FCC-ee positron linac design

(Revised version)

Y. Zhao, A. Latina, CERN

FCC-ee WP1 meeting

06 Dec 2024

Revision

- Compared with my presentation on WP1 meeting on 06/12/2024:
  - A bug is fixed in the quadrupole simulation, that the reference energy or strength is not properly set (constant instead of increasing with energy) in S2 section
  - Mainly the beam spot size and beta function are affected. The design, yield, emittance, etc. are not affected much

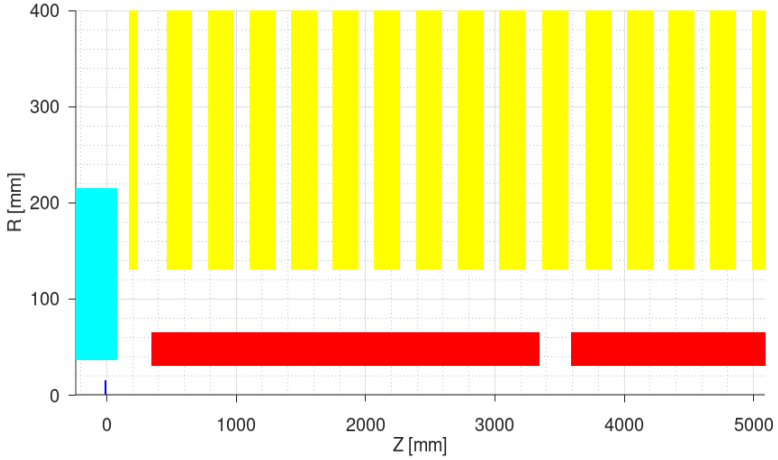
Positron production

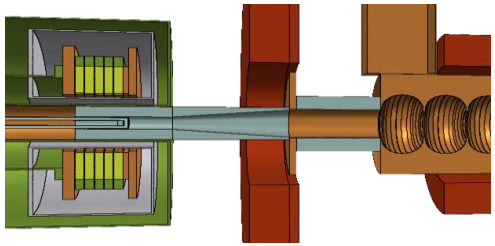
- Electrons
  - E = 2.86 GeV. σ_E / E = 0.5%†. σ_z = 1 mm
  - $\sigma_{x,y}$ = 1 mm. $\varepsilon_{n,x,y}$ = 4 mm*mrad†. Emittance can be larger or smaller, but the impact on positron yield is negligible
- Target
  - Conventional scheme (i.e. cylindrical shape, single amorphous tungsten)
  - Radius: R = 15 mm. Radius can be reduced to the minimum of 5 mm
  - Thickness: W = 15 mm

† Numbers suggested by S. Bettoni from e^- linac simulation

Capture section

- AMD
  - HTS solenoid. 2D field. B_0 ~ 14.94 T
  - Target exit position: 40 mm (w.r.t. HTS B_0)
- Matching solenoid
  - L = 72 mm. 3D field (Maxwell3D)
  - B_0 ~ 0.245 T
  - Center position: 244 mm (w.r.t HTS B_0)
- Shielding
  - Tapered aperture (optimized by WP3). Impact on yield is negligible
- Capture Linac (CL)
  - RF structure length: 3 m. Iris radius: a_0 = 30 mm (constant)
  - N = 6, G = 13.3 MV/m, ϕ = [235 231 233 251 286 257]° (reoptimized by WP3)
  - Regular solenoids: L = 200 mm. 3D field (Maxwell3D). B_0 ~ 0.31 T. N = 9 (per structure)

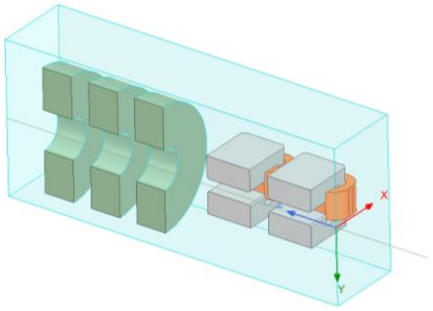




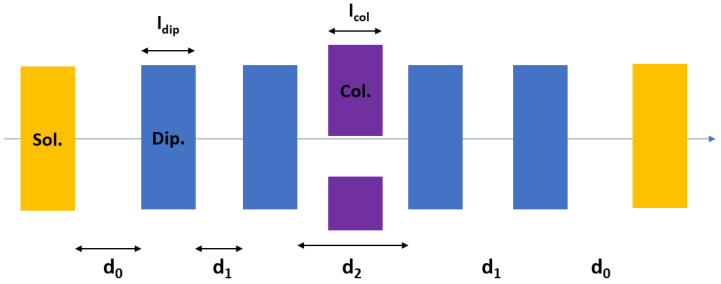
M. Daugaard

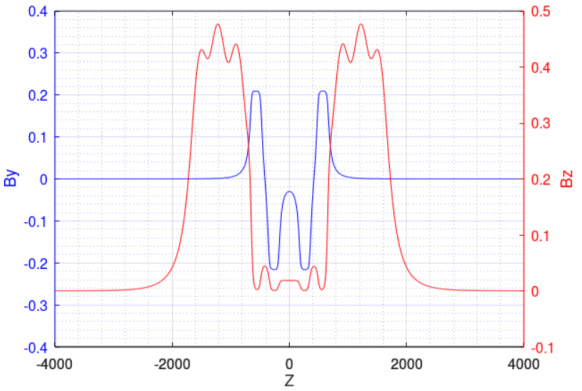
Chicane

- Chicane – “V2” (Collaboration with R. Zennaro)
  - Combined simulation of chicane (four dipoles) and 6 neighboring solenoids. Therefore, parameters (lengths, apertures, distances) are fixed by design
  - Dispersion closed by increasing 2% the current of middle dipoles
  - 3D field (Maxwell3D)
  - Dipole yoke length: **l_{dip} = 180 mm**
  - Apertures of beam pipe: **Δx = 150 mm, Δy = 50 mm (yoke aperture is 70 mm)**
  - Distances between dipole yokes: **d1 = 125 mm, d2 = 350 mm**
  - Distance between solenoid and dipole yoke: **d0 = 125 m**



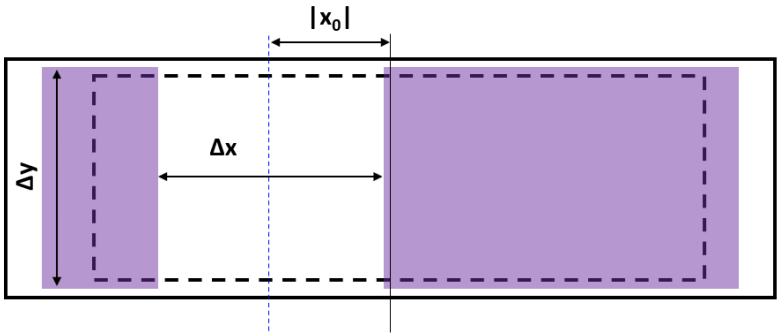
¼ view

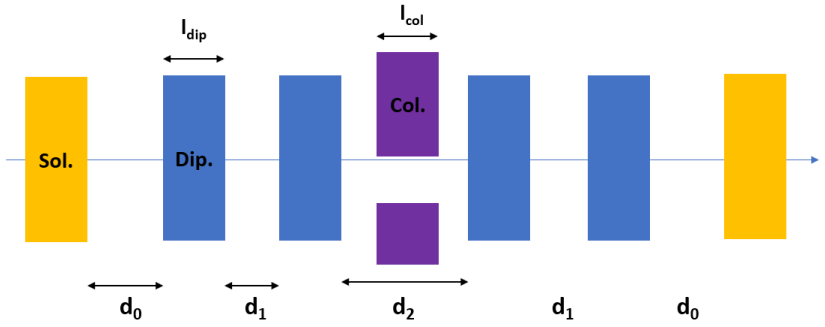


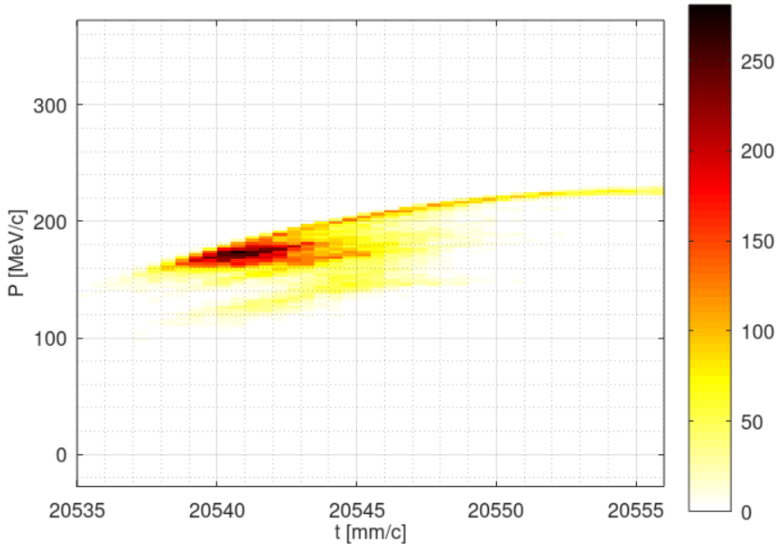


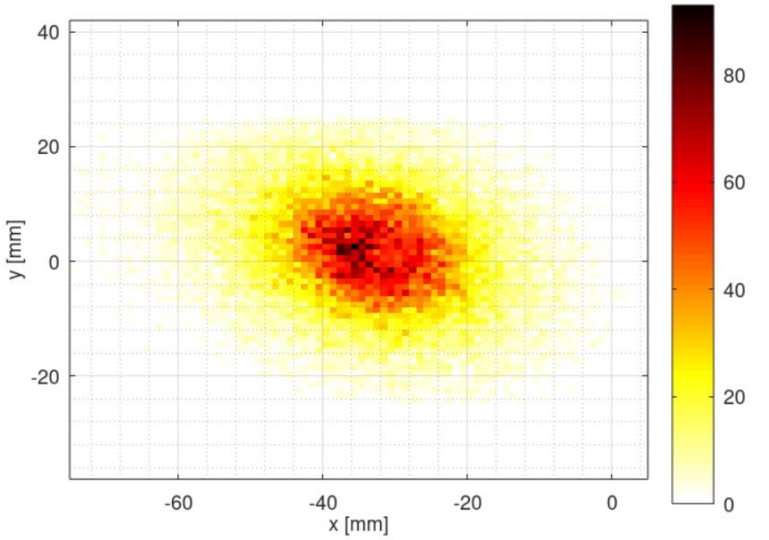
Collimator

- Collimator
  - Length: $\mathbf{l_{col} = 120\ mm}$
  - Apertures: **Δx = 70 mm, Δy = 50 mm**
  - X offset: $\mathbf{x_0 = -35\ mm}$









Positron linac design

- Section 1 (S1)
  - Same structure and solenoids as Capture Linac
  - N = 20, G = 13.3 MV/m, ϕ = -10° (optimized for max. yield)
  - Average energy (around bunch core) at exit: 931.7 MeV
- Section 2 (S2)
  - Same structure as Capture Linac
  - Periodic FODO cells. 2 structures per FODO cell. FODO phase advance: 76.345° (optimized for min. beta)
  - Quadrupole length: 0.4 m. Quadrupole-Structure distance: 0.15 m. Quadrupole spacing: 3.3 m
  - N = 52, G = 12.756 MV/m, ϕ = 5° (optimized for max. yield)
  - Average energy (around bunch core) at exit: 2.866 GeV

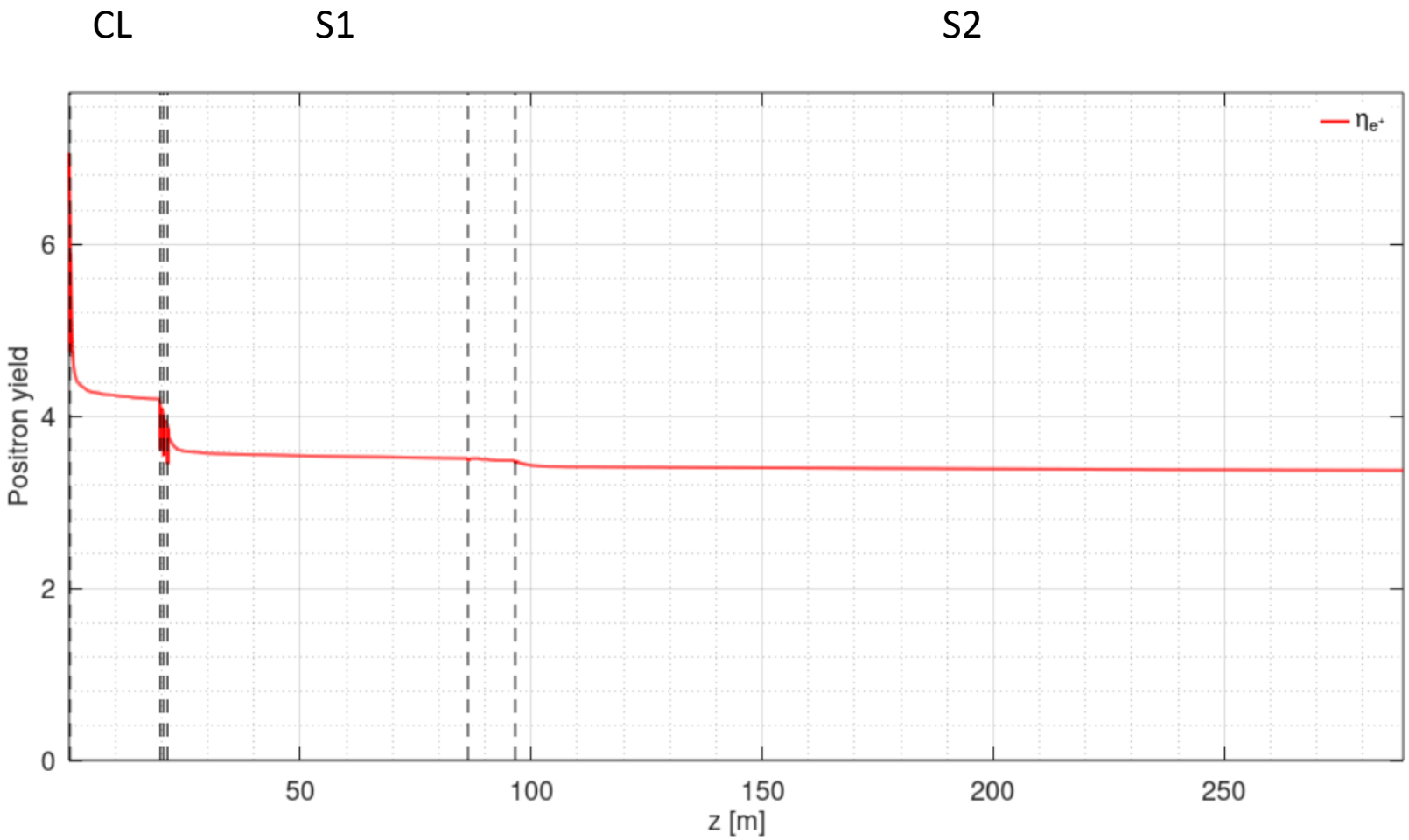
Parameter	Value
Collective effects considered	Space charge; Short-range wakefield
Primary electron bunch charge assumed for collective effects [nC]	5.0
Bunch length (around bunch core) at PL exit [mm]	2.88
Energy spread (around bunch core) at PL exit [%]	0.97
X, Y spot sizes (around bunch core) at PL exit [mm]	5.27, 2.78
Total positron yield (all positrons) at PL exit	3.37
Expected DR accepted yield with ±2% energy acceptance at PL exit	2.97
Normalized X, Y emittances (accepted positrons) at PL exit [mm*rad]	13.2, 13.1
Geometric X, Y emittances at (accepted positrons) PL exit [mm*mrad]	2.36, 2.34

Positron linac power consumption

- **Power consumption in Positron Linac** (based on discussion with J. Raguin)

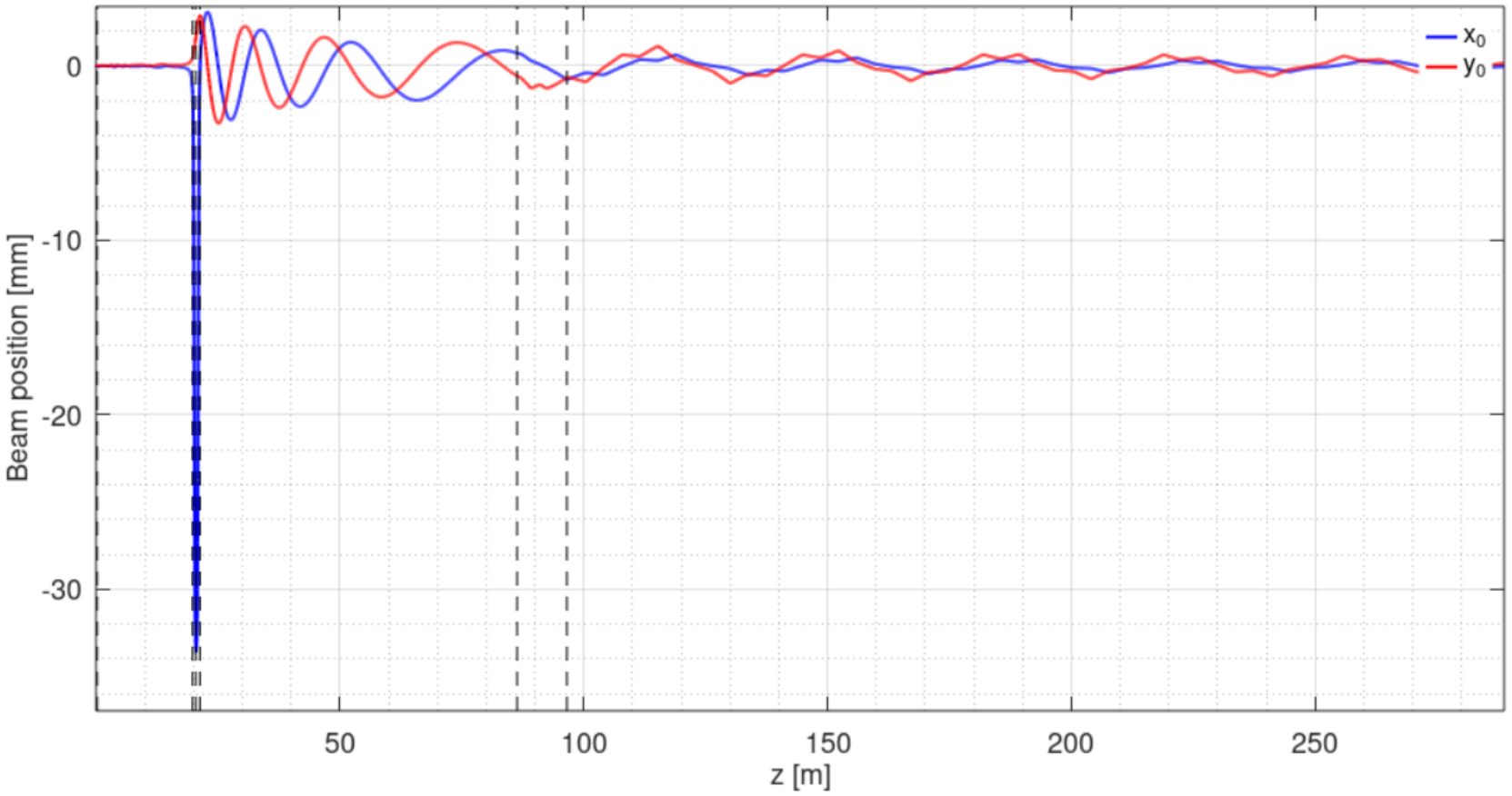
Parameter	Value
Average gradients in S1, S2 [MV/m]	~13
Number of structures per RF module	4
Number of **structures** in S1, S2 (w/ spare module)	[20, 52+4]
Total number of RF modules (w/ spare module)	5+13+1 = 19
Total number of solenoids	20*10 = 200
Total number of quadrupoles	~52+4 = 56
RF power consumption [MW]	19*0.19 = 3.61
Solenoid power consumption [MW]	200*0.016 = 3.20
Quadrupole power consumption [MW]	Neglected
Total power consumption [MW]	**6.81**

Yield evolution along z



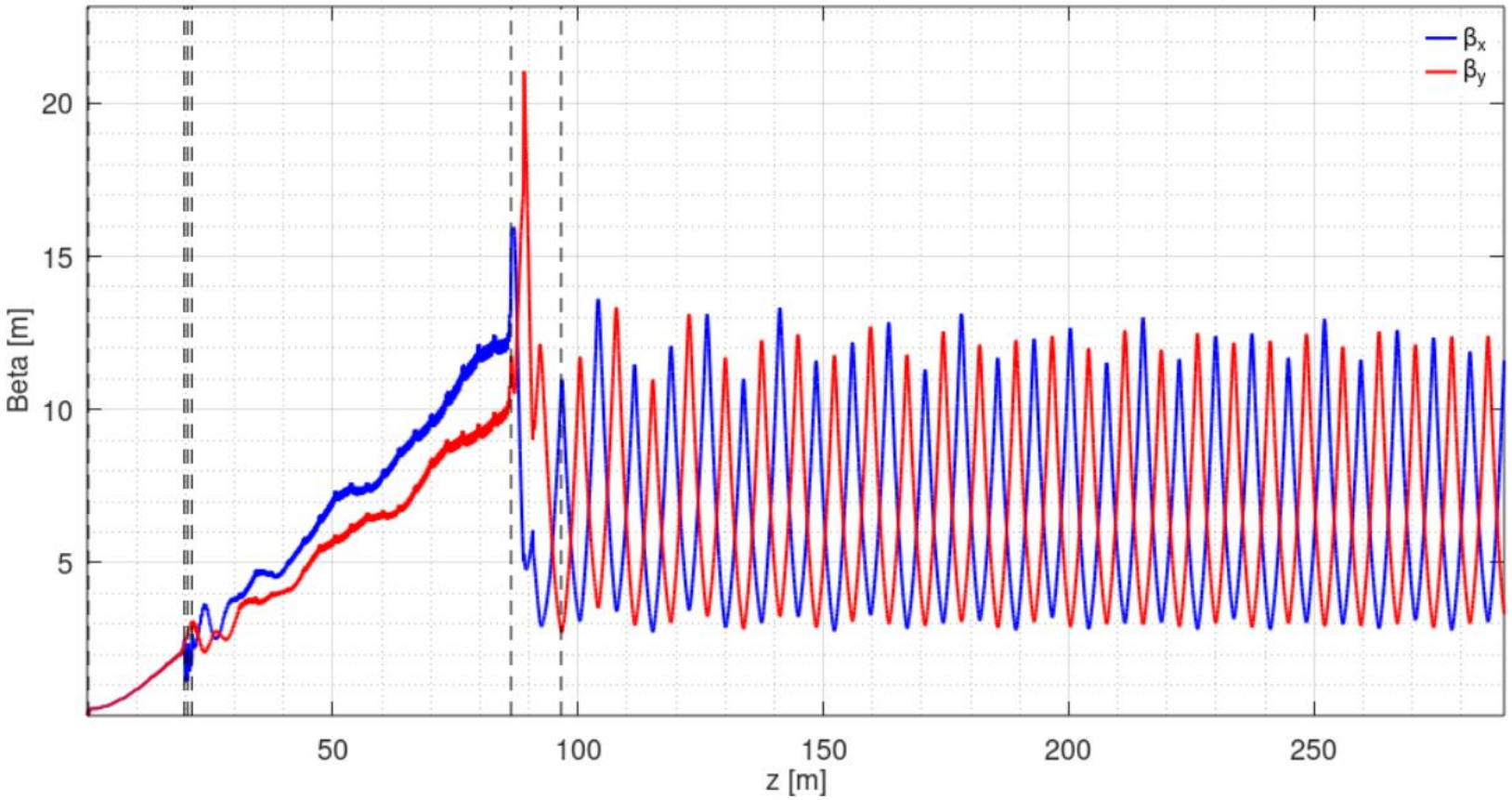
Beam position evolution along z

CL S1 S2



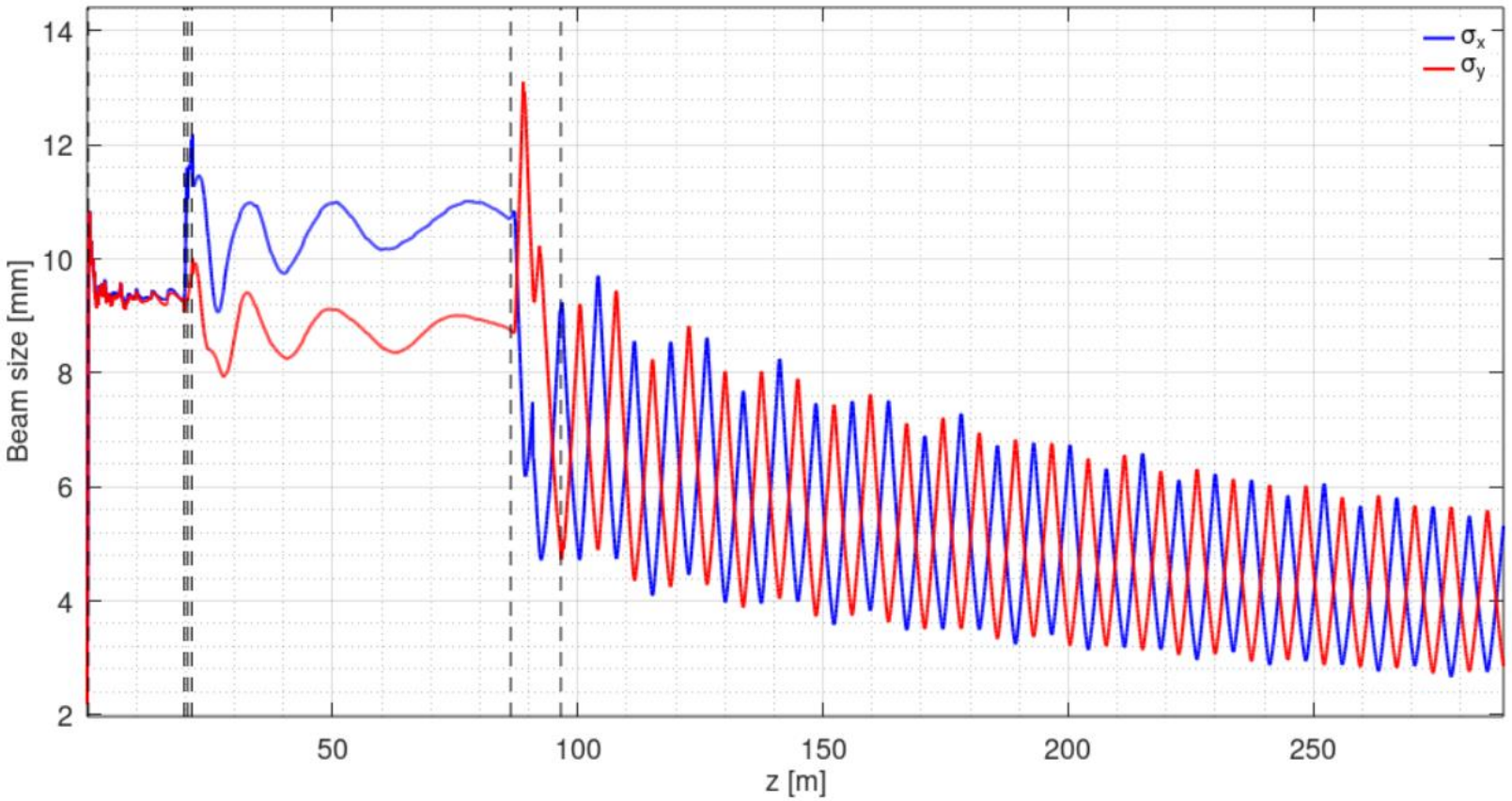
Beam beta function evolution along z

CL S1 S2



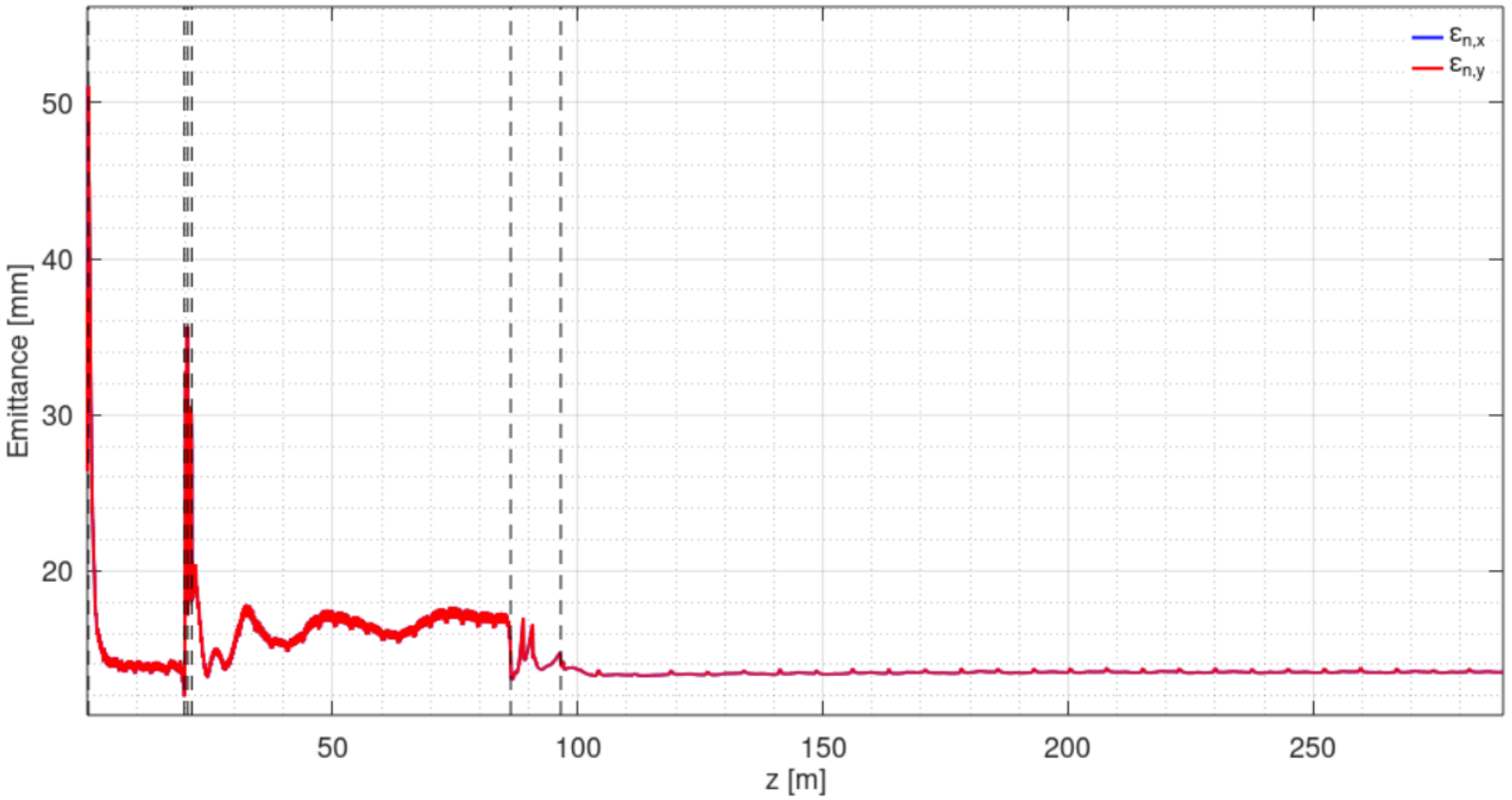
Beam spot size evolution along z

CL S1 S2



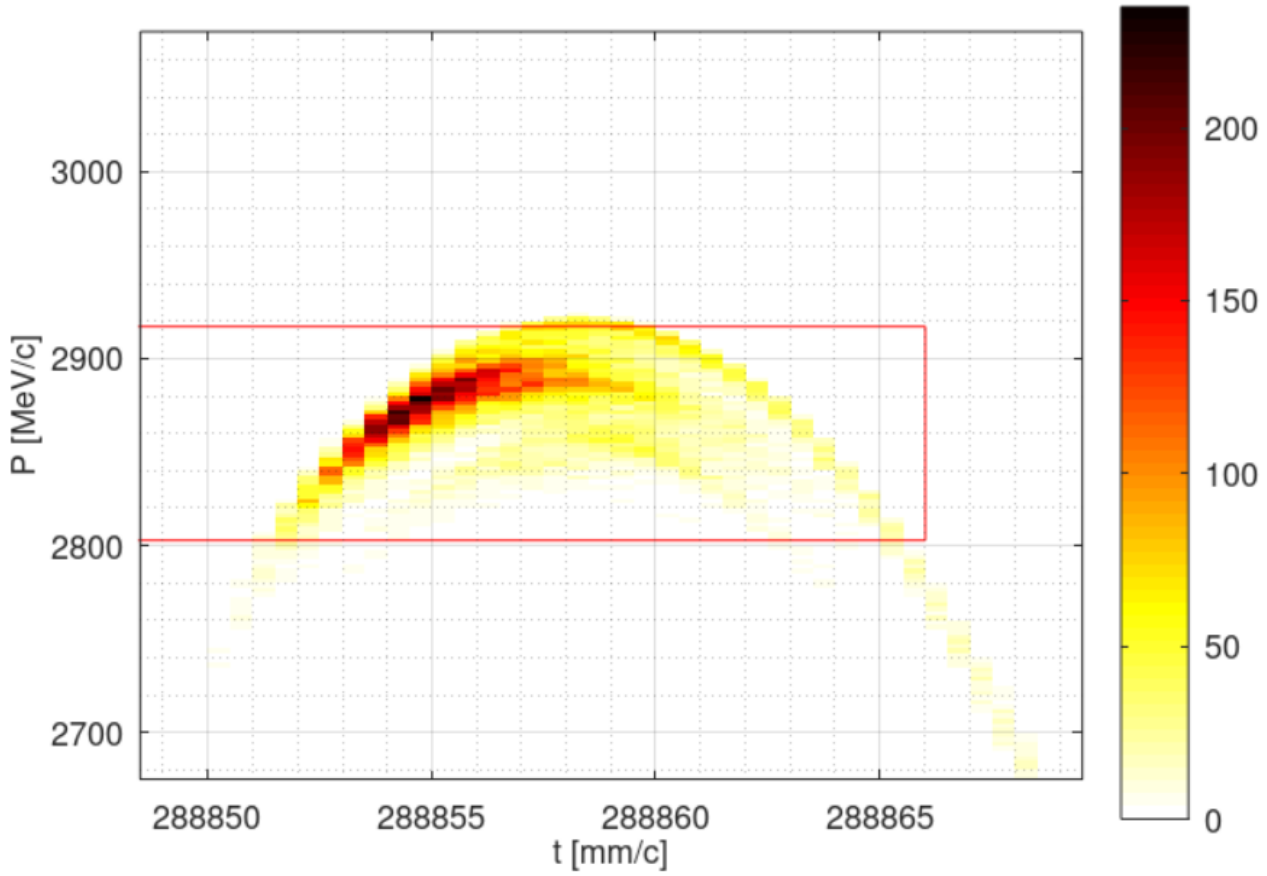
Normalized emittance evolution along z

CL S1 S2



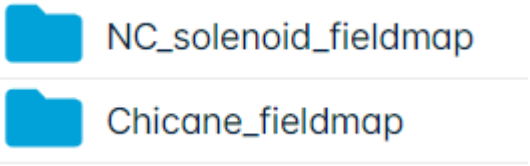
Longitudinal phase space

- At PL exit
  - Total yield: **3.37**
  - Yield with cuts (2.86 GeV ± 2% in energy, ±10 mm/c time): 2.97

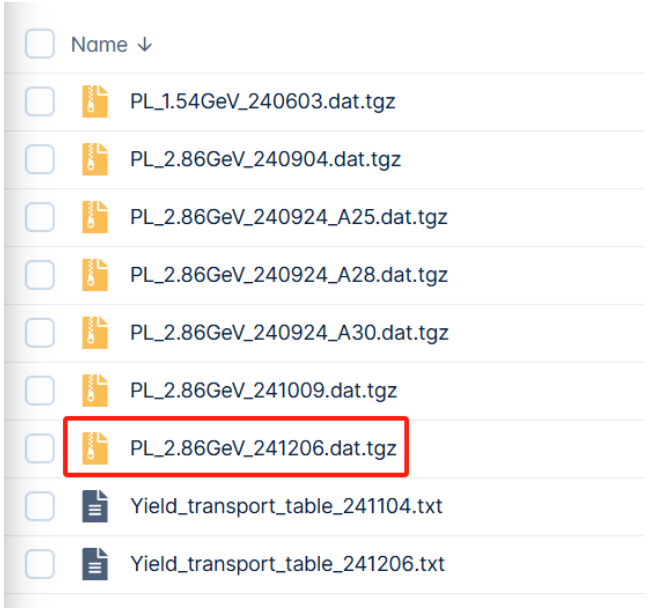


Data sharing

- Fieldmaps uploaded to FCC-ee CERNBox / task 3.1



- Positron distribution at Positron Linac exit for WP4 uploaded to my personal CERNBox / FCCee / PositronLinacOutput

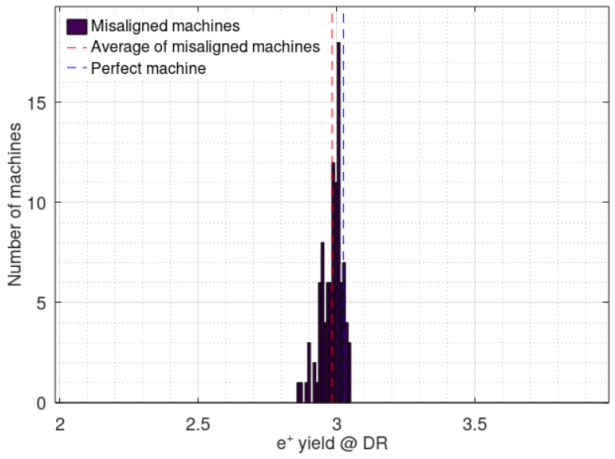


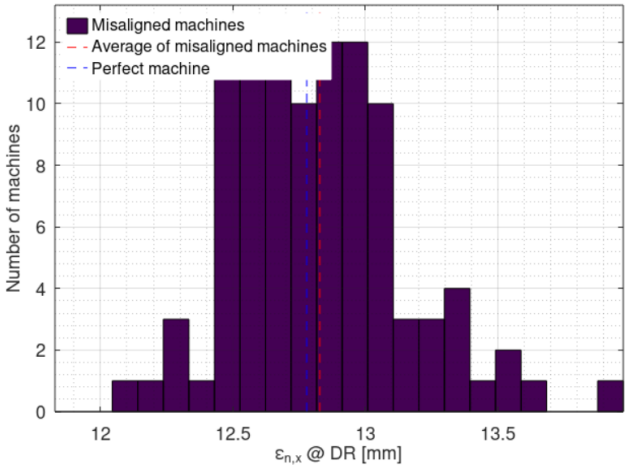
Imperfections

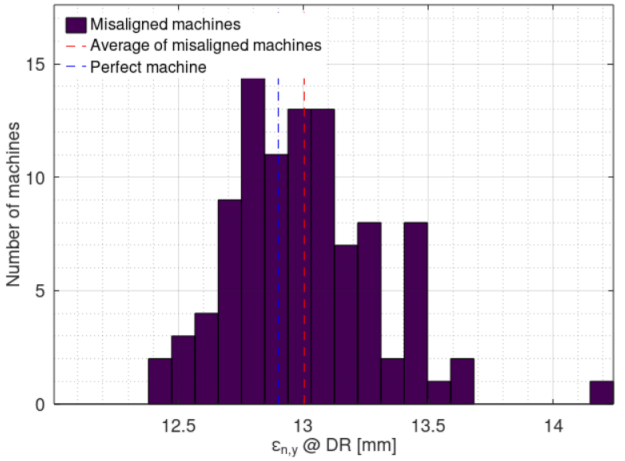
- Imperfections considered
  - **Position** error (x, y): σ = **100 um** for all elements
  - **Angular** error (roll, pitch, yaw): σ = **100 urad** for all elements, except that σ = **200 urad** for all NC solenoids and dipoles
  - Magnatic **strength** error: σ = **0.1%** for all magnets
  - RF **gradient** error: σ = **1%** for all RF structures
  - RF **phase** error: σ = **0.1°** for all RF structures
  - Beam **position jitter** (x, y): σ = **100 um** for e^+ beam from target
  - Beam **angular jitter** (x', y'): σ = **100 urad** for e^+ beam from target

Imperfections

- 100 random machines with imperfections
- Compared with perfect machine:
  - Average DR accepted e+ yield reduction: 1.3%† (2.97 → 2.93)
  - Average normalized X / Y emittance increase: 0.4% / 0.8%† (13.2 / 13.1 mm → 13.3 / 13.2 mm)
- Impact of considered imperfections is negligible







† Assuming the same effects as before. Updates in progress. Conclusions should be the same.

Backup