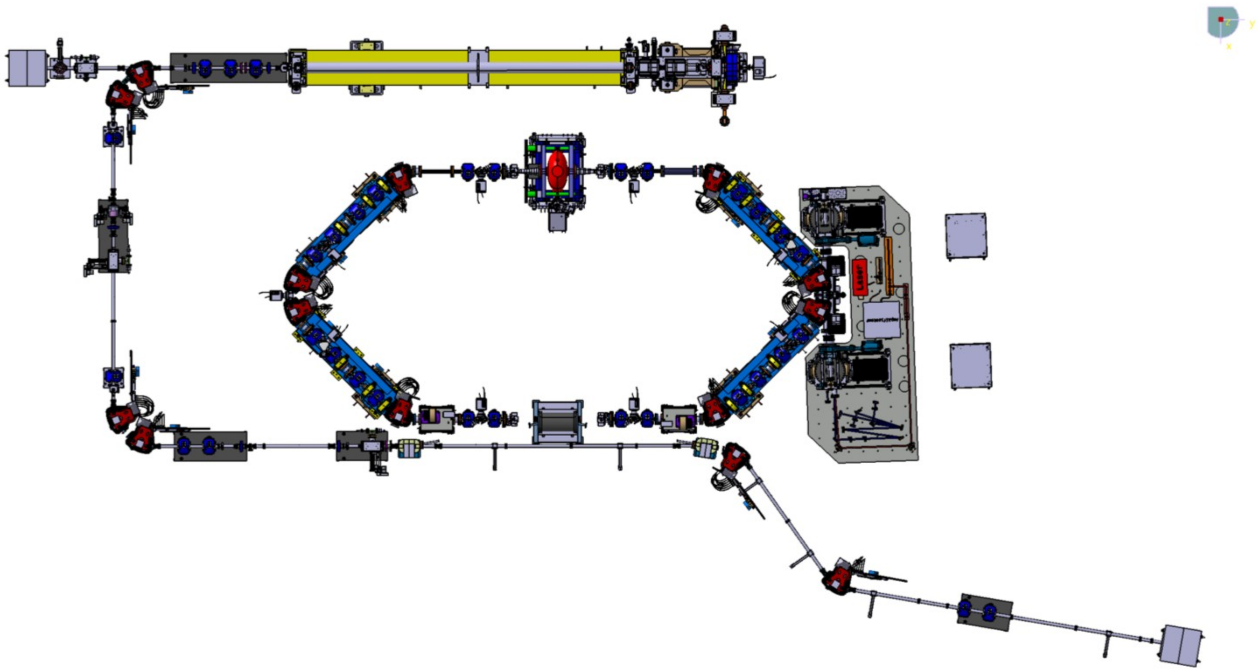
ThomX : Optimisation of ring injection

Presentation by Alexandre Moutardier (09/04/2020)



How to optimise the number of particles injected in the ThomX ring

Two paths are followed:

- **Identify the orbits** that lead to particles being injected in the ring (with MadX)
- **Calculate** semi-analytically the **effect** of the TL **correctors** on the orbit of the particles at the beginning of the ring (with Matlab)

Transfer line (TL) parameters were proposed by:

- **Ezgi E.** using **Codal** (Lattice_TL+extract.xlsx, 10/03/2020)
- **Alexandre L.** using **Beta** (TDR version)

Ring parameters were proposed by:

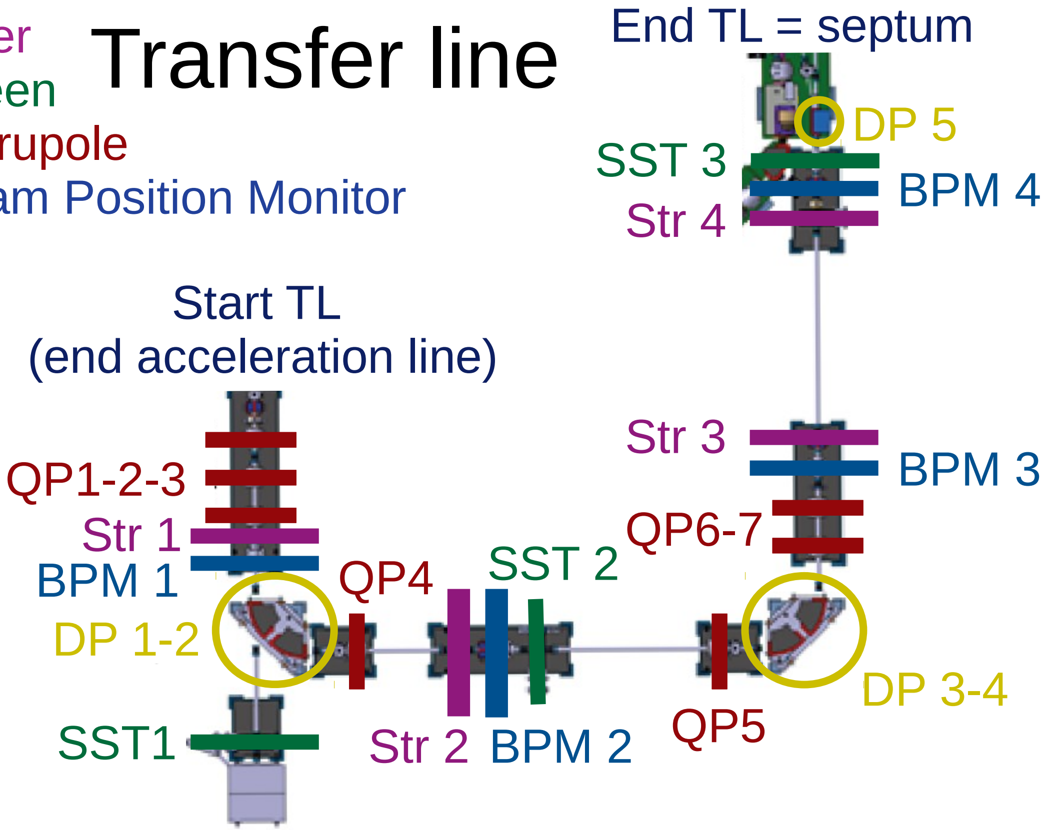
- **Iryna** using **AT** (lattice_ring_AT_14102019.txt, 14/10/2019)

Denomination

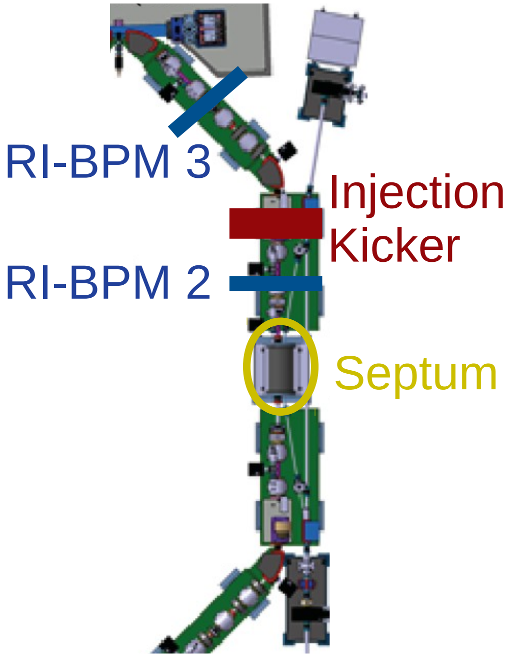
(based on ThomX nomenclature)

DP = dipole
Str = steerer
SST = screen
QP = quadrupole
BPM = Beam Position Monitor

Transfer line



Ring



Computer algebra

- Calculation of propagation of a 6D vector (x,px,y,py,z,pz) along the TL
- Simulation of a steerer using small angle approximation of a dipole's transfer matrix

  We assume that a particle deflected by the steerer deviates from the ideal orbit
- Use of first order transfer matrix for other elements (based on Trace-3D documentation, cf appendix)
- Use of Ezgi's set of quadrupole strength values for TL (see slide 9)

Particle propagation from Str 4 to RI-BPM 2

$$\begin{pmatrix} x \\ p_x \\ y \\ p_y \\ z \\ p_z \end{pmatrix}_{RI-BPM\,2} = M_{drift} \times M_{septum} \times M_{drift} \times M_{DP05} \times M_{drift} \times M_{str} \times \begin{pmatrix} X \\ P_X \\ Y \\ P_Y \\ Z \\ P_Z \end{pmatrix}_{Str\,4}$$

$$M_{str\,4} = \begin{pmatrix} 1 & L & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & Dev\,4_x \\ 0 & 0 & 1 & L & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & Dev\,4_y \\ 0 & 0 & 0 & 0 & 1 & \frac{L}{\gamma^2} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

- L the Steerer’s length
- ɣ the Lorentz factor
- $Dev4_x$ the deviation in x-plane ie: Px → Px + $Dev4_x$*Pz
- $Dev4_y$ the deviation in y-plane ie: Py → Py + $Dev4_y$*Pz

Analytical calculation : first result

$$\begin{pmatrix} x \\ p_x \\ y \\ p_y \\ z \\ p_z \end{pmatrix}_{RI-BPM2} = \begin{pmatrix} 2.67*P_X-0.236*P_Z+0.627*X+\mathbf{2.60*Dev4_x*P_Z} \\ 0.652*P_X+0.0163*P_Z-0.222*X+\mathbf{0.674*Dev4_x*P_Z} \\ 3.11*P_Y+Y+\mathbf{3.01*Dev4_y*P_Z} \\ P_Y+\mathbf{Dev4_y*P_Z} \\ 0.0379*P_Z-0.197*P_X+0.0421*X+Z-\mathbf{0.202*Dev4_x*P_Z} \\ P_Z \end{pmatrix} \begin{pmatrix} X \\ P_X \\ Y \\ P_Y \\ Z \\ P_Z \end{pmatrix}_{at\,Str4}$$

Analytical calculation : Analysis

- Steerer's effect:

  $\Delta x \sim 2{,}60\ dev4_x * P_z$

  $\Delta y \sim 3{,}01\ dev4_y * P_z$

- Same algebraïc equation can be computed everywhere on the line
- Lots of constants can be changed or set as analytics parameters like quadrupole forces
- Some corrections have yet to be done on the injection in the ring

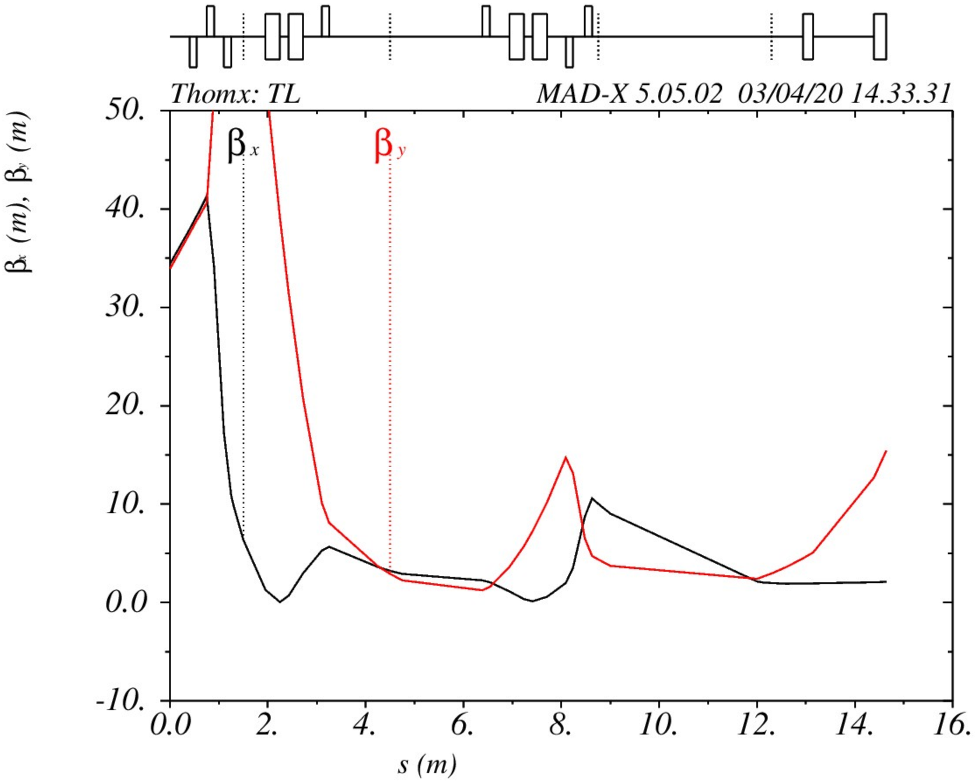
Beam simulation along the transfer line

- TL simulation to understand which orbits enter the ring done with madX

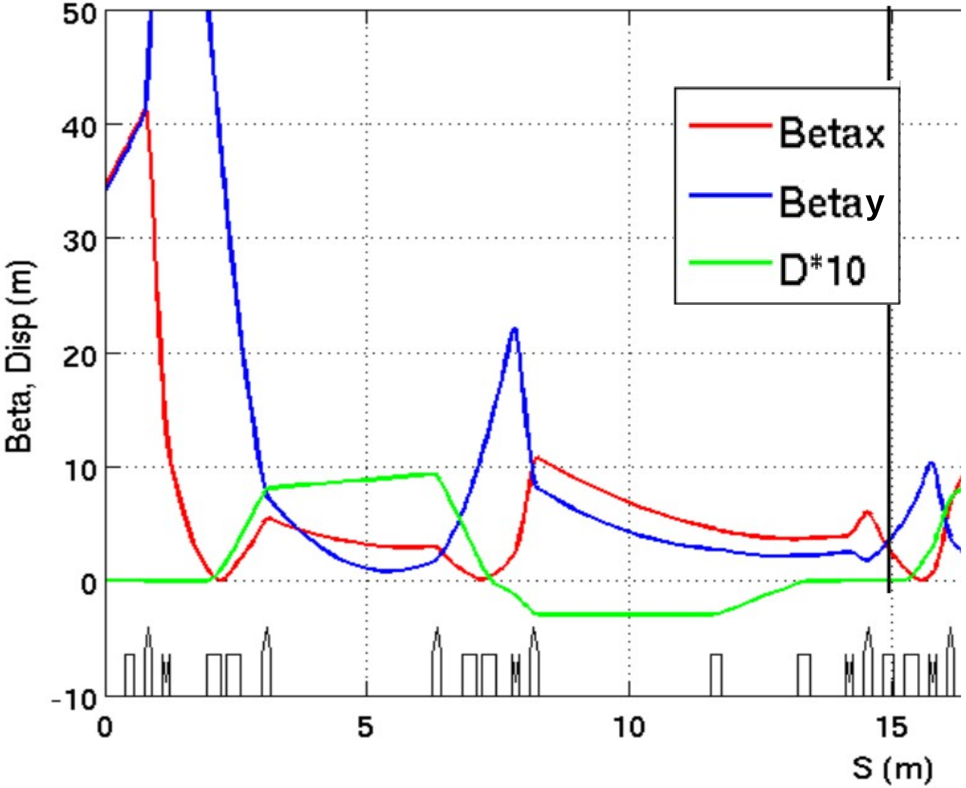
- Study of the Beta-function and tracking of the particles

MadX simulation : TL lattice

madX calculation

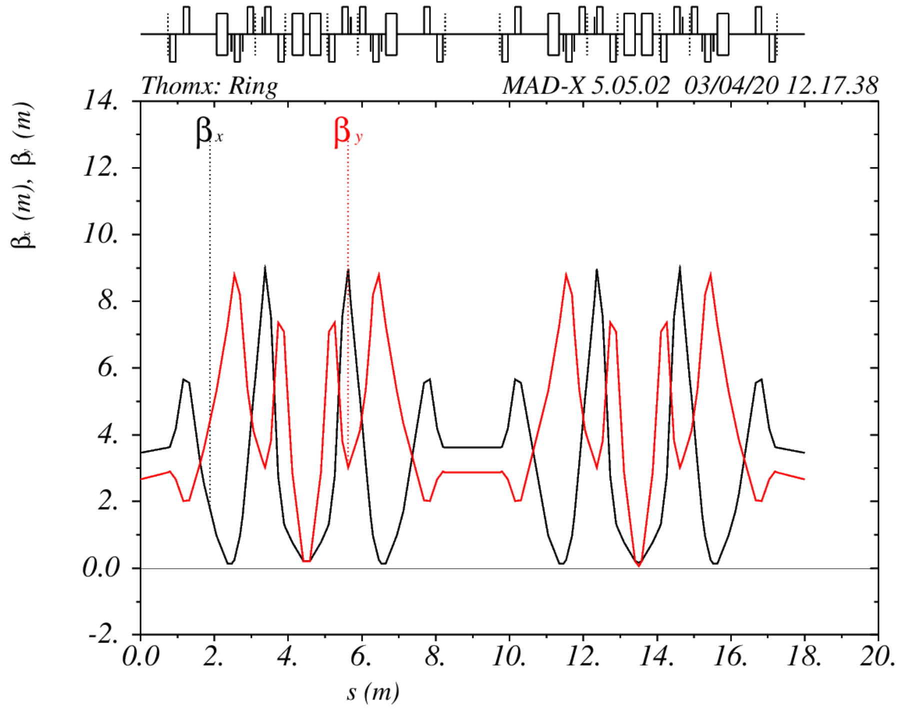


Beta calculation (from ThomX TDR)



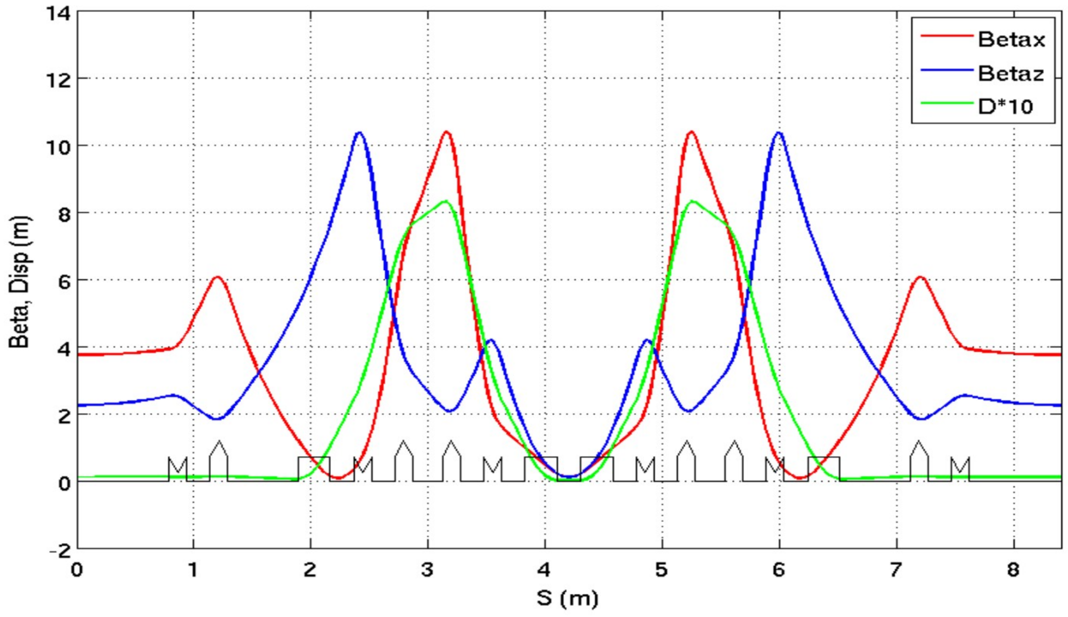
MadX simulation : Ring lattice

MadX simulation : full ring (two periods)

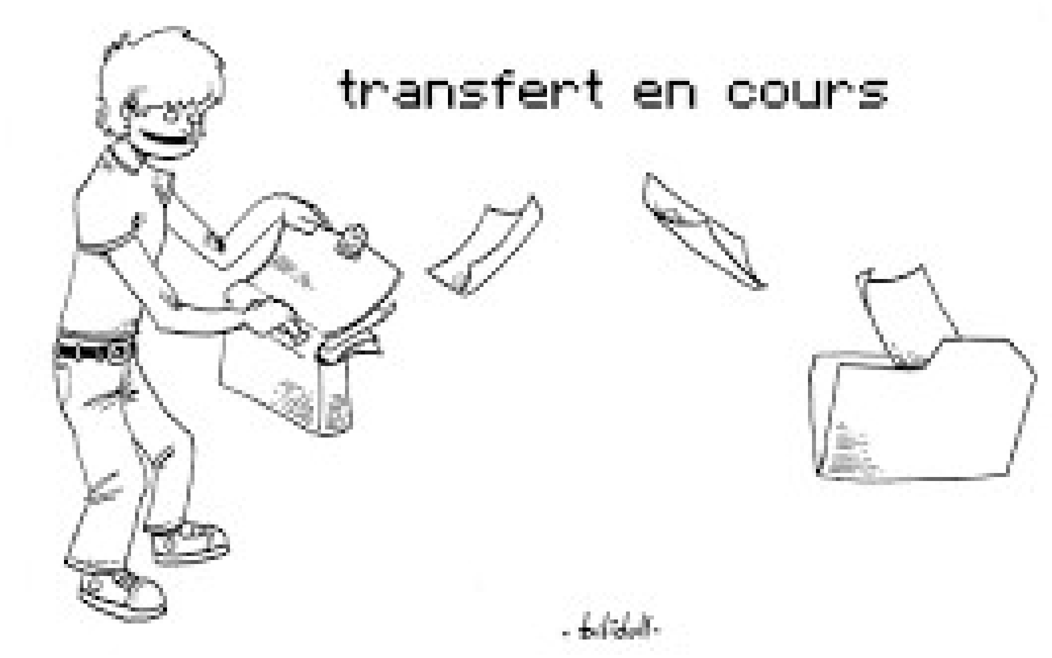


Beta simulation (Alexandre L.) :

One period



More details on the transfer line

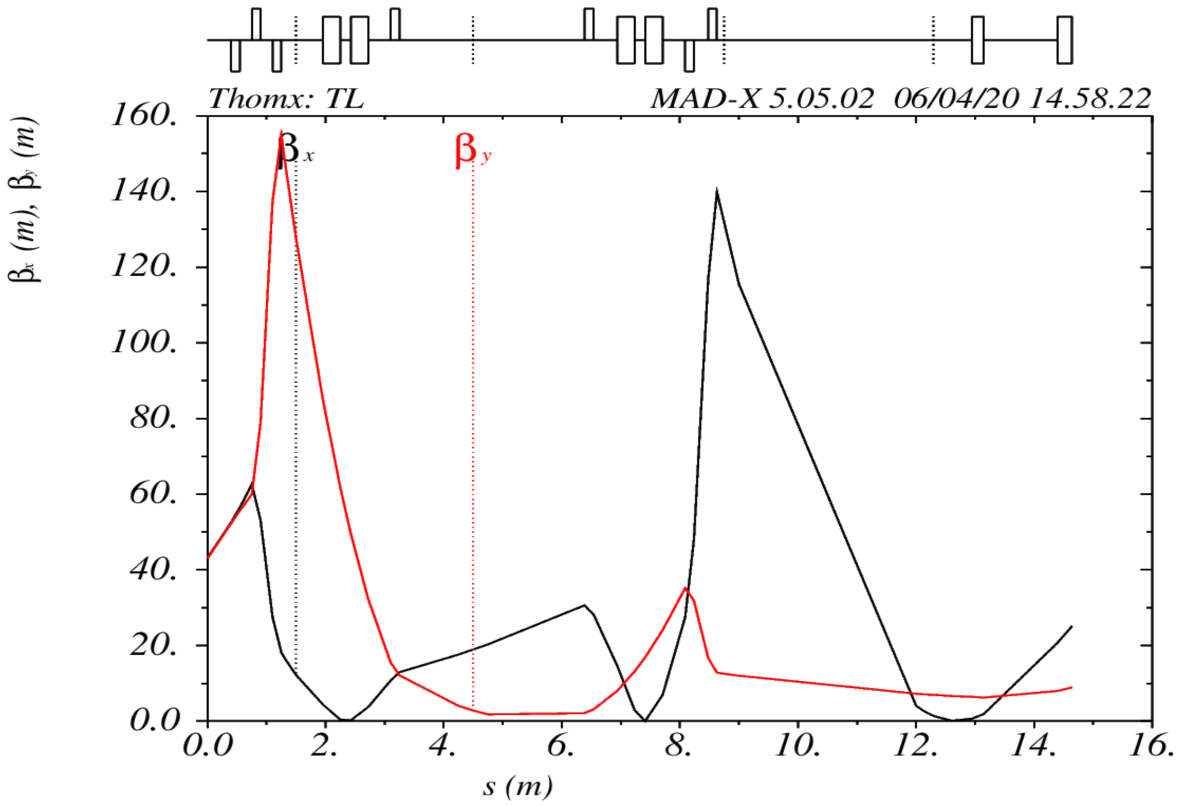


source

Value matching according to Ezgi

βx at start	43.25 m	K for QP2	10.473 m^{-2}
βy at start	43.13 m	K for QP3	-10.170 m^{-2}
αx at start	-11.00	K for QP4	5.634 m^{-2}
αy at start	-10.97	K for QP5	5.267 m^{-2}
Δp at start	1 MeV	K for QP6	-10.409 m^{-2}
K for QP1	-0.265 m^{-2}	K for QP7	11.011 m^{-2}

Beta-function along the TL

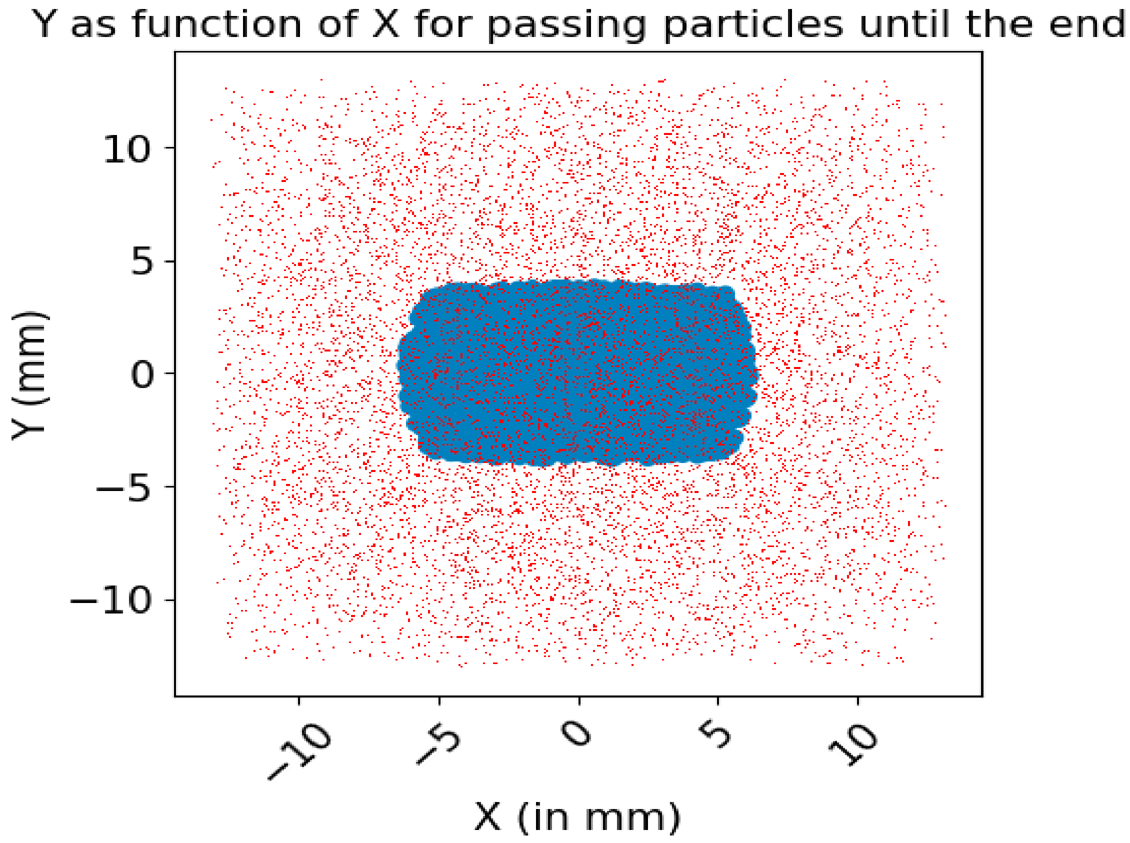


- Focal point at the position of screen 3
- High divergence at the end
- Beam wider than higher

Beam acceptance calculation

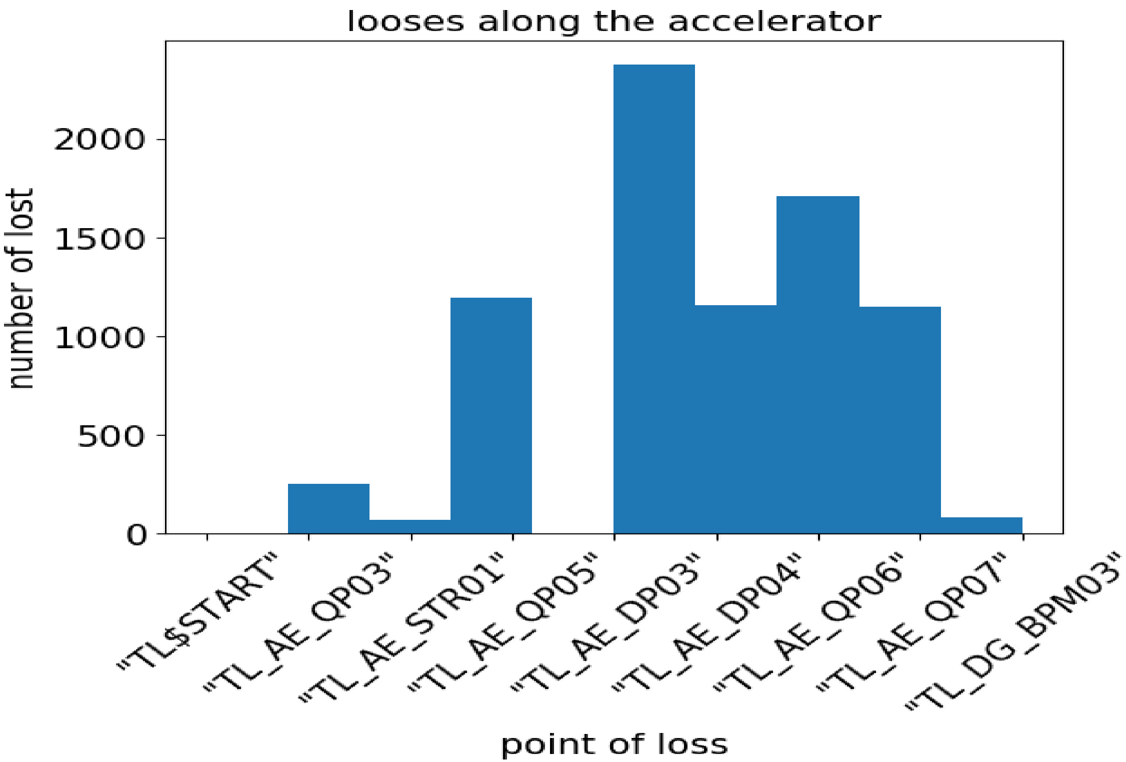
- Tracking of particles done on madX
- Taking 10^4 particles within a beam 10 times larger than the beam defined by Ezgi
- Check at the entrance of each element if the particles go on the pipe and exclude them
- Plot the initial position of the particles that are going from start to end of the TL without being excluded

Maximal possible size at start



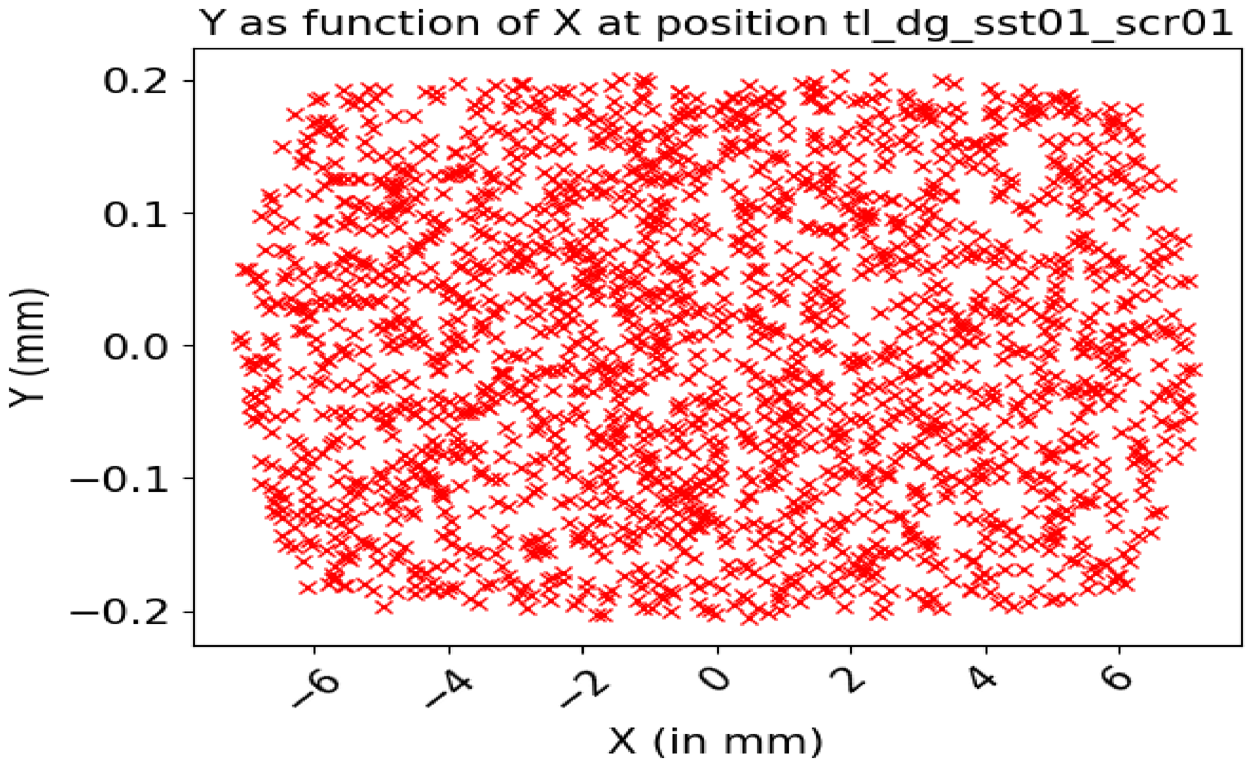
- Beam acceptance on TL :
  - 6 mm in x
  - 4.5 mm in y

Acceptance losses along the TL



- lots of losses between dipole 3 and quadrupole 6
- check aperture on dipole
- ~1/7 of particles passing

Projection of particles passing through TL at screen 1

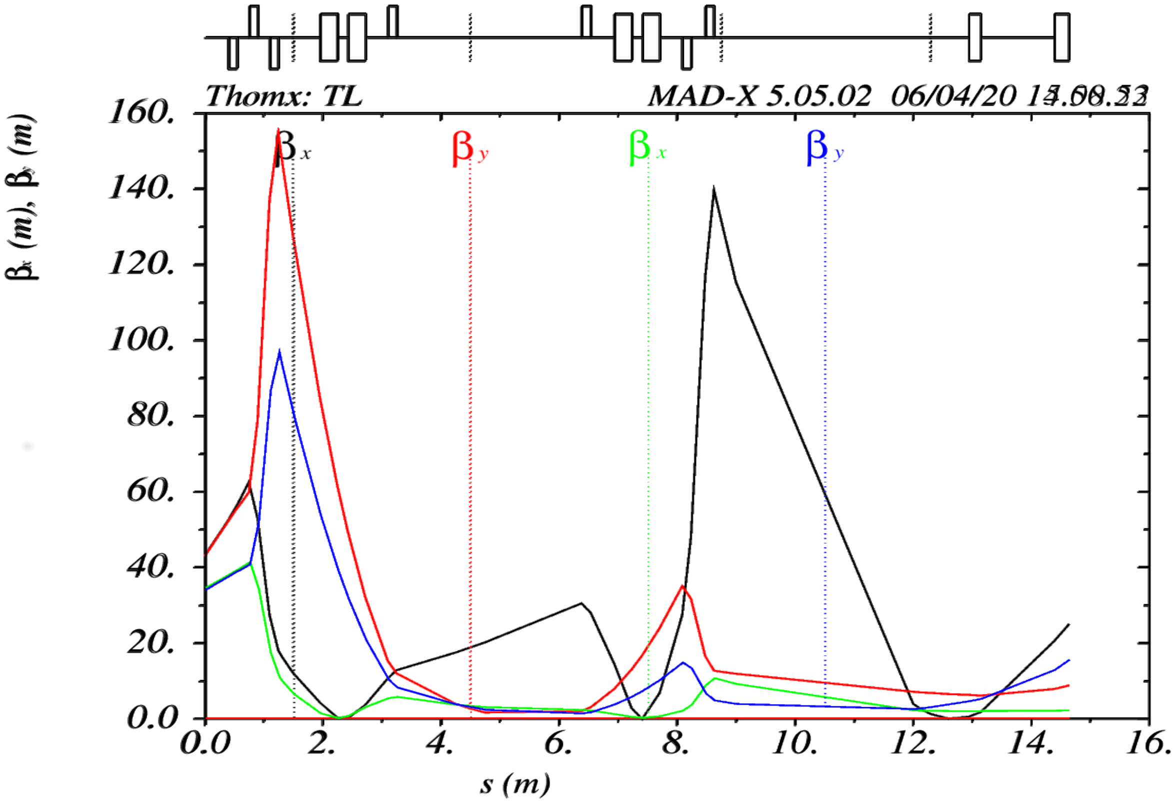


Can be used to caracterize the beam before turning on the dipole

Value matching according to Alexandre L.

βx at start	34.46 m	K for QP2	9.829 m^{-2}
βy at start	33.96 m	K for QP3	-9.666 m^{-2}
αx at start	-4.24	K for QP4	5.831 m^{-2}
αy at start	-4.34	K for QP5	5.353 m^{-2}
Δp at start	1 MeV	K for QP6	-10.821 m^{-2}
K for QP1	-0.048 m^{-2}	K for QP7	10.872 m^{-2}

Ezgi vs Alexandre L.



Ezgi's case :

- Divergence higher
- Focal point at the position of screen 3
- Beam wider than higher

Alexandre L.'s case :

- Beam smaller than Ezgi nearly everywhere
- Initial beam smaller and less divergent
- Beam higher than wider

Alexandre L. matching

- Same study has been done and results are pretty much the same
- A little larger losses acceptance
- Beam smaller (even initialy)
- A little less losses but at the same place

Conclusion

- First analytical calculations have been done to caracterize the effect of the steerers on the beam position
- Some improvements have to be done to correctly simulate the injection on the ring
- My simulations under MadX are in good agreement with those of Ezgi and Alexandre L. however some minor differences are still to be understood
- Two different matchings of TL have been tested and in first approximation Alexandre L.'s matching seem to have a larger acceptance (to be discussed)
- Good agreement between the MadX and AT simulations of the ring

Next step

- Take into account off-axis elements in injection in both codes
- ThomX lattice implemented, ready to work on injection
- Simulate ring injection
- Simulate ring injection with kicker that does not kick well to see what happens when the kick is insufficient

Appendix

Transfer matrix of dipole (length L)

$$M=\begin{pmatrix} 1 & L & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & L & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & \frac{L}{\gamma^2} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Transfer matrix of quadrupole (length L , strength k)

$$F=\begin{pmatrix} \cos(kL) & \frac{1}{L}\sin(kL) \\ -k\sin(kL) & \cos(kl) \end{pmatrix}, D=\begin{pmatrix} \cosh(kL) & \frac{1}{L}\sinh(kL) \\ k\sinh(kL) & \cosh(kl) \end{pmatrix}, R_{zz}=\begin{pmatrix} 1 & \frac{L}{\gamma^2} \\ 0 & 1 \end{pmatrix}$$

- F is the sub-matrix in the focal plane
- D is the bus-matrix in the defocal plane
- R_{zz} is the sub-matrix in the longitudinal plane
- No couplage between planes

Transfer matrix of bending magnet

- Cf : TRACE 3-D Documentation, K. R. Crandall and D. P. Rusthoi, Third Edition (LA-UR-97-886), May 1997, Los Alamos National Laboratory
- Page 14
- https://laacg.lanl.gov/laacg/services/traceman.pdf

Transfer matrix of steerer

$$M=\begin{pmatrix} 1 & L & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & Dev_x \\ 0 & 0 & 1 & L & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & Dev_y \\ 0 & 0 & 0 & 0 & 1 & \frac{L}{\gamma^2} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

- length L
- deviation in x-plane : Dev_x
- deviation in y-plane : Dev_y

Comparison Ezgi/Alexandre matching

βx	43.25 m	K for QP2	10.473 m^{-2}
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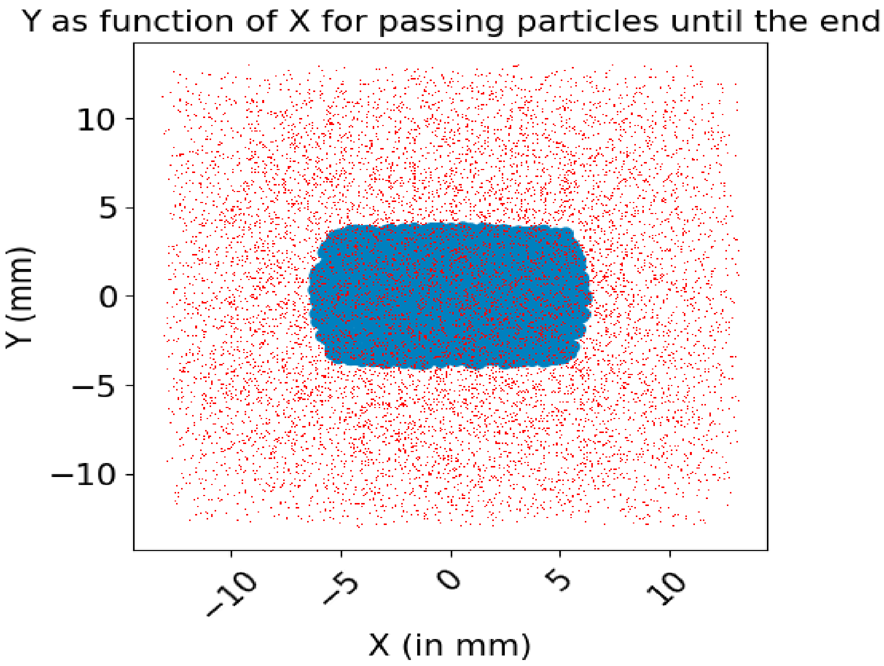
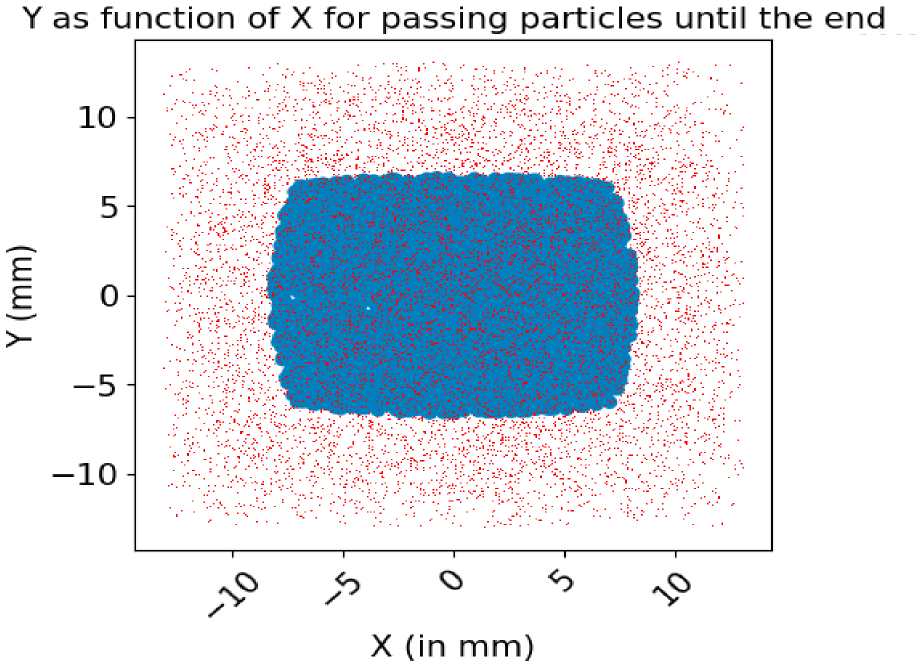
Comparison : Maximal size at start

Ezgi



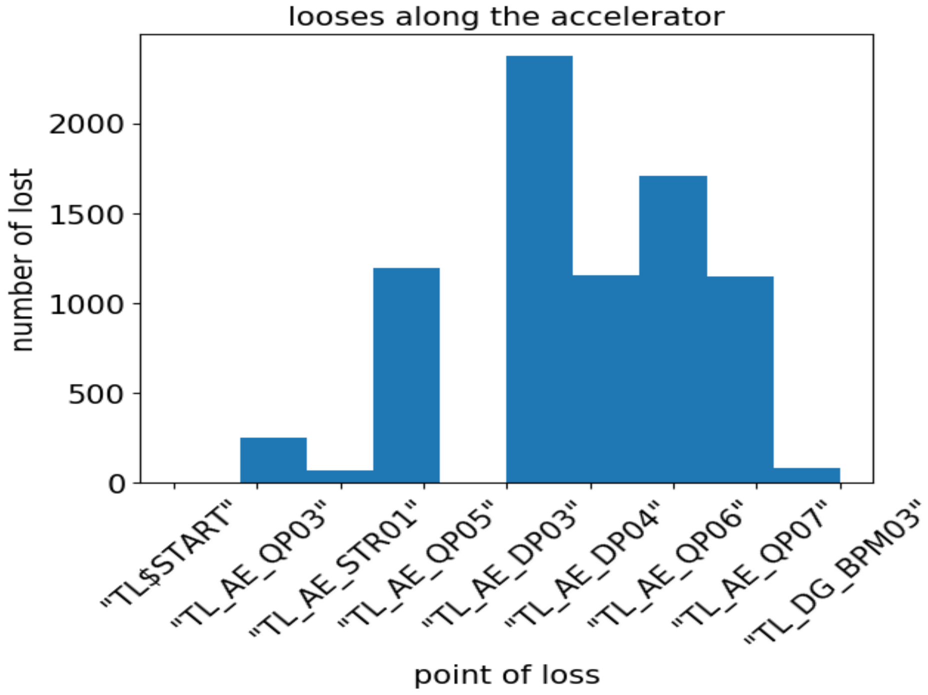
Alexandre L.



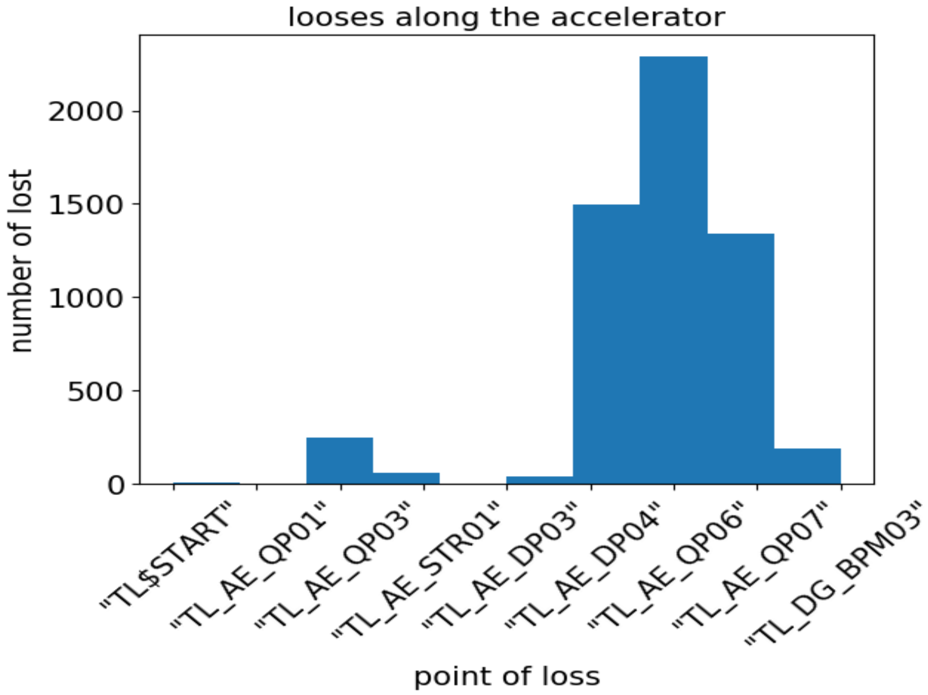
- Larger beam at start can go to the end in Alexandre L. case
- Beam acceptance on TL: around 5mm in x and y

Comparison : acceptance losses along the TL

Ezgi



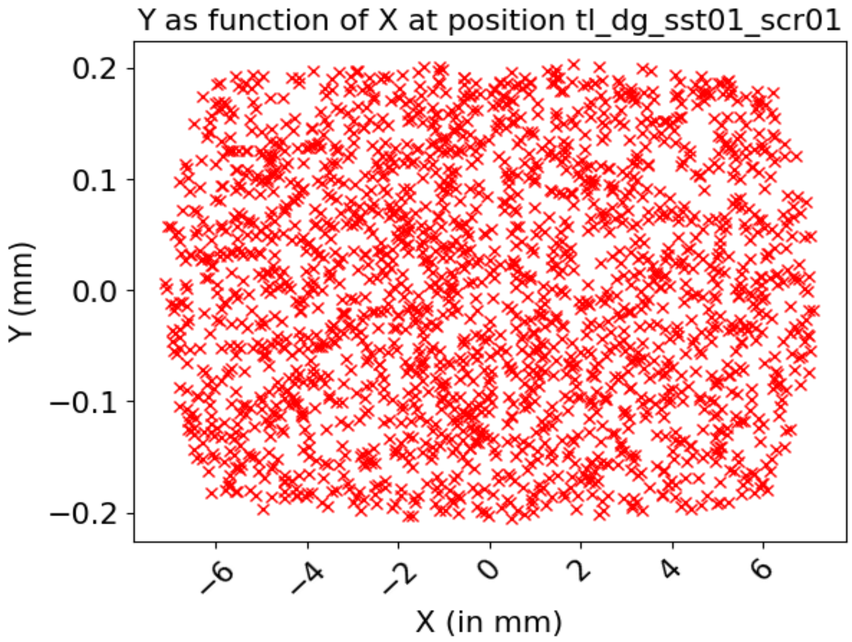
Alexandre L.



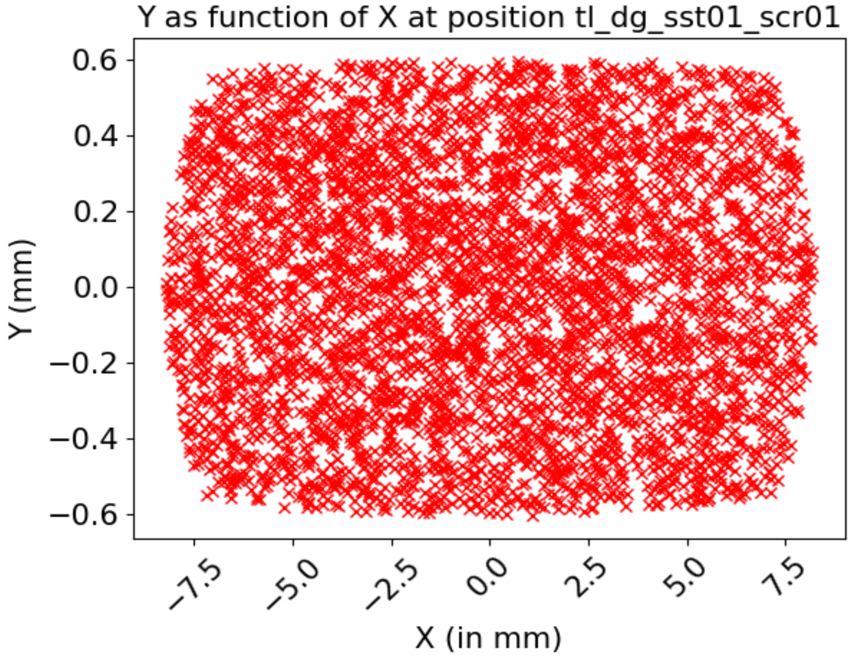
- Lower losses in Alexandre L.'s case
- In both cases: lots of losses between dipole 3 and quadrupole 6 (check apperture on dipole)

Projection of particles passing through TL at screen 1

Ezgi



Alexandre L.



Can be used to caracterize the beam before turning on the dipole