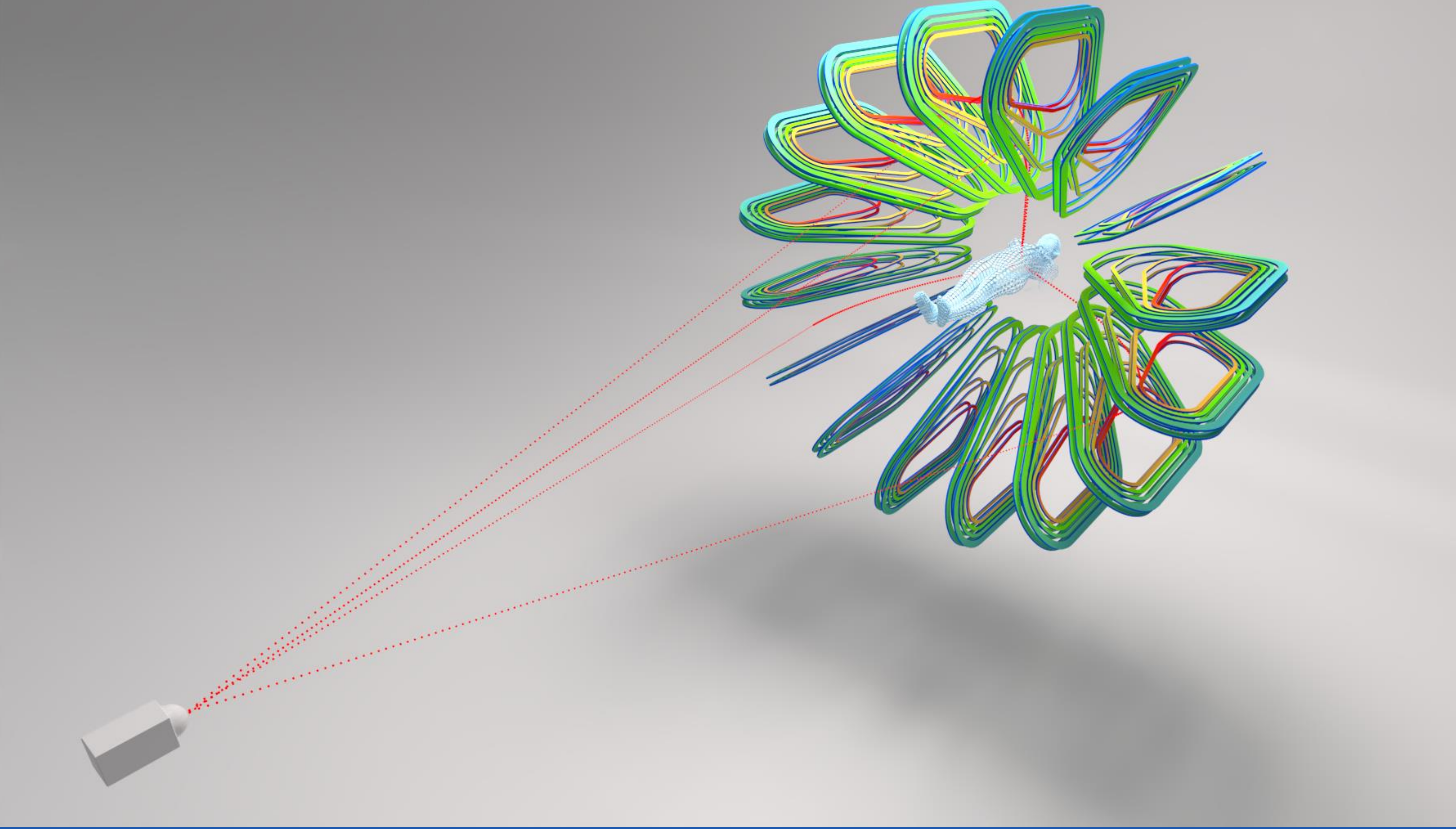


Beam optics studies for GaToroid

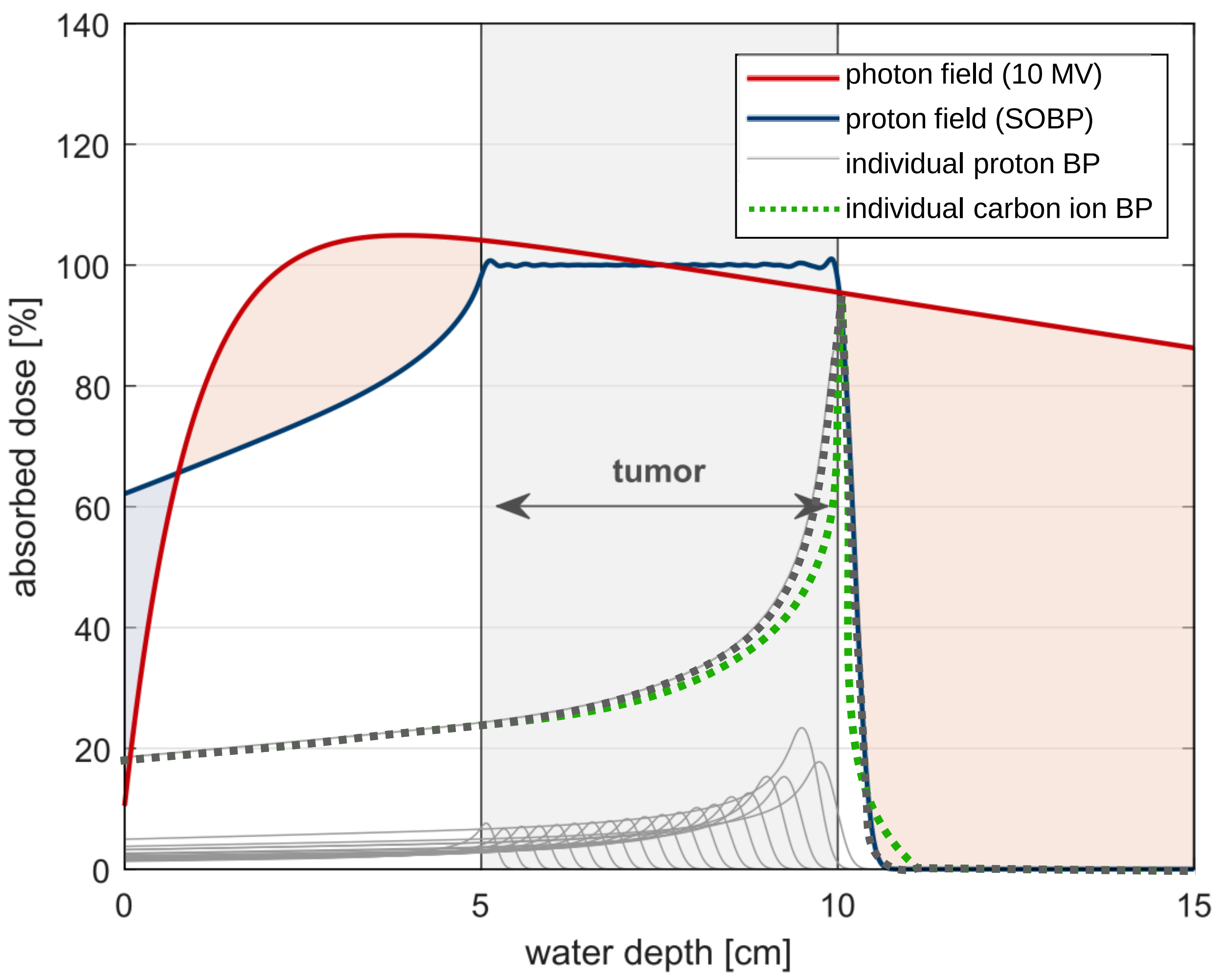
Ewa Oponowicz, Yann Dutheil
In collaboration with Alex Gerbershagen, Luca Bottura, Ariel Haziot

CERN Knowledge Transfer Seminar
6 October 2021

Photon, proton or carbon ion therapy?

- Aim: deliver large enough dose per unit mass to the tumour and spare the healthy tissues
- Radiation therapy worldwide:
  - Mainly photon therapy (15.000 centres)
  - Around 100 centres for charged particle therapy (protons and carbon ions)

- Physical dose of protons and carbon ions is similar:
  - C-ions have a sharper Bragg peak and a tail on the fall-off part
- Main difference between protons and carbon ions from a clinical point of view: relative biological effectiveness



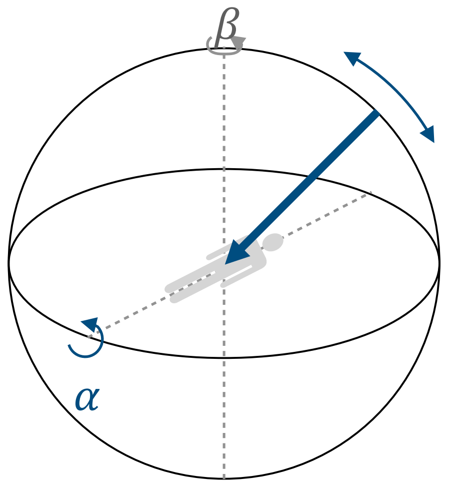
G. Klimpki, “Continuous irradiations in proton therapy: balancing risks and benefits” 2018

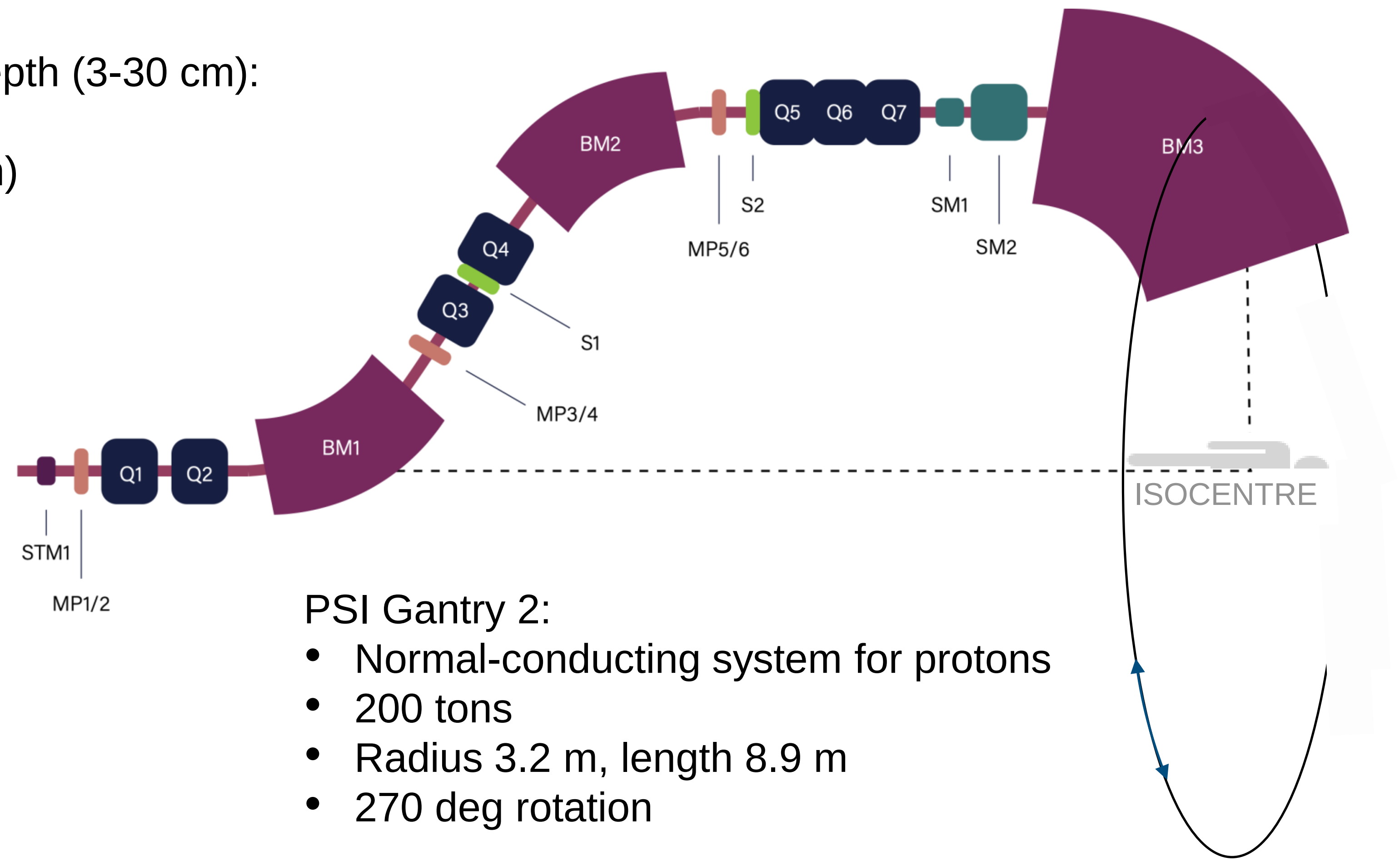
Hadron beam delivery

- Some requirements at the isocentre:
  - Round beam x/y = 4-10 mm FWHM
  - Spot precision < 0.5 mm
  - Beam normal to the irradiation plane
  - Zero dispersion
  - Irradiation field around 30x40 cm^2

- Kinetic energies for the same penetration depth (3-30 cm):
  - Protons @ 60-220 MeV (1.1-2.3 Tm)
  - C-ions @ 120-430 MeV/u (3.2-6.6 Tm)

- Ideally 360 degrees irradiation

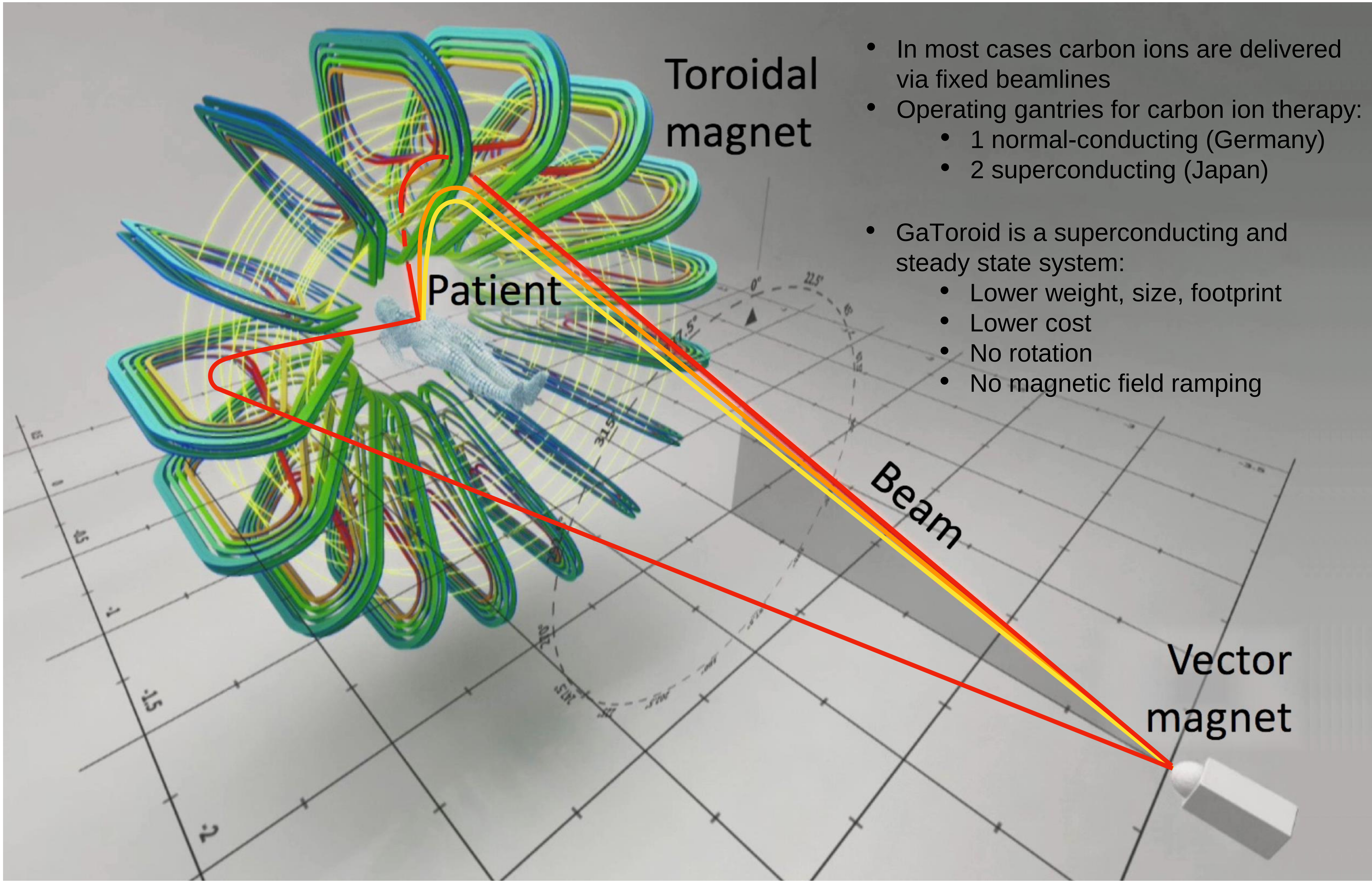




PSI Gantry 2:
- Normal-conducting system for protons
- 200 tons
- Radius 3.2 m, length 8.9 m
- 270 deg rotation

E. Oponowicz, "Superconducting gantry for proton therapy and proton computed tomography" 2021
K. P. Nesteruk, et al., "Large energy acceptance gantry for proton therapy utilizing superconducting technology" 2019

GaToroid: the concept



- In most cases carbon ions are delivered via fixed beamlines
- Operating gantries for carbon ion therapy:
  - 1 normal-conducting (Germany)
  - 2 superconducting (Japan)

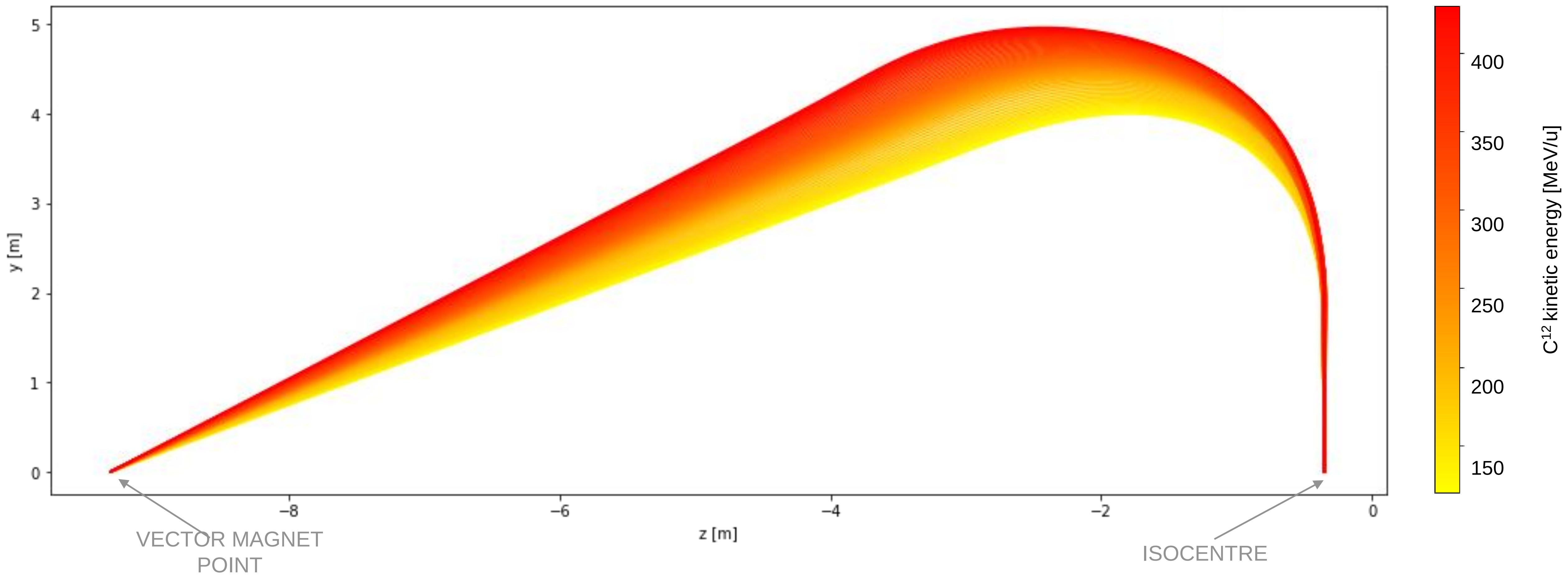
- GaToroid is a superconducting and steady state system:
  - Lower weight, size, footprint
  - Lower cost
  - No rotation
  - No magnetic field ramping

E. Felcini, “Analysis of a novel toroidal configuration for hadron therapy gantries” 2020

2D: central trajectories

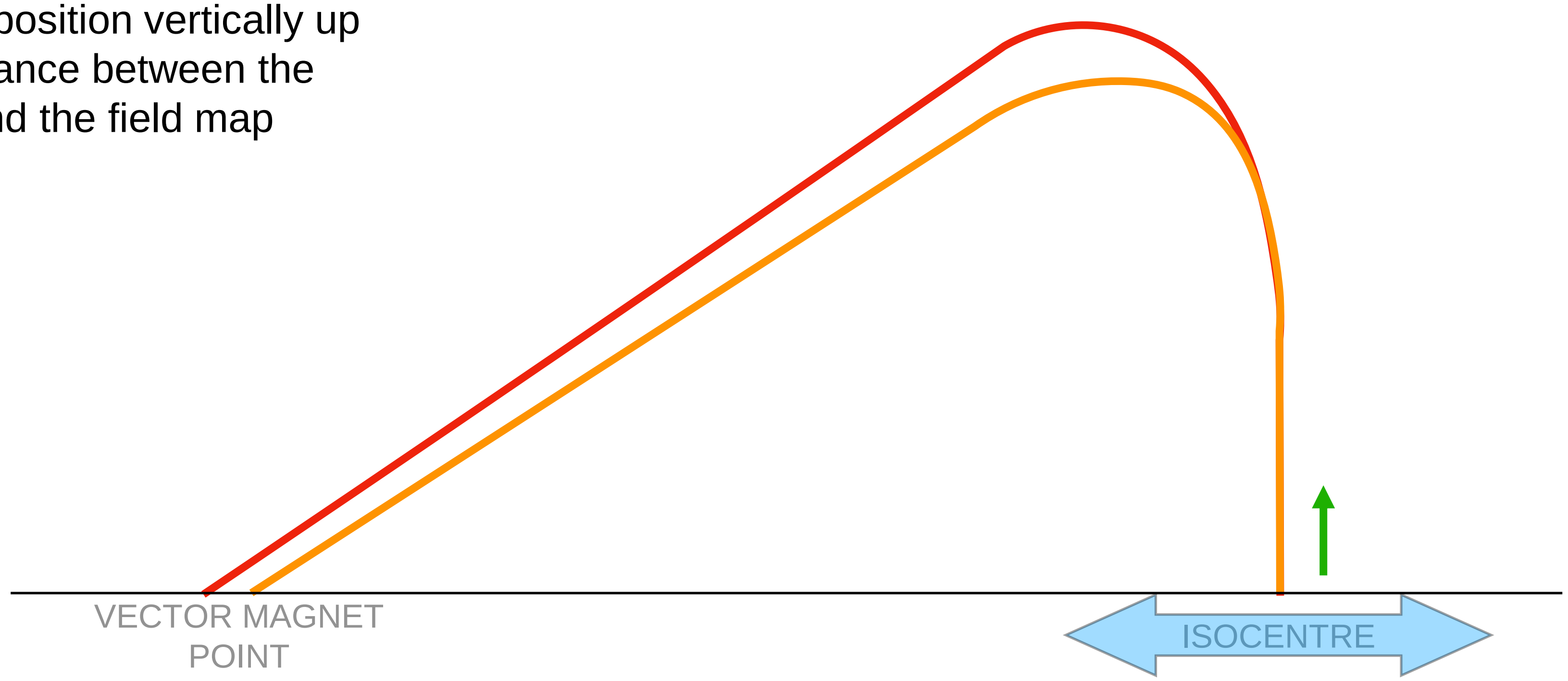
- Carbon ion beams of various energies:
  - are given different kicks in the vector magnet point (VM), e.i. entrance angle to the region of the coil
  - should reach the isocentre normal to the irradiation plane

- Where is the VM?
- Where is the isocentre?

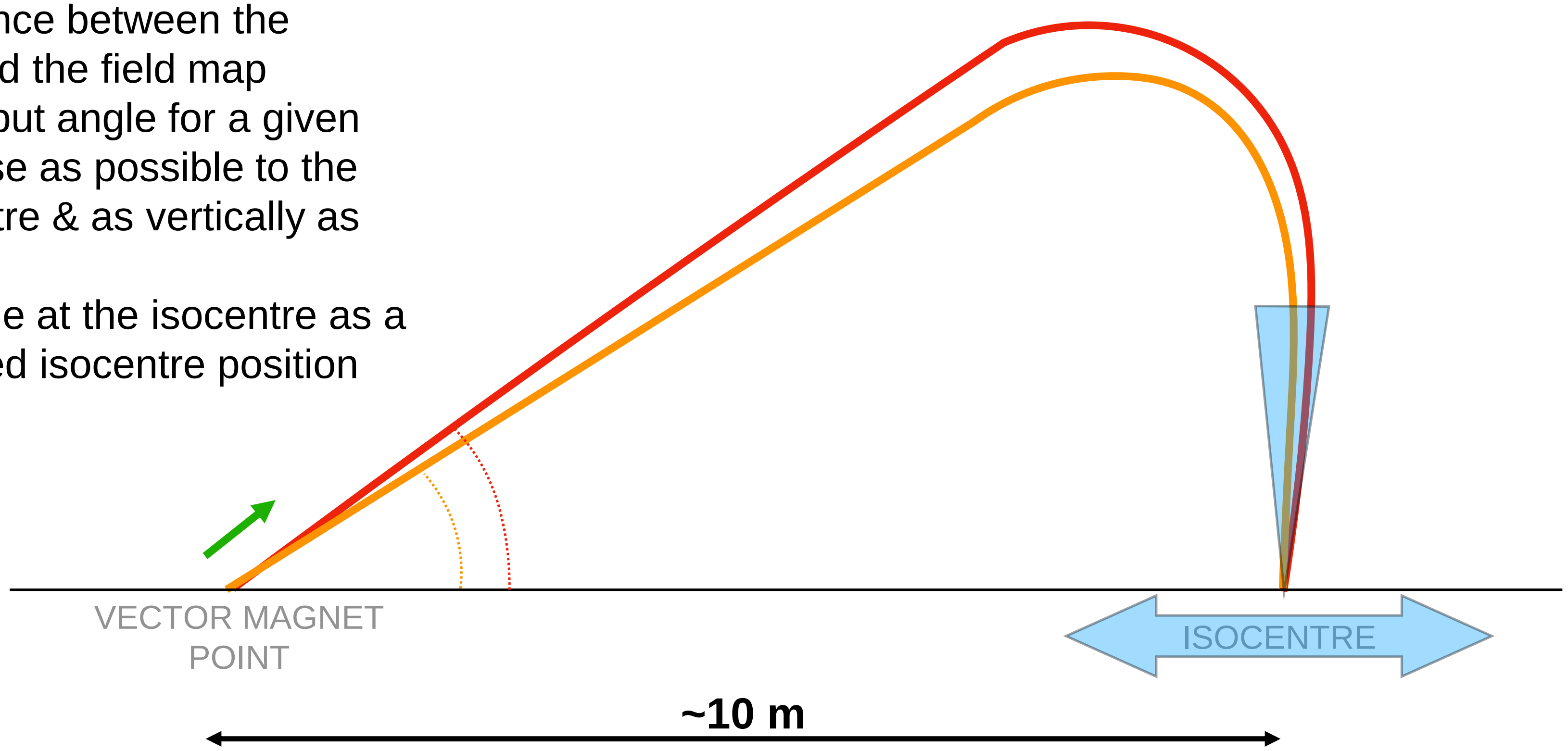


2D: central trajectories

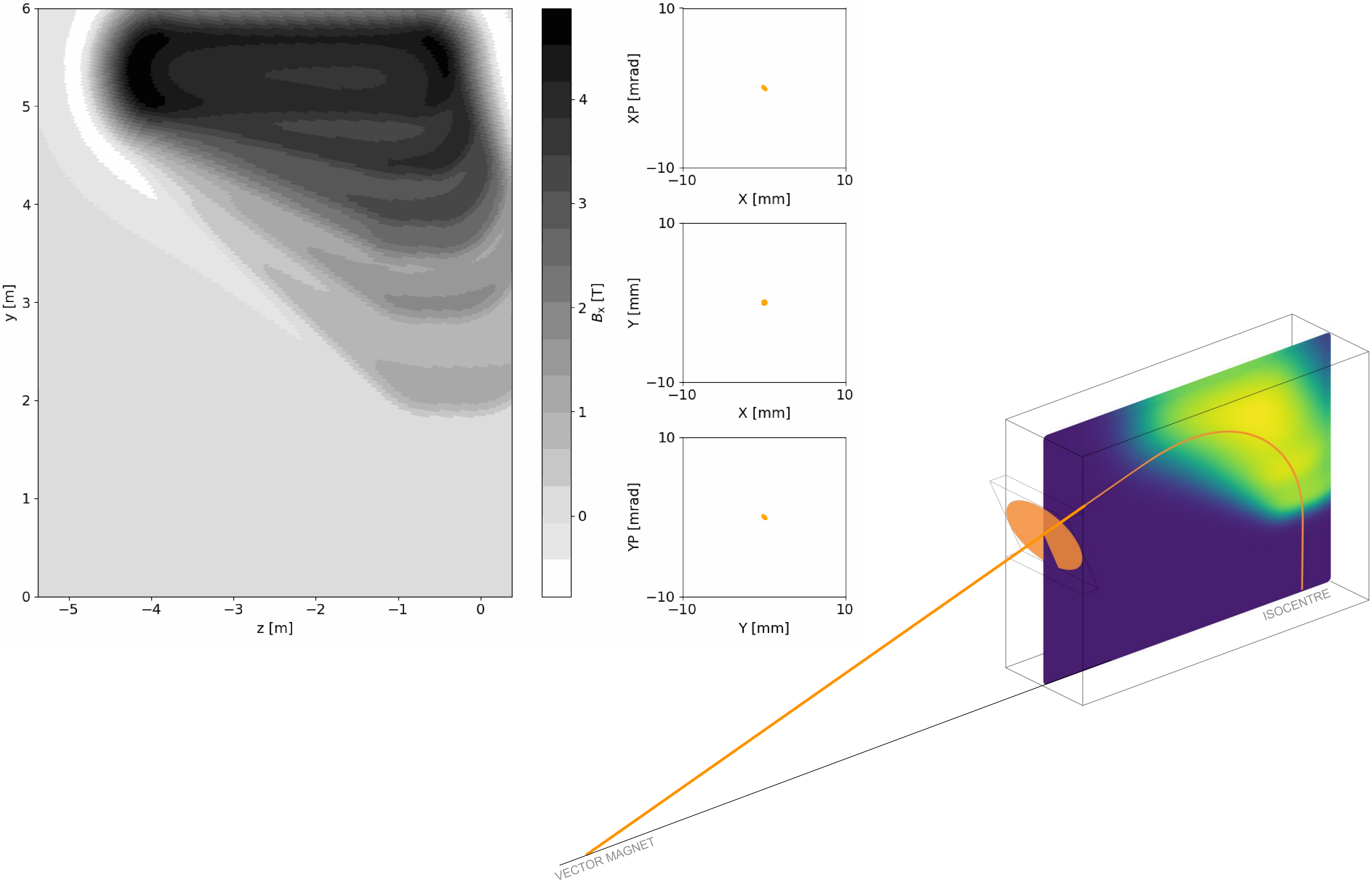
Backward-tracking (for many energies)
- from a fixed isocentre position vertically up
- to find an average distance between the vector magnet point and the field map



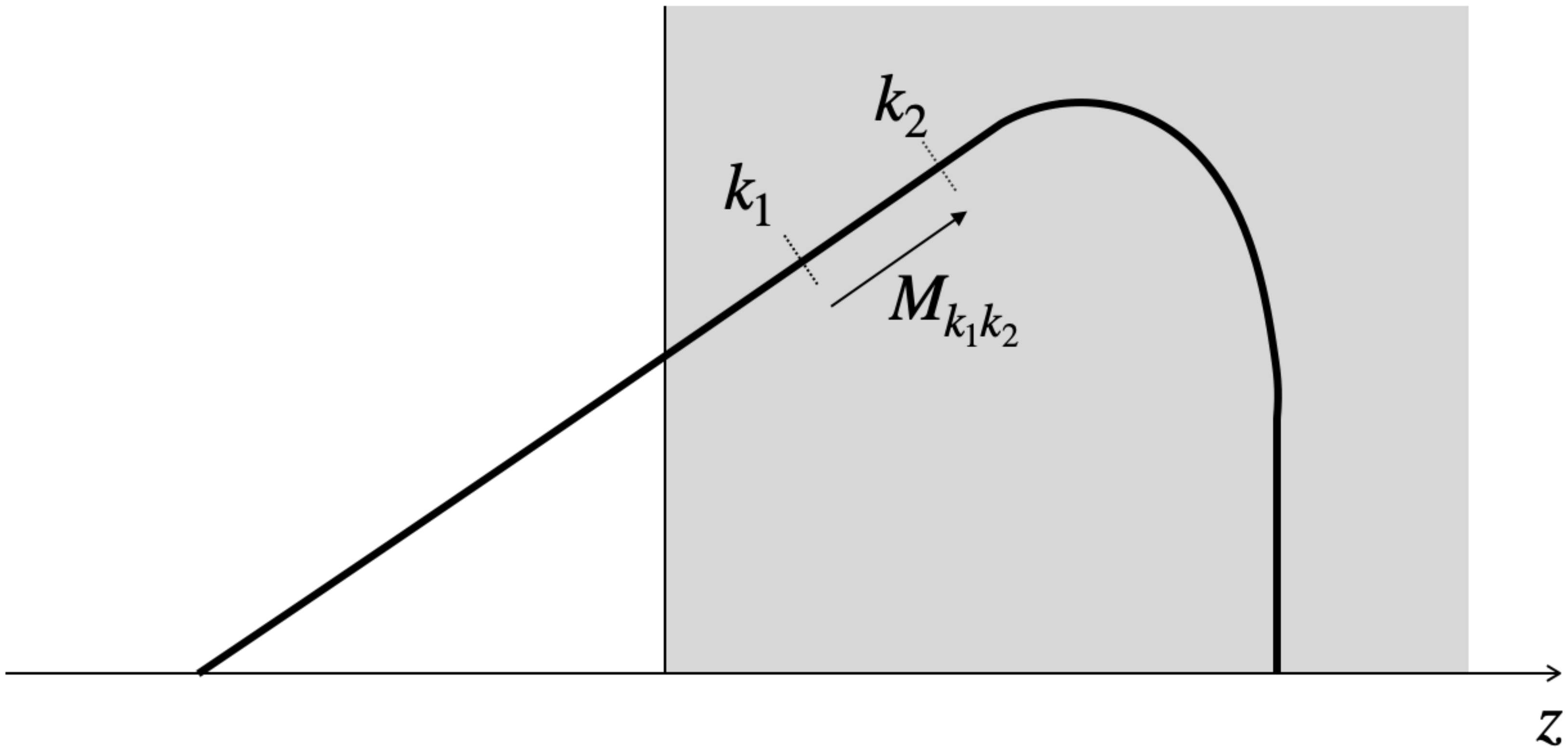
Forward-tracking
- from the average distance between the vector magnet point and the field map
- optimising the alpha input angle for a given energy to reach as close as possible to the previously fixed isocentre & as vertically as possible
- checking the theta angle at the isocentre as a function of different fixed isocentre position



3D beam dynamics



3D beam dynamics: focusing terms



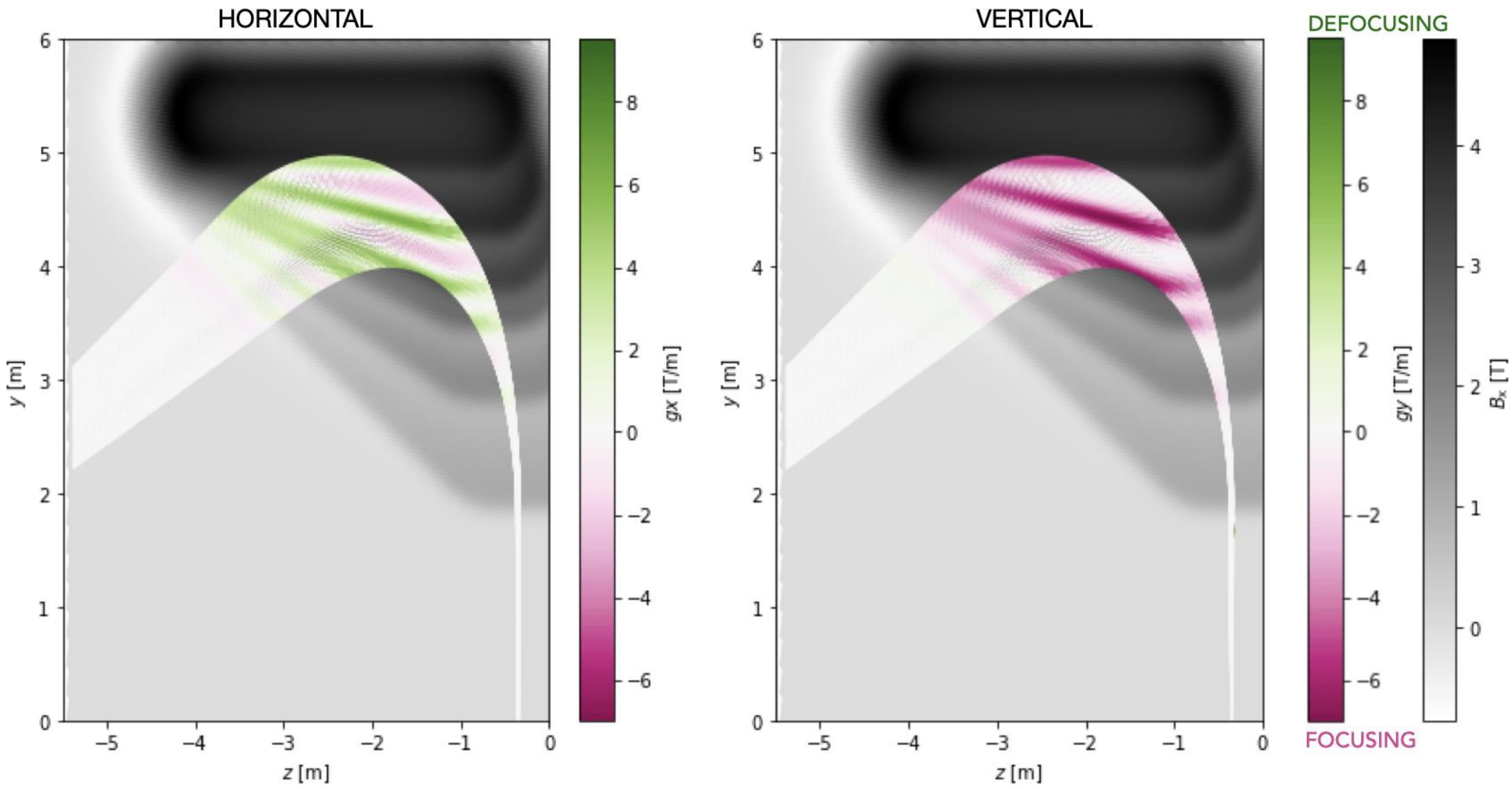
$$M_{k_1k_2} = M_D M_{Q(thin)} M_D$$

$$M_{k_1k_2} = \begin{bmatrix} 1 & L \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ kl & 1 \end{bmatrix} \begin{bmatrix} 1 & L \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 + Lkl & 2L + L^2kl \\ kl & 1 + Lkl \end{bmatrix}$$

$$g \;\; [T/m] = \frac{kl \cdot B\rho}{l} \;\; \left[\frac{m^{-1} \cdot Tm}{m} \right]$$

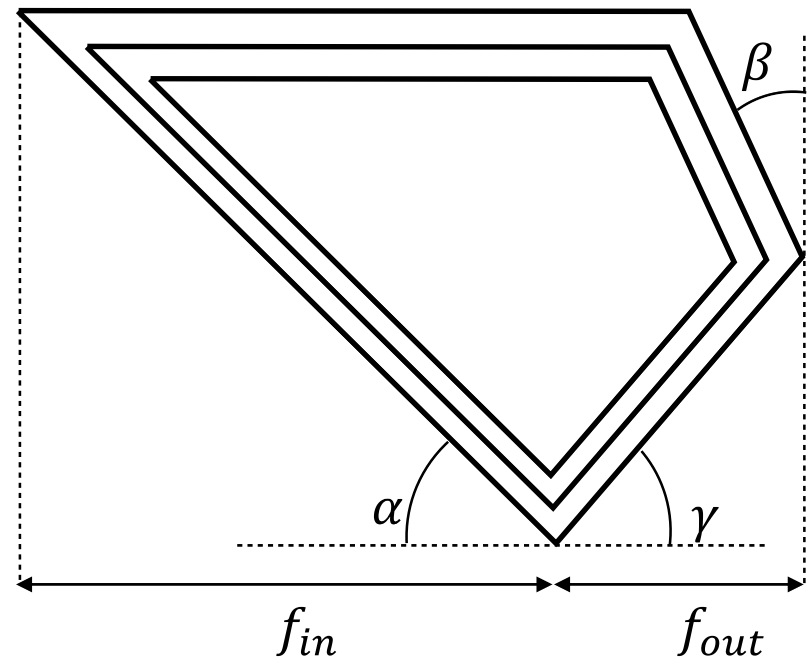
https://gitlab.cern.ch/abt-optics-and-code-repository/simulation-codes/pybt

3D beam dynamics: focusing terms



Next steps

- Coil design optimisation
  - Iterative process including beam dynamics and parameters of the set of coil
  - Decreasing computing time
- Considerations of the upstream beamline elements:
  - GaToroid as a complete system from the synchrotron extraction point to the patient
- Both protons and carbon ions



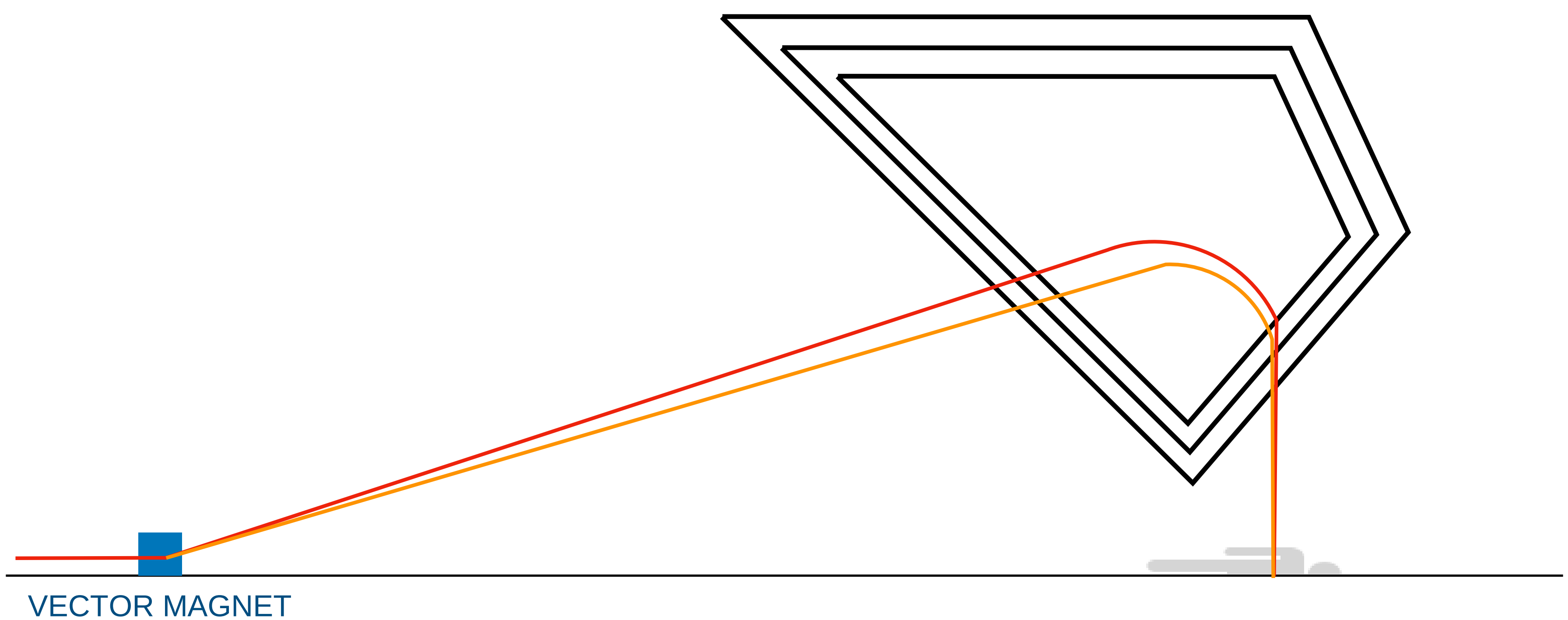
Coil configuration:
- Shape of the coil
- Number of windings
- Spacing between the windings

Current adjustment

Field recalculation

Central trajectories

Beam optics



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