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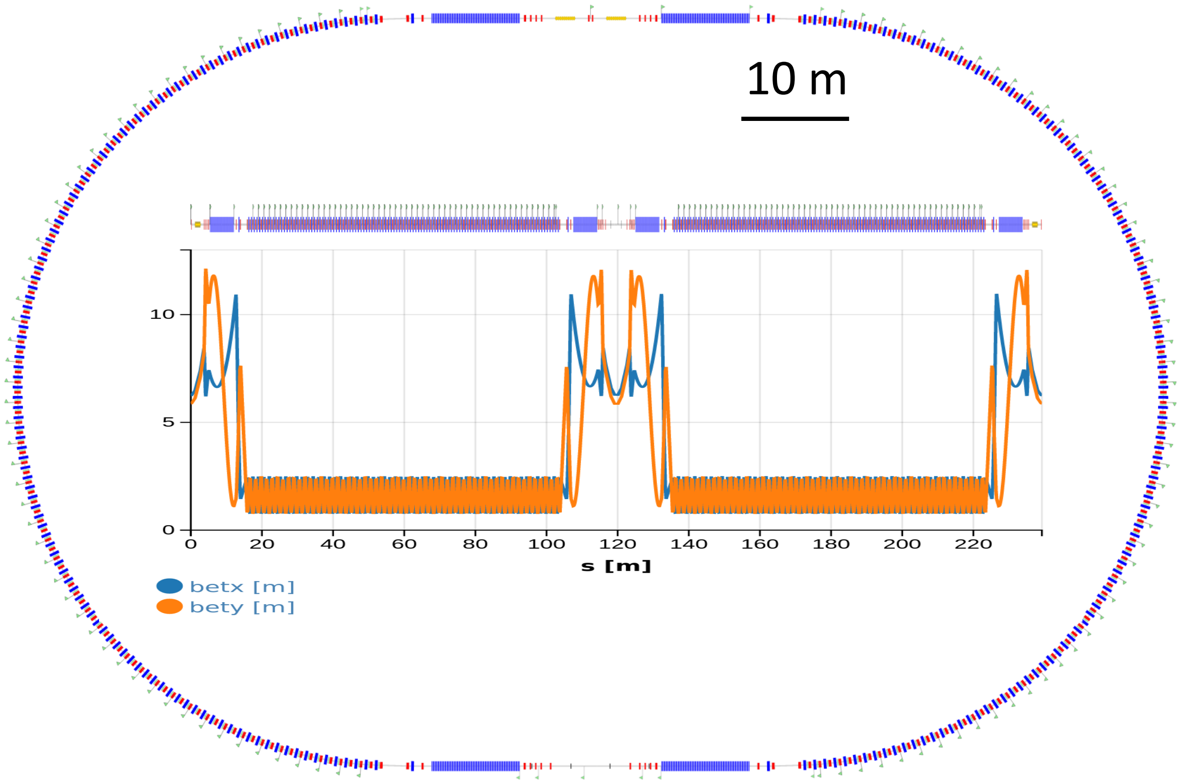
FCC-ee pre-Injector
WP4
Damping Ring, and Transfer General Status

Milardi C., De Santis A., (LNF-INFN, Italy)
Etisken O., (Kirikalle University, Turkey, and LNF-INFN Italy)
Ramjiawan R. L., Y. Dutheil , (CERN, Geneva, Switzerland)

Damping Ring

Damping Ring optics has been optimized starting from the layout initially proposed by K. **Oide** and S. **Ogur** in 2020, with special attention to: dynamic aperture evaluation, beam acceptance and injection section design.

Parameter	FCC_ee DR (CDR)
Circumference	241.8 m
Equilibrium emittance (x/y/z)	0.96 nm/ - /1.46 µm
Dipole length, Field	0.21 m / 0.66 T
Wiggler #, Length, Field	4, 6.64 m, 1.8 T
Cavity #, Length, Voltage	2, 1.5 m , 4 MV
Bunch # Stored, Charge	16, 3.5 nC
Damping Time $\tau_x/\tau_y/\tau_z$	10.5 / 10.9 / 5.5 ms
Store Time	40 ms
Kicker Rise Time @1.54 GeV	50 ns
Energy Loss per Turn	0.225 MV
SR Power Loss Wiggler	15.7 kW



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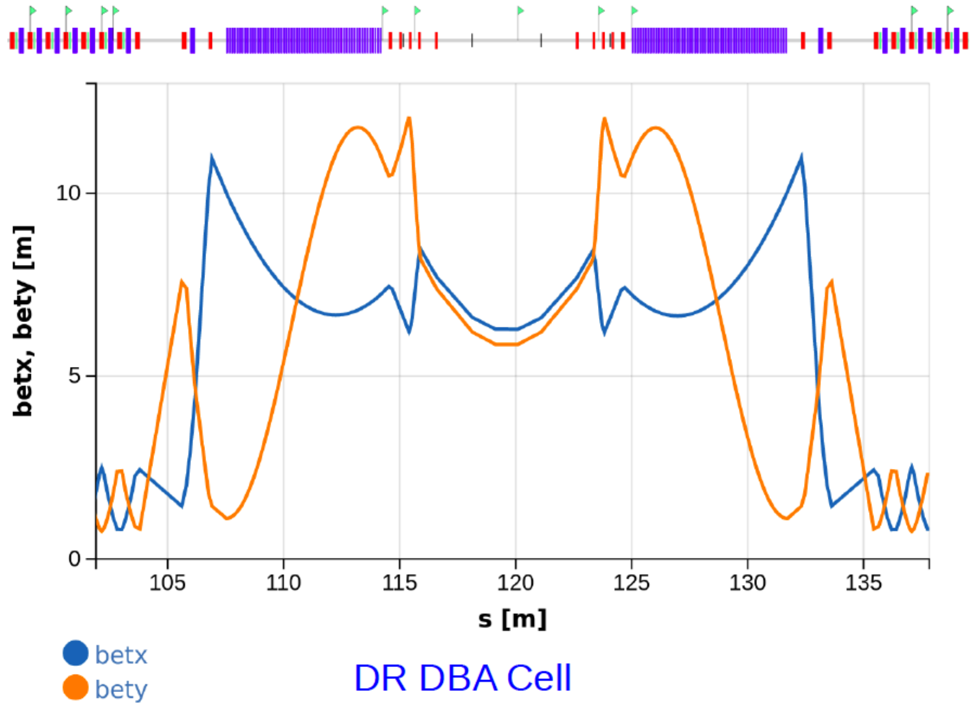
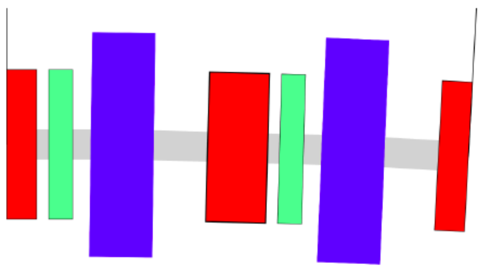
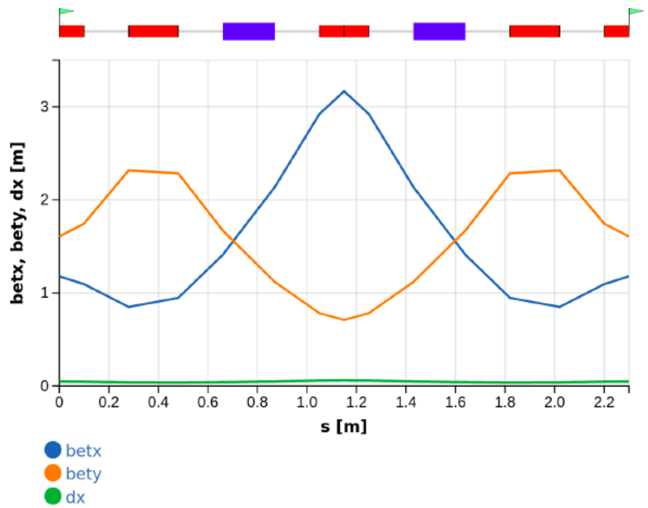
Damping Ring Optics



DR DBA Cell



Straight section details.
Two of the four wigglers are shown.
Straight sections are designed to host RF cavities and Injection/Extraction equipments.



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Damping Ring

Comprehensive ***tools for tracking studies*** have been set up.

Dynamic aperture has been evaluated over a wide δ_E range (± 4%).

DR ***longitudinal beam dynamics*** parameters have been evaluated in the approximations:

stationary bunches
equilibrium conditions
assuming to install on the ring the 400 MHz LHC type SC RF cavity

A preliminary estimated of the ***RF power*** necessary to restore the incoherent synchrotron radiation emission has been done considering the bunch filling scheme of the DR.

A preliminary parametric analysis aimed at evaluate the impact of **collective effects** has been done for an intermediate DR layout version, it must be repeated for the latest DR optics.
Collaboration with other LNF expert and with La Sapienza have been established in order to address more systematic studies.

DR Beam Dynamics Parameters

Relying on DR parameters:

E_s = 1.54 GeV

L = 239.2628817 m

$\alpha_c = 0.001535$

$\boldsymbol{h = 319}$

	V= 8MV	V= 6MV	V= 4MV	V= 2MV
U_0 [KeV]	227.1			
DE/E_s	0. 71 • 10^{-3}			
Ω_s [KHz]	25.313	21.918	17.888	12.618
T_0 [μsec]	0.79801			
ω_0 [s^{-1} rad]	7.87 10^6			
ν_s	0.003215	0.00278	0.002272	0.0016
L_{bunch}[m]	**0.00207**	0.00239	0.00293	0.00415
φ_s [rad]	0.0283967	0.0378663	0.0568164	0.113817
(E – E_s) [GeV]	0.124	0.107	0.0862	0.058
$\Delta\varphi$ [unit of π]	1.8	1.7769	1.7269	1.6016
L_{bucket}[m]	0.6788	0.6664	0.6476	0.6006

Short bunch length can be an issue:

- lifetime,
- injection must be carefully tuned,
- impedance and bunch lengthening more harmful,
- beam coupling with RF system
- CSR,
- IBS,
- beam instability impact.

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Injection/Extraction timing

A general scheme to implement injection/extraction process in/from the DR has been proposed, it aims at:

- making the DR filling with bunches as uniform as possible,
- assuring the proper storing time suitable for e^+ beam damping,
- providing the necessary delay time, 2.5 msec, required to guarantee single beam, species operations in the common LINAC,
- keeping timing properties of injection kickers pulse compatible with the state of the art in the field.

Concerning:

DR acceptance

Evaluation of positron capure yield

Details will be presented in the Antonio De Santis talk.

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Rationale for a New DR Layout

Motivations to review the DR design:

- The latest DR optics uses a quite large number of elements (232 dipoles) which determine:
  high number of components such as: quadrupoles, sextupoles, octupoles, steering magnets, and beam diagnostics
  high realization costs,
  complicate installation and alignment procedures.
- Injection section can be optimized
- Long damping WIGGLER magnets (the CDR includes 4, 6.64 m long magnets)
- Magnetic field intensity in the dipole is rather low and can be safely pushed toward values higher than 0.66 T,
- Having 3-4 straight sections, instead of 2, might be better in terms of NLD and to avoid interferences among: damping wiggler magnets, RF and injection/extraction.
- Arc cells phase advance for the beam emittance damping can be optimized.

Preliminary design approach:

- Higher magnetic field which makes damping time shorter,
- Less magnets leding to larger emittance,
- Optimum phase advance for the FODO lattice,
- Three straight sections,
- Robinson WIGGLER has been added for emittance cooling.

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Starting from extensive parametric analysis an alternative DR layout has been defined.

As a latest approach we are considering to adopt combined function dipole for the arc cell bending magnets, in order to optimize ring parameters and achieve a more compact layout.

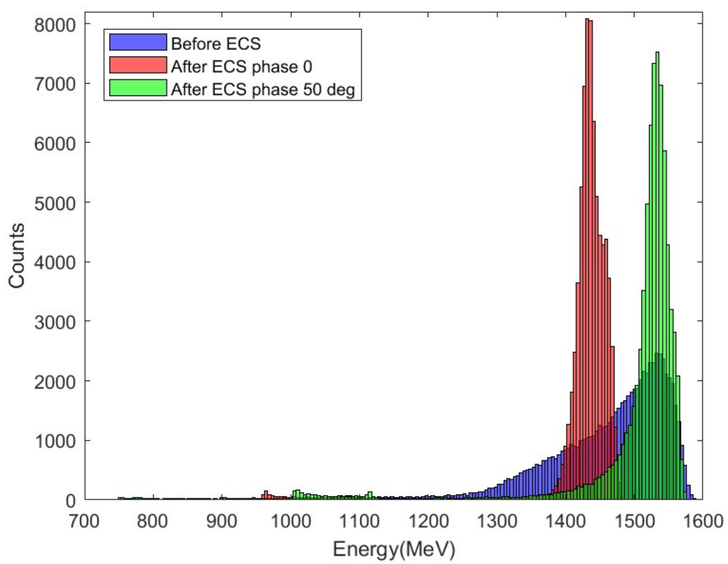
Higher energy DR option seems also very interesting to study.

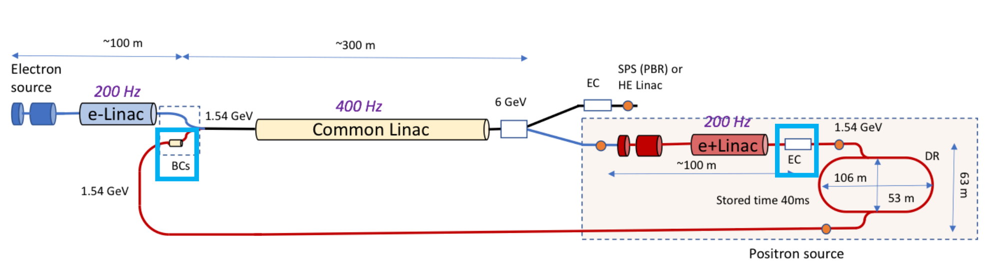
Details will be presented in the Ozgur Etisken talk.

Energy Compressor

- Energy compressor reduces the width of the energy distribution and increases the number of particle accepted by the DR
- Elegant tracking of the distribution provided by Mathias
- Preliminary consideration about the bunch compressor design

Details will be presented in the Simone Spampinati talk





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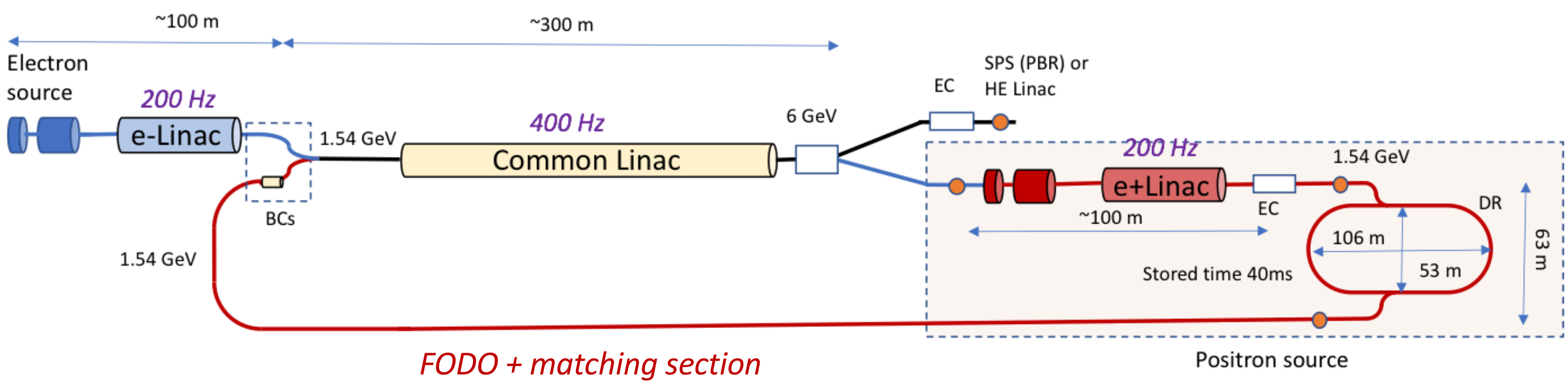
Transfer Lines

Several injector layout have considered with different TL arrangements

Latest FCC-ee injector layout 6 GeV option (since April 2022)



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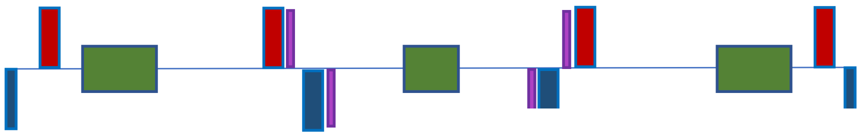
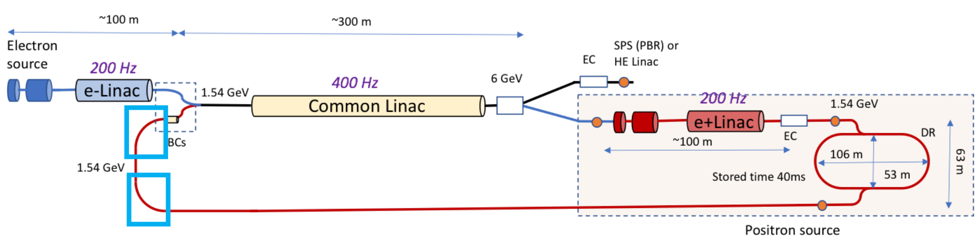
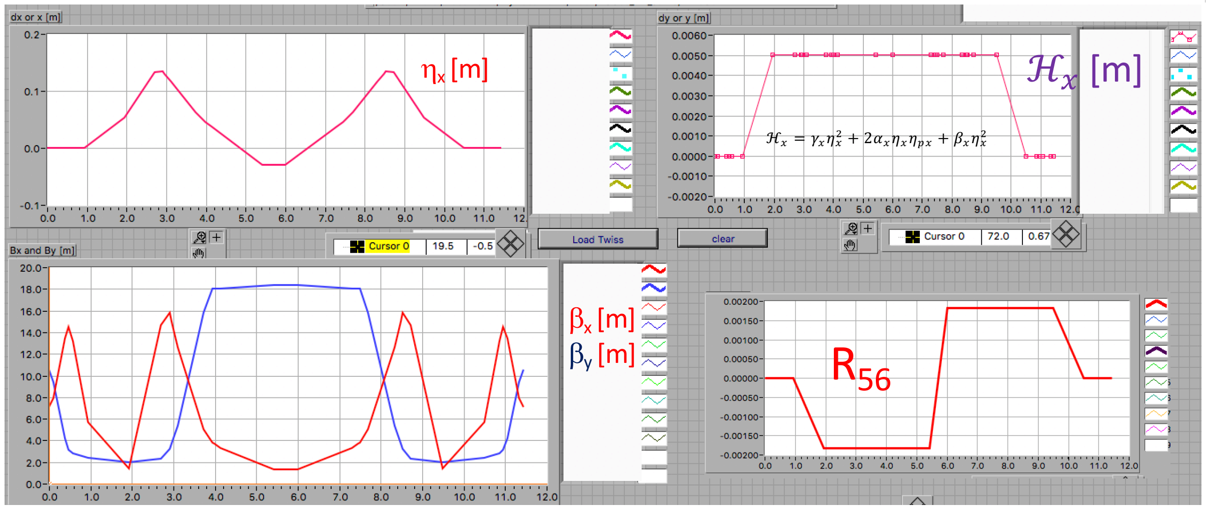
Triple Bend Achromat Cell for Arcs





θ_b [rad]	0.104719
L_b [m]	1.0/0.5767
ρ [m]	5.736/3.304
B [T]	0.5366/0.9315
nQUADS	8
L_{QUA} [m]	0.2
L_{cell} [m]	11.435



Quadrupole gradient m^{-2}

K1qf	7.01
K1qd	-3.160
K1qfe	8.752
K1qde	-11.335

Sextupole gradient m^{-3}

K2sf
K2sd

- $\beta_{x,y} < 20$ m
- low η_x
- $\alpha_{x,y} = 0$ both ends
- achromatic
- isochronous
- low invariant

$q_x = 1.32$
$q_y = 0.31$

$\xi_x = -2.85$
$\xi_y = -3.71$

Present desig is going to be modified in order to provide R56 for BC

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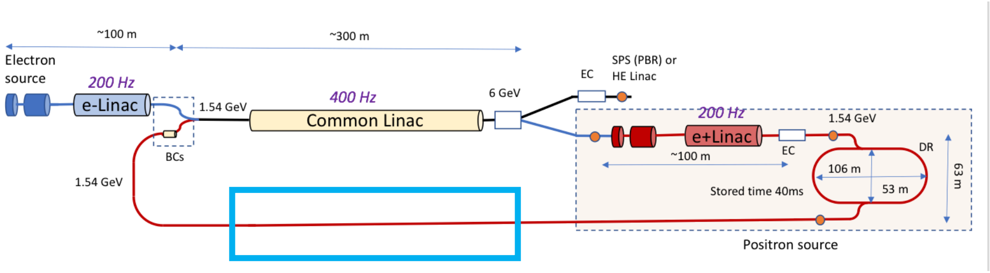
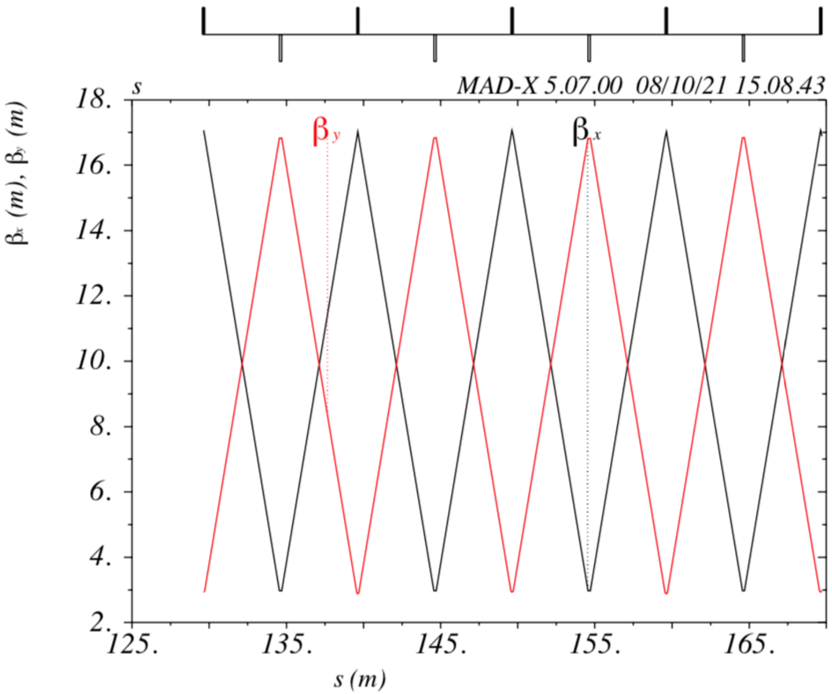
TL straight sections

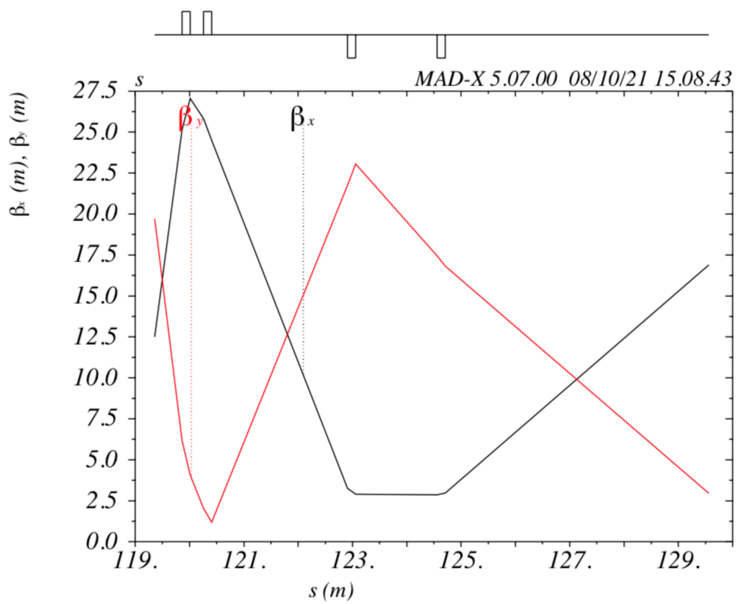


FODO Section



Matching Section

(between TBA and FODO)



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Damping Ring Injection

On - Axis injection in the horizontal plane

Incoming particles are injected on the ring nominal orbit at the end of the injection kicker.

Septum and kicker field must not perturb the stored beam

In order to minimize injection kicker strength septum must be as close as possible to the ring nominal orbit

Septum stray field must be very well shielded

TL Injection Section

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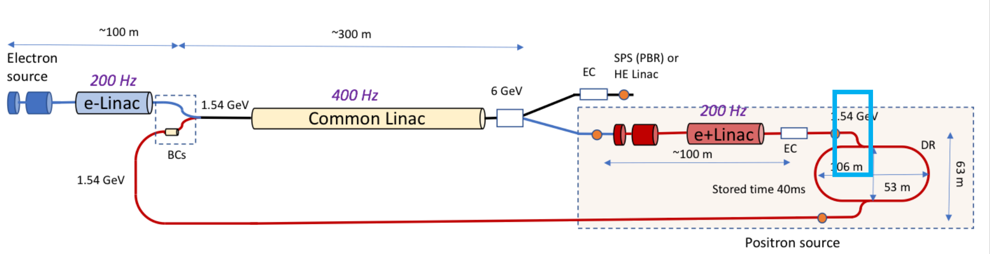
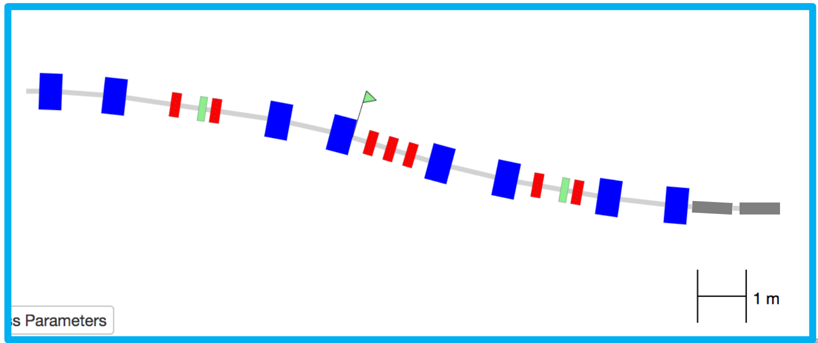
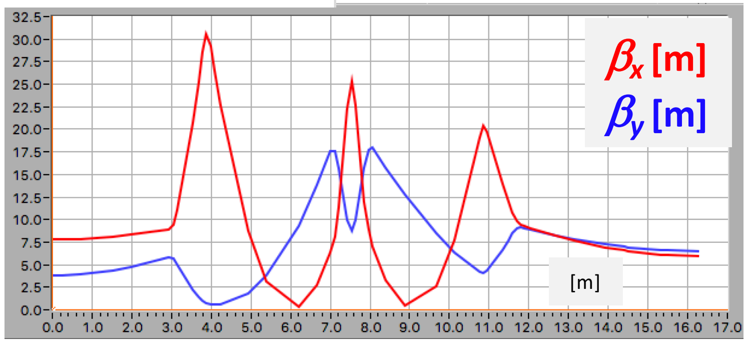
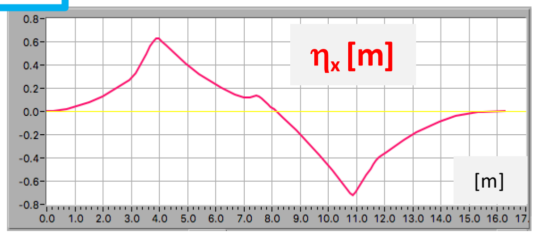
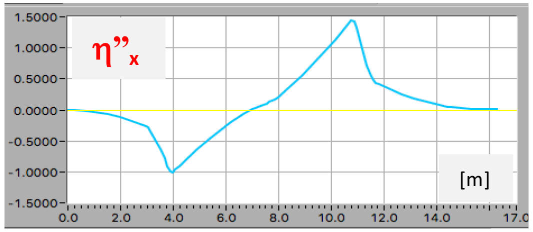




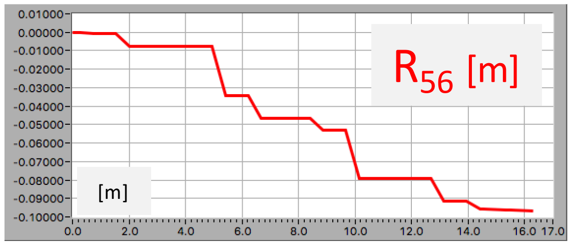


- *flexible*
- *achromatic*
- *R_{56} ~ - 9.5 cm*





	Angle [degree]	Length [m]	Field [T]	Thickness [mm]
B1	4.2	0.47	0.8	
B2	-3.4	0.47	-0.65	
SPT1	-2	0.8	-0.044	7
SPT2	-1.2	0.8	-0.026	2 - 4



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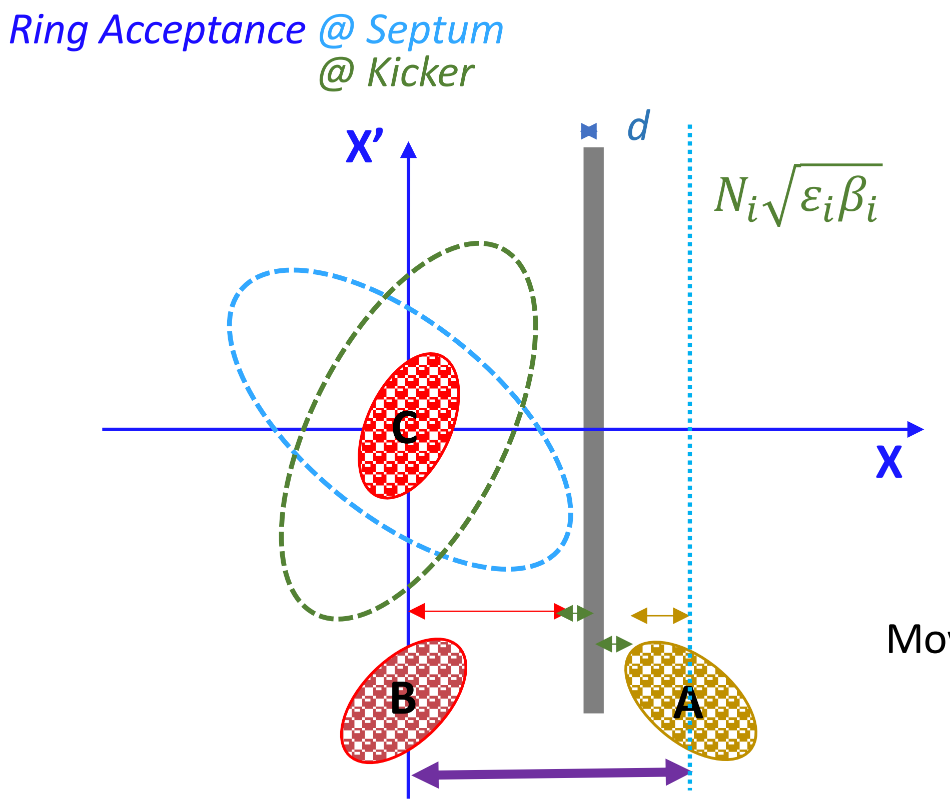
On-Axis Injection

Horizontal transverse phase space



***N_i** number of standard deviation of the incoming beam*
ε_i emittance of the incoming beam
***d** septum thickness*
*Incoming beam matched with the ring at the entrance **A***
*Beam injected on axis in **C***

$$x_{inj} = HW_{inj} + 2*trj + d + HW_{acc}$$

Moving to normalized phase space coordinates ***X, X'***

$$\boldsymbol{X} = \frac{x}{\sqrt{\beta}} \qquad \boldsymbol{X}' = \frac{(\alpha x + \beta x')}{\sqrt{\beta}}$$

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Kicker Strength

$$\begin{pmatrix} X_{kck} \\ X'_{kck} \end{pmatrix} = \begin{pmatrix} \cos\mu_x & \sin\mu_x \\ -\sin\mu_x & \cos\mu_x \end{pmatrix} \begin{pmatrix} X_{spt} \\ X'_{spt} \end{pmatrix}$$

$X_{spt} = x_{inj}$
$X_{kck} = 0$
X'_{kck} determined so to minimize kicker strength

With some algebra

$$\boldsymbol{X'_{spt}} = -\frac{\cos\mu_x}{\sin\mu_x} X_{inj}$$

$$\boldsymbol{X'_{kck}} = -\frac{X_{inj}}{\sin\mu_x}$$

Going back to the initial coordinates

$$x'_{spt} = -\frac{x_s}{\beta_{spt}}\left(\frac{\cos\mu_x}{\sin\mu_x} - \alpha_{spt}\right)$$

$$x'_{kck} = -\frac{x_s}{\sin\mu_x \sqrt{\beta_{spt}\beta_{kck}}}$$

$$\theta_{kck} = \frac{x_{inj}}{\sin\mu_x \sqrt{\beta_{spt}\beta_{kck}}}$$

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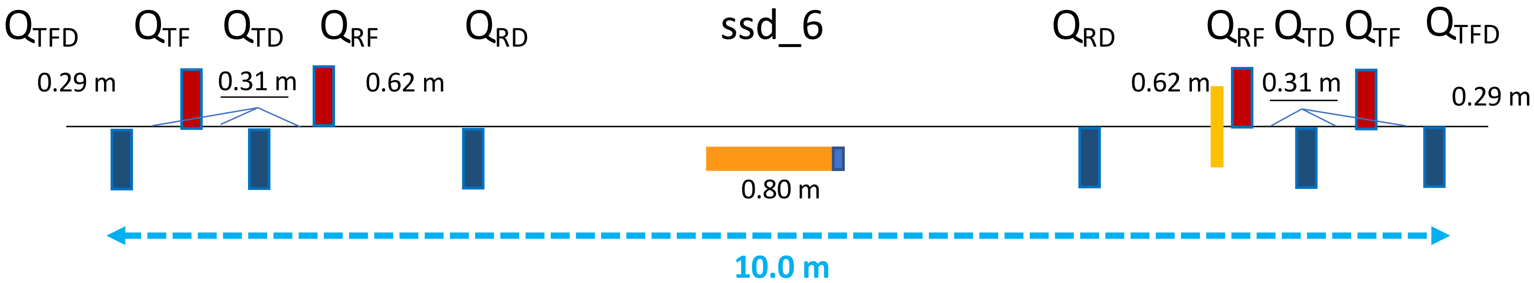
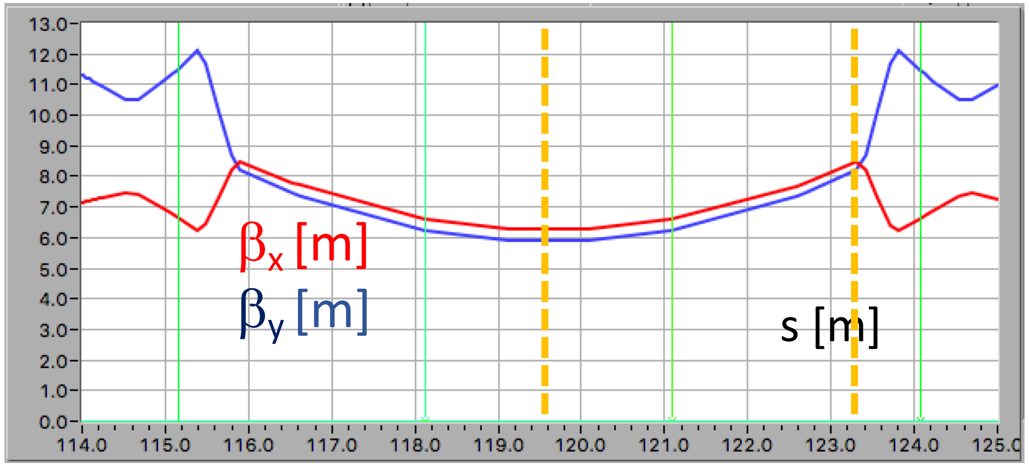
DR Injection Section



Twiss functions at injection septum:

- $\beta^{spt}_x = 6.3$ m
- $\alpha_{x,y} = 0$
- $\eta_{x,y} = 0$

$\beta^{kck}_x = 8.4$ m
Δmux(spt-kck) = 0.0728721
rather far from optimal



Ideal section no SXT
Injection Kicker position could be optimized
Twiss functions are not optimal for injection

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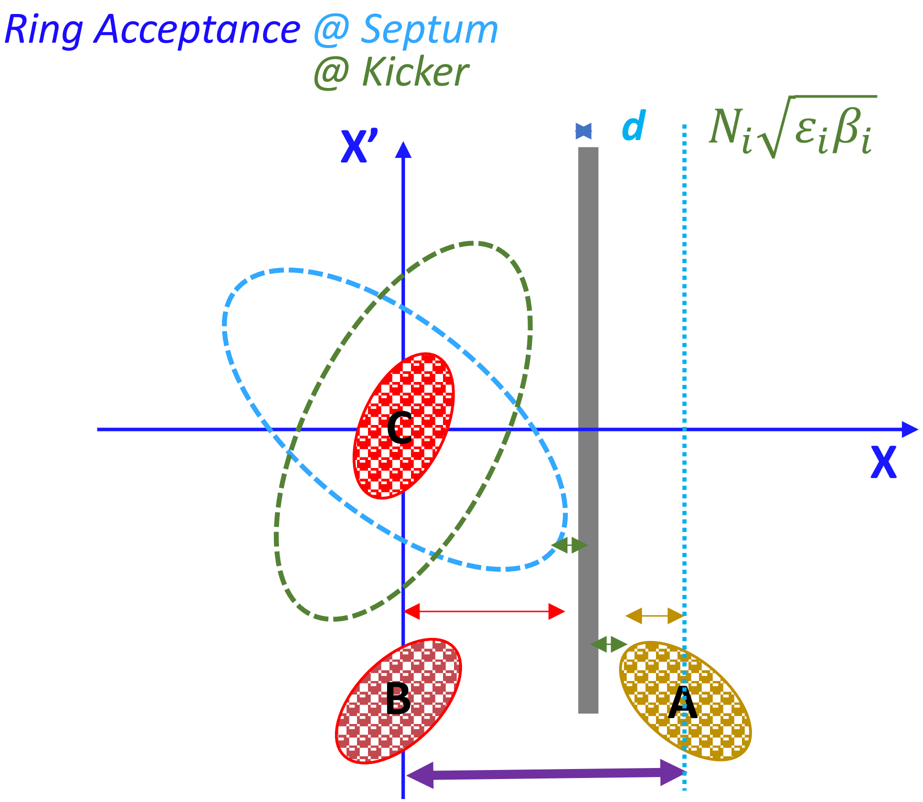
On-Axis Injection

$$\theta_{kck} = \frac{x_{inj}}{\sin\mu_x \sqrt{\beta_{spt}\beta_{kck}}}$$

Horizontal phase space



x_{inj} = HW_{inj} + 2*trj + d + HW_{acc}

HW_{inj} = 0.0055 m
2*trj = 0.002 m
d = 0.002 m
HW_{acc} = 0.006 m

x_{inj} = 0.0155 m

$$\theta_{kck}\,[rad] \sim 5\,mrad$$

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Conclusions

Systematic **tracking studies** have been set up in order to to characterize in detail transverse beam dynamics and evaluate DR acceptance at injection.
Dynamical Aperture has been evaluated for the latest DR optics and the latest positron beam parameters at the injection.

DR acceptance at injection is very good
New distribution at the end of the e+ LINAC will even improve the present result and will relax requirements on energy compressor.
Impact of lattice error has not been evaluated yet.

Longitudinal beam dynamics parameter have been computed for the beam equilibrium configuration assuming to install on the DR the 400 MHz LHC type SC RF cavity.

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Conclusions

Transfer Line design has been organized following high modularity criteria in order to cope with the unavoidable modifications.
Preliminary studies aimed at outlining possible CSR effect in the TL arcs have been done by using Elegant simulation code, no emittance dilution has been observed, however the exercise will be repeated with different codes.
A preliminary version of the DR injection/extraction section has been designed.

A preliminary parametric analysis aimed at evaluate the impact of **collective effects** has been done for the 'After CDR' DR layout version, it must be repeated for the latest DR optics.
Collaboration with other LNF expert and with La Sapienza have been established.

An injection/extraction timing scheme, compliant with the present injector layout, has been proposed.

Studies aimed at defining an optimized DR layout are under way, they will not enter in the next cost evaluation

Thank you

SPARES