Imperial College London

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Nonlinear Nonscaling FFAGs (NNS-FFAGs) and their applications

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Motivation and background for NNS-FFAG

- The scaling law provides the non-perturbative zero-chromatic solution.

- There must exist zero-chromatic solution outside this principle.

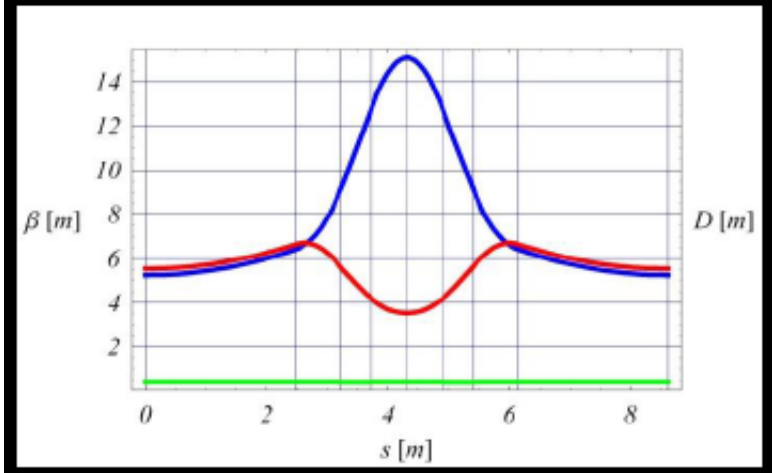
- It does not obey the similarity of orbits.

- There exists no underlying theory.

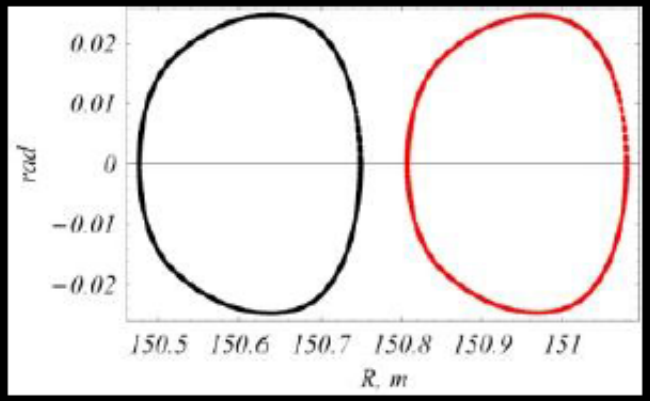
- The solution may be found within certain energy range by using numerical search for a multipole expansion.

- It may be justified by performance (smaller orbit excursion, isochronicity, easier magnet construction).

J.Pasternak: Scaling FFAG - triplet

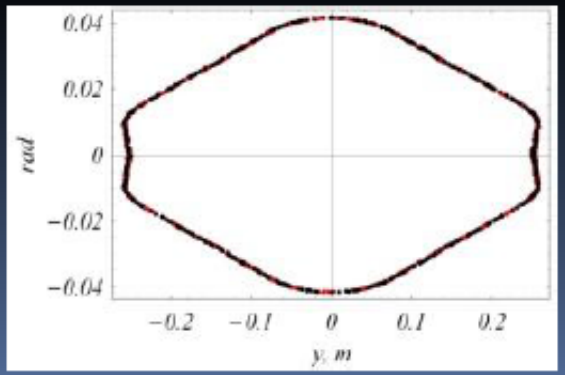


Parameter	Large-C	Small- C
Circumference	948m, 110 cells	474m, 54 cells
Tunes (ν_x, ν_y, γ_t)	28.2, 22.4	14.4, 9.3
F, D lengths	0.78, 1.16m	0.76, 1.14m
Magnet B, B' (8GeV)	5.5T, 14T/m	7.4T, 13T/m
Lattice functions ($\beta_{x,m}$, $\beta_{y,m}$, η)	7, 15, 0.4m	6.4, 14, 0.56m
k value	383	133



- Lattice FDF triplet
- N 54
- Magnets combined function, rectangular
- R 75.44 m
- Orbit excursion ~25 cm
- Dispersion at 8 GeV 0.29 m
- (Qx, Qy) (14.43, 9.29)
- B_{max} 6.0 T
- P_f 0.31
- Injection energy 3000 MeV
- Extraction energy 8000 MeV
- h 85 (53.46 MHz)

Horizontal Dynamic Aperture at 3 and 8 GeV

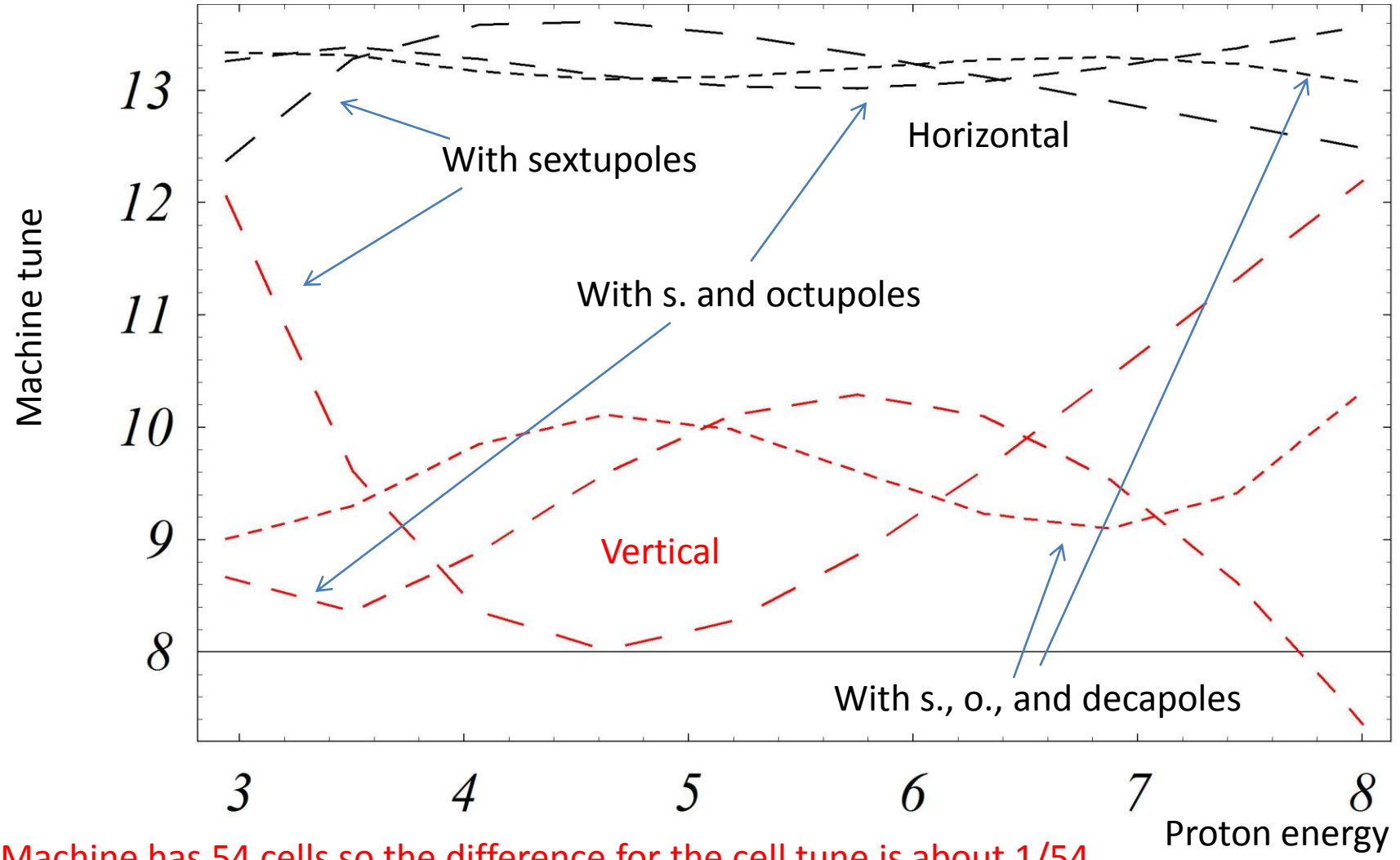


Assumptions

- Rectangular magnets (robust, easy case for superconducting designs).
- Multipole expansion up to octupole (decapole in some cases)

- Matching example: tunes for 3 energies (central and $\pm\Delta E$), orbit at 2 symmetry points of the cell (8 parameters)
- Degrees of freedom for triplet (2 dipoles+ 2 quads, +2 sextupoles + 2 octupoles =8)
- Sometimes decapole included.

Chromaticity correction in the NNS-FFAG for proton acceleration (3-8 GeV) – work with L. Jenner



Machine has 54 cells so the difference for the cell tune is about 1/54 and is OK for the horizontal plane! Vertical needs further improvements.

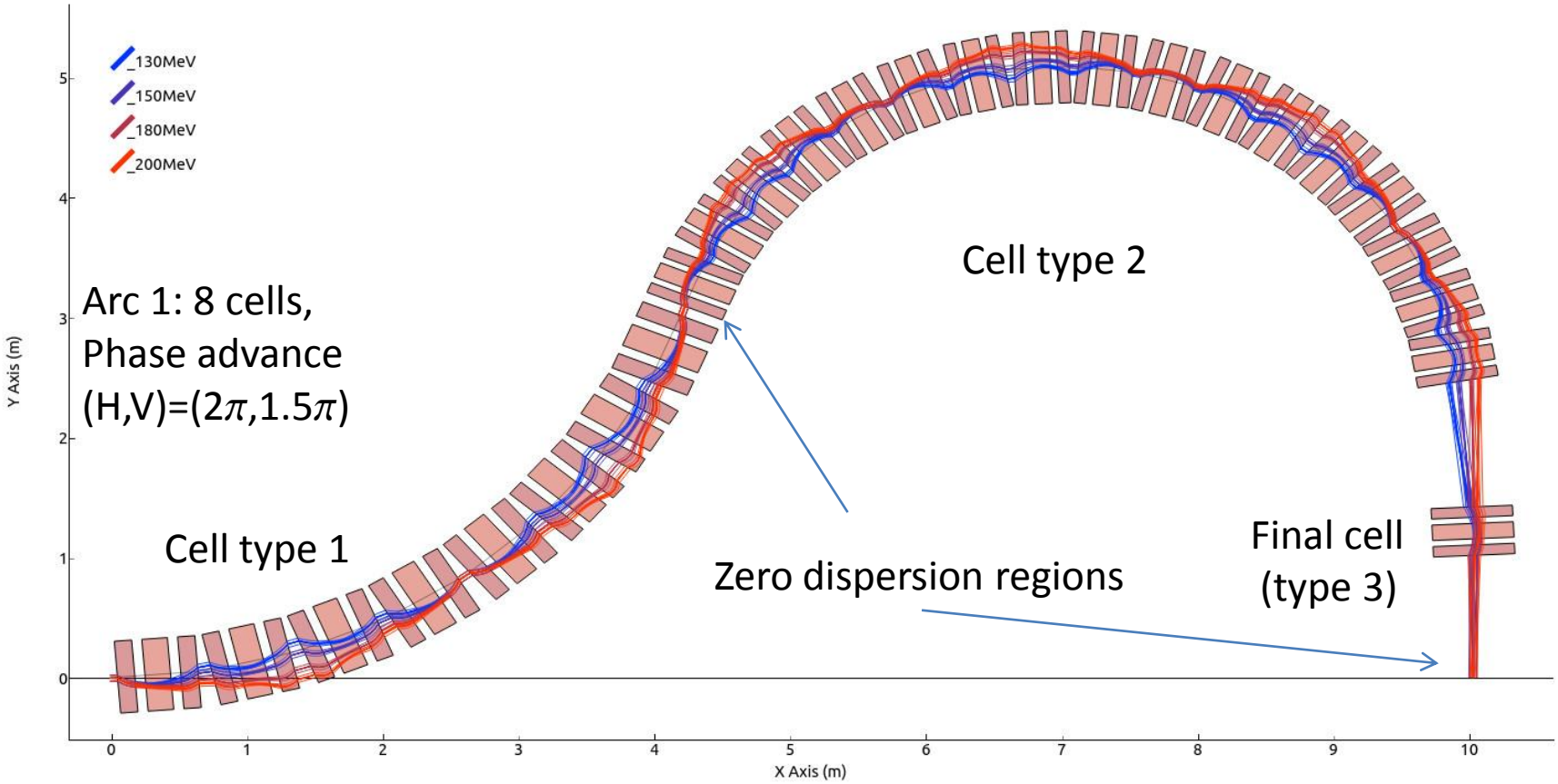
Let's try to design proton gantry based on NNS-FFAG method (work in collaboration with P. Posocco, G. Walton, P. Holland, M. Aslaninejad)

Assumptions:

- to use NNS-FFAG
- To use only positive bends at central orbit
- to use SC magnets with modest fields.
- to make identity transformation in phase space for a
- broad momentum case
  (100-200 MeV for pediatric case)
- make the aperture small
- Use radius of ~3m

Gantry and its orbits (size enlarged)

Arc 2 (including the final cell: 17+1 cells,
Phase advance (H,V)=(4π,2π)



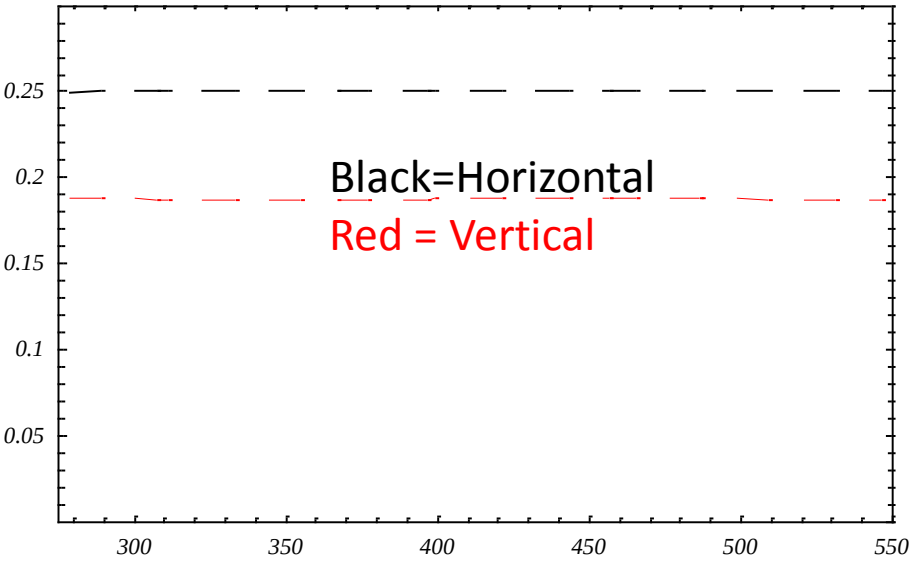
Orbit similarity is not present!

Tracking in PiZgoubi

Tunes per cell, matching

Tunes/cell

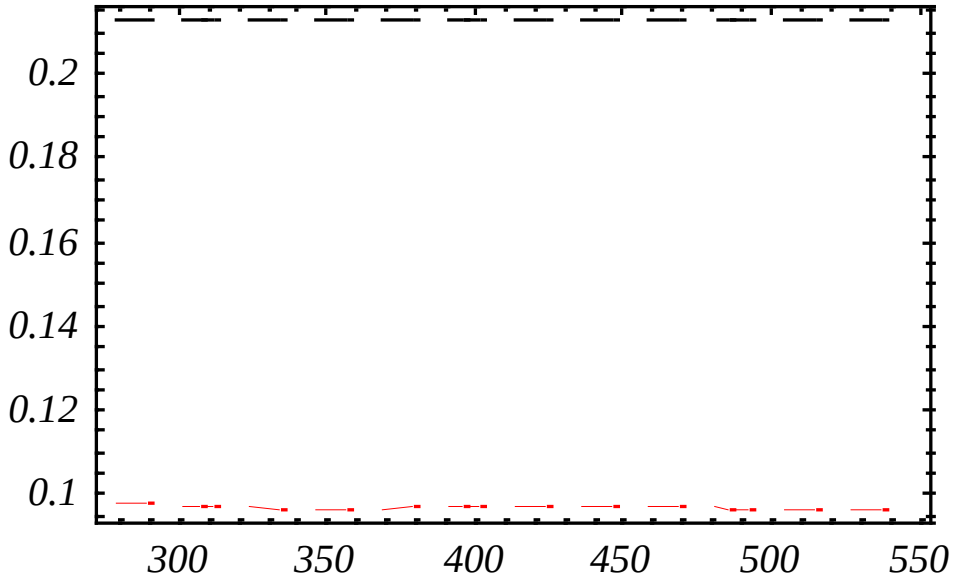
Cell 1



Black=Horizontal

Red = Vertical

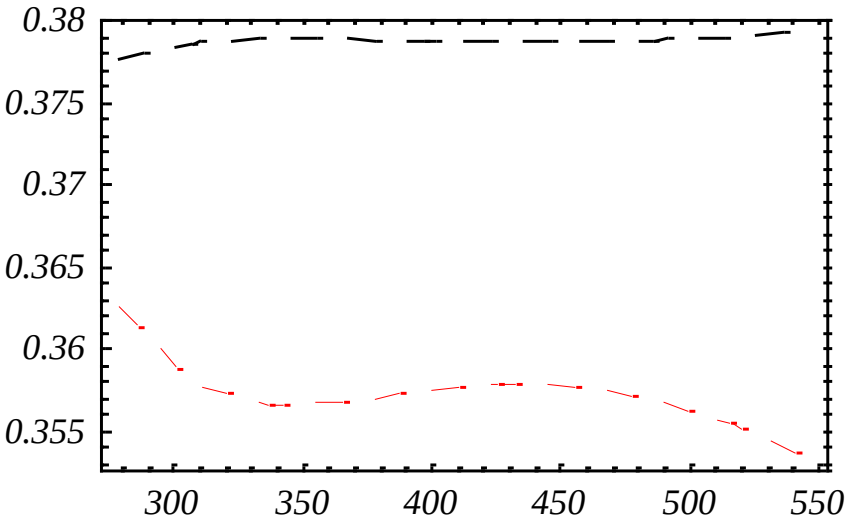
Cell 2



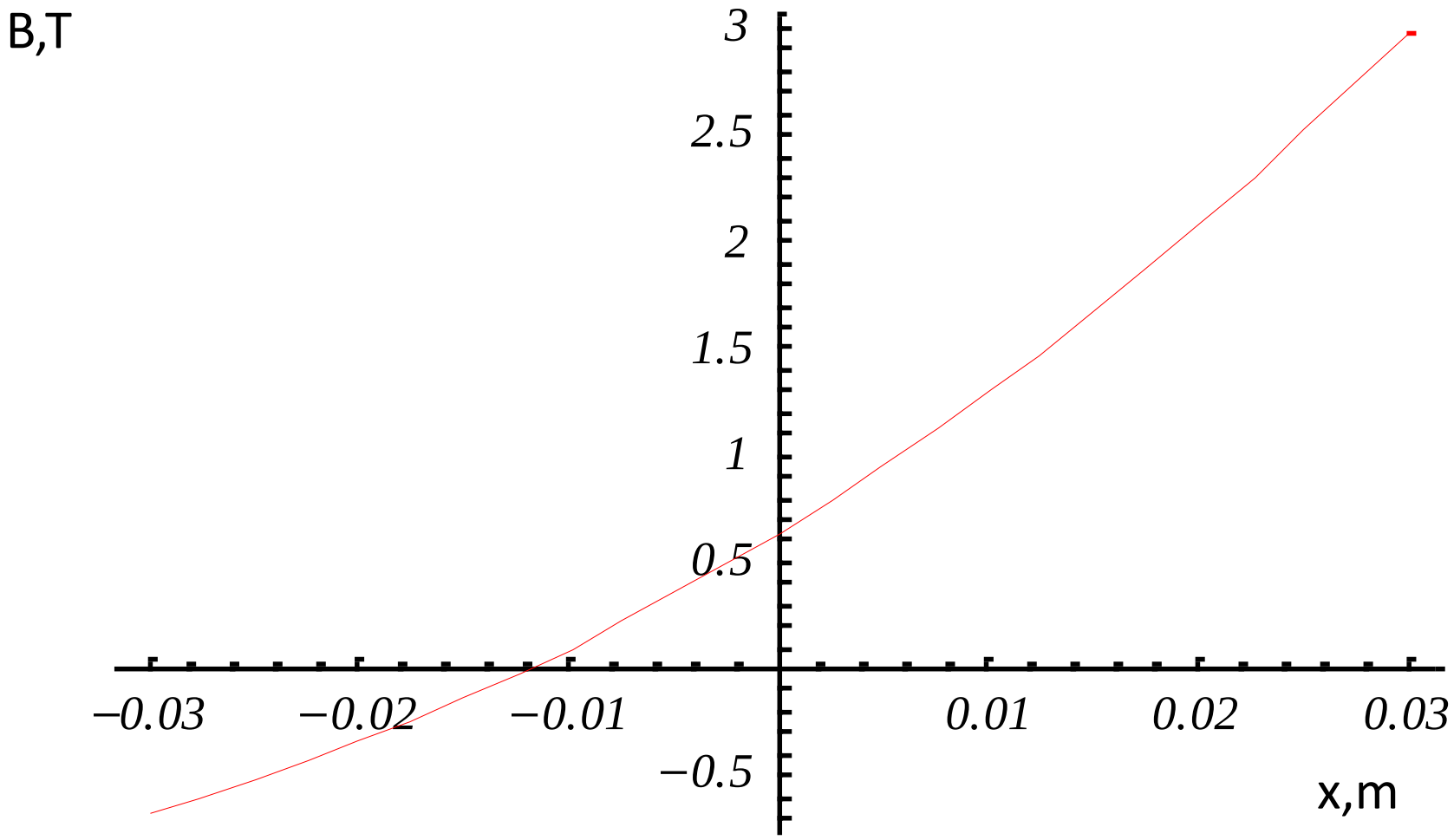
Cell 1

Equivalent muon energy range

Cell 3, final cell

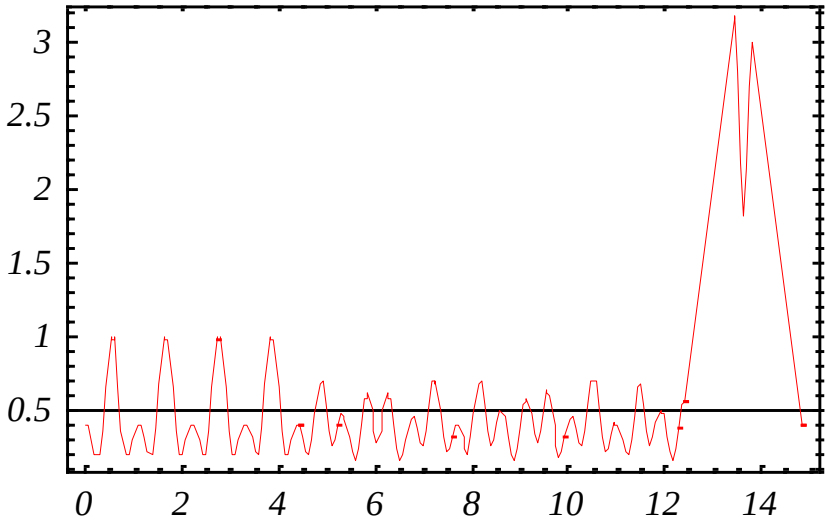


Magnetic field in example magnet

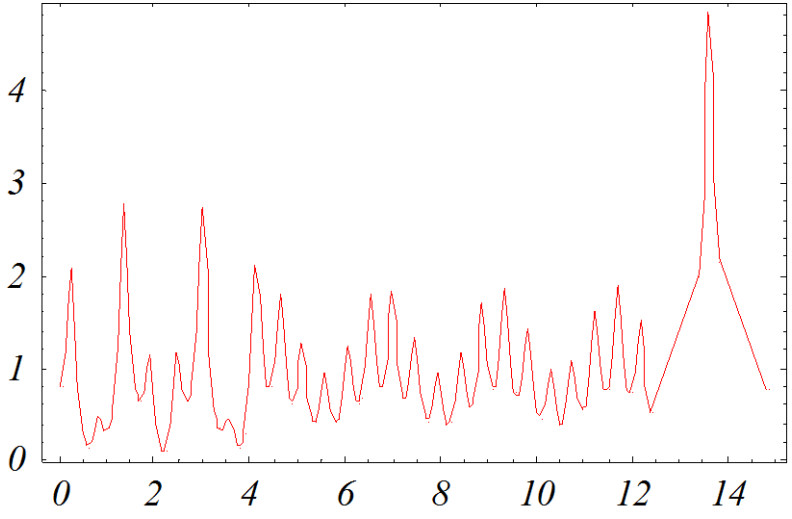


Scaling condition is broken!

Beta Functions



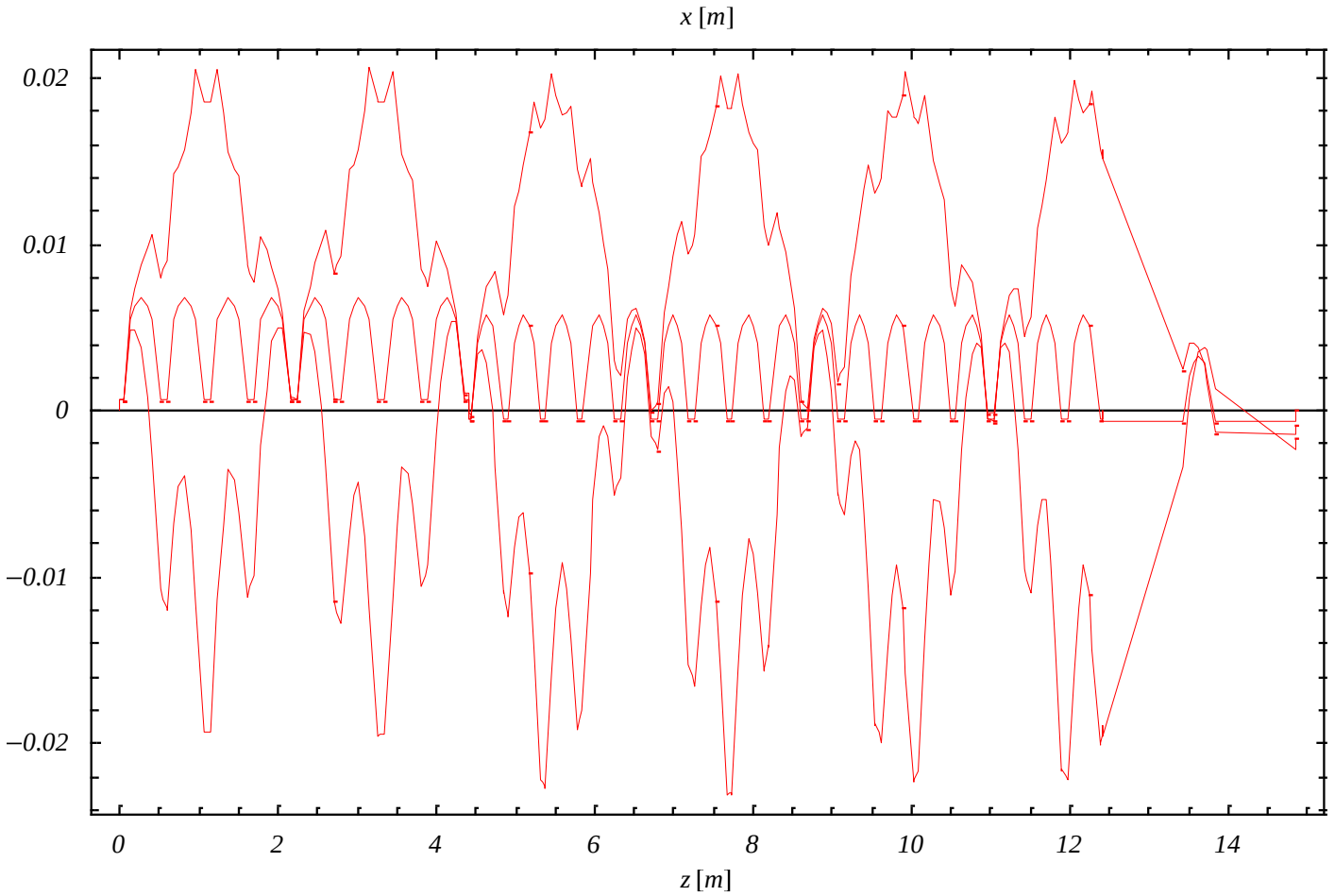
Horizontal



Vertical

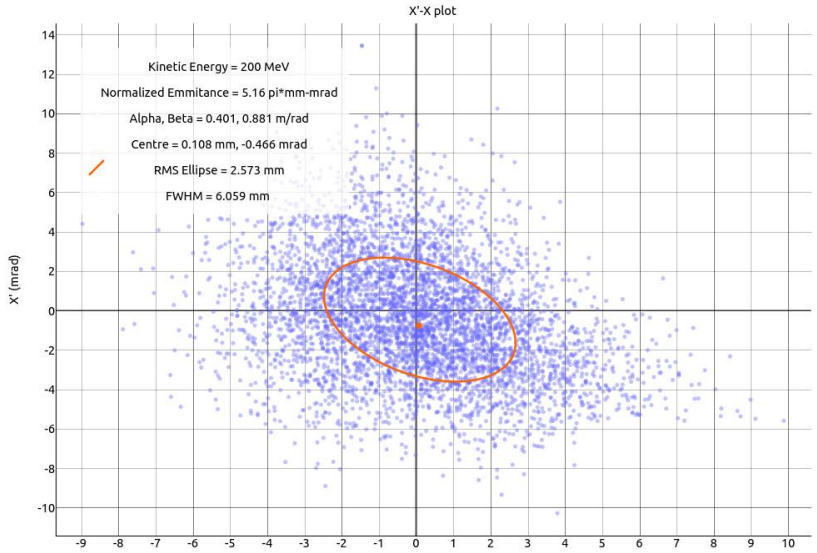
S,m

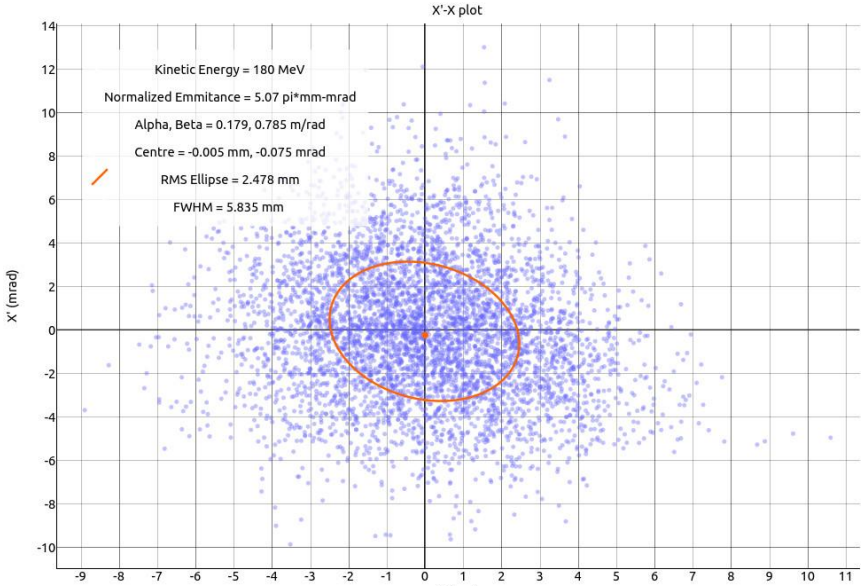
Horizontal orbits for 100,150 and 200 MeV

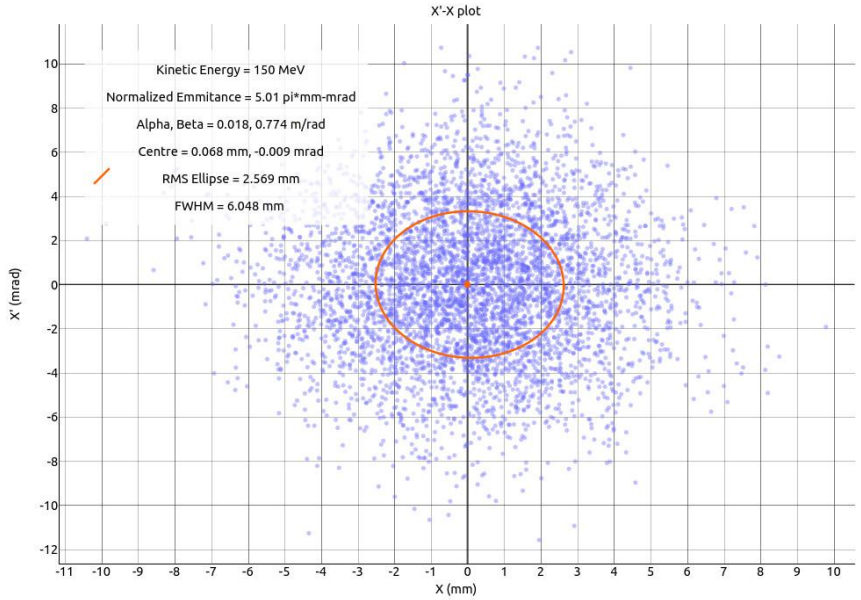


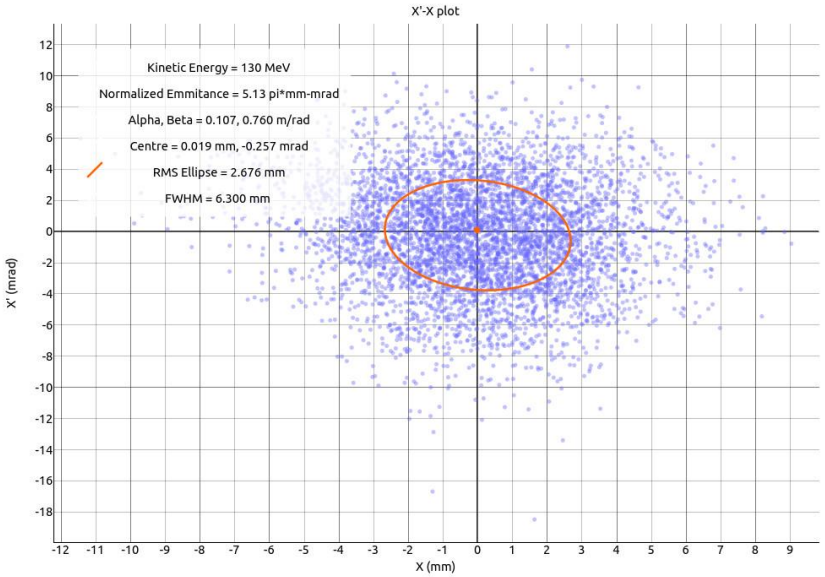
Dispersion matching seems to work!

Horizontal phase space at the end of Arc 1

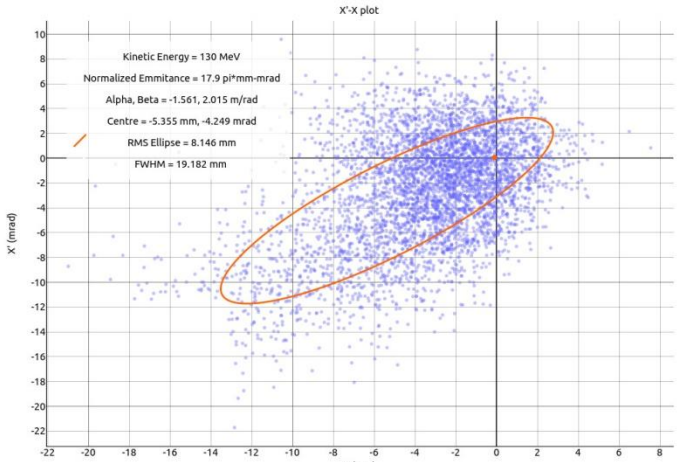


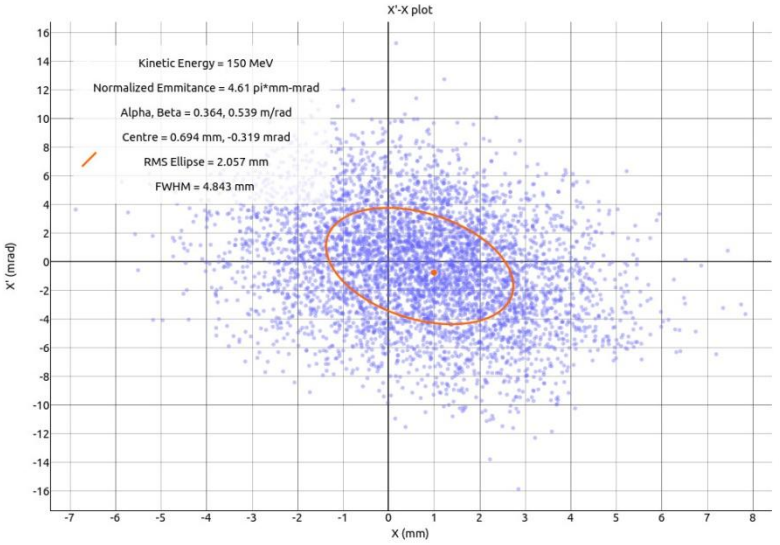


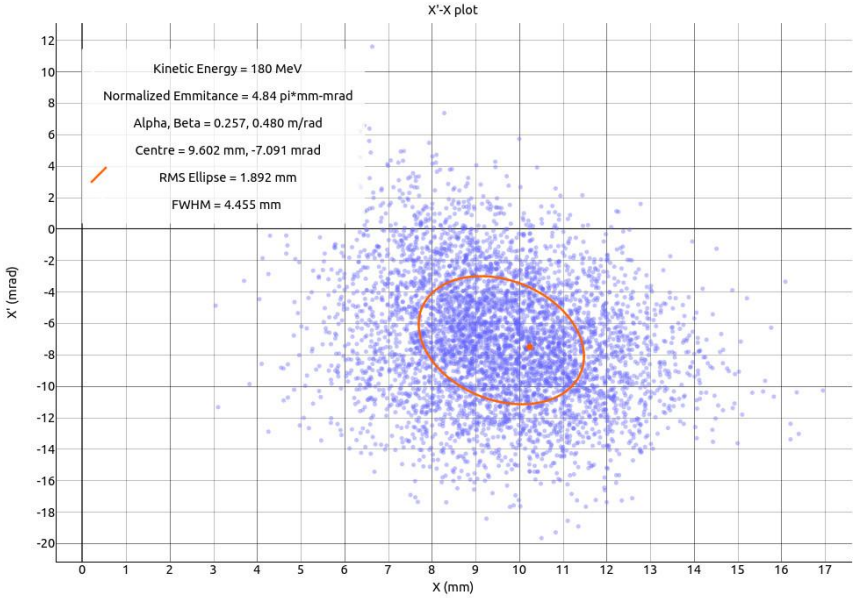


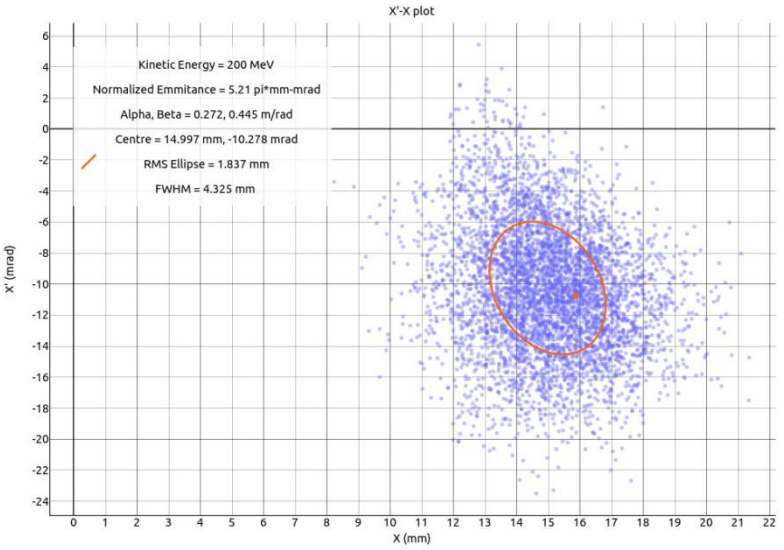


Horizontal phase space before the final cell



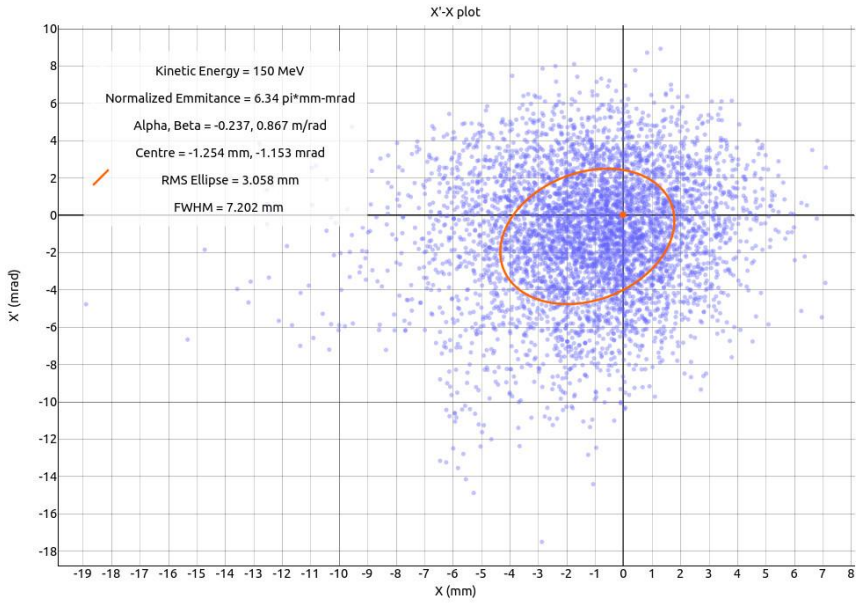




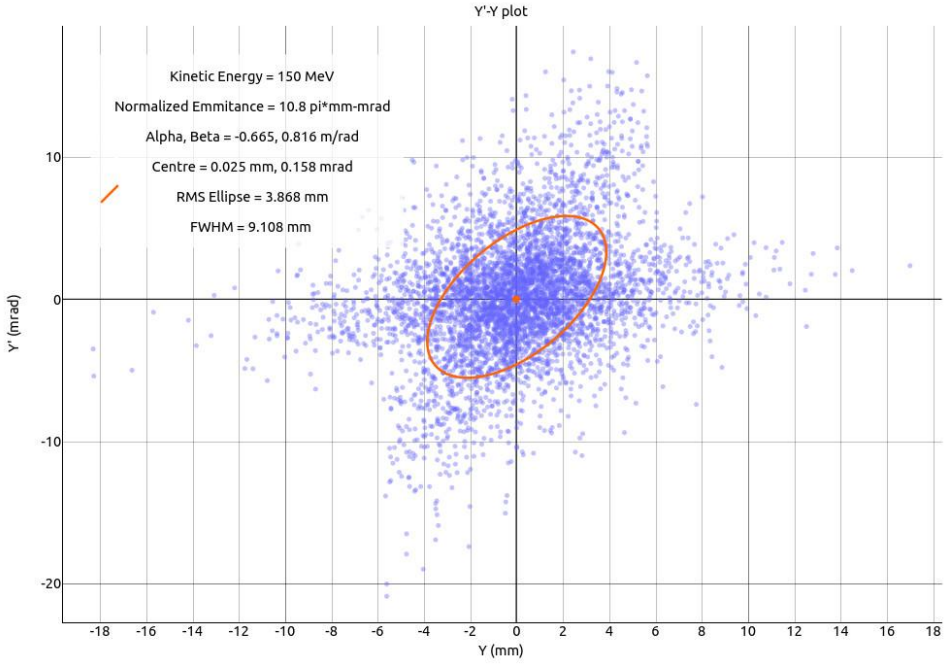


Final phase space at 150 MeV

Horizontal



Vertical



Unfortunately, off momentum result is not that great due to the choice of the phase advance per cell in the final cell!

Conclusions

- NNS-FFAG solution can be made zero-chromatic.
- Nontrivial matching conditions can be made.
- Gantry shows promising results except the final cell, which needs to be improved.