FCC-ee positron imperfections

Y. Zhao, A. Latina, CERN

FCC-ee WP1 meeting

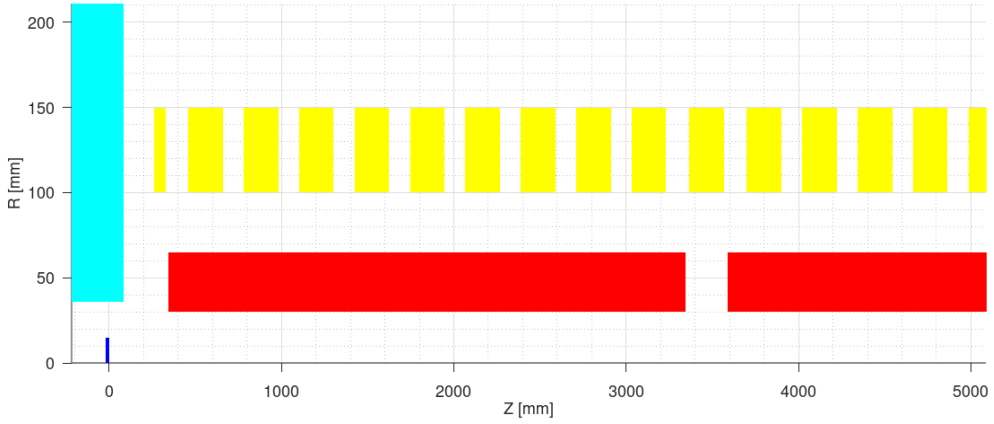
31 May 2024

News

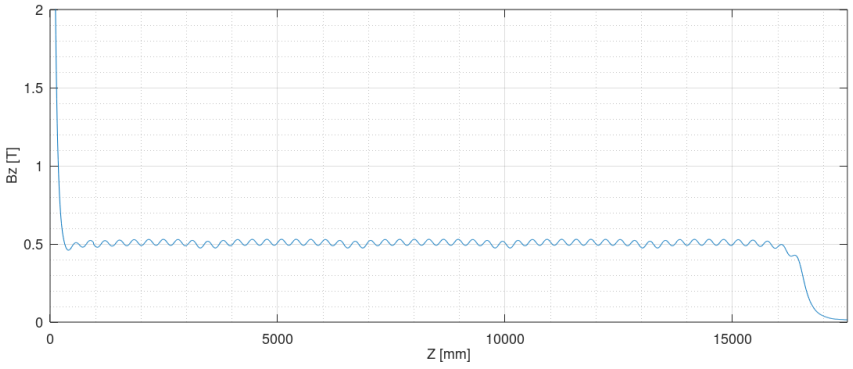
- Geant4 yield bug related to mesh (/score/) confirmed by Geant4 experts (many thanks to Fahad for the communication). For the moment, keep using conservative yield (mesh off) before the bug is fixed
- Yield updates
  - **3rd May** @ WP1 meeting: Good benchmarking of "V0" with Mattia (DR accepted yield: **~6.7**). First results of "V1" (current baseline) simulation. "V1" DR accepted yield: **~5.7** (w/o collective effects)
  - **13th May** @ WP3 meeting: RF-Track updates (fixes and robustness). "V1" DR accepted yield: **~5.2** (~5.3 w/o collective effects). Investigation found that reoptimisation needed due to RF-Track updates.
  - **31th May (today)** @ WP1 meeting: gradient & phases reoptimised. "V1" DR accepted yield: **~5.6** (~5.7 w/o collective effects)
- Imperfections updates
  - Using **larger angular error** for small elements (as Riccardo suggested)
  - Using **separate single dipole field** instead of combined field in chicane for better misalignments
  - Magnet **strength errors**, RF **gradient and phase errors** and **beam jitters** included

“V1” configuration review

- Electron drive beam: **1 mm** spot size
- AMD: HTS solenoid (2D fieldmap). Target exit located at **40 mm** w.r.t. peak field
- Capture linac (CL): up to **~205 MeV** (peak energy)
  - 1 short (72 mm long) tuning solenoid (1D fieldmap) between AMD and RF structures
  - 9 regular (200 mm long) solenoids (1D fieldmap) surrounding each RF structure
  - 1 regular solenoid between neighbouring RF structures
  - **5** RF structures (2D fieldmap). Each 3 m long, large aperture (R = 30 mm), G = **19.748236 MV/m** (as it is in the fieldmap, obtained from autophase, which was just thought to be exactly 20 MV/m previously)



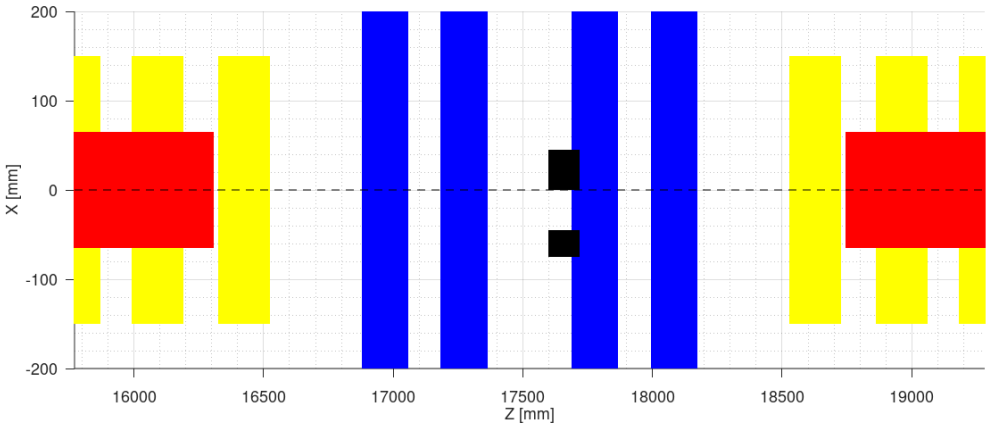
Schematic layout (partial)



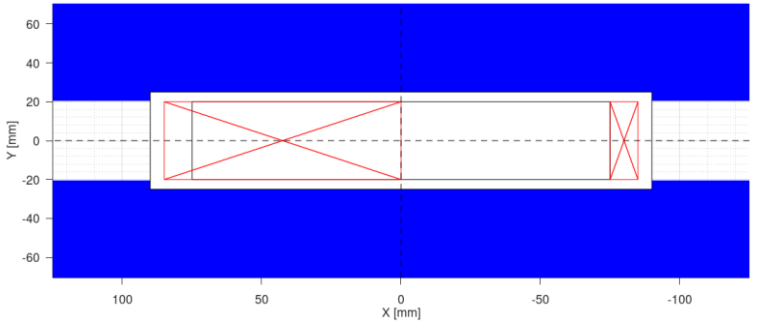
HTS + NC solenoids field

“V1” configuration review

- Chicane (CC)
  - Designed by Riccardo & Mattia
  - Beam pipe (rectangle): Rx = 75 mm, Ry = **20 mm**, L = 2 m
  - Dipole: 3D field map. Peak field: ~0.2 T
  - Collimator (CM): Rx = 37.5 mm, Ry = 20 mm, L = 120 mm, z0 = **132.5 mm** (w.r.t CC center)
  - Keeping it as it is now, though aperture is a bit small and collimator position is not physical



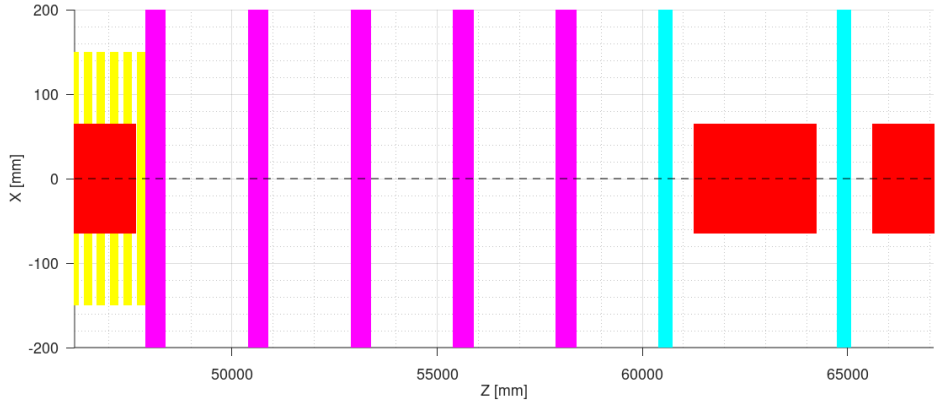
Schematic layout (longitudinal sectional drawing)



Transverse sectional drawing

“V1” configuration review

- Positron linac (PL)
  - Designed by Mattia
  - Section 1 (PL1): up to **~730 MeV** (peak energy). Same structure with CL. **9 structures**. **G = 19.78 MV/m** (19.55 MV/m if w/o short-range wakefield). **φ = -10°**
  - Matching section (PLM): **5 quadrupoles**. Quadrupole (0.5 m long) distance fixed to 2 m
  - Section 2 (PL2): up to **1.54 GeV**. Same structure with CL. **14 structures** in 7 FODO cells. Quadrupole (0.35 m long) distance fixed to ~4 m. **G = 19.78 MV/m** (19.55 MV/m if w/o short-range wakefield). **φ = -10°**



Schematic layout (partial)

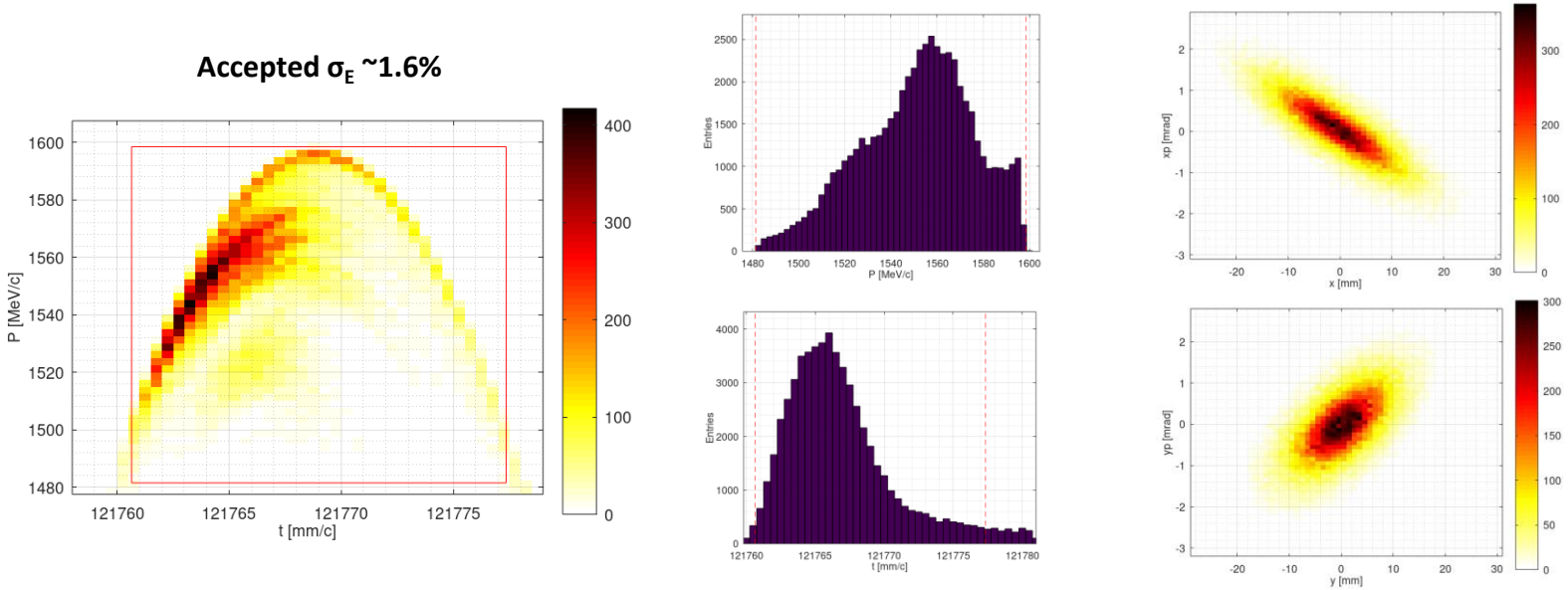
- Energy compressor (ECS): not yet simulated
- Damping ring (DR): not simulated. Simple acceptance cuts applied
  - Energy window: 1.54 GeV **± 3.8%**. Time window: **16.7 mm/c**

Nominal results

- Perfect machine (w/o imperfections)
- Collective effects considered
  - Space charge. Short-range wakefield in positron linac

Results	Yield after Target, CL, PL and DR cuts	$\varepsilon_{n,x,y}$ after DR cuts [mm]
W/o collective effects	13.9, 8.1, 6.3, **5.7**	**10.3, 10.9**
W/ collective effects	13.9, 8.0, **6.2**, **5.6**	**10.3, 10.9**

Accepted σ_E ~1.6%

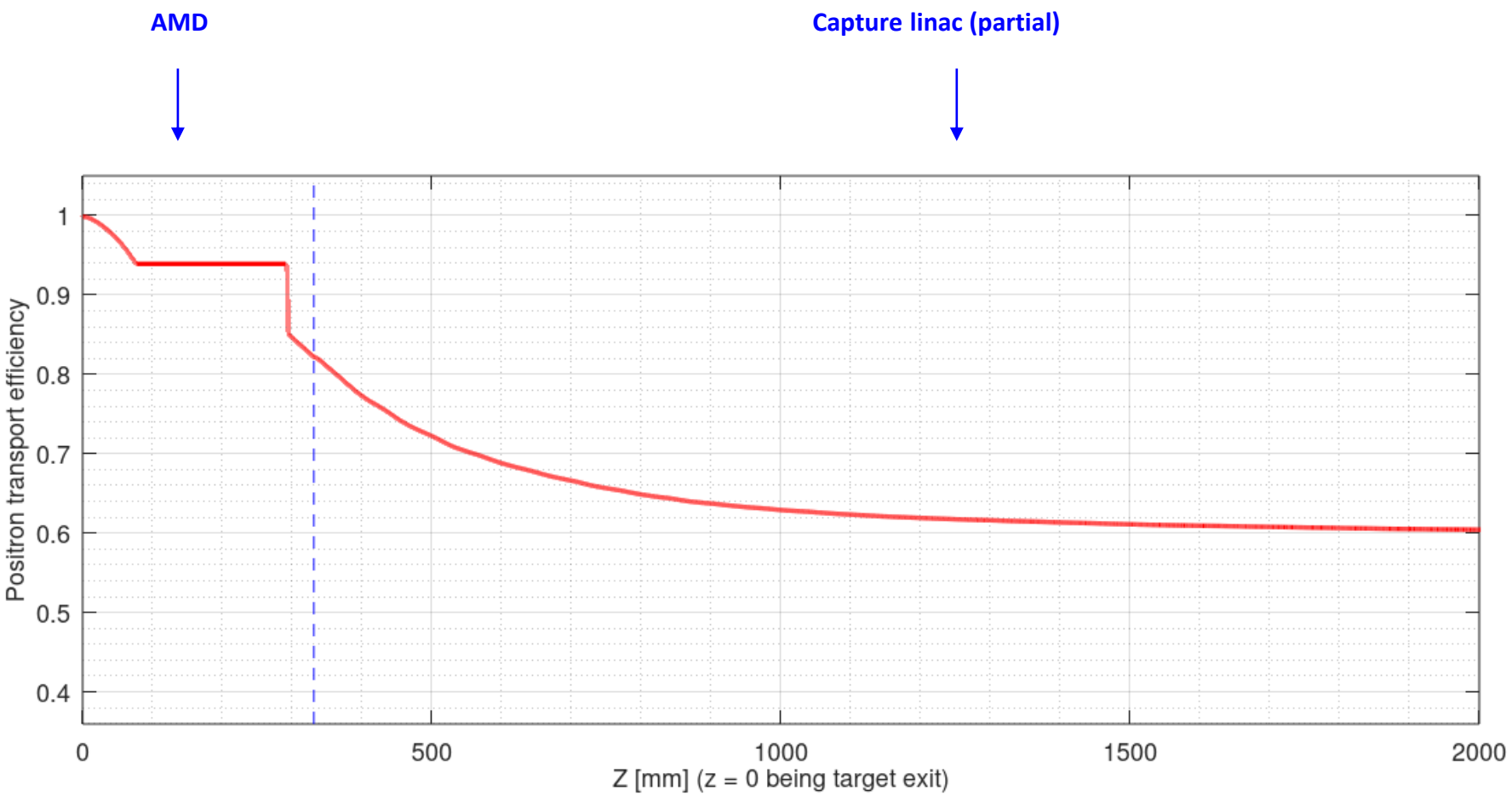


Longitudinal phase spaces

Transverse phase spaces

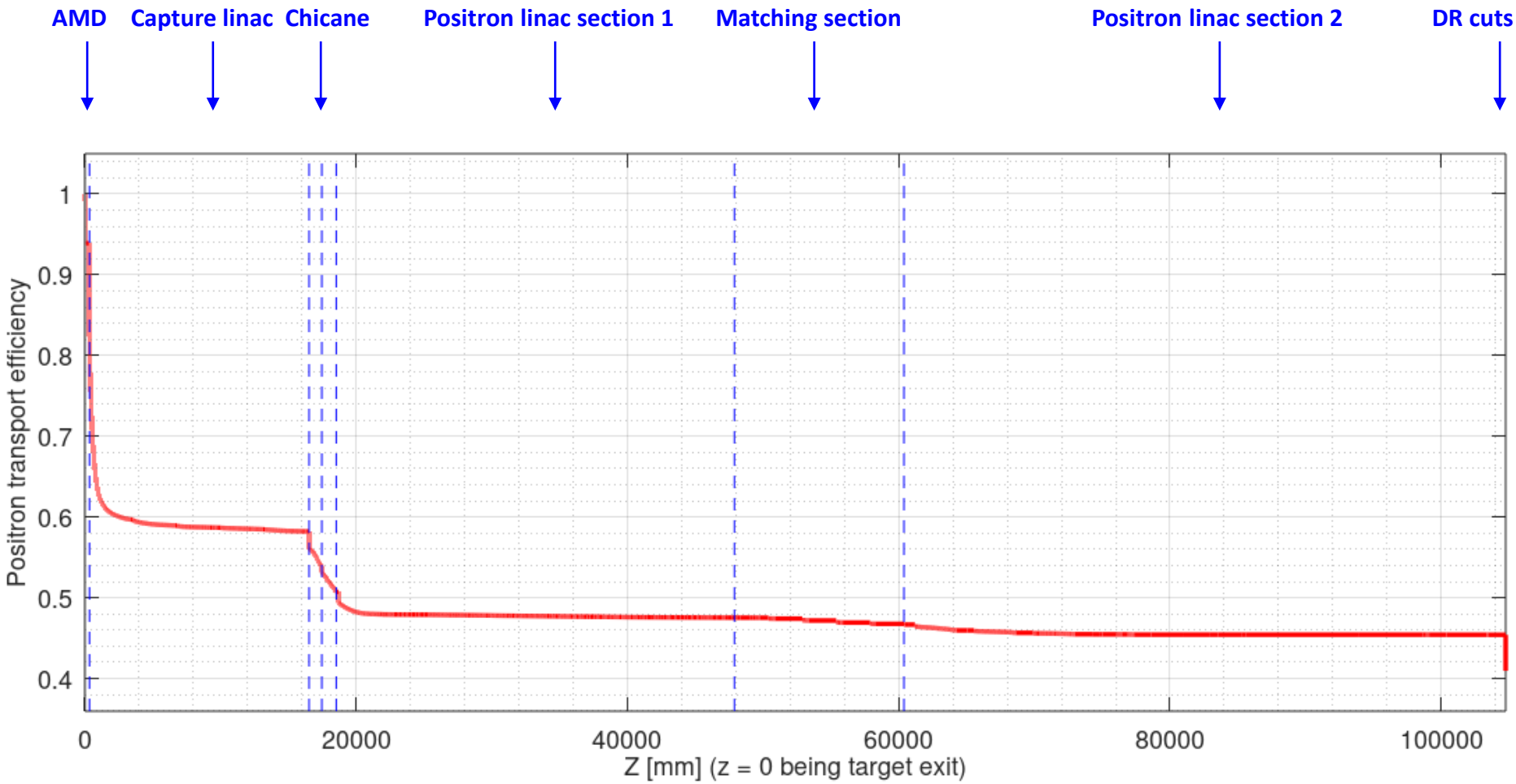
Loss map

- Positron transport efficiency



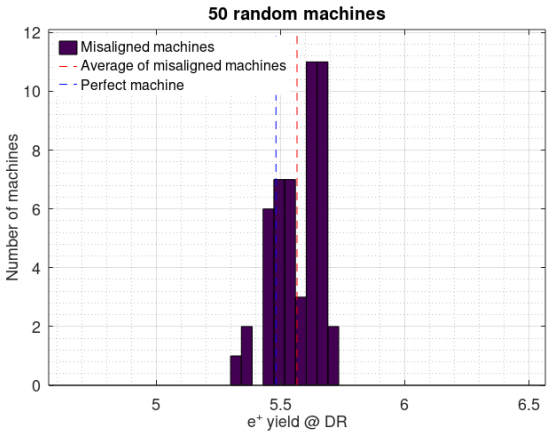
Loss map

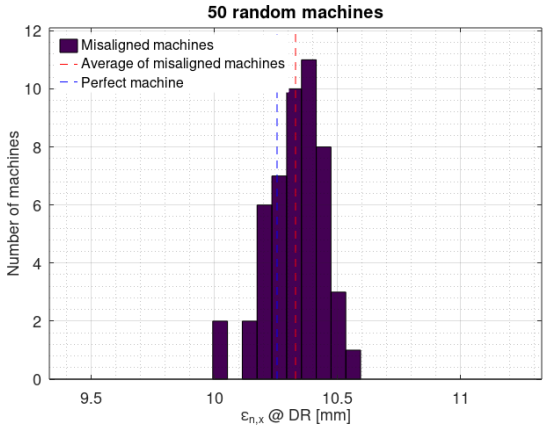
- Positron transport efficiency

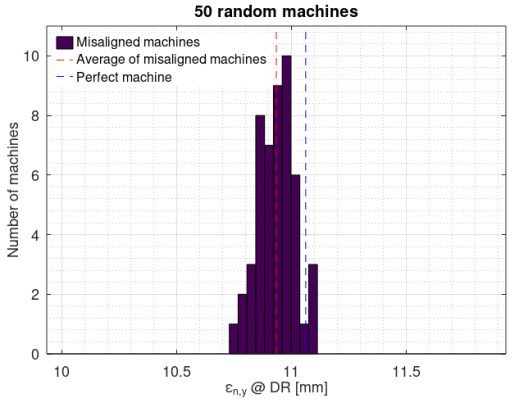


Imperfections

- 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



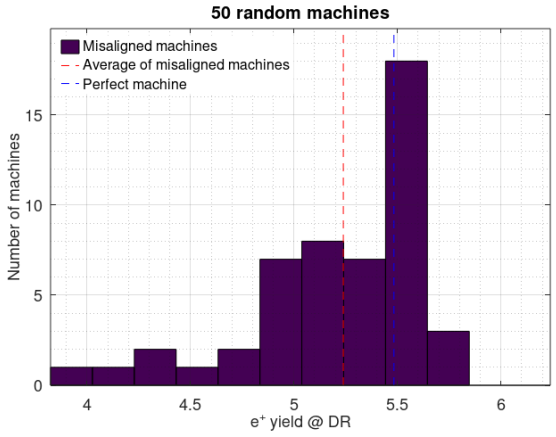


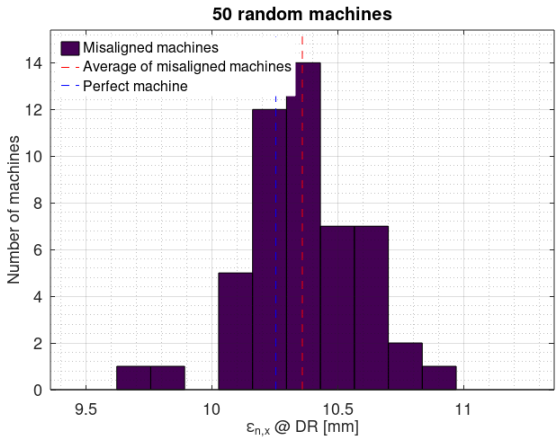


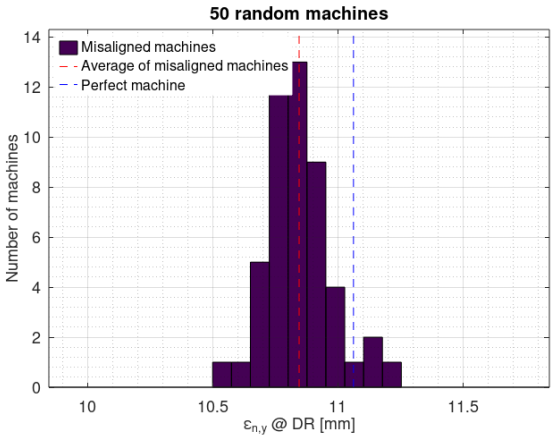
Imperfections

- 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 = **5%** for all RF structures
  - RF **phase** error: σ = **0.5°** 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

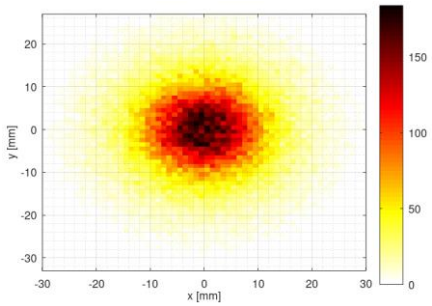
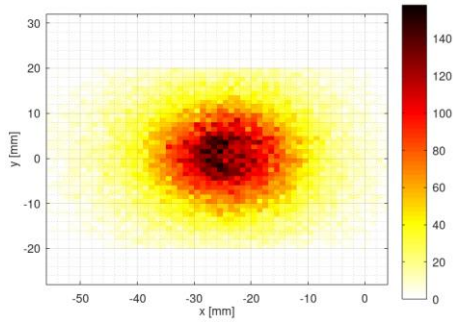
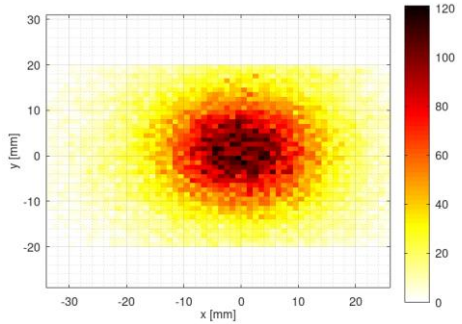
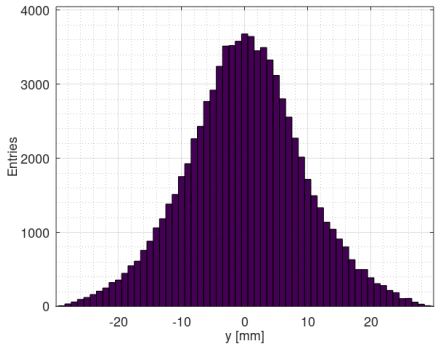
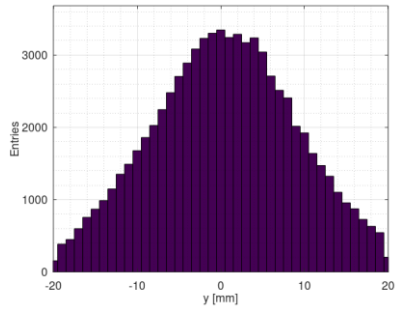
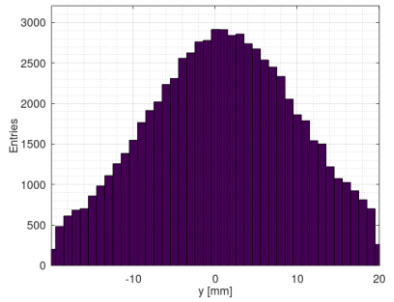
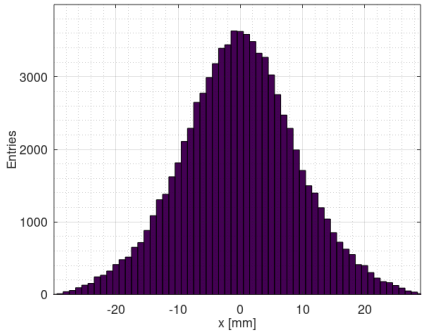
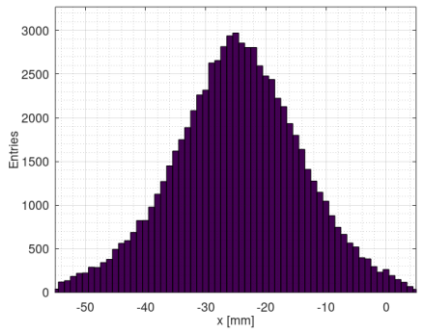
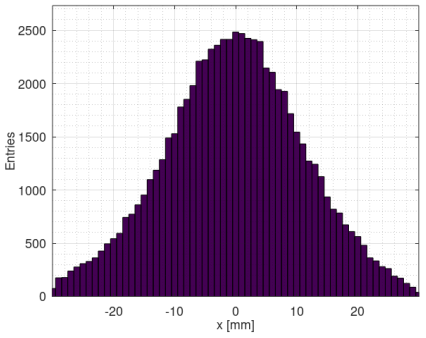
Very large gradient and phase errors





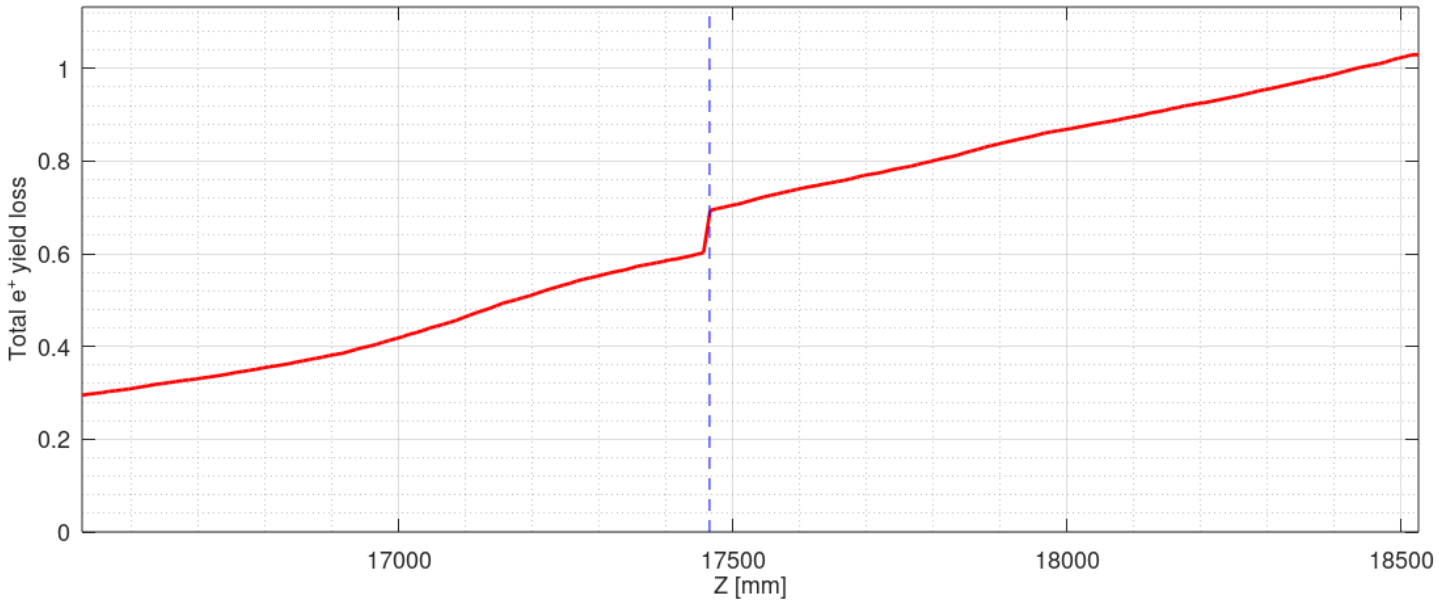


Additional studies: spot size in chicane

Chicane entrance	Chicane center	Chicane exit
		
		
		

Additional studies: loss in chicane

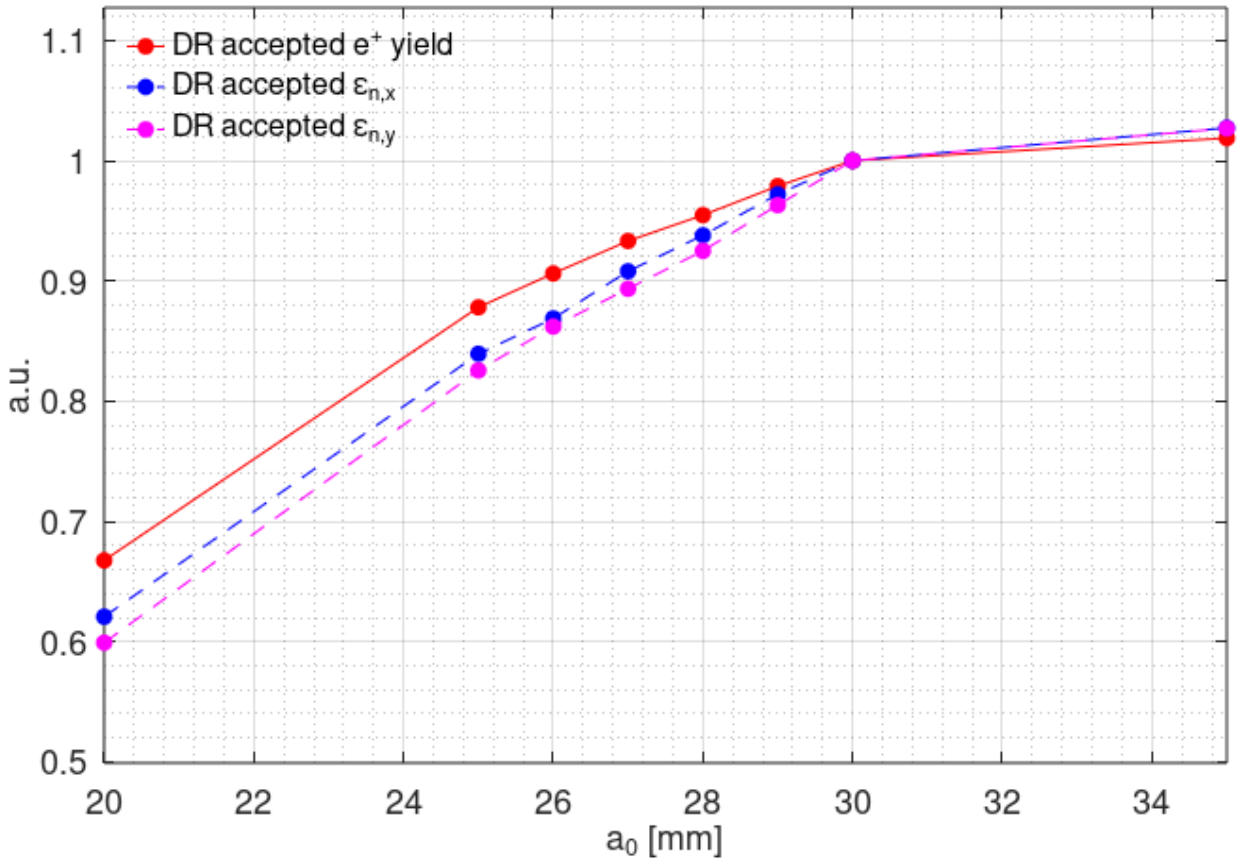
- Yield (not the DR accepted yield) **loss** in chicane: **~1.0** e^+/e^-



- DR **accepted** yield **loss** in chicane is **~0.2** e^+/e^-
  - Estimated by turning off dipole field, using very large beam pipe apertures and removing collimator in chicane

Additional studies: RF aperture scan

- Very simple scan of RF structure geometric aperture, a_0
  - Same field map used
  - 10% particles from target used

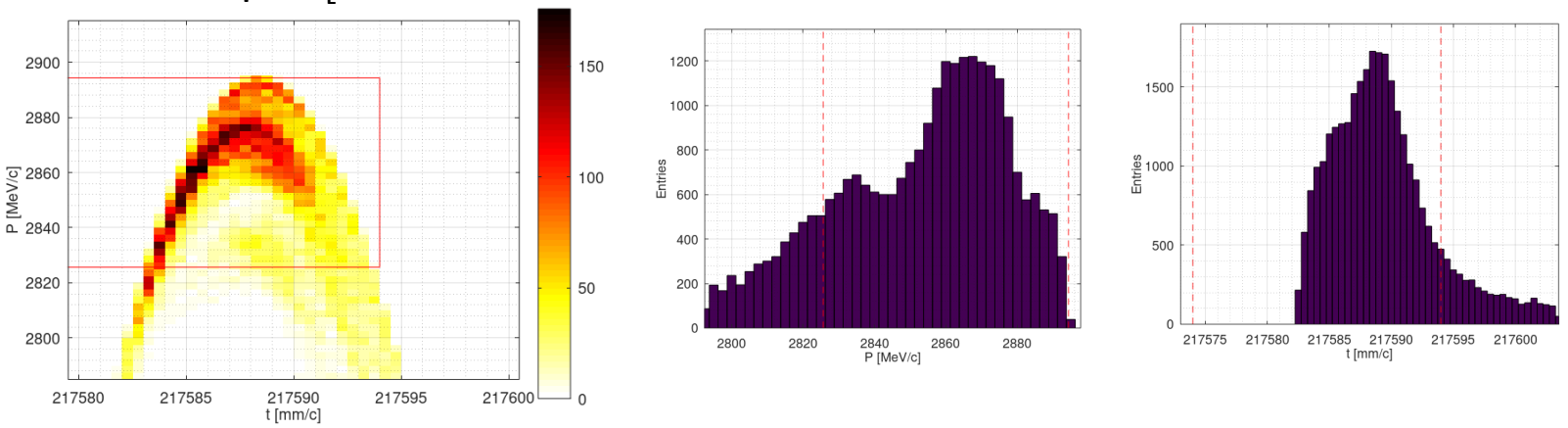


Additional studies: DR @ 2.86 GeV

- Similar configuration with 1.54 GeV, except that:
  - Electron beam energy: **2.86 GeV** (instead of 6 GeV)
  - Target thickness: **15 mm** (instead of 17.5 mm)
  - Positron linac (PL): G = 19.65 MV/m, φ = -5°
  - Positron linac section 2 (PL2) extended to **36** structures (instead of 14) with the same FODO lattice
  - DR acceptance energy cut: **±1.2%** @ 2.86 GeV (instead of ±3.8% @ 1.54 GeV)
  - DR acceptance time window: **20 mm/c** (instead of 16.7 mm/c)

Results	Yield after Target, CL, PL and DR cuts	$\varepsilon_{n,x,y}$ after DR cuts [mm]
W/o collective effects	7.1, 4.1, **3.2**, **2.2**	**9.2**, **10.2**

Accepted σ_E ~0.6%



Conclusions

- **Nominal** results and **imperfections** study presented for positrons
- **Effect** of imperfections is **very small**, unless when **very large gradient and phase errors** are assumed
- **Loss in chicane** studied, which is not negligible and can be reduced
- **Very preliminary** results for DR @ **2.86 GeV**
- Next steps (after FCC week)
  - **Chicane** (and collimator) **to be optimised** (to discuss with Riccardo)
  - **Energy compressor to be included** in the simulation
  - **More DR requirements to be specified** for accepted yield estimation. Currently the requirements might be too simple - maximum yield in time and energy cut window at positron linac exit

Backup