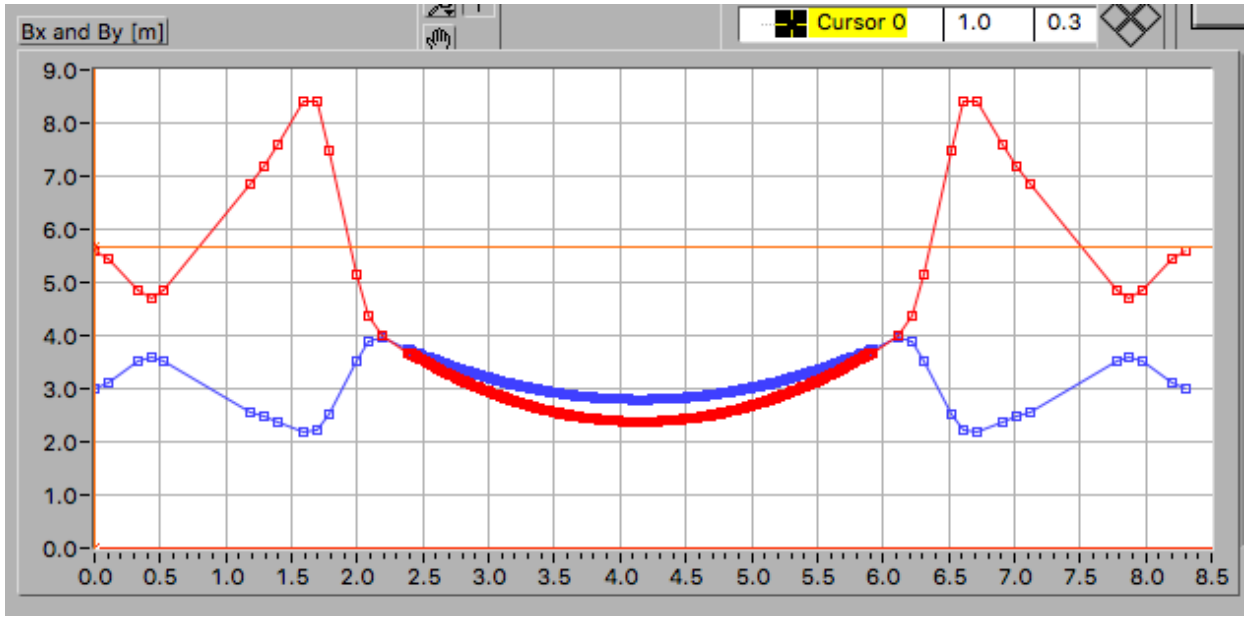
B_{wgl} = 1.8 T

L_{wgl} = 3.5 m

November 11th 2024

Wiggler Insertion

nper = 6.900000000e+01
lw = 0.05 m
angwig = 1.625014651e-01 degree
pole length ~ 0.02 m



Wiggler magnet length and field
3.5 m
1.8 T $\tau_{x,y}$ **~ 16.9 msec (using 3 insertion)**

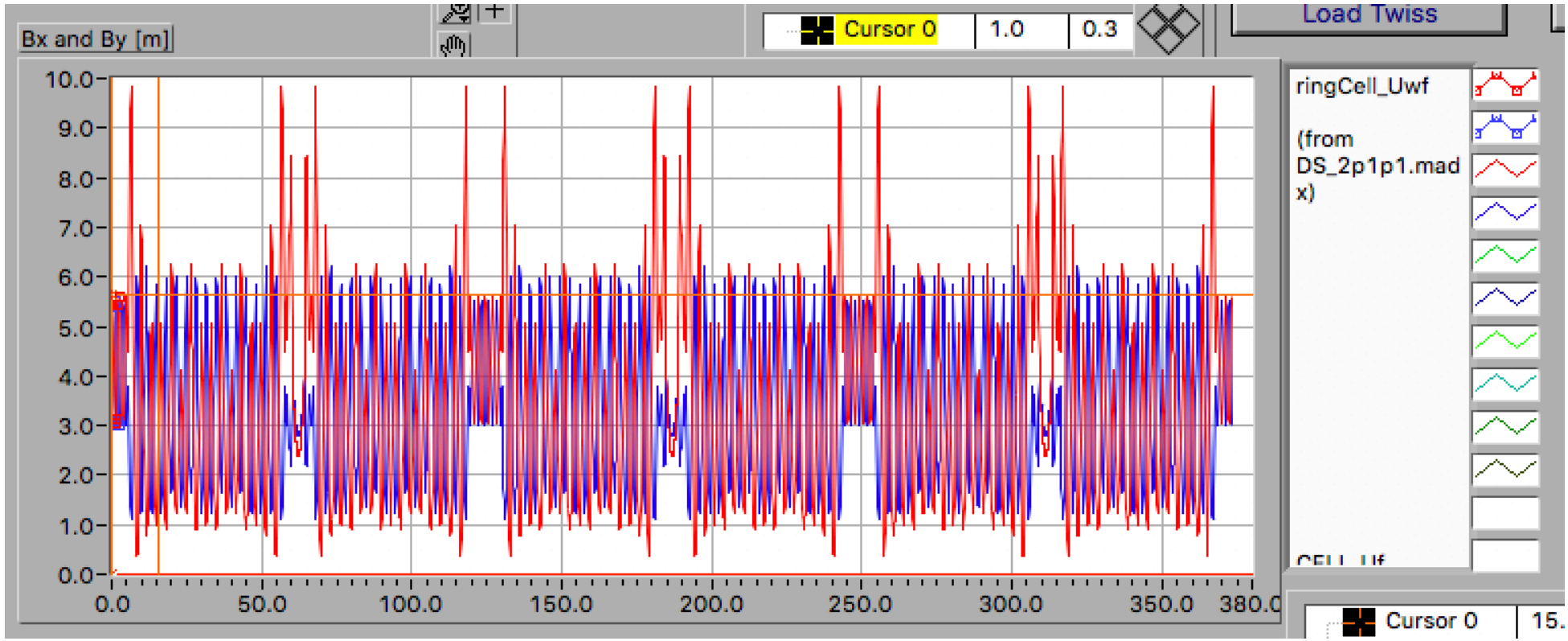
Insertion optics improved
$\tau_{x,y}$ is shorter wrt the version presented on Nov. 11th

Chromaticity Correction

3 Sextupoles families (not yet optimized)

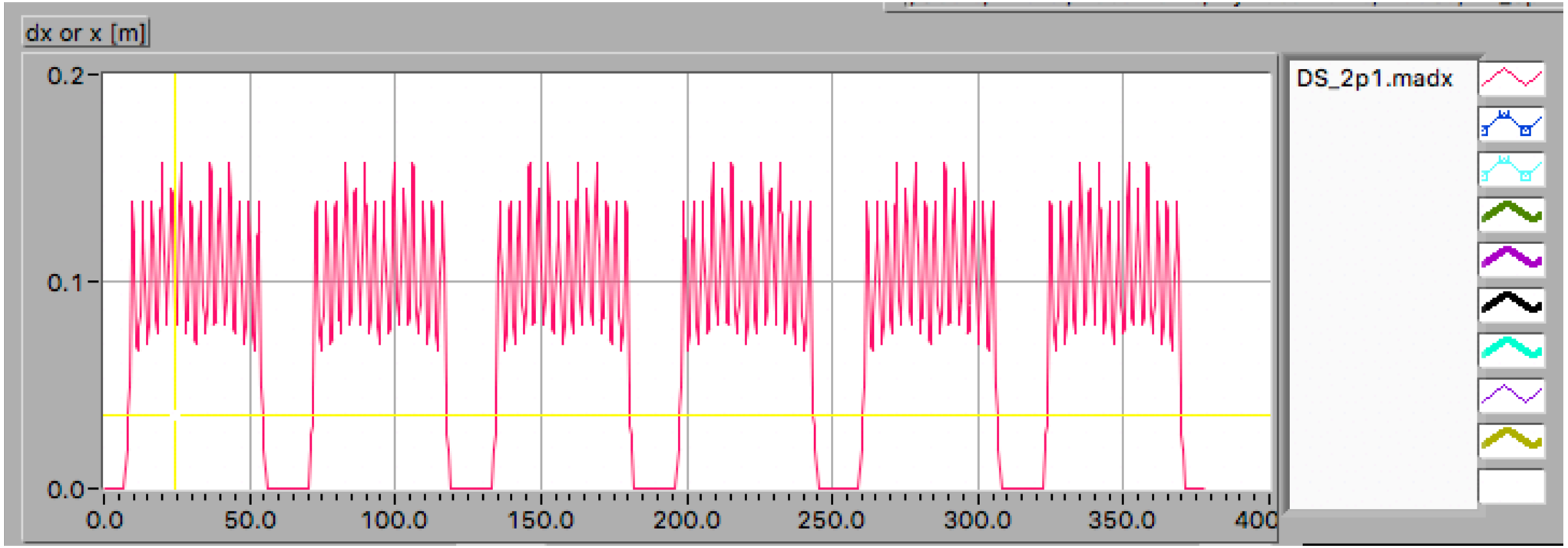
ksf1	9.86397e+01	m^{-3}
ksd1	-8.13142e+01	
ksf2	-1.00334e+02	

Twiss Parameters



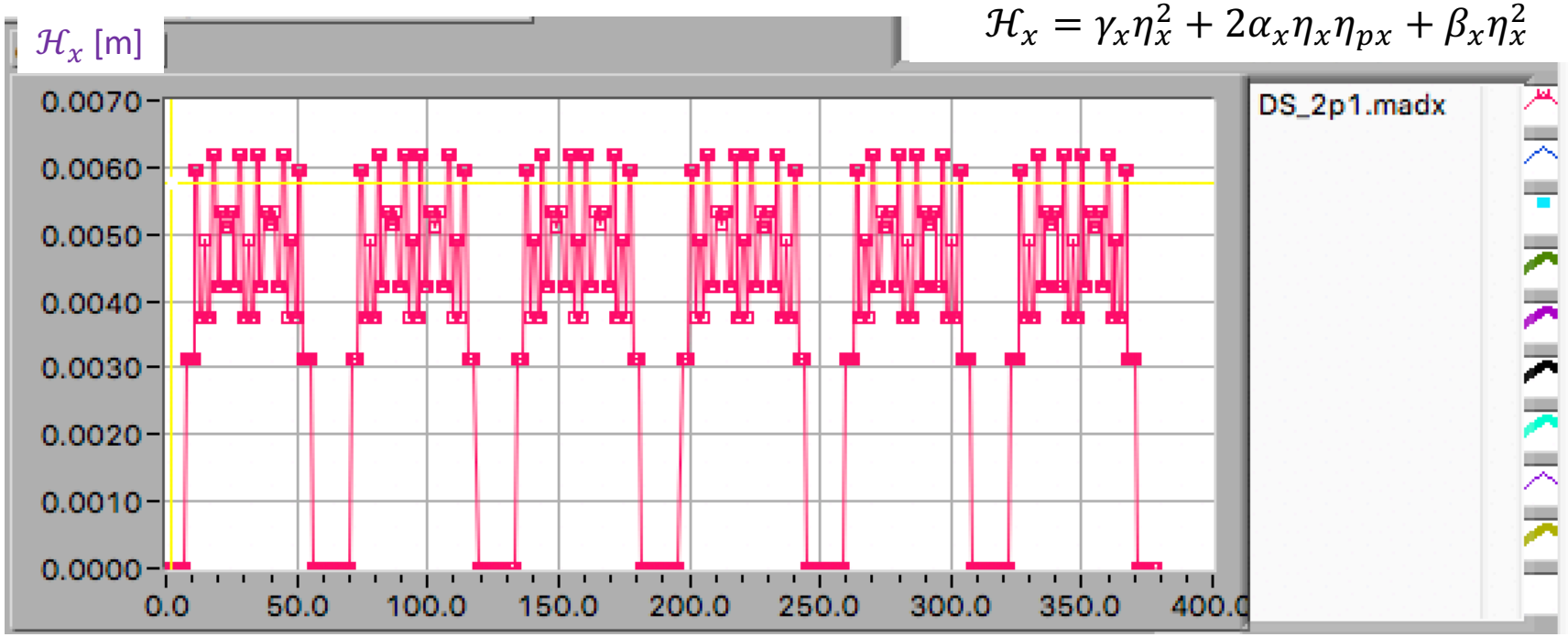
Ring is shorter wrt the version presented on Nov. 11th

Twiss Parameters



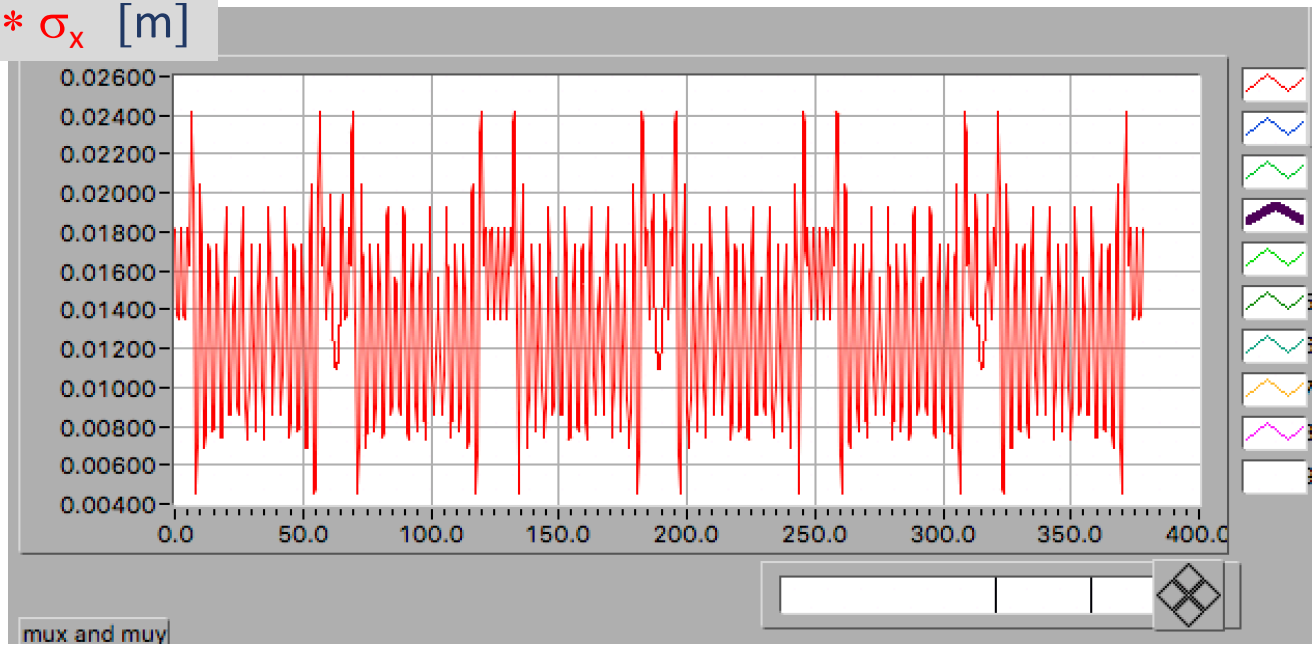
Twiss Parameters

$$\mathcal{H}_x = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_{px} + \beta_x \eta_x^2$$

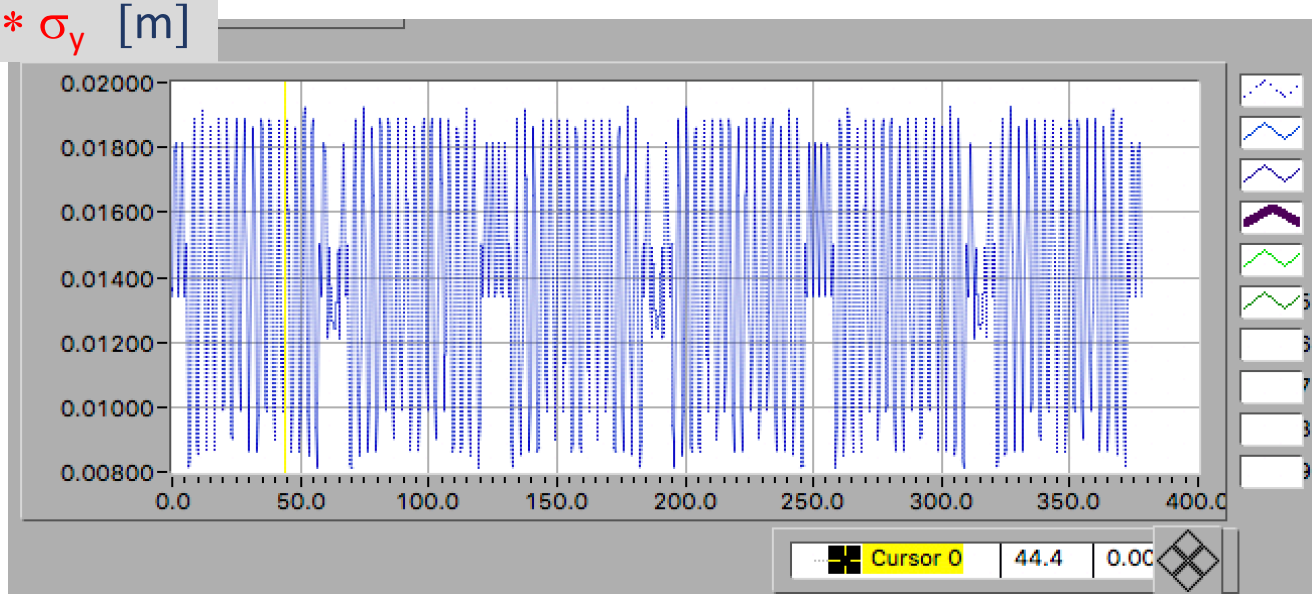


Beam Envelope

$5 * \sigma_x$ [m]



$5 * \sigma_y$ [m]



First turn

$\varepsilon^{inj}_{x,y}$ = 2.38E-6 mrad;

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DR parameters

For the most promizing option at the moment

	DS_2p1p1.madx	
Energy [GeV]	2.86	2.86
Circumference [m]	3.7346e+02	3.7346e+02 + 25
Lattice	6-fold symmetry based on Multi-bend arc	
Br [Tm]		
Nat geo emit WGL off /WGL on	2.23 / 1.3 e-09	/ 1e-9
Nat bunch lenght		
Natural E spread WGL off /WGL on	5.076 e-04 / 7.2 e-04	/ 8.207e-04
Damp Time x,y WGL off / WGL on [msec]	2.937e-02 , 2.924e-02 / 1.69e-02 , 1.69e-02	/ 1.26e-02, 1.26e-02
Mom. Comp. WGL off /WGL on	1.552e-03 / 1.571895839e-03	1.552e-03 / 1.484e-03
Tune x,y		
E loss per turn [GeV] WGL off /WGL on	2.467e-04 / 4.22134e-04	2.467e-04 / 5.976e-04
T_0 [sec]	1.2457e-06	1.319244341e-06
Num Bends	179	
1 WGL length [m] / field [T] / n WGL	3.5 / 1.8 / 3	3.5 / 1.8 / 6
Nat cromaticity x/y	-38.2 , -28.3	
betx / bety Max [m]	9.66 / 6.49	
betx / bety min [m]	0.5 / 1.1	

Several Wiggler sections have been studied
Each section includes 4 wiggler magnets
Each wiggler parameters

- 3.5 m
- 1.9 T

tx = 6.950088510e-03 ;
ty = 6.932373325e-03 ;
tz = 3.461774778e-03

hemit = 3.198602875e-09 ;

Wiggler Insertion

Damping time can be efficiently reduced by increasing the number of wiggler insertions in the ring.

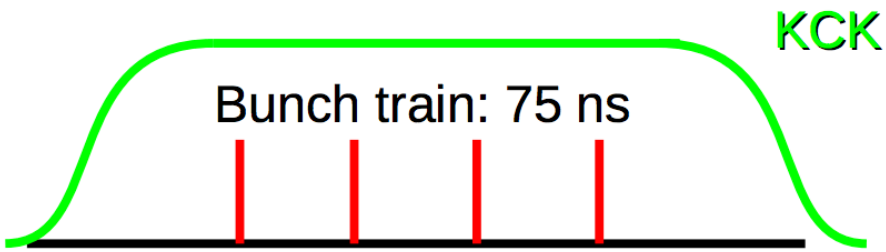
Till now configurations with 3 – 6 – 12 insertions have been preliminary studied

However, Wiggler magnets introduce several limitations

- are source of non-linearities,
- Give a major contribution to the e-cloud formation harmful for e+ operations that must be mitigated by properly beam pipe design, require demanding vacuum equipment design and expensive device realization.

Final evaluation about the optimal Wiggler insertion number requires DA, and beam acceptance, and collective effects studies.

Injection Strategy and Damping Time



$$n(train) = \frac{T_{per}}{\Delta t + t_K} \simeq 10$$

$$\epsilon(t) = \epsilon_{inj} e^{-\frac{2t}{\tau}}$$

$$T_{store} = -\frac{\tau}{2} \ln \frac{\epsilon_{ext}}{\epsilon_{inj}} \simeq 5\tau$$

$$\tau \leq \frac{n(train) T_{pulse}}{5(\Delta t + t_K)} \simeq 20 \text{ ms}$$

T_{per} revolution period ~ 1.25 μsec
Δt batch length form LINAC ~ 75 nsec
t_K kicker rise time ~ 50 nsec

Assuming to inject 10 batches from the LINAC with $\varepsilon^{inj}_{x,y}$ = 2.38E-6 mrad

(Courtesy of A. De Santis)

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Conclusions

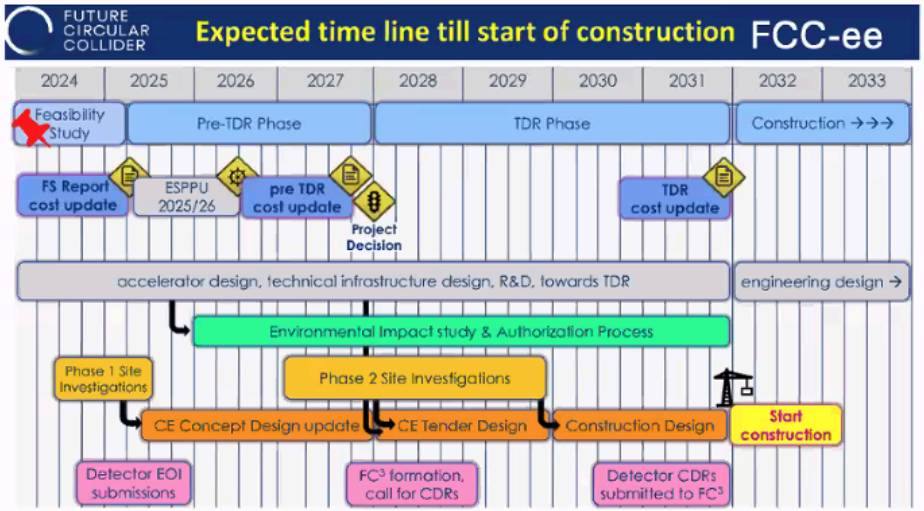
We have a solid baseline design for the high energy DR

Da and acceptance studies must be done but we are convinced that the modular structure of the ring will help us in the optimization process

A preliminary desig for the energy and bunch lenght compressors has been prepared as well as some preliminary TLs layout.

Thank you

Time plan FCC-ee and FCC-ee Injector



FCC-ee Injector: Technical Design Report, 2025-2028:

- Following the completion of the Feasibility Study phase (March 2025), a preliminary technical design report (pre-TDR) will be produced by mid-2027.
- The objective of the pre-TDR is to provide detailed specifications for the accelerator and technical infrastructure requirements necessary for the initial phase of the civil engineering (CE) design.
- By the end of 2028, the final Technical Design Report (TDR) for both the accelerator and the technical infrastructure will have been completed.

Injector Project schedule (as proposed by Michael Benedikt in preliminary discussion)

- Start 2028 – end 2030 CE design and tendering (3 years)
- Start 2029 – end 2031 Accelerator engineering and technical infrastructure designs
- Start 2030 – end 2033 Civil construction (4 years)
- Start 2031 – end 2040 Component production (assuming similar production rates for RF structures as for SwissFEL)
- Start 2034 – end 2036 Technical infrastructure installation
- Start 2035 – end 2040 Component installation and testing
- Start 2042 beam commissioning

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