FCC-ee Injector

WP4

General status, and Transfer Line Overview

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

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

FCC-ee Injector
project organization

WP0 - Coordination

WP1 – e+/e- 6 GeV Injector LINACs

WP2 - e+/e- LINAC extension studies

WP3 – Positron source: target and capture system

WP4 – Damping Ring and Transfer Lines

WP5 – CDR +

WP6 – PoP e+ source at SwissFEL

Coordinators:
Alexej Grudiev (CERN)
Paolo Craievich (PSI)

Laboratories involved:
PSI
CERN
IJCLab - CNRS
LNF -INFN

Agreement

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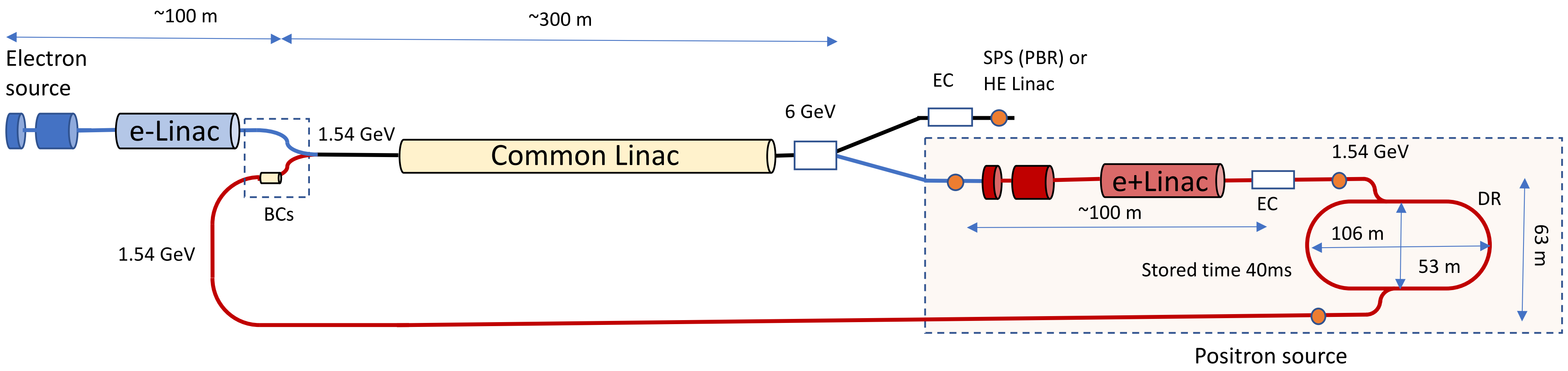
FCC-GOV-CC-0205 / 2419615 VERSION 1.0 (RELEASED) 18 September 2020

ADDENDUM FCC-GOV-CC-0205 (KE 4907)

The European Organization for Nuclear Research ("CERN"), an Intergovernmental Organization having its seat at Geneva, Switzerland, and INFN Laboratori Nazionali di Frascati ("INFN-LNF") Hereinafter each individually referred to as a "Party" and collectively as the "Parties".	
This Addendum defines a contribution by one or more Participants under Article 6 of the Memorandum of Understanding for the FCC Study **(FCC-GOV-CC-0004, EDMS 1390795)**	
Address:	**INFN**, Via Enrico Fermi, 54, 00044 Frascati RM, Italy **Suppliers Code:** INFN-50 **Address code:** SC27, **Budget code:** 10811

FCC-ee Injector



Electron beam from a low-emittance RF gun is accelerated by an S-band LINAC up to 6 GeV.

Positron beam is generated by hitting the electron beam on a positron target then it is accelerated up to 1.54 GeV and injected in the Damping Ring for emittance cooling. DR also provides delayed extraction required for single species operation in the common LINAC.

A complex system of Transfer Lines is used to bring back the positron beam from the Damping Ring to the 1.54 GeV LINAC stage in order to accelerate it up to 6 (or 20) GeV.
Transfer Lines includes turnaround loops, bunch compressor section in order to keep under control the RSM bunch length, and energy pre-compressor system to maximize the injection efficiency.

*In this context, and in the framework of the **FCC-ee Injector Conceptual Design and Positron Source test stand at PSI, INFN takes on coordination of the WP4 working package**.*

WP4 Manpower

	FTEY
C. Milardi	**0.3**
A.De Santis	**0.3**
O. Etisken	0.5
S. Spampinati	0.5

O. Etisken (postDoc position 1+1 year since next Mar 23),
S. Spampinati (temporary position 1+1 year, starting on Dec 5th 22).

Since WP4 activities are co-funded by INFN and CERN S. Spampinati as well as O. Etisken, who is going to take a postdoc temporary position, will work for 50% of their time on DAΦNE.

Recruiting manpower with a minimum experience in beam optics has been definitely quite difficoult.

WP4 Structure and Organization

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Laboratori Nazionali di Frascati

WP4 coordinator Catia Milardi (LNF)

4.1 Damping Ring coordinator C. Milardi:
- **C. Milardi,**
- A.De Santis,
- R. L. Ramjiawan (CERN),
- Y. Dutheil (CERN),
- O. Etisken (postDoc position for 1 year since Mar 23),
- *CERN collaboration on RF systems.*

4.2 Transfer Lines to/from Damping Ring, coordinator A. De Santis:
- C. Milardi,
- **A. De Santis,**
- R. L. Ramjiawan,
- Y. Dutheil,
- O. Etisken,
- S. Spampinati (temporary position starting on Dec 5th 22).

4.3 Energy pre-compression before injection into DR:
- C. Milardi,
- A.De Santis,
- S. Spampinati ,
- *CERN collaboration.*

4.4 Bunch compression scheme before reinjection in the high energy LINAC:
- C. Milardi,
- A.De Santis,
- S. Spampinati.

Project Timeline

TDR frozen by summer 2023 for the FCC-ee mid-term review meeting

Report providing a cost evaluation by the end 2023

It might very well be that the FCC-ee Injector study will be prolonged beyond the end of 2023.

FCC-ee feasibility report document by end 2025

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Damping Ring studies:

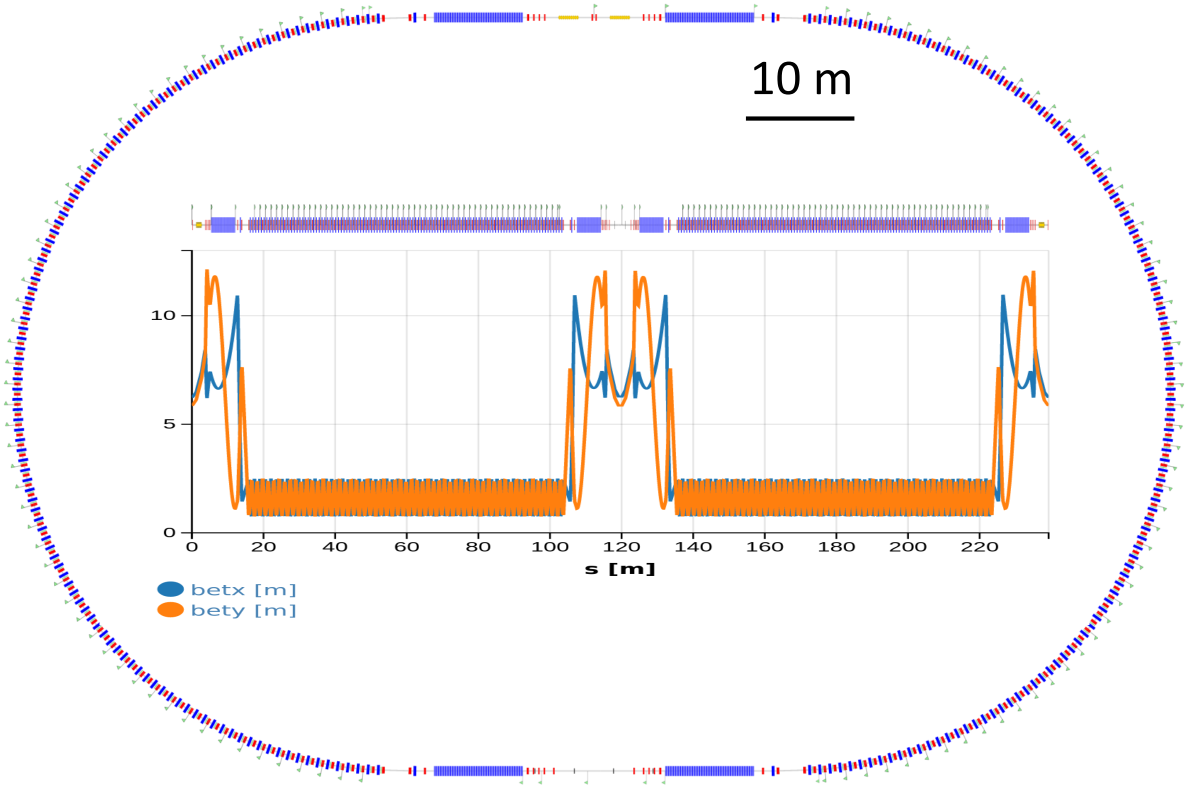
Optics,

Transverse and longitudinal dynamics.

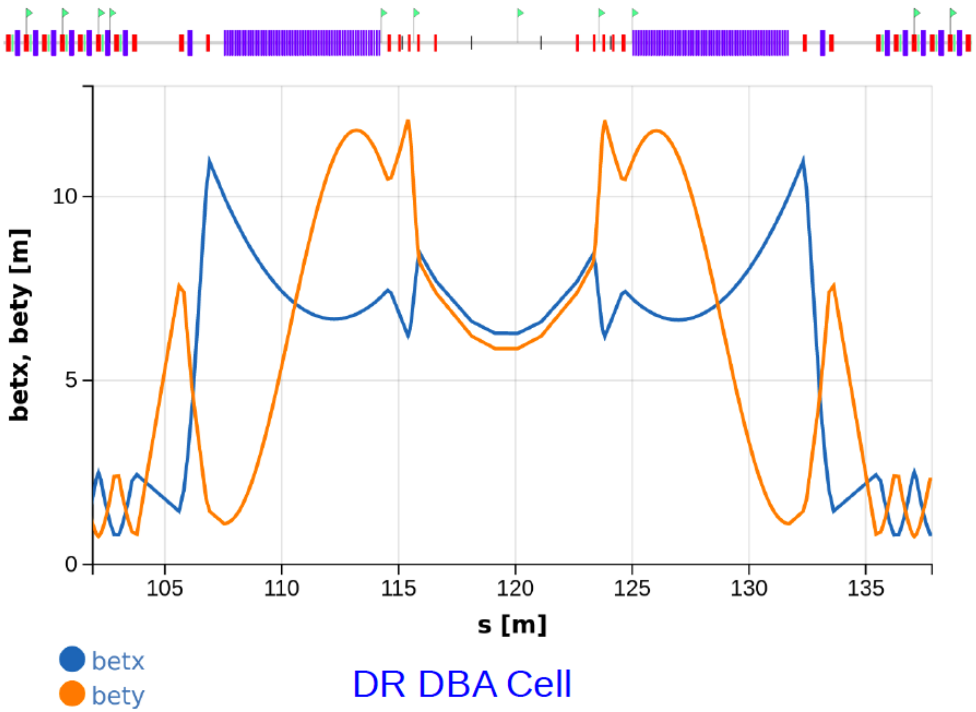
Damping Ring

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

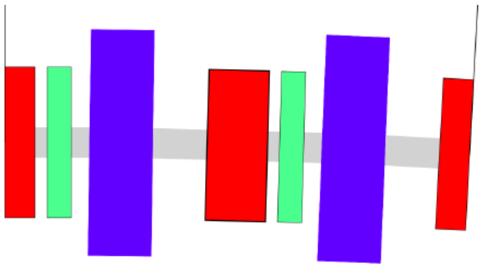


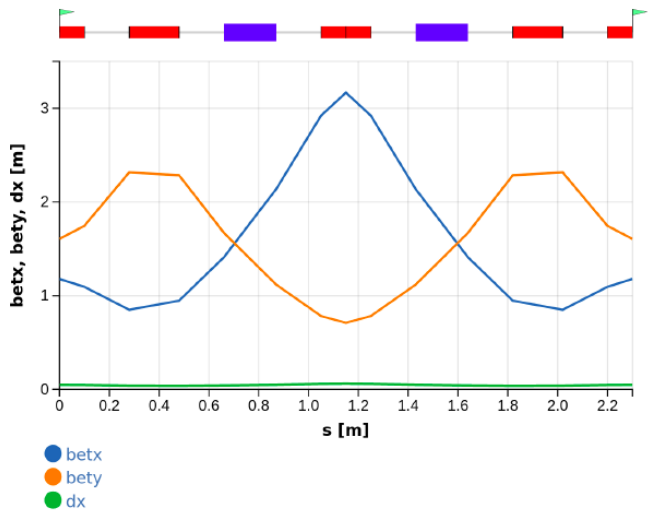
Damping Ring Optics



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

DR DBA Cell





DR dynamical aperture: Tracking parameters

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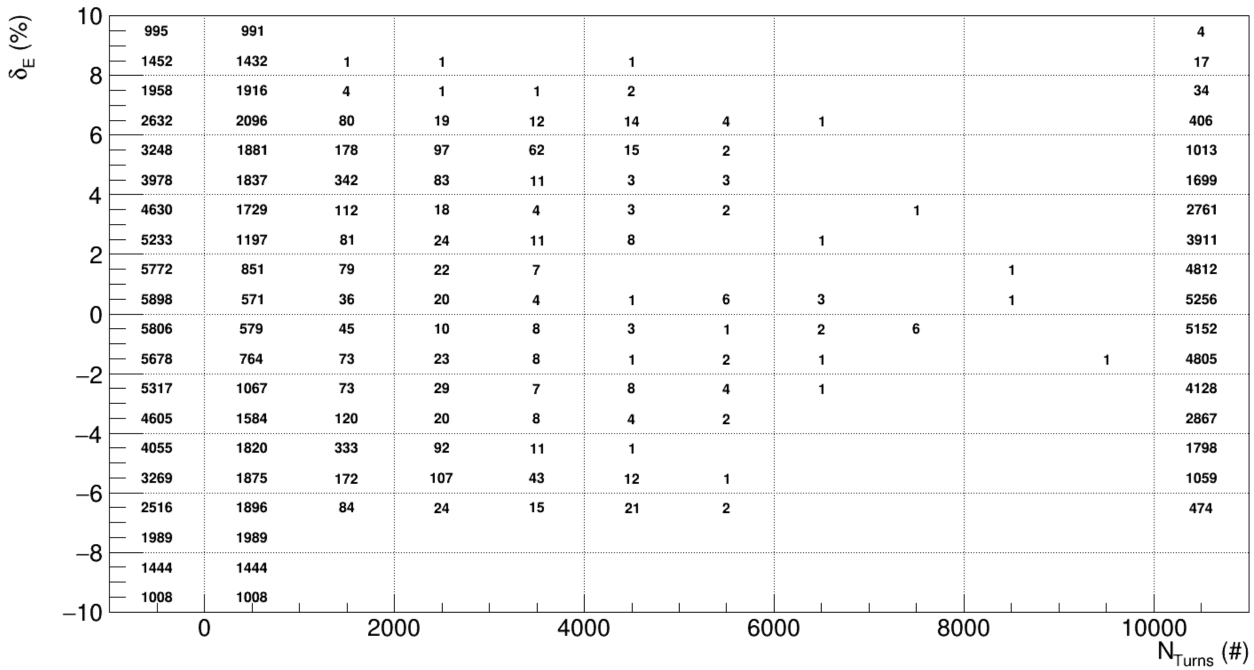

Tracking has been performed with **PTC (MAD-X** interface) for **10k turns**.
Initial distribution are Gaussian with **nominal emittance** (CDR ε_x:1.29 ε_y:1.22 10^{-6}m rad).
Tracking includes **radiation loss** and **RF effects**.
The numbers In the table refer to the particles lost at a given turn (1k bin width). The first column is the number of initial particles.
The range of energy considered is quite large in order to estimate the acceptance as a function of the energy deviation.

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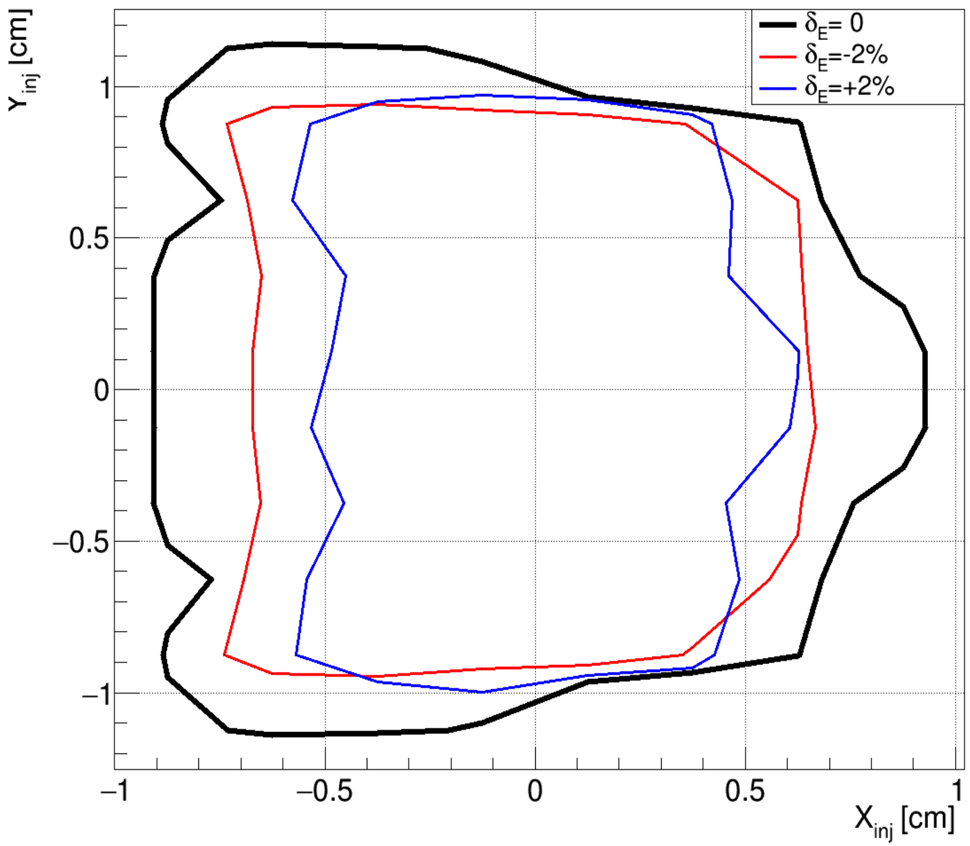
DR dynamical aperture



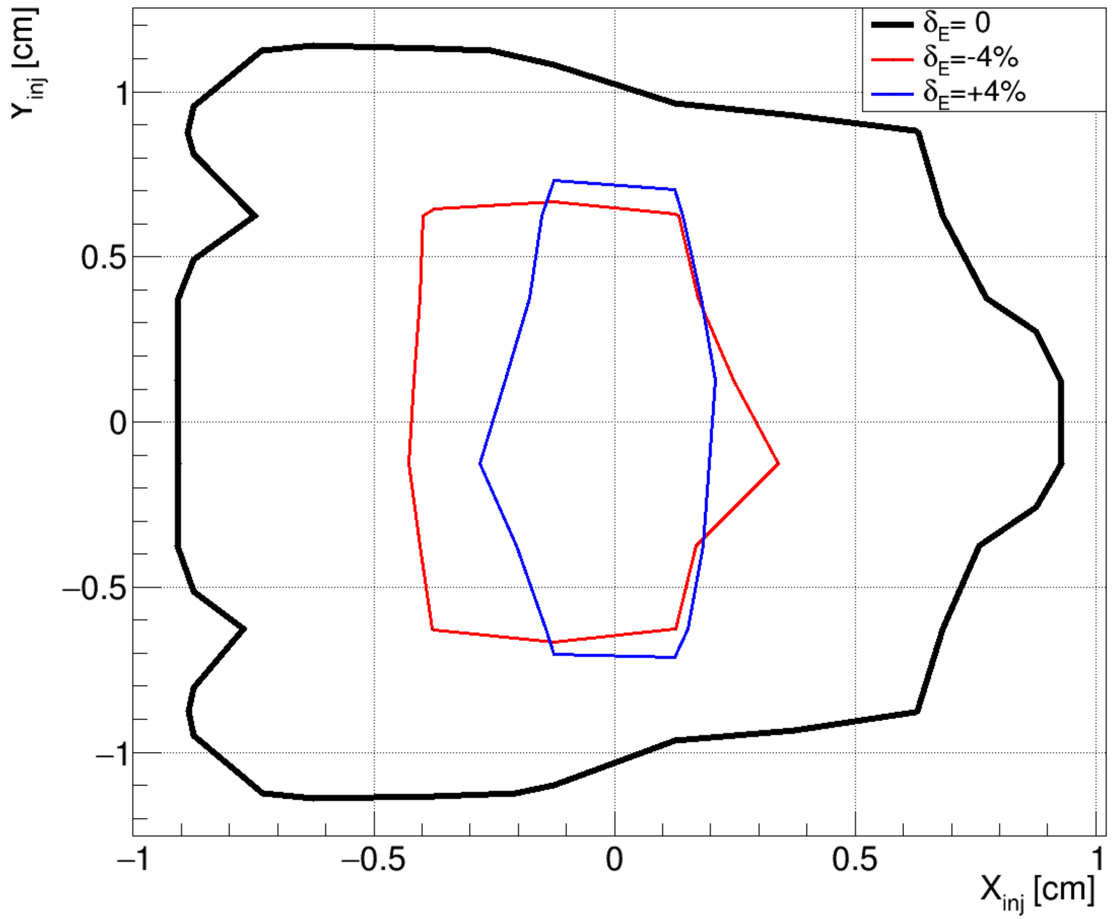
2000 turns have been tracked (~15% damping time). The estimated loss of accuracy is below 1% at the nominal energy.

The phase space have been sampled up to *3x3 cm² in the transverse plane*. Only **on-axis particles** have been simulated (x'/y'=0).

Radiation damping has been neglected allowing a much faster tracking of the DR.

The stability region in the transverse plane have been evaluated for different energy deviation, in the range between ±2%.
Contours represents regions where at leas 90% of the initial conditions leads to a successful tracking.
A probability definition is needed in order to get the average value over the surface.

DR dynamical aperture



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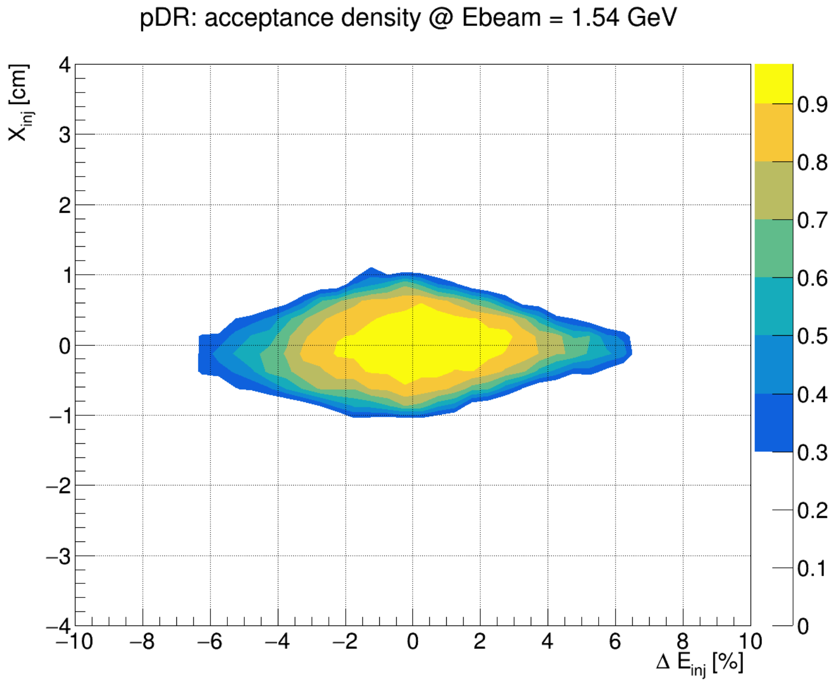
The estimated loss of accuracy is below 1% at the nominal energy.

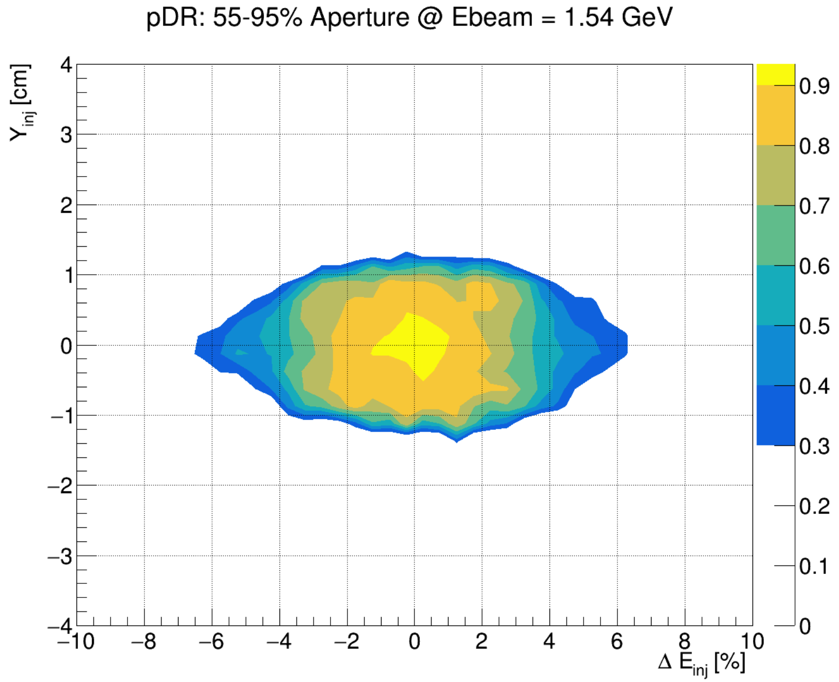
The phase space have been sampled up to 3x3 cm^2 in the transverse plane.
Only on-axis particles have been simulated (x'/y'=0).

Radiation damping has been neglected allowing a much faster tracking.

For larger energy variations (±4%) the stability region shrinks, and it is no longer symmetric w.r.t. the energy variation itself, in the transverse plane being considerably smaller at higher energy (blue) w.r.t. lower energies (red). The stability region at the nominal energy has been reported for reference.

DR Acceptance Probability





DR acceptance probability has been evaluated starting with nominal beam parameters at the injection: Gaussian profile with nominal width at the injections (σ ~ 2mm in both planes).
The energy distribution has been assumed Gaussian with 5% resolution.

The color map represent the *projection of the* ***survival probability*** associated to the different position in space: horizontal and vertical, respectively.

A full matrix in phase space will be delivered to reshape particle distribution at the positron source.

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Longitudinal Beam Dynamics and RF system

Longitudinal Beam Dynamics

RF system must:

- restore energy lost by Synchrotron Radiation emission U_0,
- provide a suitable energy acceptance compliant with the large energy spread of the incoming positron beam,
- Assure beam parameters compatible with stable beam dynamics conditions.

Energy Acceptance at injection for e^+ beam

$$\left(\frac{\Delta E}{E_s}\right) = \pm\beta\sqrt{\frac{eV}{\pi h \alpha_c E_s}\mathcal{R}(\varphi_s)}$$

$$\mathcal{R}(\varphi_s) = \lfloor 2\cos\varphi_s + (2\varphi_s - \pi)\sin\varphi_s \rfloor$$

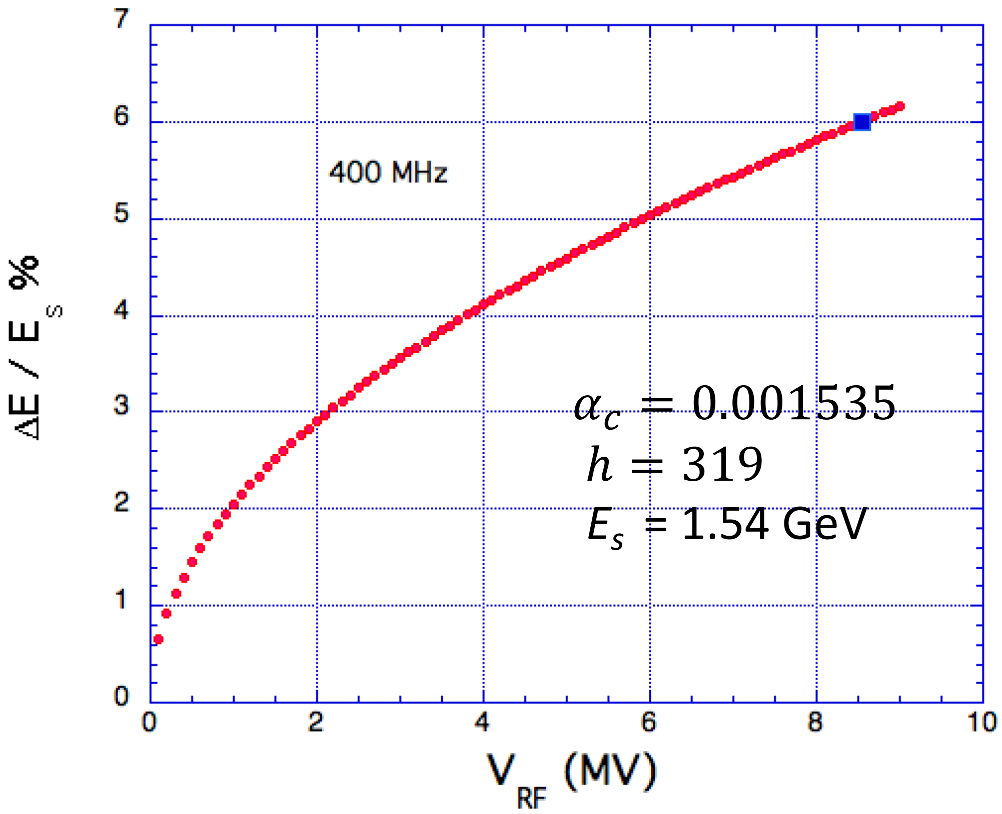
If an energy acceptance of the order of

$$\left(\frac{\Delta E}{E_s}\right) \sim 6\ \%$$

is requested in injection

V_{RF} = 8.53 MV

SC RF cavities working at 400 MHz and providing at last 4 MV are considered.



Minimum RF cavity voltage request to compensate the energy lost per turn is E_{LT} = 0.225 MV

C. Milardi, FCC-ee Injector WP4,
Joint FCC France-Italy Workshop, Nov. 21-23, 2022, Lyon, France

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 for:

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

Separatrix

W* - *Φ representation, canonical coordinates

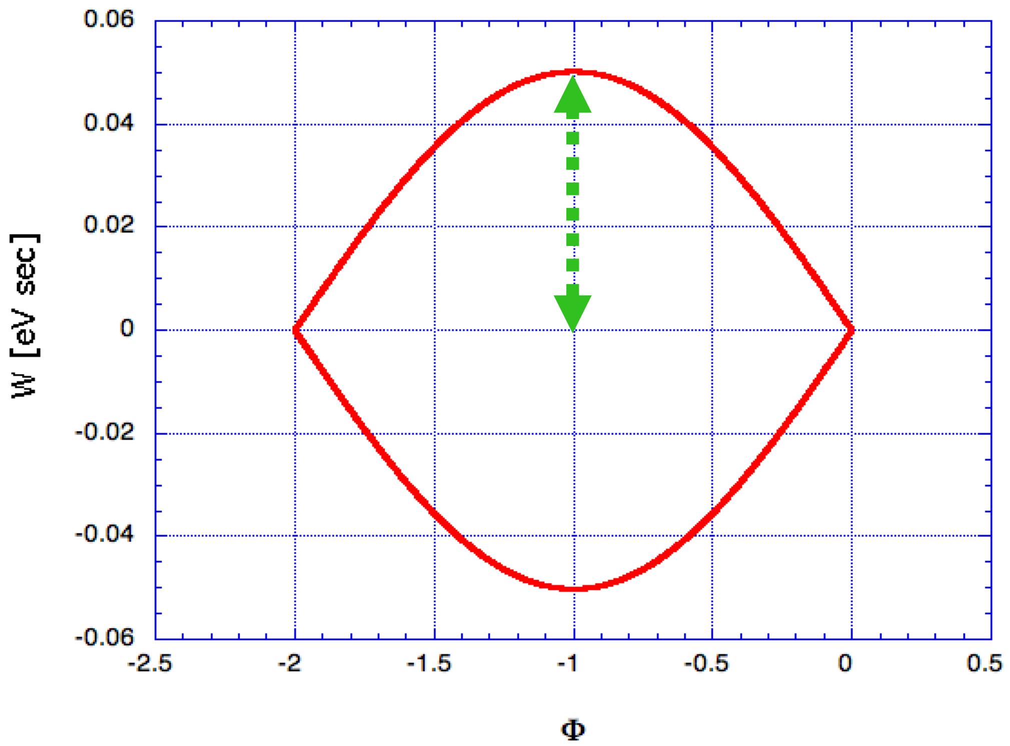
$$W_{bh} = \frac{L}{\pi h c}\sqrt{\frac{eV E_s}{2\pi h \eta_{tr}}}$$

$$A_{bk} = 2\int_0^{2\pi} W\, d\varphi = 8\, W_{bh}$$

$$\frac{1}{\Omega_s}\frac{d\varphi}{dt} = \frac{2\pi c}{L}\sqrt{\frac{2\pi h^3 \eta_{tr}}{E_s eV \cos\varphi_s}}\, W$$

- The area of the bucket is an adiabatic invariant, ***longitudinal acceptance***
- *Bunch area is* ***longitudinal emittance***

$\varepsilon_t = 4\pi\, \sigma_E\, \sigma_t$ **[eV sec]**



Assuming:

$\alpha_c = 0.001535$
$h = 319$
V = 8 MV
E_s = 1.54 GeV

W_{bh} = 0.0501813 (eV sec)
A_{bk} = 0.401451 (eV sec rad)

DR acceptance

DR energy acceptance of the DR may be reduced to 3.5% by lowering the voltage in order to increase the bunch length and to avoid any possible risk of emittance dilution due to coherent synchrotron radiation (CSR).

For this reason, the incoming e+ beam may be collimated at the end of the LINAC at 3.5% or an energy compressor could be installed.

There is a clear limit on the DR acceptance coming from transverse beam dynamics.

RF System

RF as in the CDR

LHC type 400 MHz,
SC cavities.
two RF modules providing 4 MV each,
1.5 m long (3.5 with cryostat).

Total RF Power Requirement

$$P_b = I_b \frac{\Delta U_0}{e} \qquad P_l = \frac{V_{RF}^2}{2 n_{RF} R_{shunt}}$$

$$P_{RF} = P_b + P_l$$

Positron charge from LINAC	I_b [mA]	I [mA] $n_b = 2 \div 18$	P_b [KW]
4.5 [nC]	5.638	11.3 ÷ 101.5	2.6 ÷ 23
0.5 [nC]	0.6	1.3 ÷ 11.3	0.285 ÷ 2.56

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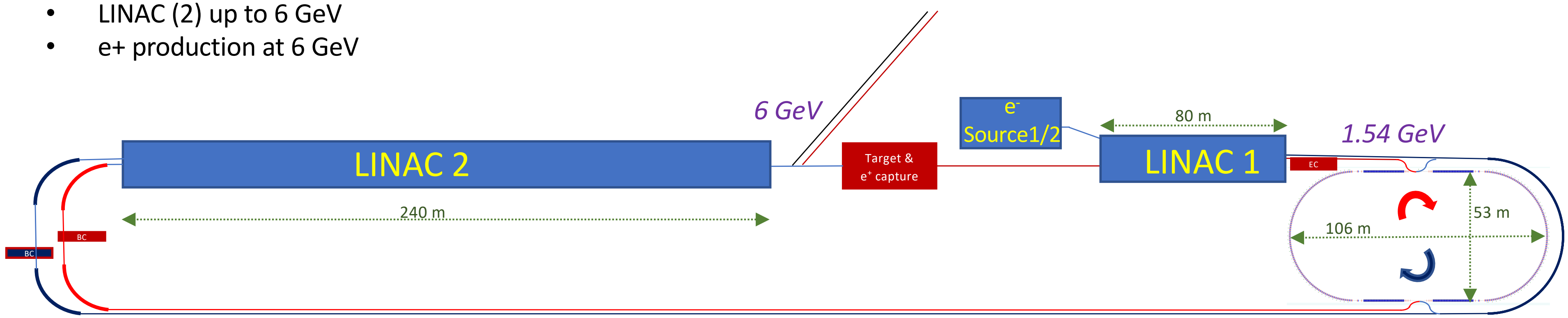
Transfer Lines

Injector Layout (initial configuration)

- e- source
- Linac (1) up to 1.54 GeV
- Energy compressor (EC, for e+), damping ring (DR, for e+/e-) at 1.54 GeV and bunch compressor (BC, for e+/e-)
- LINAC (2) up to 6 GeV
- e+ production at 6 GeV



- Injection system is designed to damp positron and electron either
- **Simplified** and **modular design** based on:
  - 90 degree arc
  - 180 degree arc
  - asymmetric dogleg in the two injection sections
  - straight sections based on FODO cell
- Transfer lines are independent for the two beams beams and for injection/extraction
- Damping ring can store electron and positron without any modification
- Design flexible and compatible with requirements imposed by:
  - LINAC operation
  - Collider injection requirements

(presented at the meeting on Nov. 30th 2021)
https://indico.cern.ch/event/1100972/

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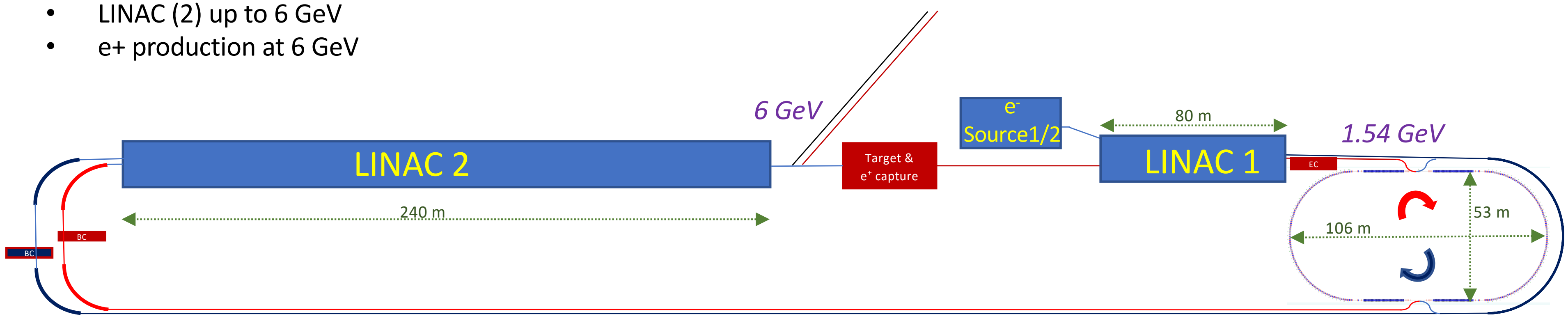

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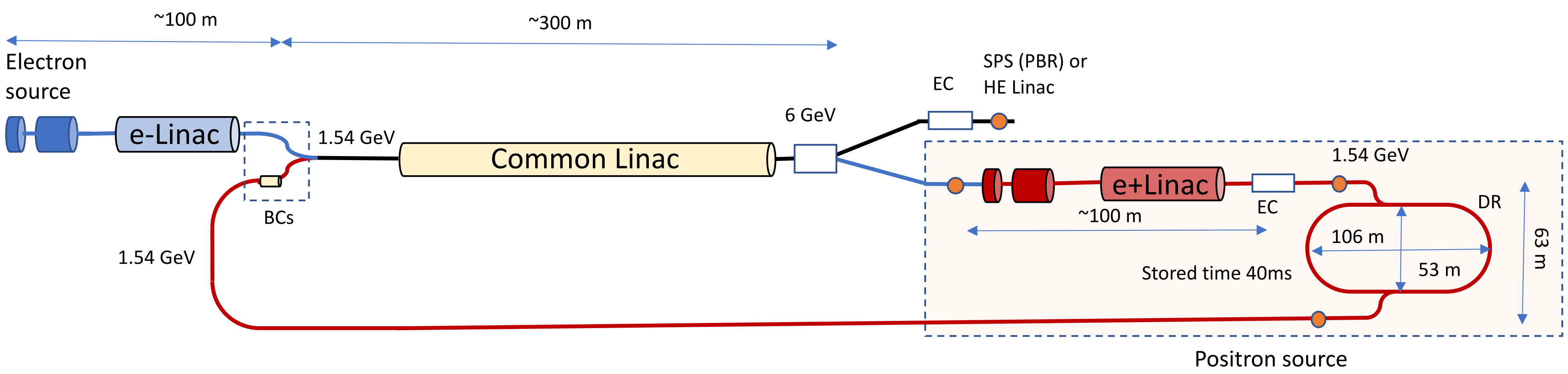
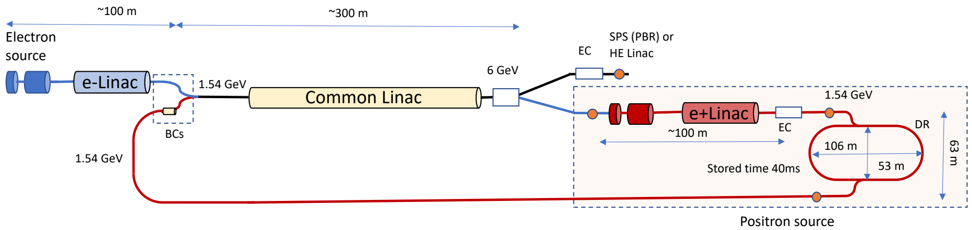
Layout revised on April 2022

(presented at the meeting on Nov. 30th 2021)
https://indico.cern.ch/event/1100972/

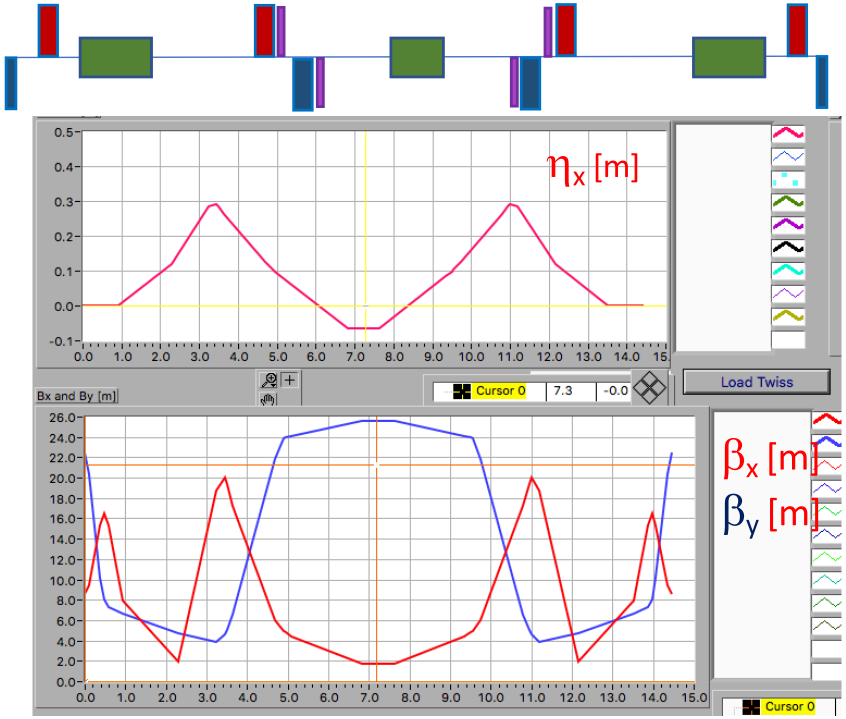
FCC-ee injector layout 6 GeV option



Triple Bend Achromat Cell for Arcs



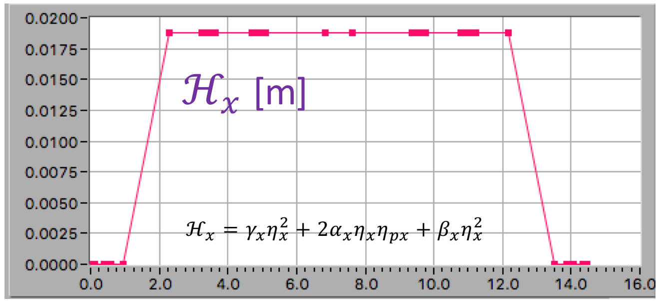
The TL design developed for the previous injector layout is still valid

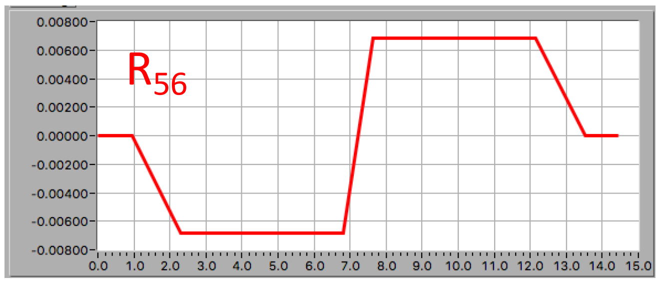


- $\beta_{x,y}$ < 30 m
- low η_x
- $\alpha_{x,y}$ = 0 both ends
- achromatic
- isochronous
- low invariant

mu_x = 1.32
mu_y = 0.31

ξ_x = -4.27
ξ_y = -2.06





θ_b[rad]	0.174532925
L_b[m]	1.506/0.865
ρ[m]	8.633/4.959
B[T]	0.595/1.035
nQUADS	8
LQUA	0.2
Lcell	16.2573

Quadrupole gradient m^{-2}

$K_{D01} = K_{D04}$ = -9.840
$K_{D02} = K_{D03}$ = -1.905
$K_{F01} = K_{F04}$ = 7.281
$K_{F02} = K_{F03}$ = 4.623

Sextupole gradient m^{-3}

$K^s_{D01} = K^s_{D02}$ = -58.738
$K^s_{F01} = K^s_{F02}$ = 44.294

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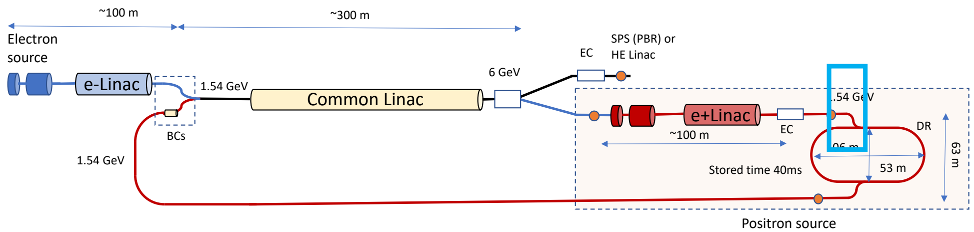
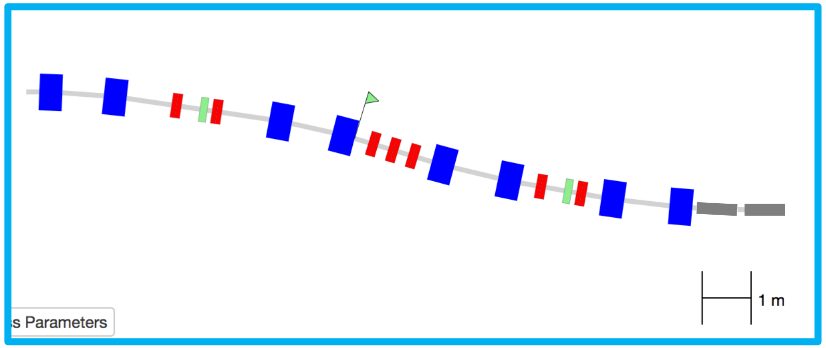
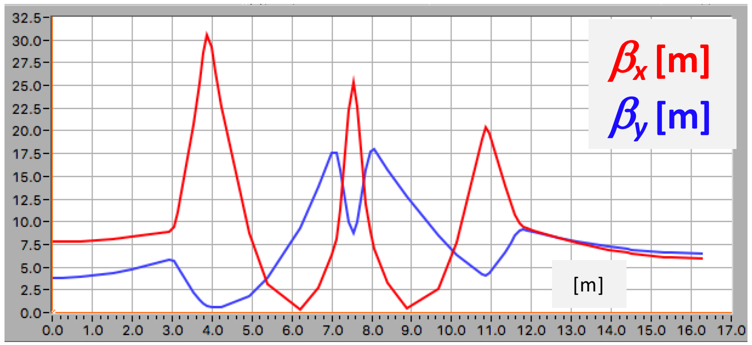
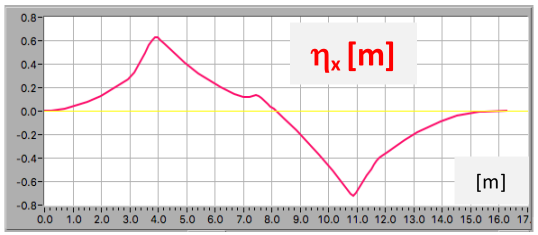
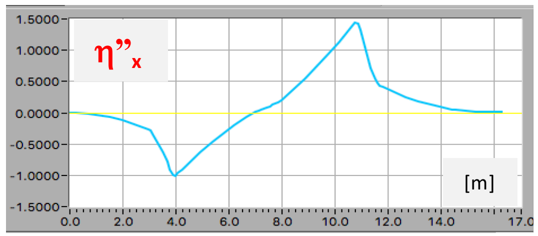
TL Injection Section





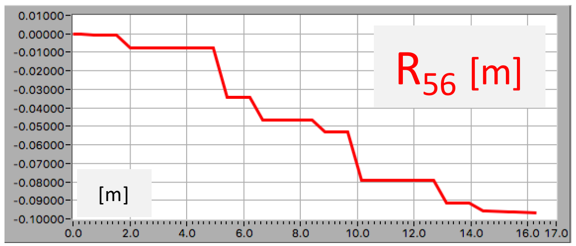






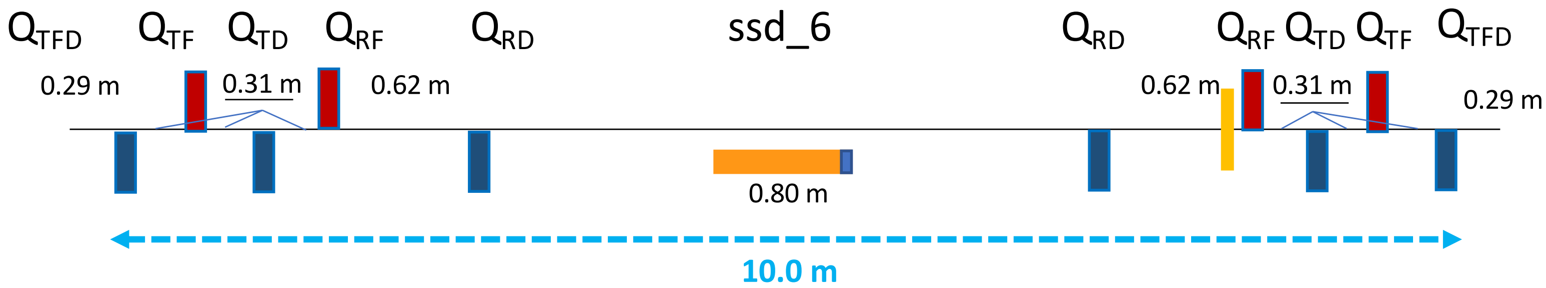
- *flexible*
- *achromatic*
- *R_{56} ~ - 9.5 cm*

	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



C. Milardi, Damping Ring and Transfer Lines Overview,
FCC-ee Injector Studies Mini-Workshop, Nov. 24-25, 2022, IJCLab, France

DR Injection Section



On –Axis Injection

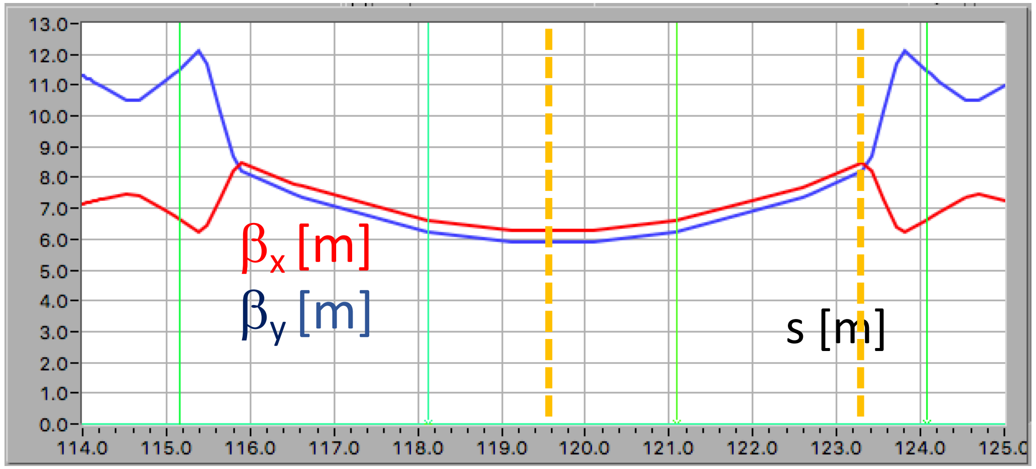
Twiss functions at injection septum:

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

$\beta^{kck}{}_x = 8.4$ m

Δmux(spt - kck) = 0.0728721

θ_{kck} *too large*



Ideal section no SXT

Injection Kicker position optimized

Twiss functions are not optimal for injection

C. Milardi, Damping Ring and Transfer Lines Overview,
FCC-ee Injector Studies Mini-Workshop, Nov. 24-25, 2022, IJCLab, France

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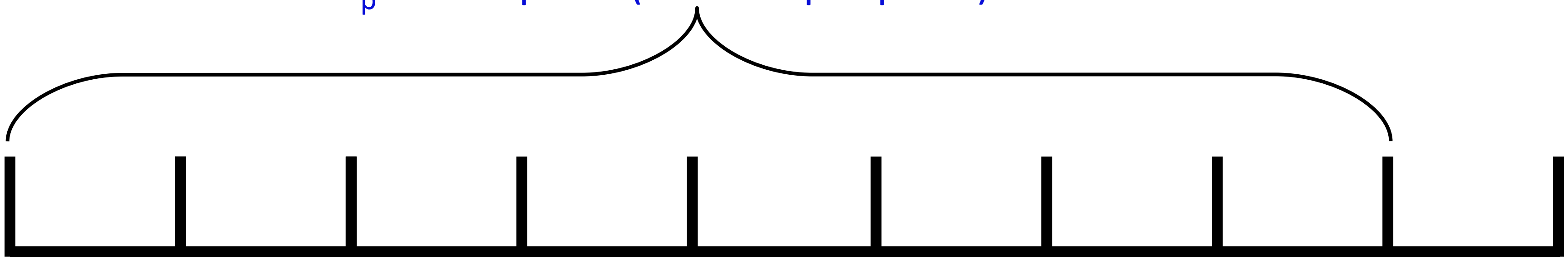
Timing considerations

DR Injection timing

N_p LINAC pulse (2 bunch per pulse) stored in DR



$$\Delta_b = INT[h/N_p]$$

Space between first bunches in different pulse

$$\mathrm{T}_{gun} = iT_1 + \Delta_b T_{RF}(1\%np)$$

Gun is phased with DR RF so that the "first" gun pulse fills #bkt=0

$$\Delta T_{DR} = (N_p - 1)T_1 \geq \alpha\tau_D$$

Store time

To store for at least 4 damping times

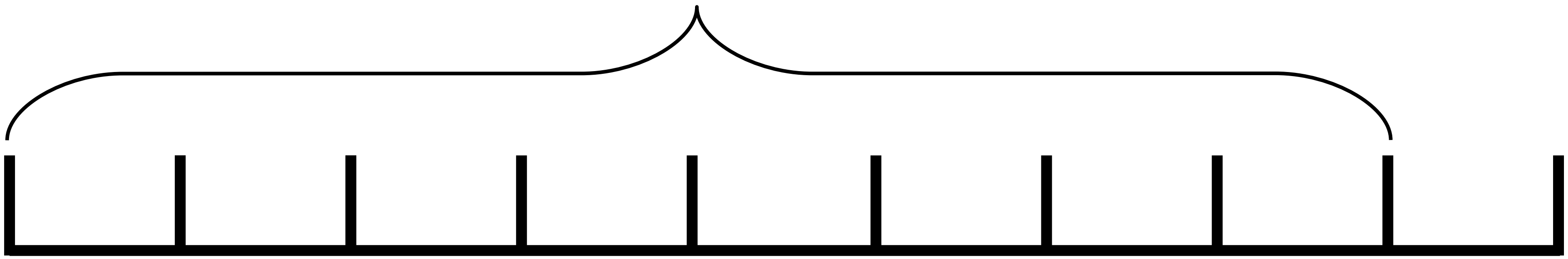
$$\mathrm{N}_p \geq 9 \quad \Rightarrow \quad \Delta_b \leq 35$$

$$\mathrm{h}\%\mathrm{N}_p \neq 0 \Rightarrow \Delta_b \equiv \Delta_b(i)$$

If Δ_b = 35 the last filled bucket is the 281^{st} , 38 buckets before the last one

C. Milardi, Damping Ring and Transfer Lines Overview,
FCC-ee Injector Studies Mini-Workshop, Nov. 24-25, 2022, IJCLab, France

Timing: DR Extraction



#pls	0	1	2	3	4	[...]		np-1	np
#bkt	0	Δb	2Δb	3Δb	[...]			0=h	Δb
#ext		-	-	-	[...]		0	1	

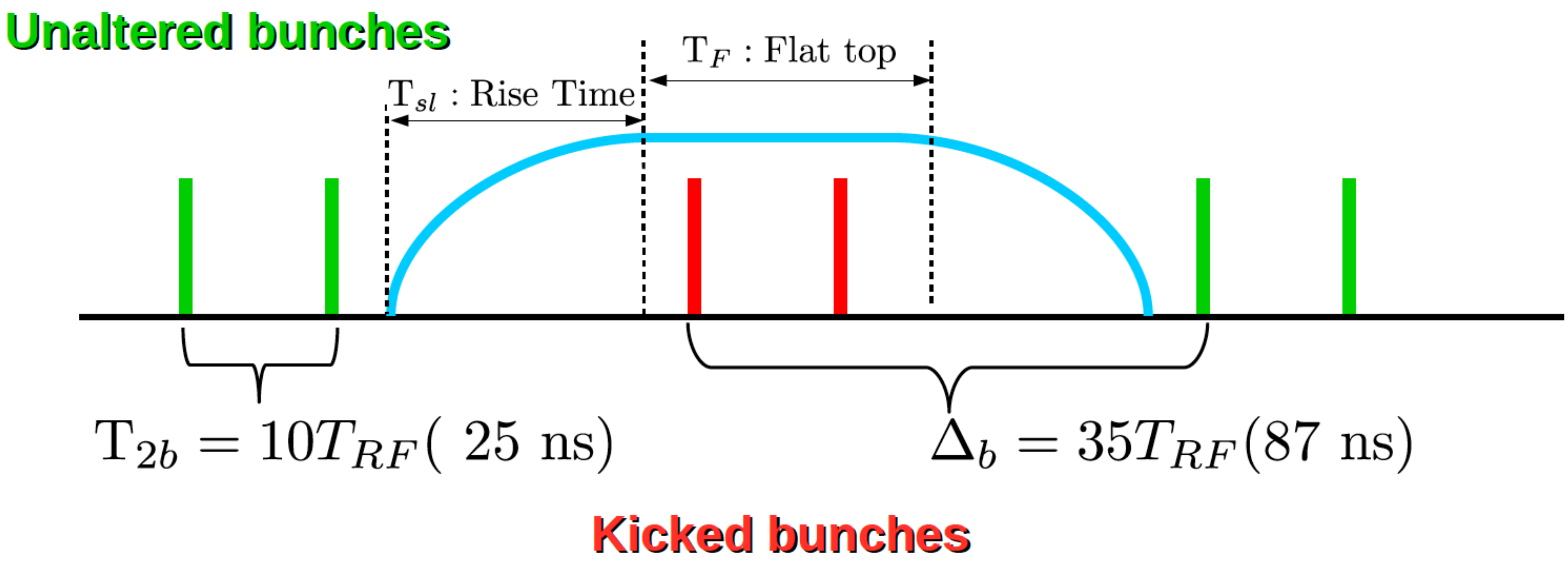
$$\mathrm{T}_{EXT} = \boxed{T_{gun} + \Delta T_{DR}} + \boxed{T_S/2} + \boxed{T_2 - \Delta T_{12}}$$

Arrival + Storage time

Half turn to reach the extraction section

Phasing with "empty" Common LINAC pulses.
Δ_{12} accounts for propagation time from DR to Common LINAC
Time is measured in T_S units

Extraction Kickers Timing



Time differences between the two bunches of the same pulse (25 ns) and between different pulses stored (87.5 ns) has the following implications on kickers pulses:

$$T_{sl} + T_F \leq 35T_{RF} \ \wedge \ T_F \geq T_{2b}$$

$$T_{sl} \leq 62\ \text{ns} \qquad T_F \geq T_{2b} = 25\ \text{ns}$$

Reasonable values could be: T_{sl} = 50 ns and T_F = 30 ns

C. Milardi, Damping Ring and Transfer Lines Overview,
FCC-ee Injector Studies Mini-Workshop, Nov. 24-25, 2022, IJCLab, France

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Studies about a new Damping Ring Layout

C. Milardi, FCC-ee Injector WP4,
Joint FCC France-Italy Workshop, Nov. 21-23, 2022, Lyon, France

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Rationale for a New DR Layout

Reasons 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 has not optimal Twiss functions
- Long damping WIGGLER magnets (the CDR includes 4, 6.64 m long magnets)
- Magnetic field intensity in the dipole can be safely pushed toward values higher than 0.66 T,
- 3 Straight sections instead of 2, which might be better in terms of NLD and to accommodate damping wiggler magnets,
- Arc cells had not optimal phase advance for the beam emittance damping.

New design approach:

- Higher magnetic field which makes damping time shorter,
- Less magnets (positive) which make larger emittance,
- Optimum phase advance for the FODO lattice,
- Three straight sections,
- Robinson WIGGLER has been introduced for emittance cooling.

Damping Ring Required Parameters

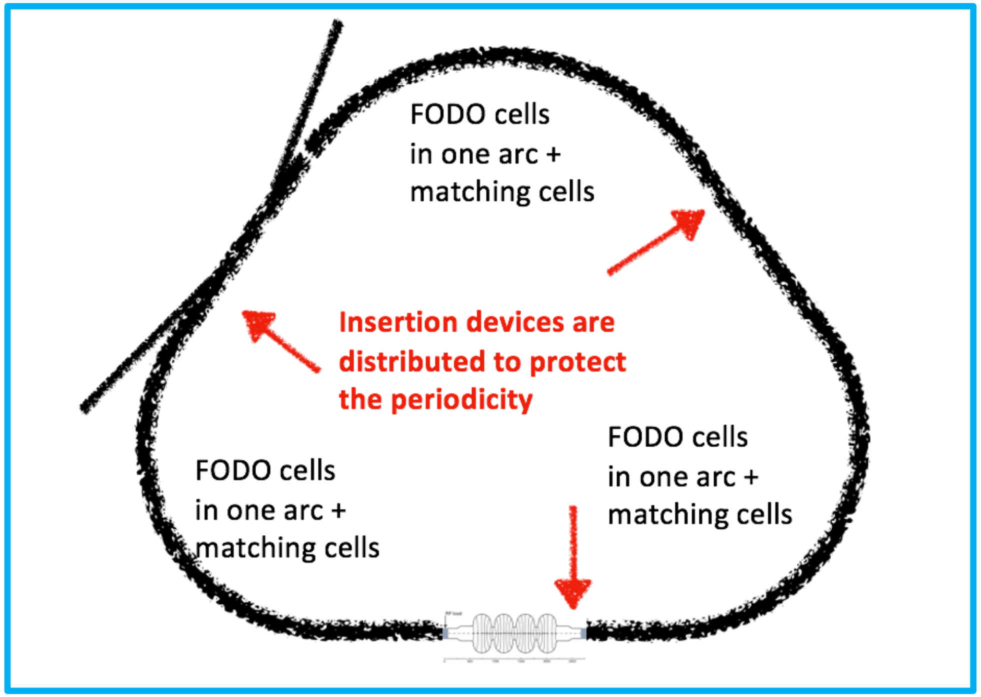
Required Parameters	
Energy [GeV]	1.54
Circumference [m]	~250 m
Stored time [ms]	40
Damping time (hor.) [ms]	≈10
Extraction geo. emittance (hor.) [nm.rad]	≈5
Number of bunches	16
Energy spread @ extraction [%] (rms.)	-
Injection type	on axis
Number of straight sections	3
Injected Parameters	
Injected emittance (h) (e^-/e^+) [nm.rad/µm.rad]	5.5/1.29
Injected emittance (v) (e^-/e^+) [nm.rad/µm.rad]	6/1.22
Injected momentum spread [%] (e^-/e^+) (rms.)	0.2/5
Injected bunch length (e^-/e^+) (mm)	1/3.4

According to latest discussions, required emittance and damping time parameters are changing. New targets are:

- **7.5 ms** for horizontal damping time,
- **2 nm rad** for horizontal emittance.

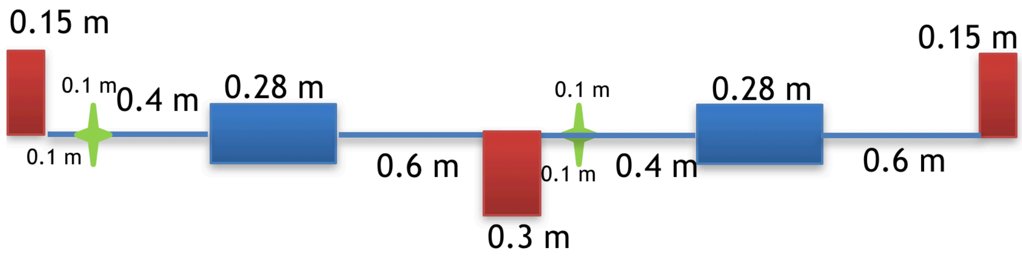
DR Layout

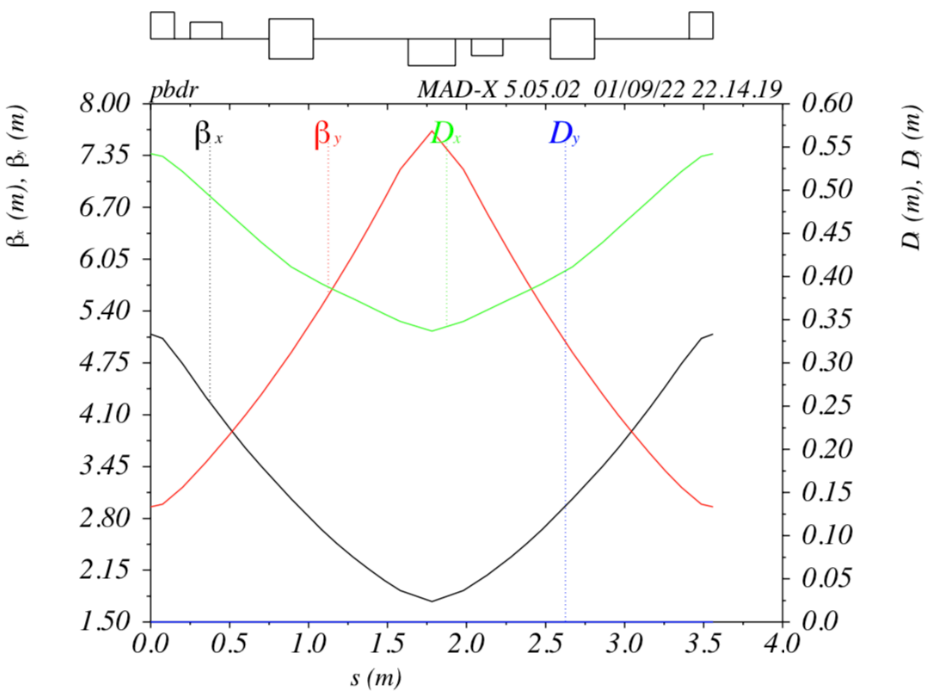
- A new DR layout has been designed relying on parametric considerations and numerical simulations.
- The new ring consists of 3 arcs and 3 straight sections.
- Arcs include 11 FODO cells.
- Each straight section is made up of 4 FODO cell without dipole magnets.

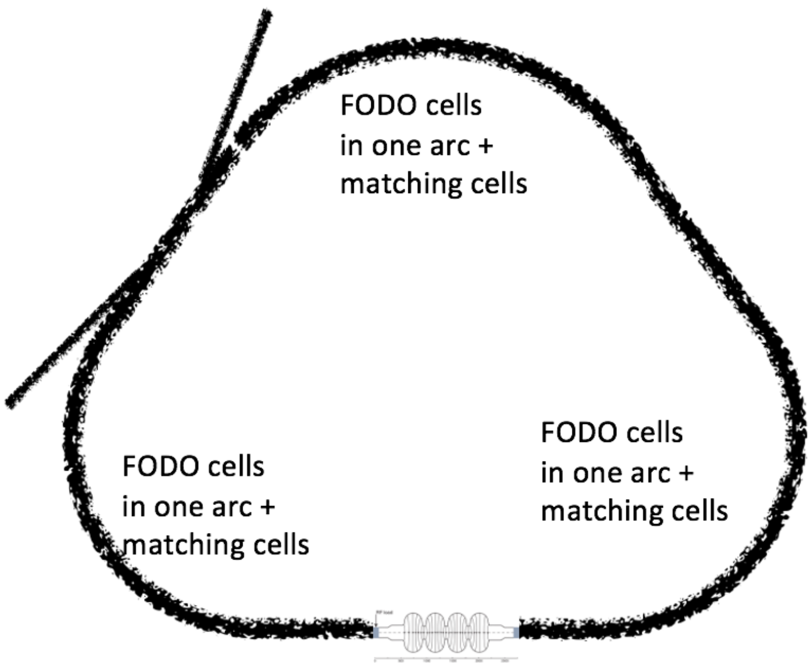


Arc Cell

Arcs include 11 FODO cells.

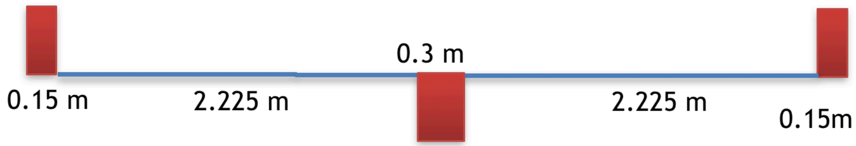


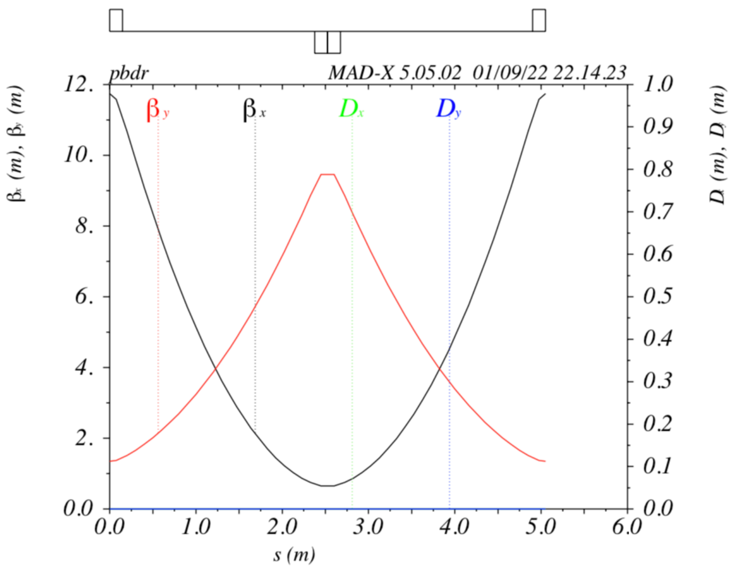


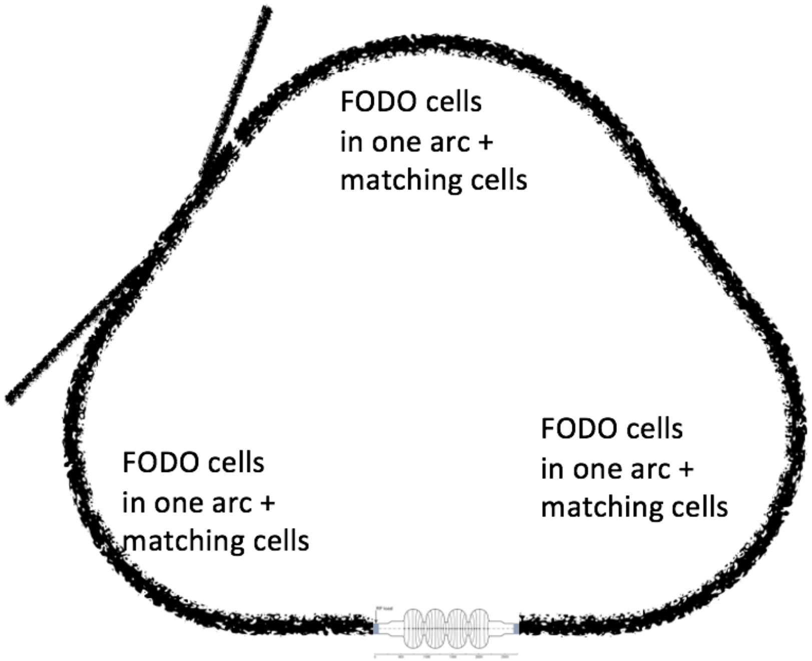


Straight Section

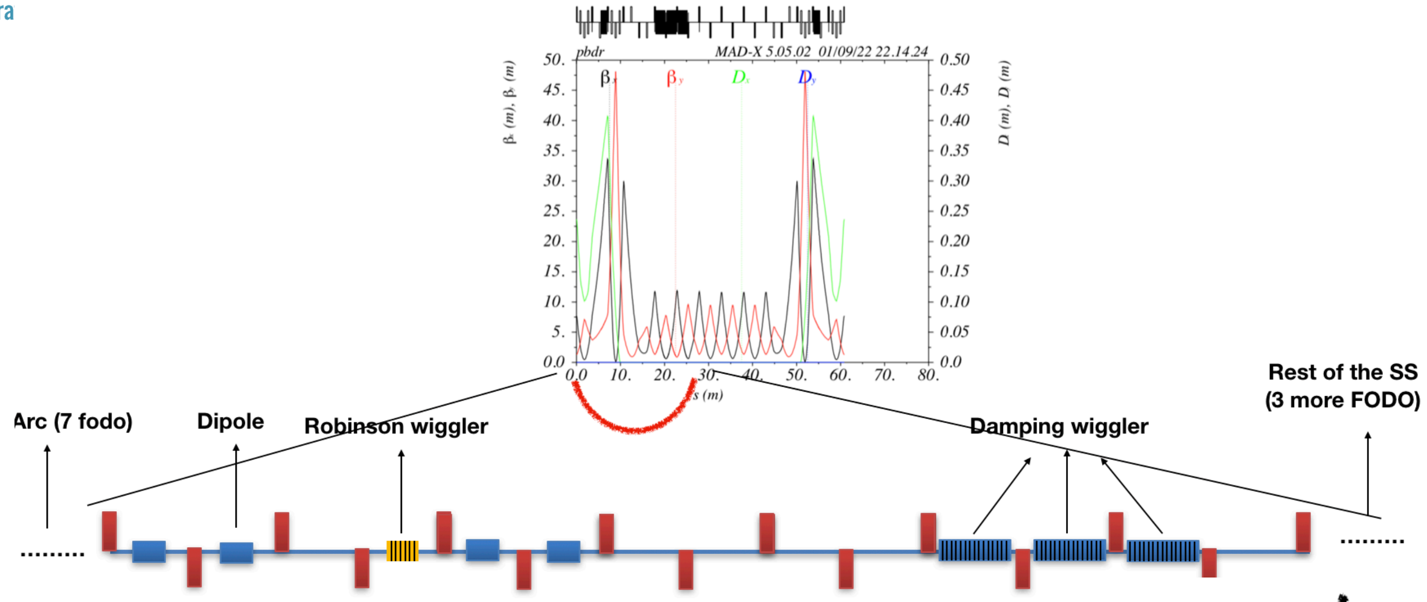
Each straight section is made up of 4 FODO cells.







Straight Section

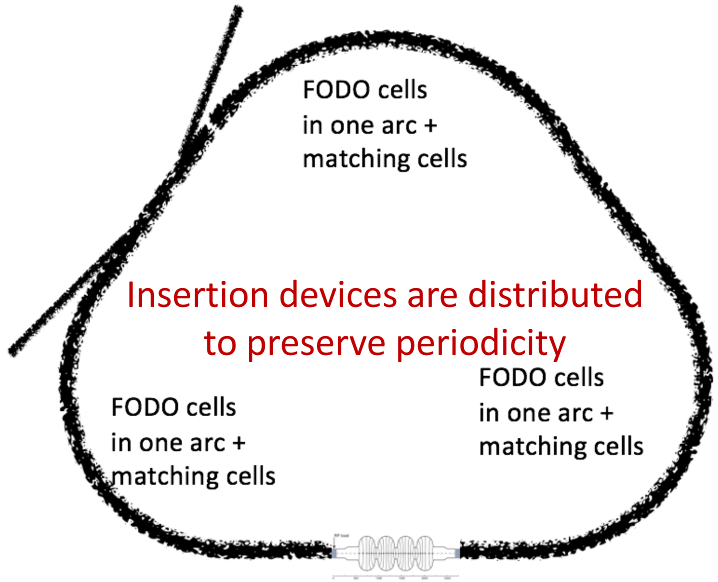


Straight Section (SS) area with 5 cell;

- **3 damping WIGGLER magnets** each of them is about **2 m** long.

Straight Section (SS) area + matching area:

- **Robinson WIGGLER** in a high dispersion area.



C. Milardi, FCC-ee Injector WP4,
Joint FCC France-Italy Workshop, Nov. 21-23, 2022, Lyon, France

Summary and Further Development

Parameters	CDR	After CDR	New
Bending Magnet number	232	212	72*
Dipole magnet length [m]	0.21	0.21	0.28
Bending angle [degree]	1.55	1.55	5
Dipole magnetic field [T]	0.66	0.66	1.8
Filling factor	0.2	>0.2	0.07
Damping wiggler magnet	26.5 m / 1.8 T	68 m / 1.8 T	18 m / 2 T
Robinson wiggler magnet	-	-	3.8 m / 1.2 T
Circumference	242 m	240 m	257.31 m
Emittance	2 nm.rad	1.25 nm.rad	4.89 nm.rad
Damping time	10.5 ms	5.9 ms	6 ms
Energy loss per turn	0.255 MeV	0.47 MeV	0.253 MeV

Further studies are on the go to:

- meet the latest parameter requirements:
  - emittance ~ 2 nm.rad,
  - damping time ~ 7.5 ms.
- Avoid Robinson WIGGLER magnet
- Keep dipole magnetic field below 1.5 T.

Summary and Further Development

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Parameters	CDR	After CDR	New
Bending Magnet number	232	212	**72***
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Robinson wiggler magnet	-	-	**3.8 m / 1.2 T**
Circumference	242 m	240 m	**257.31 m**
Emittance	2 nm.rad	1.25 nm.rad	**4.89 nm.rad**
Damping time	10.5 ms	5.9 ms	**6 ms**
Energy loss per turn	0.255 MeV	0.47 MeV	**0.253 MeV**

Abandoned

Further studies are on the go in order to:

- meet the latest parameter requirements:
  - emittance ~ 2 nm.rad,
  - damping time ~ 7.5 ms.
- Avoid Robinson WIGGLER magnet
- Keep dipole magnetic field below 1.5 T.

INFN

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Lab

Conclusions

FCC hh ee he

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.

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.

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 it's parameters can be exploited, in combination with a chirped bunch, for bunch compression.

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 has been proposed it is compliant with the new injector layout.

A new optimized DR layout is under study

Thank you

SPARES

Timing: Some definitions

$\mathrm{R}_1(T_1)$: Repetition rate (Period) L1: 200 Hz

$\mathrm{R}_2(T_2)$: Repetition rate (Period) L2: 400 Hz

$\mathrm{RF}(\mathrm{T}_{RF})$: DR Radio Frequency (RF Period): 400 MHz

ΔT_{ep} : Delay between Electron Gun an DR injection

T_S : DR Revolution period: $\sim 0.8\ \mu\mathrm{s}$

h: DR harmonic number: 319

N_p : Number of LINAC pulses stored (2 bunch each)

τ_D : Damping time: $\sim$10 ms

The number of stored pulses depends on the time needed to damp the incoming positron beam.

General considerations about RF System

DR RF system must have rather high voltage in order to provide the required energy acceptance necessary to accommodate the positron beam coming from the LINAC which has a large energy spread, of the order of 6%.

If a *NC RF cavities* are considered, assuming to maintain the same operating frequency 400 MHz, in order to not change the harmonic number, it would be necessary to use many more cavities to achieve the same voltage.
Generally at most about 0.5 MV per module can be achieved using NC technology.
A lower RF frequency should be considered in order to reduce the voltage requirement.

As far as the total RF power requirement is concerned, wall dissipation for a NC cavity is considerably higher than for SC cavity.

SC cavities provide higher gradient

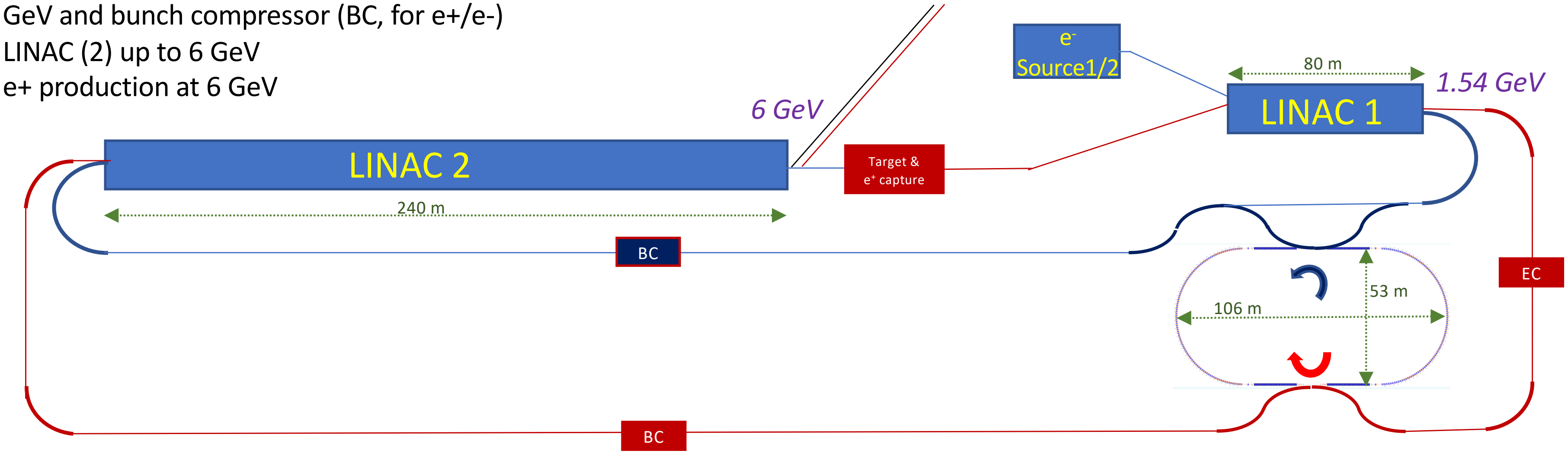
HOM are less harmful for SC cavities

It's convenient to use the same RF cavity for the different accelerator in the FCC ee project, in order to contain the R&D efforts.

Injector Layout

28/10/21

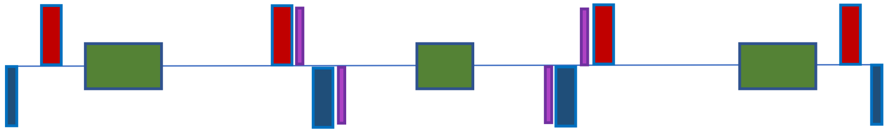
- e- source
- Linac (1) up to 1.54 GeV
- Energy compressor (EC, for e+), damping ring (DR, for e+/e-) at 1.54 GeV and bunch compressor (BC, for e+/e-)
- LINAC (2) up to 6 GeV
- e+ production at 6 GeV



- Injection system is designed to damp positron and electron either
- **Simplified** and **modular design** based on:
  - 90 degree arc
  - 180 degree arc
  - dogleg
  - straight sections based on FODO cell
- Transfer lines are independent for the two beams beams and for injection/extraction
- Damping ring can store electron and positron without any modification
- Design flexible and compatible with requirements imposed by:
  - LINAC operation
  - Collider injection requirements

Triple Bend Achromat Cell for Arcs

28/10/21



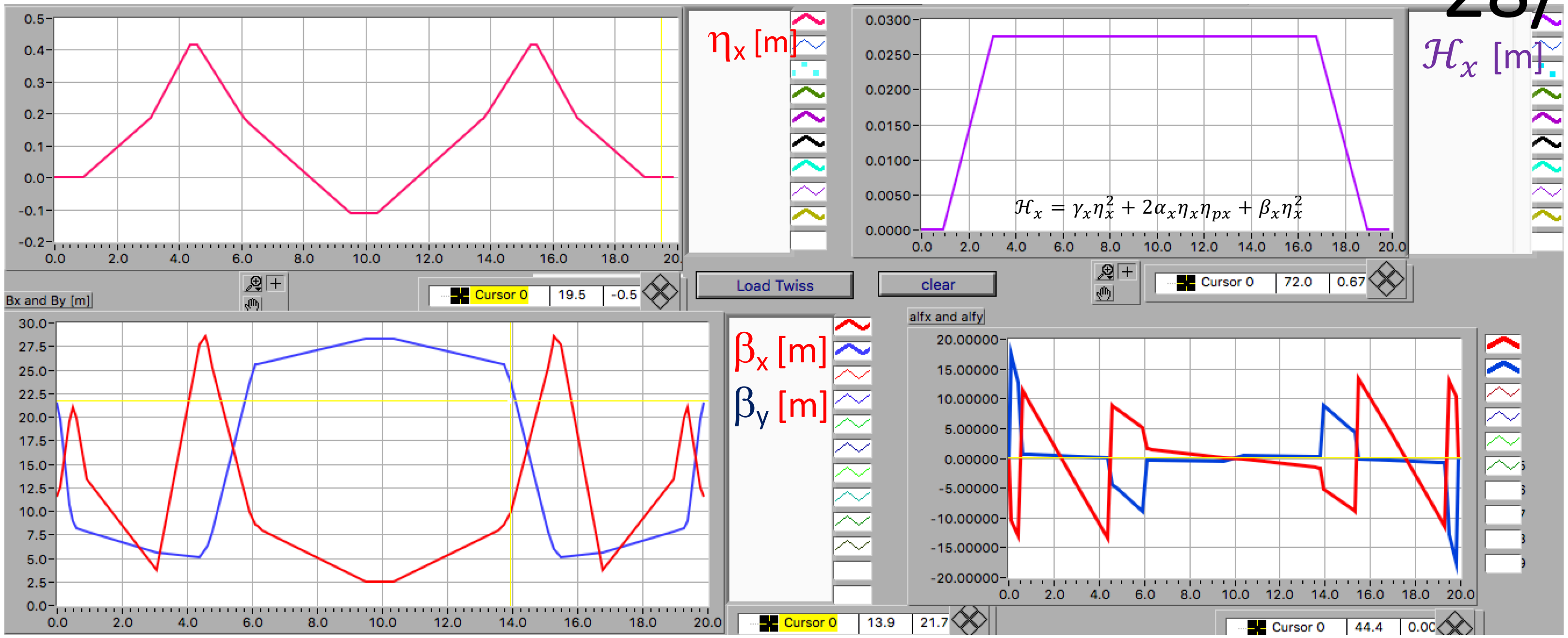
θ_b [rad]	0.174532925
L_b [m]	2.163/0.853
ρ [m]	2.864789
B [T]	0.415/1.05
nQUADS	8
L_{QUA} [m]	0.2
L_{cell} [m]	19.88

Quadrupole gradient	m^{-2}
K1qf	3.92436
K1qd	-1.76910
K1qfe	6.07971
K1qde	-8.56306

Sextupole gradient	m^{-3}
K2sf	2.64432e+01
K2sd	-3.58626e+01

TBA Twiss functions

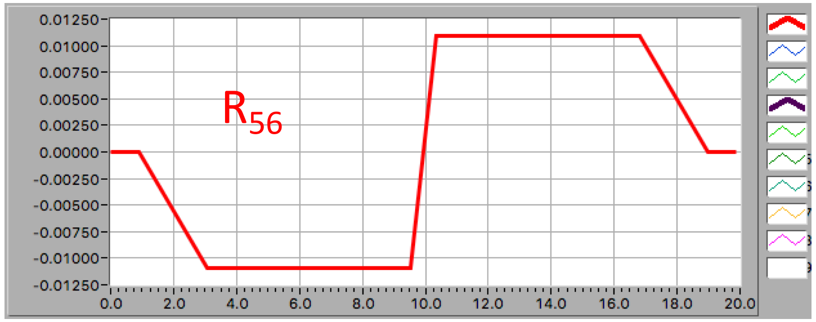
28/10/21



- $\beta_{x,y}$ < 30 m
- low η_x
- $\alpha_{x,y}$ = 0 both ends
- achromatic
- isochronous
- low invariant

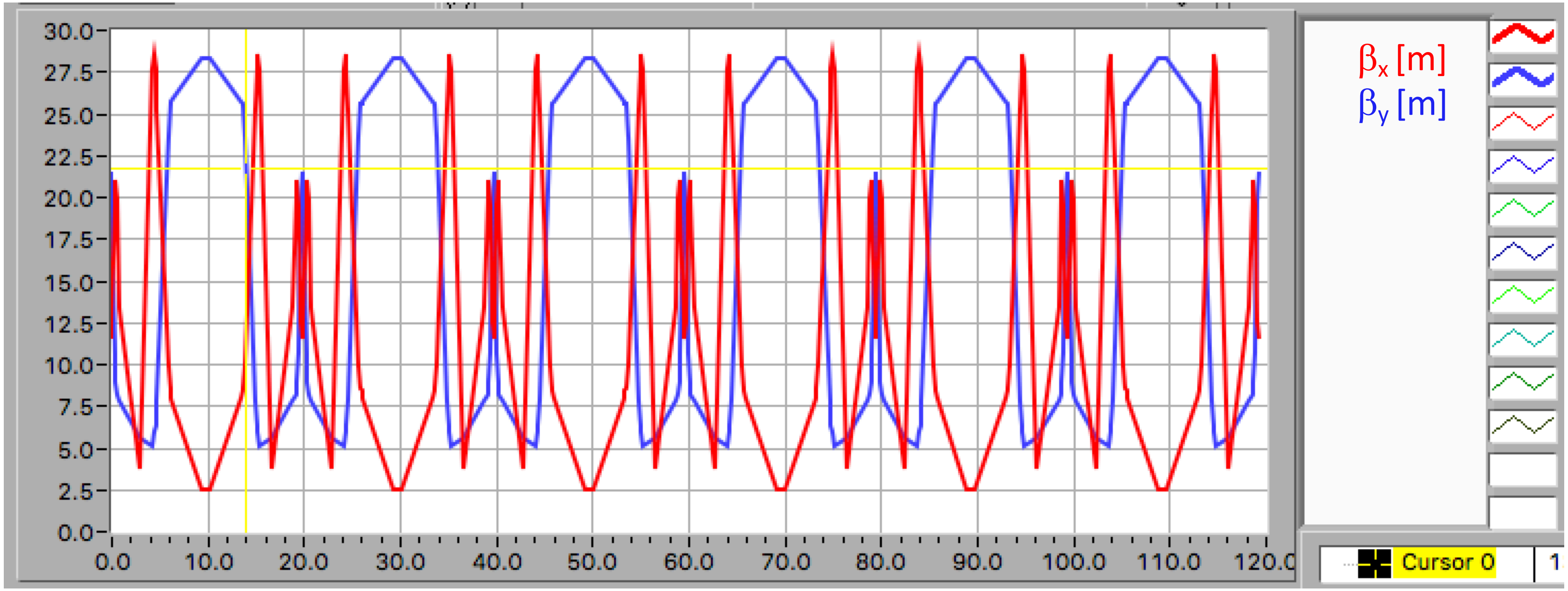
$q_x = 1.32$
$q_y = 0.31$

$\xi_x = -4.27$
$\xi_y = -2.06$



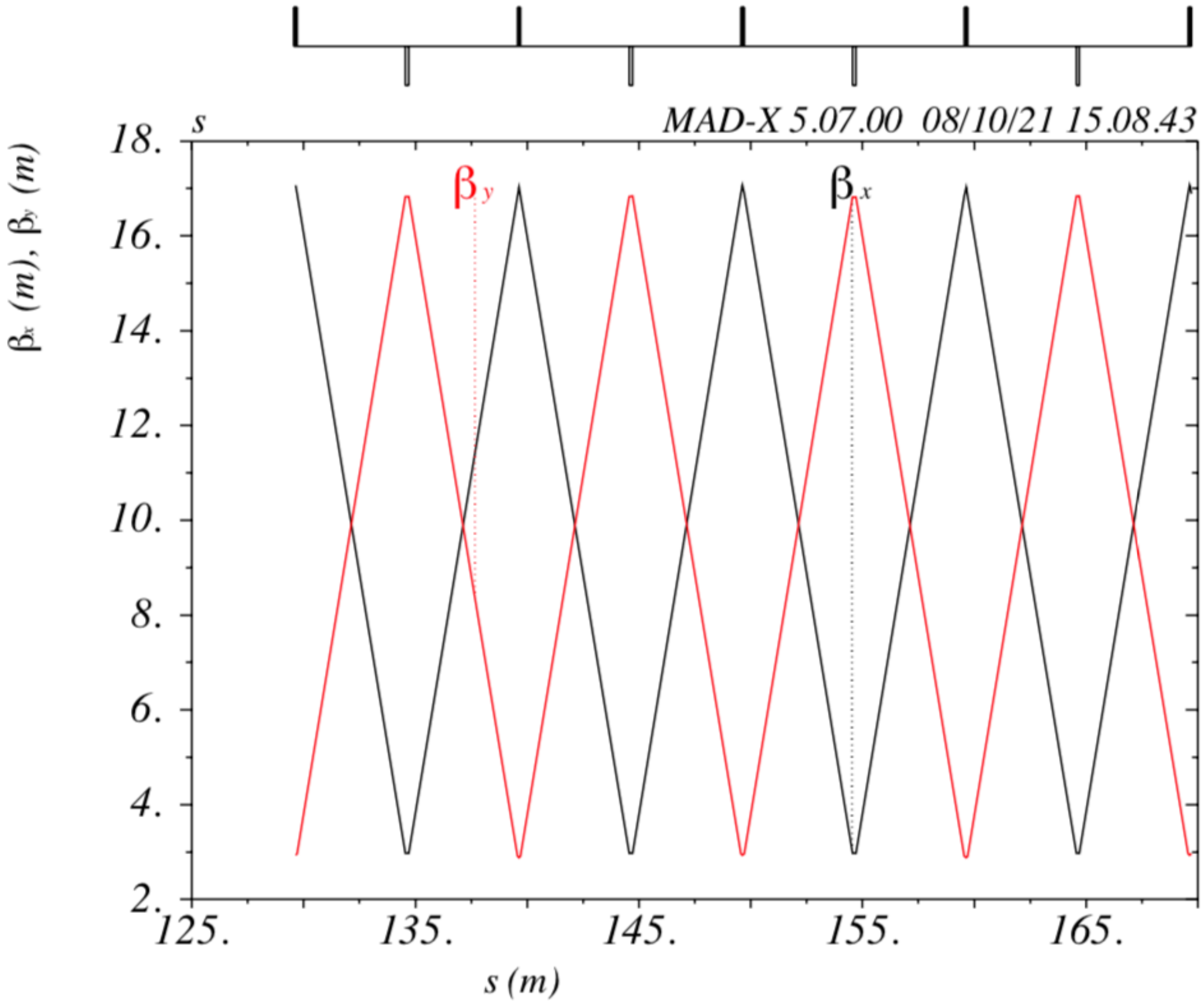
Sextupoles must be optimized in order to provide isochronicity at higher order

Twiss functions in the Turn around Loop 28/10/21



FODO Section

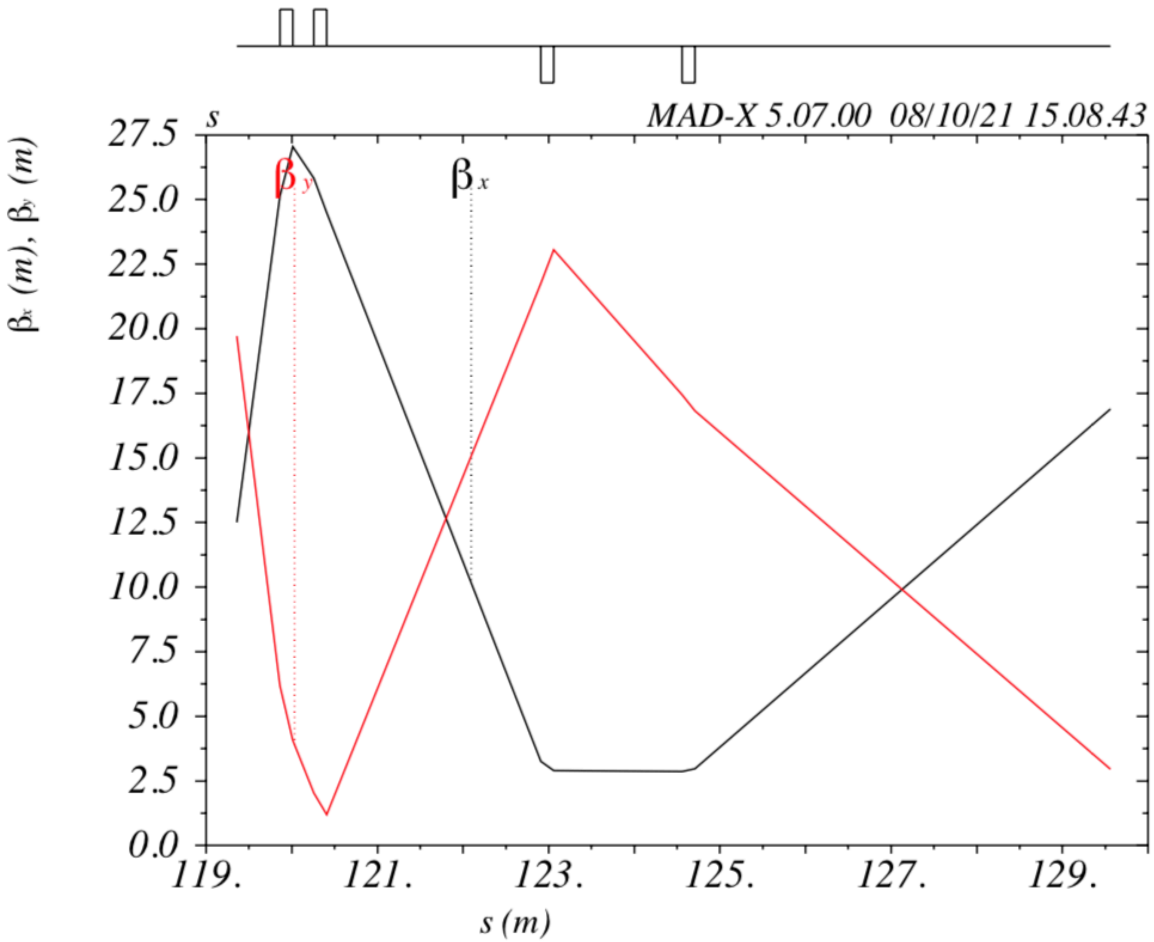
28/10/21



Matching Section

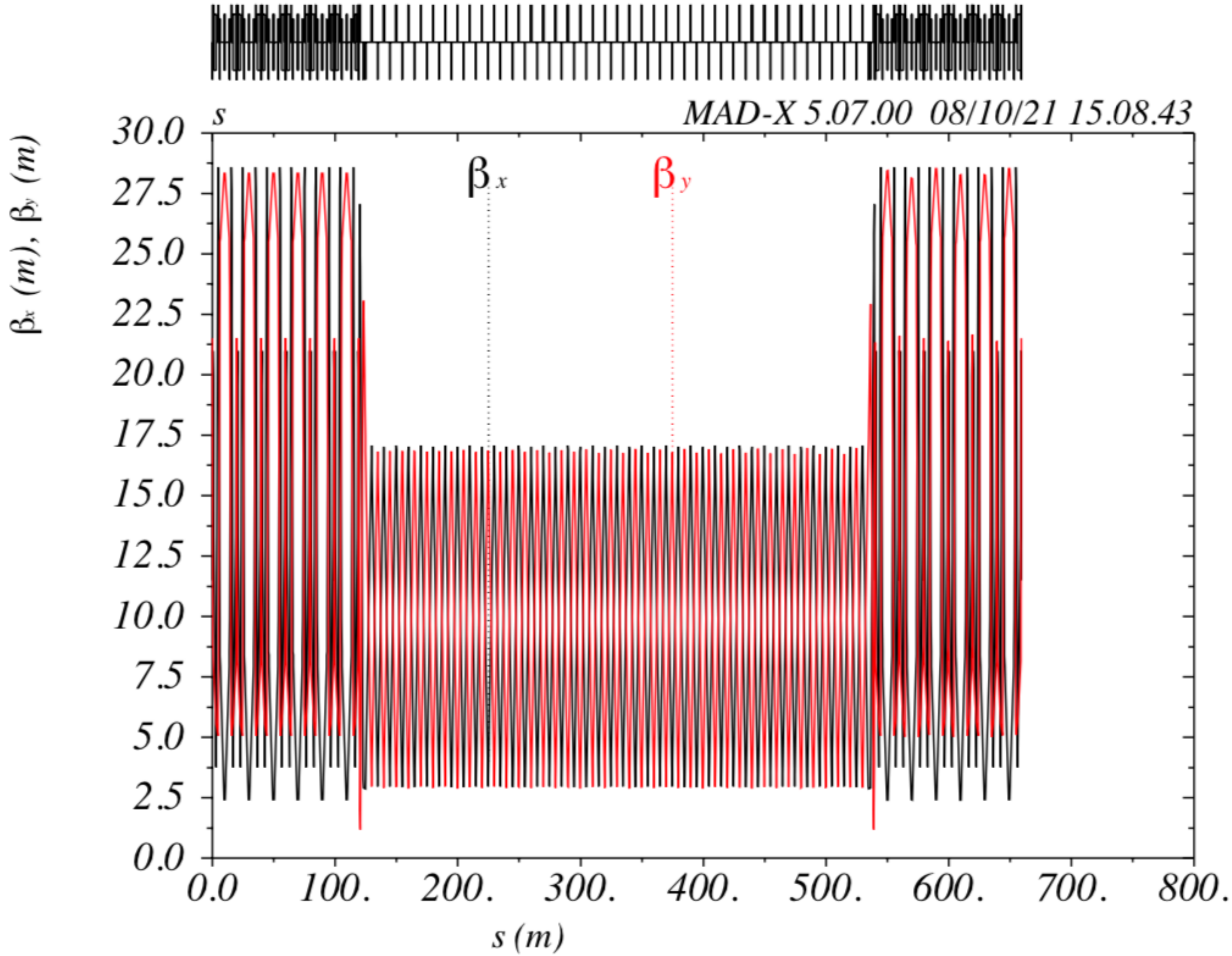
(between TBA and FODO)

28/10/21



TL Twiss functions

28/10/21



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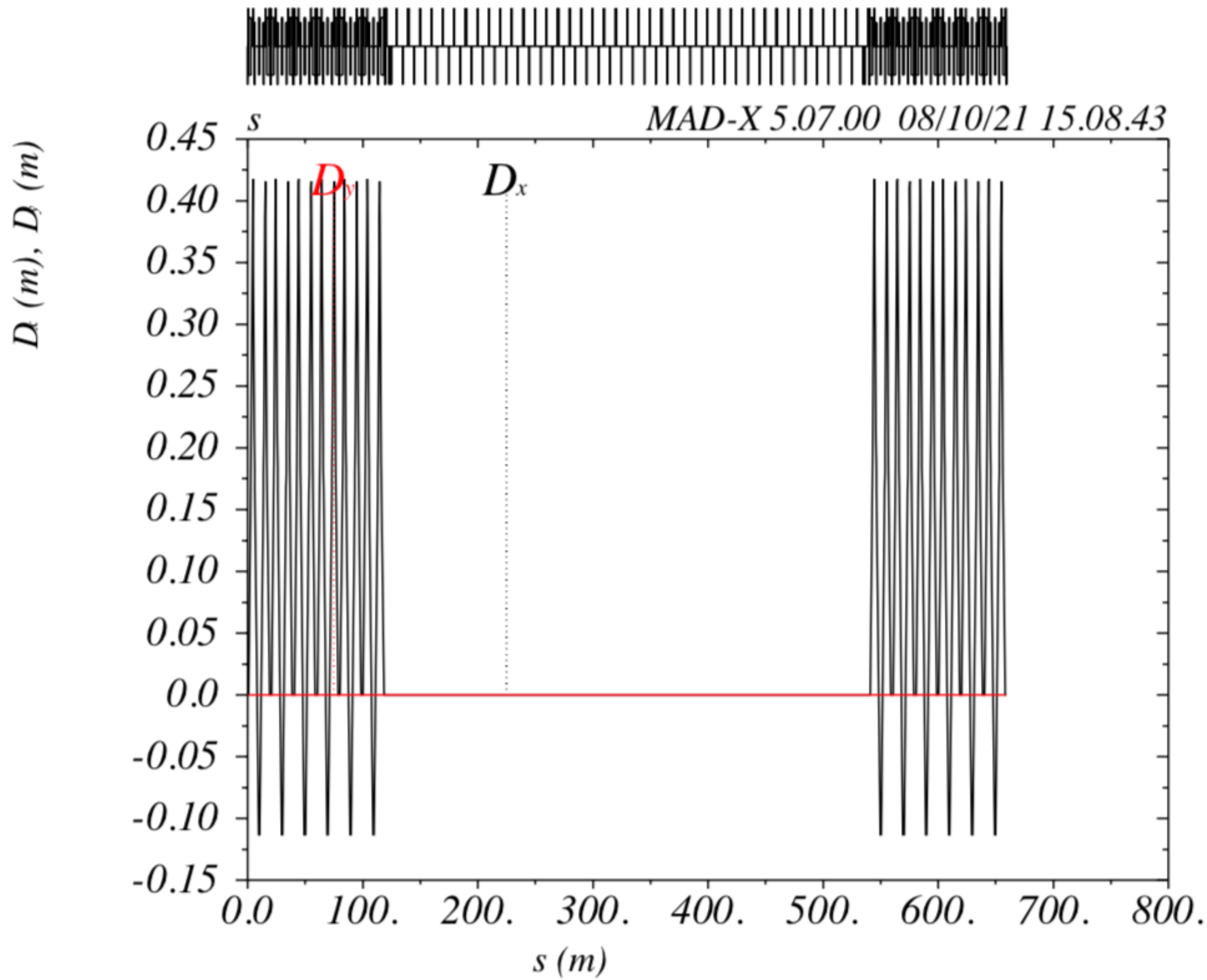
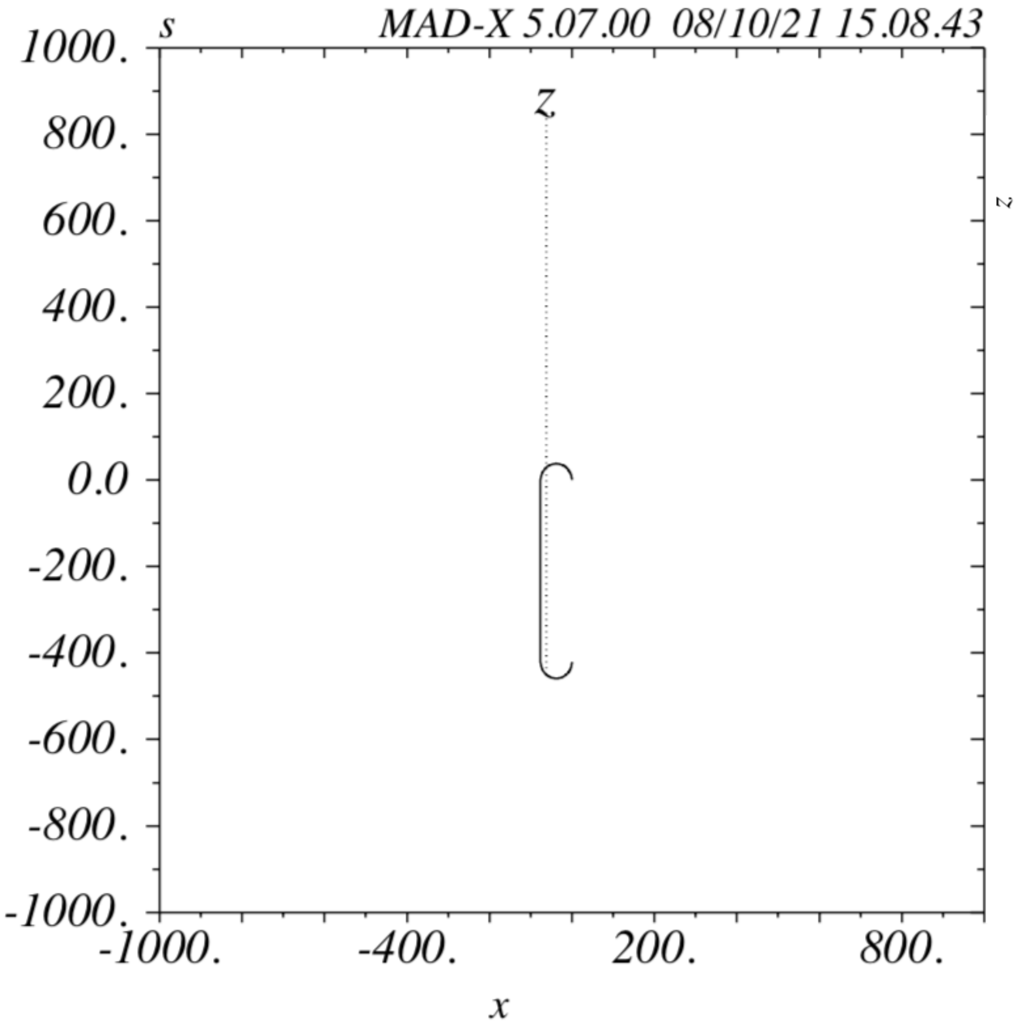
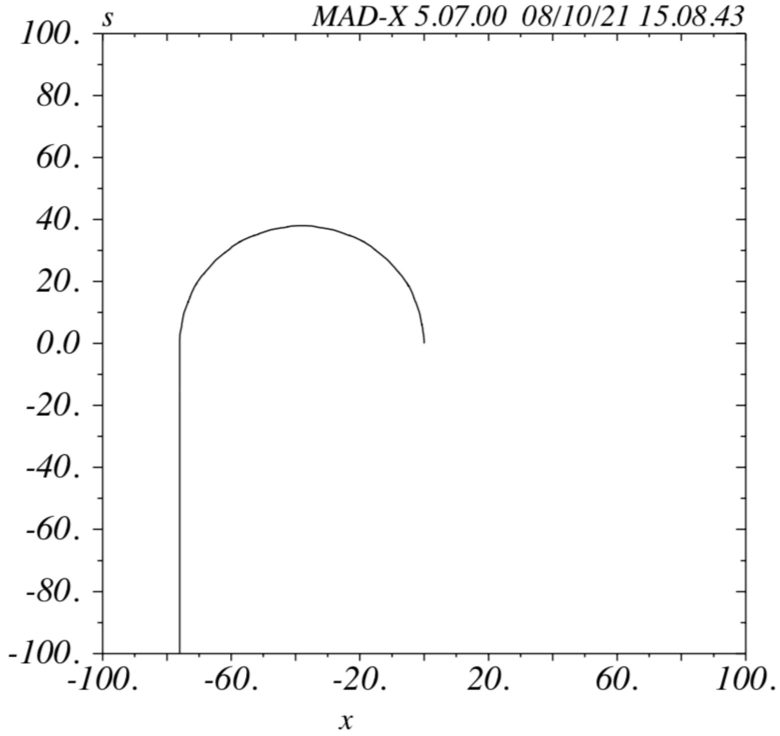


s
MAD-X 5.07.00 08/10/21 15.08.43
D_y
D_x
D_x (m), D_y (m)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.0
-0.05
-0.10
-0.15
0.0
100.
200.
300.
400.
500.
600.
700.
800.
s (m)

TL Survey

28/10/21





Transfer Lines

28/10/21

- The present TL design can be further improved in order to:
  make the layout more compact and keep costs under control
  assure the request beam acceptance
  provide isochronicity at higher order
  minimize the CSR impact on emittance diluition, if any

- Tolerances studies must be addressed

- Vacuum equipment and beam diagnostics must be defined

- Special sections have to be designed:
  Bunch compressor (not clear if it is really necessary)
  Energy compressor

At this stage it has been assumed the beam is on the TL beam pipe axis at the end of LINAC1 and at the entrance of LINAC2

Twiss functions at the end of LINAC1 and at the entrance of LINAC1 must be defined

Injector Layout update

27/01/22

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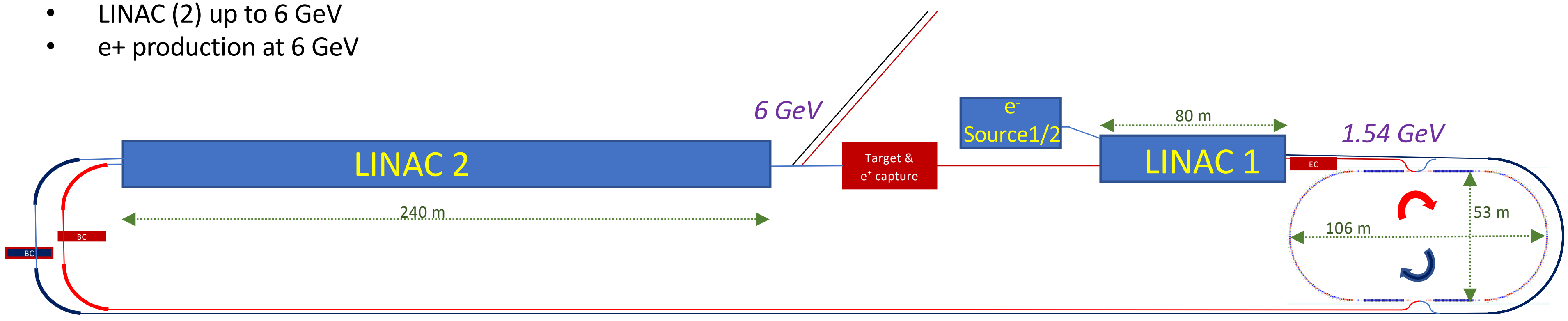

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(presented at the meeting on Nov. 30th 2021)
https://indico.cern.ch/event/1100972/