GaToroid:

Novel Toroidal Configuration for Hadron Therapy Gantry

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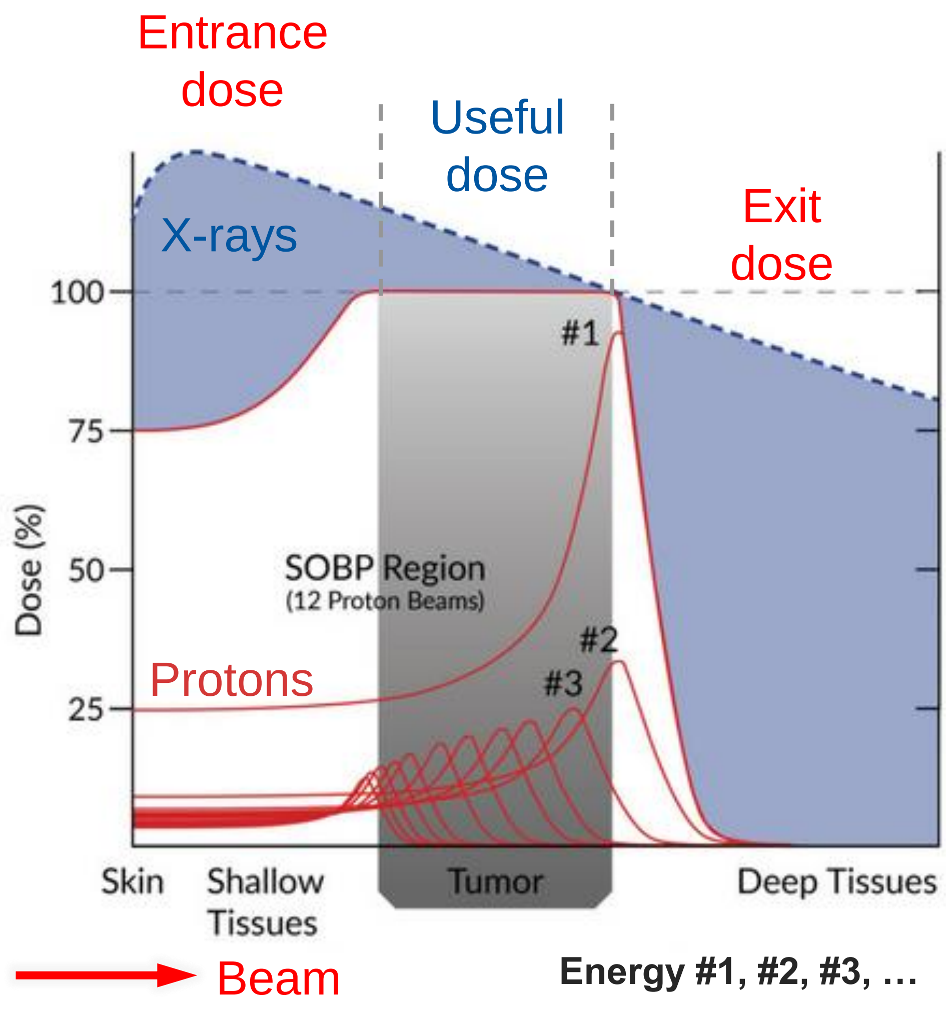
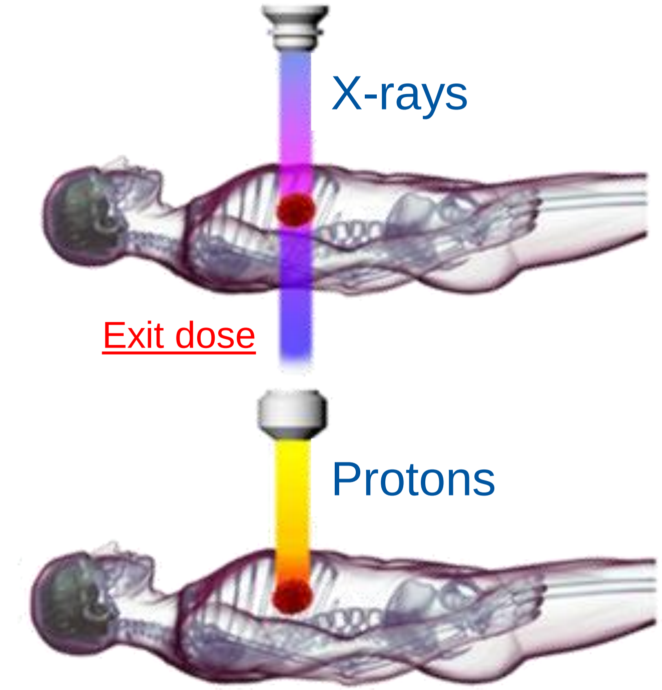
Outline

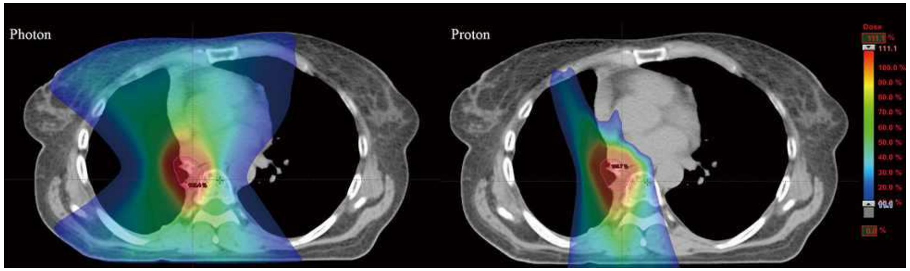
- Hadron Therapy and Gantries
- GaToroid: a new concept
- GaToroid for Protons
- HTS Demonstrator

Hadron Therapy





X-rays Protons



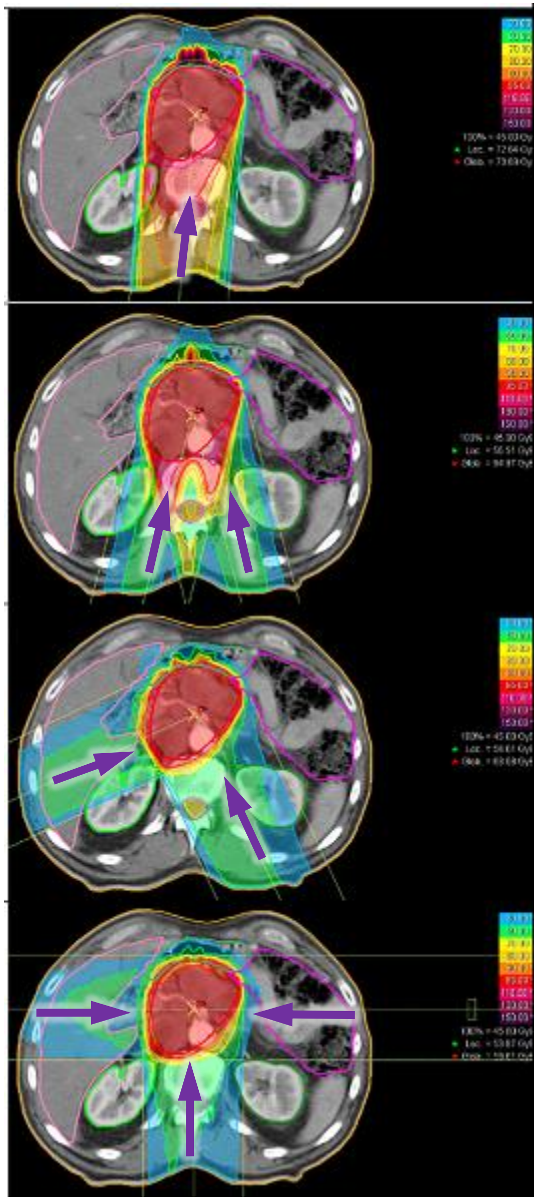
SOBP: Spread Out Bragg Peak

Translational Lung Cancer Research, 6(2), 2017

Gantry

Rotating magnetic transfer line

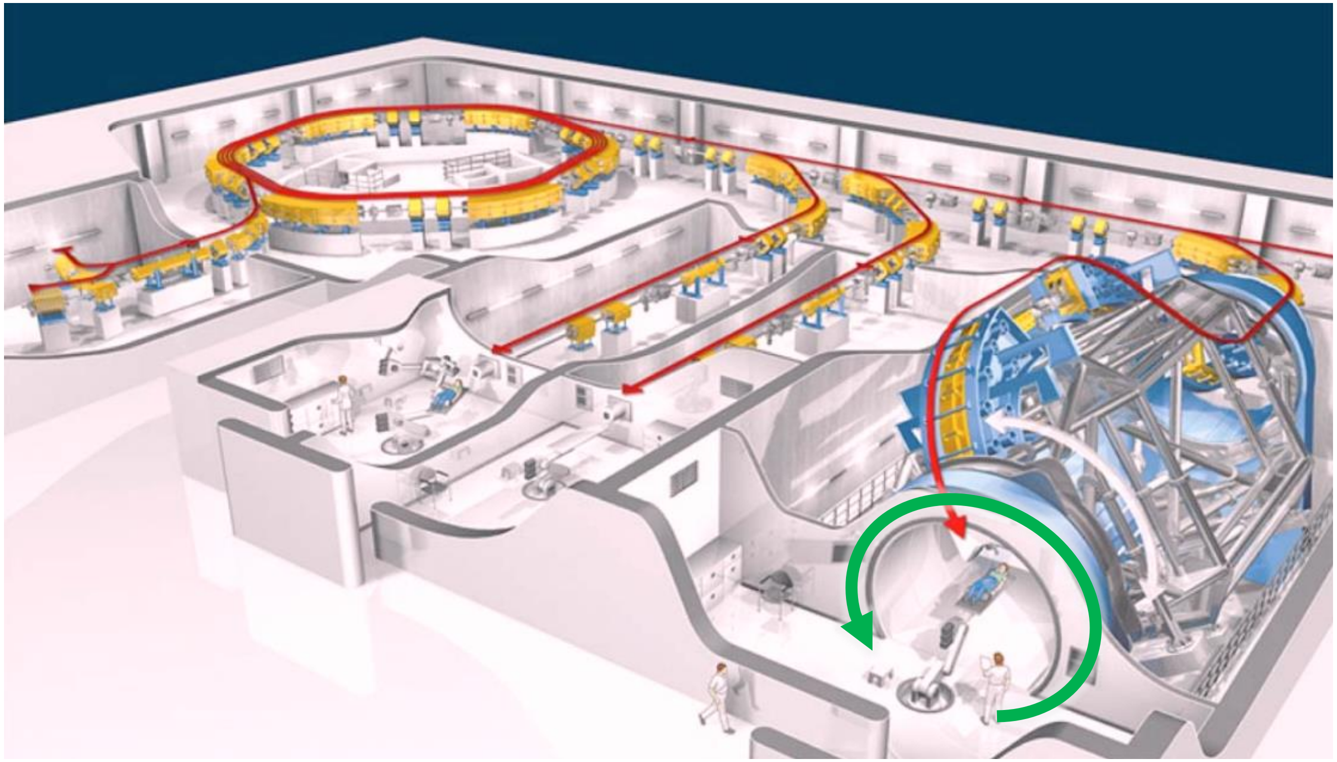
- Proton Gantries: radius 4…5 m - weight 100…200 tons
- C-Ions Gantries: radius 6…7 m - weight 350…670 tons

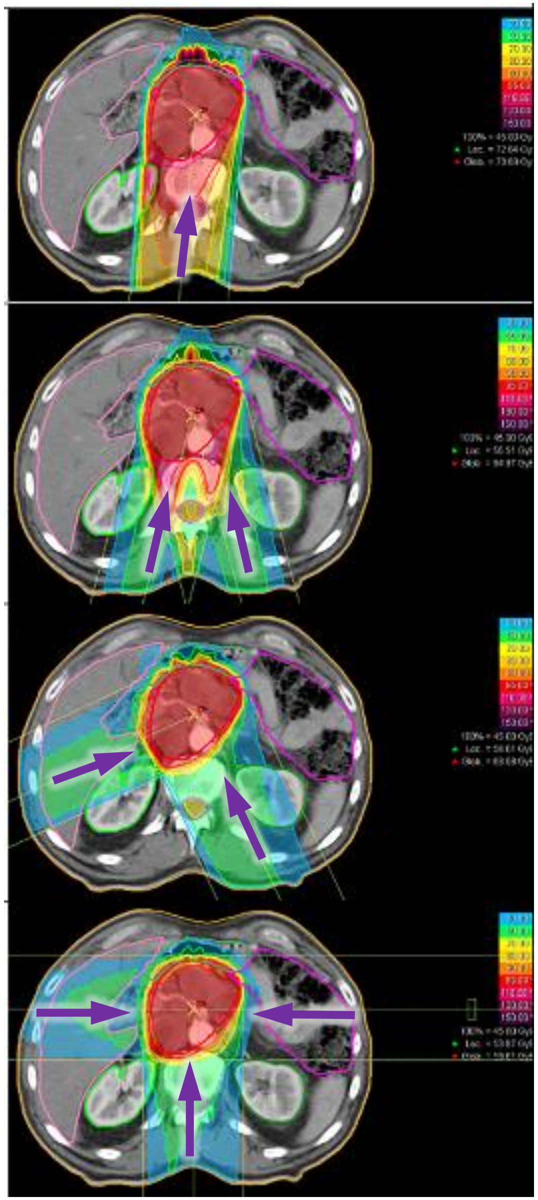


PLoS ONE 11(10): e0164473, 2016

Gantry

Rotating magnetic transfer line





PLoS ONE 11(10): e0164473, 2016

- Proton Gantries: radius 4…5 m - weight 100…200 tons
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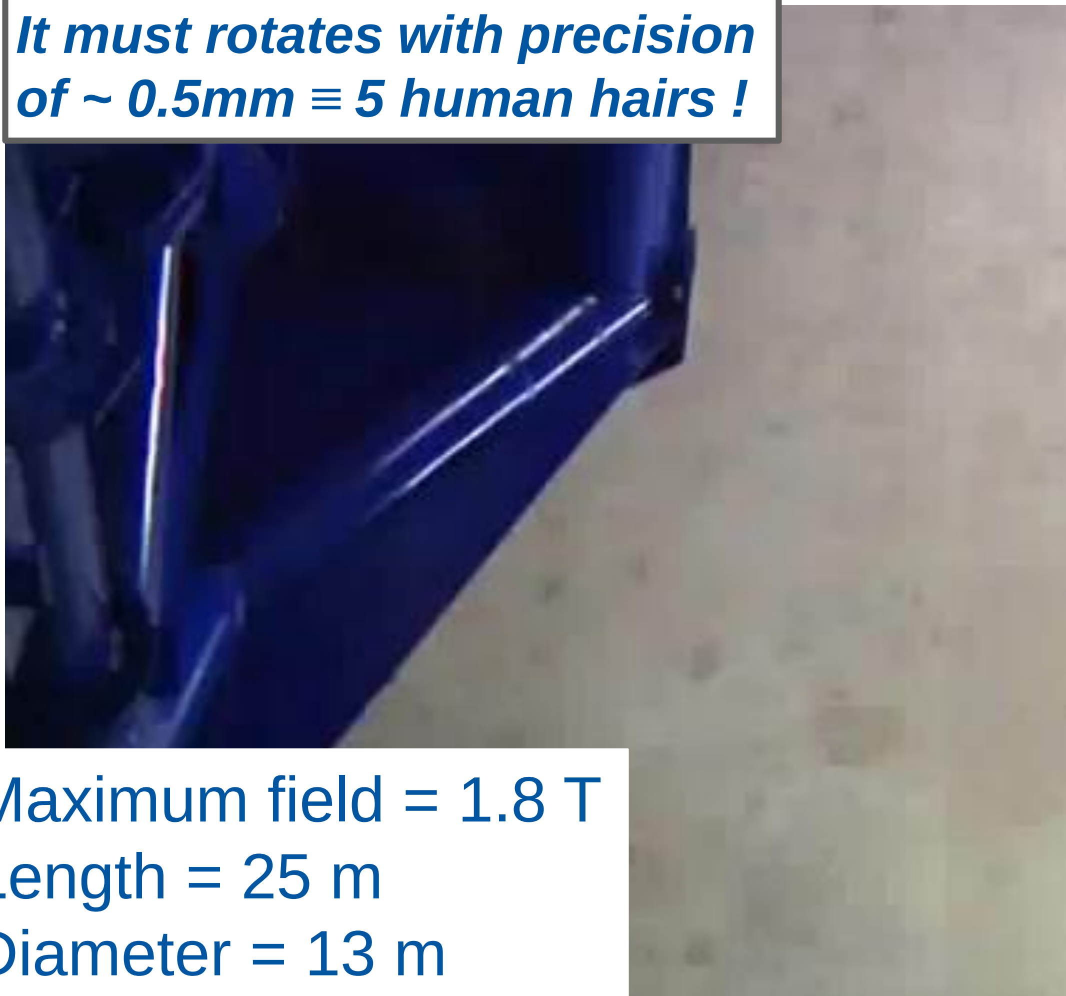
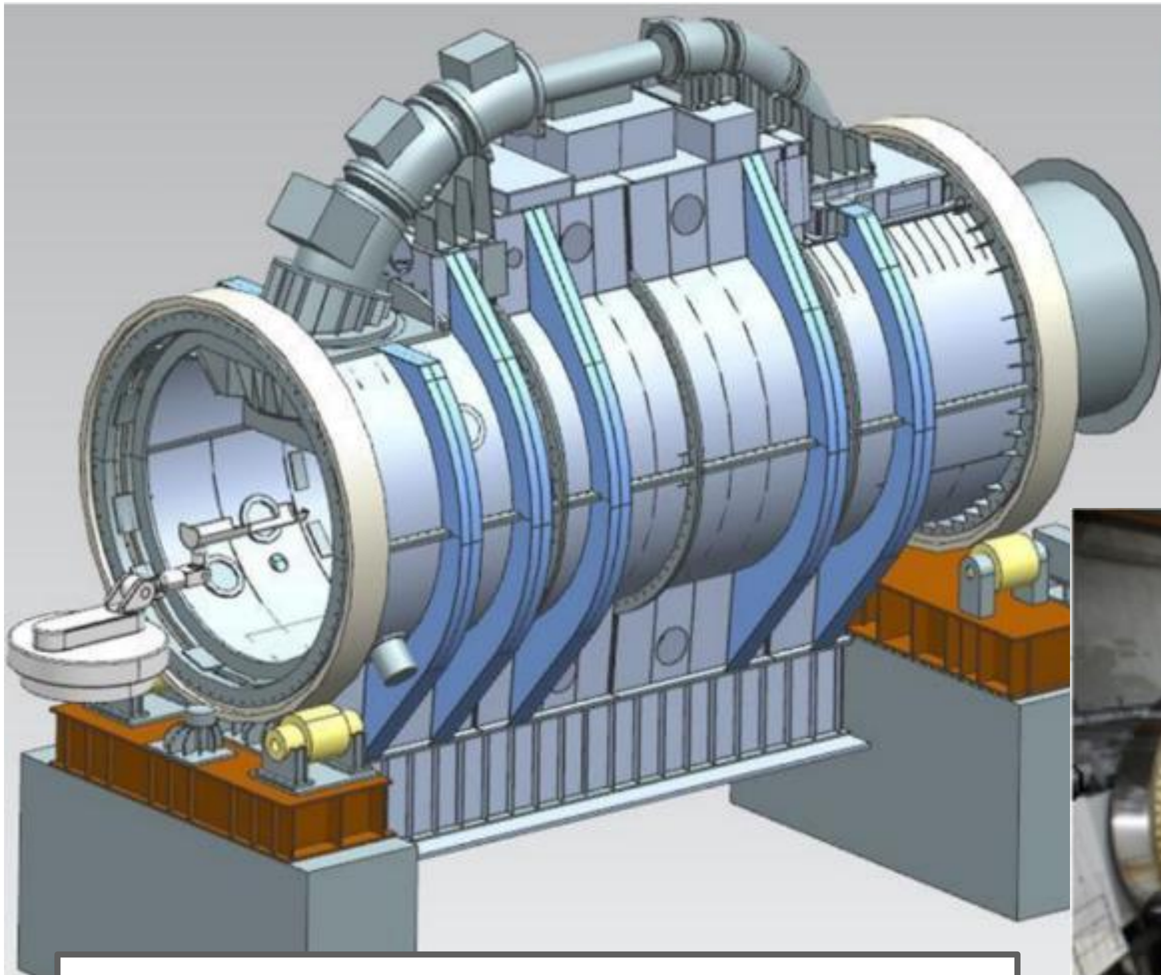
Heidelberg Ion-Beam Therapy (HIT)

It must rotates with precision of ~ 0.5mm ≡ 5 human hairs !



Maximum field = 1.8 T
Length = 25 m
Diameter = 13 m
Weight = 670 tons

Heavy Ion Medical Accelerator in Chiba (HIMAC)



Maximum field = 2.9 T
Length = 13 m
Diameter = 11 m
Weight = 350 tons

It is a smaller machine, but at 4.2 K !

New paradigm for gantries

Hadron therapy gantries are massive:

- Limited magnetic field to bend particles
- Stability requirements during rotation (~0.5 mm)

Basic idea:

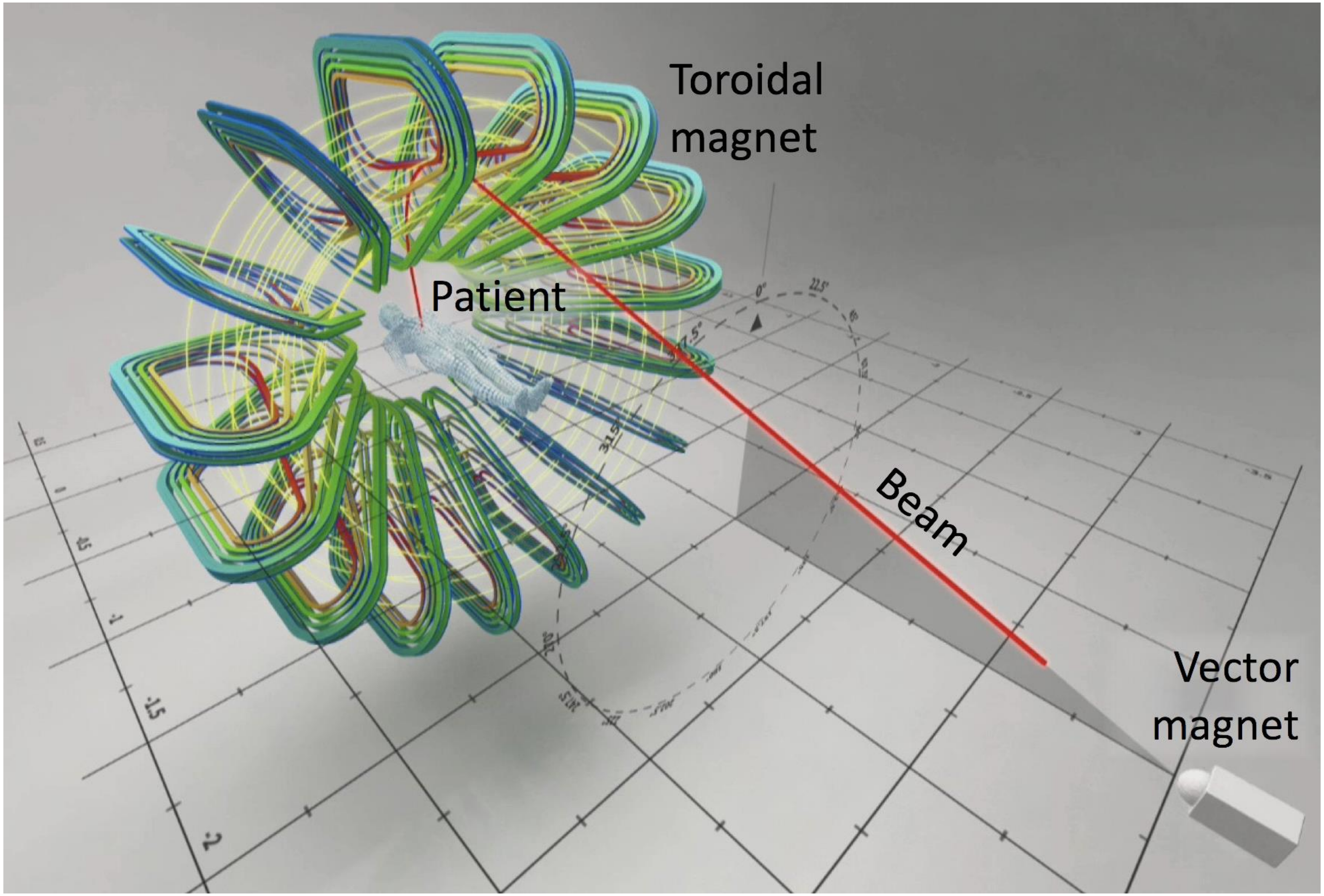
Steady state and non rotating gantry
→ Simplifications on mechanics and cryogenics

Superconducting magnets to increase the field
→ Reduction of mass, weight and footprint

GaToroid concept

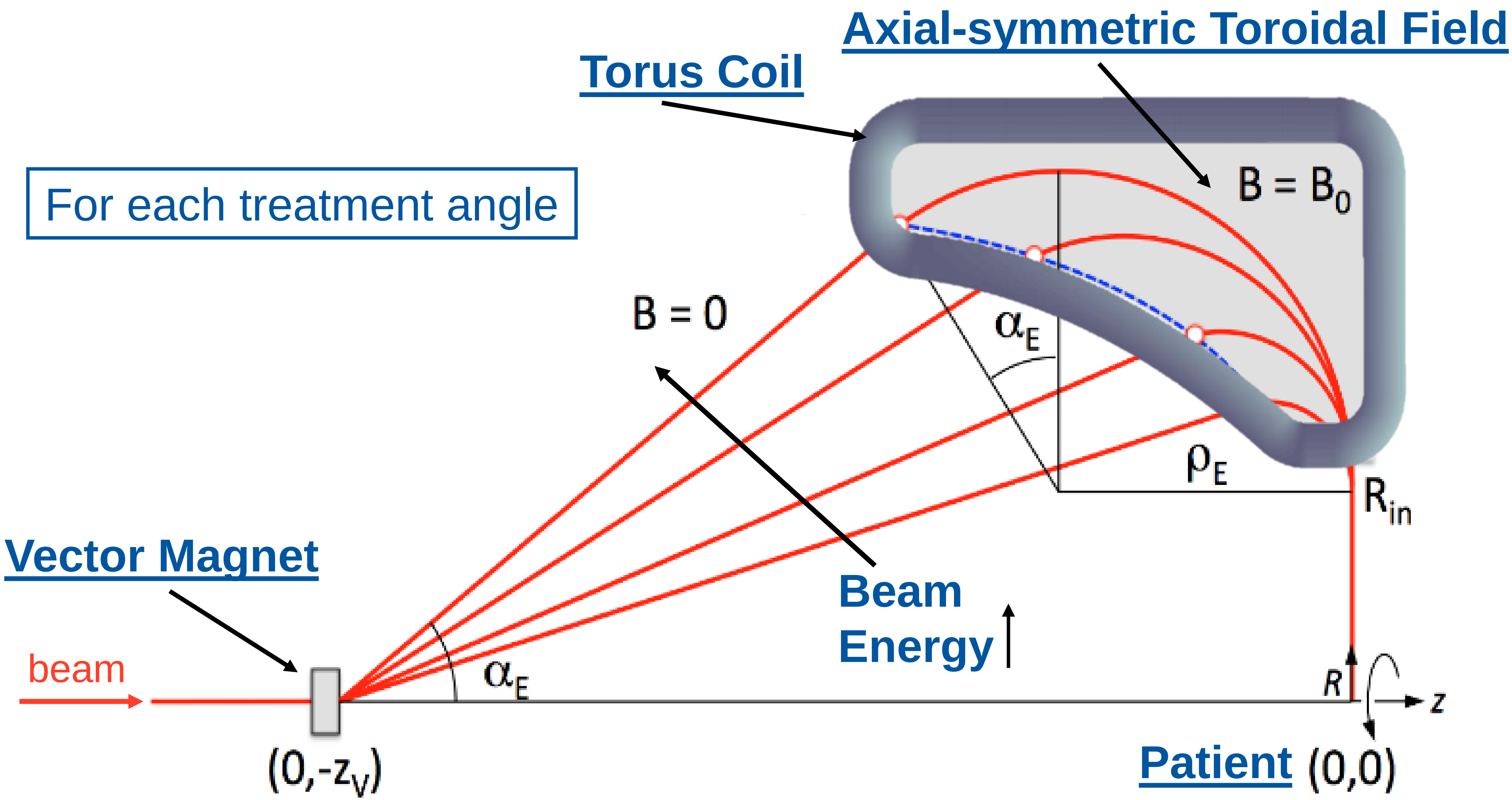
Graphics courtesy of Daniel Dominguez
(CERN Design and Visual Identity Service)

GaToroid concept

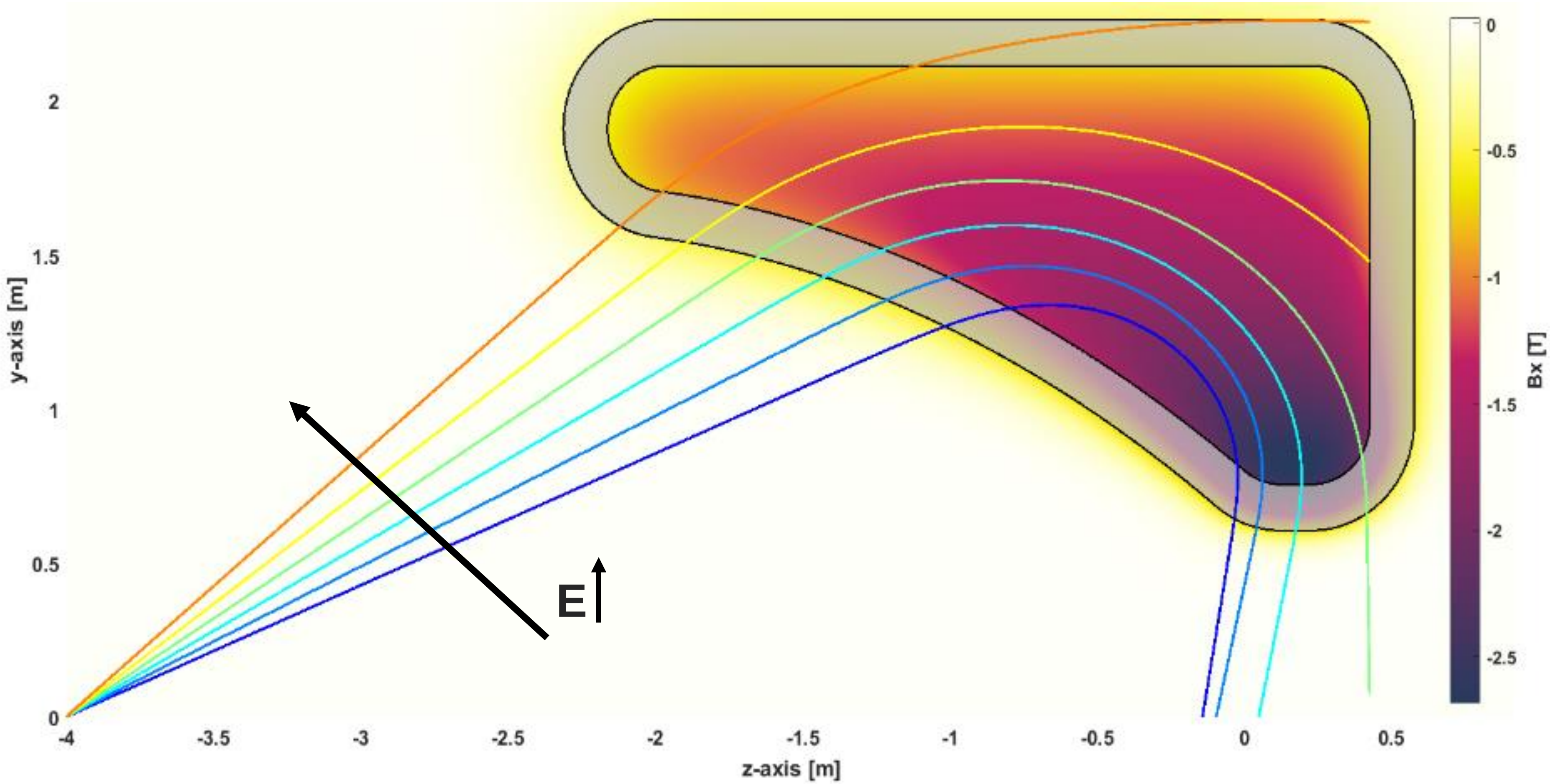


GaToroid Concept

For each treatment angle



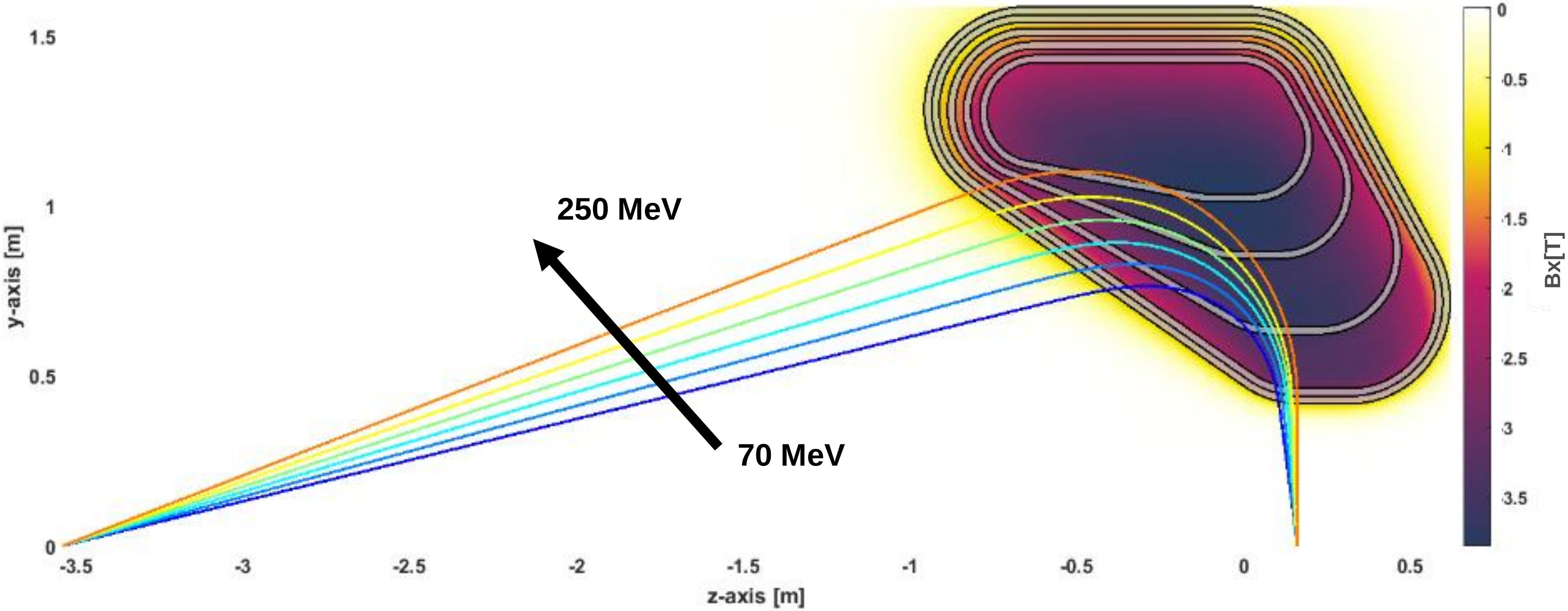
Coil Design



In a torus, the magnetic field decreases with the radius !

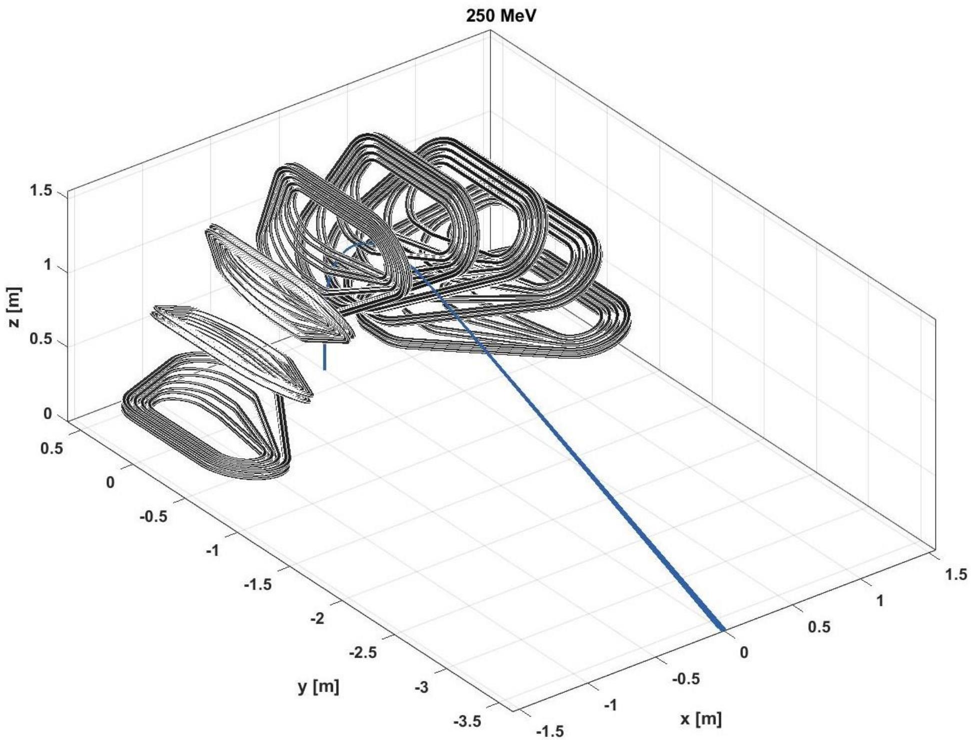
Single particle tracking

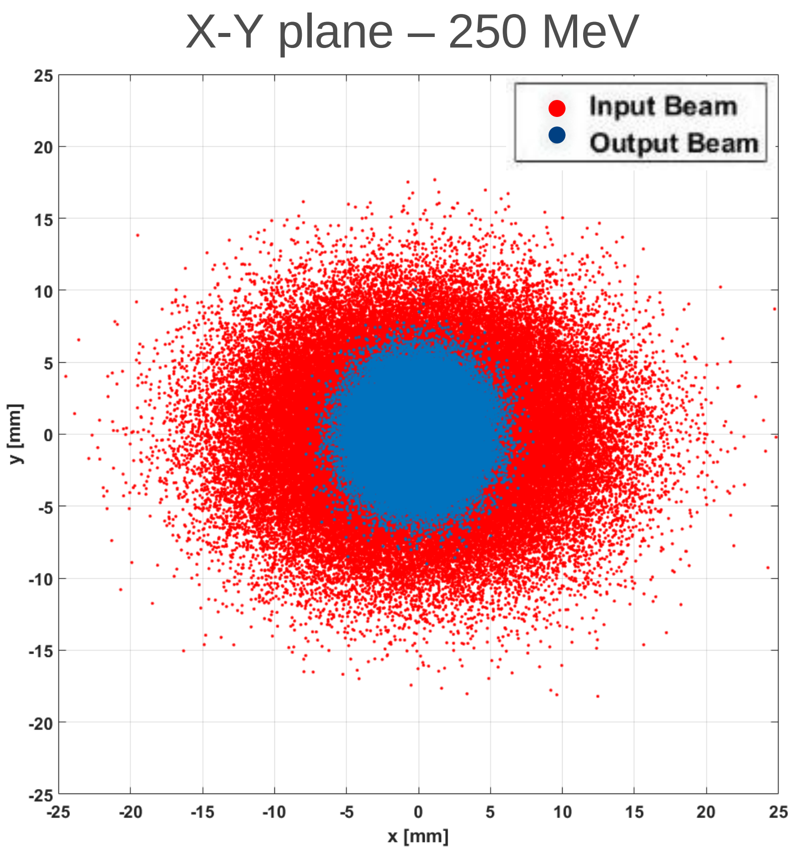
Integration of magnetic field map calculation and 2D particle tracking for optimization



Excellent acceptance and isocentric properties

3D particle tracking





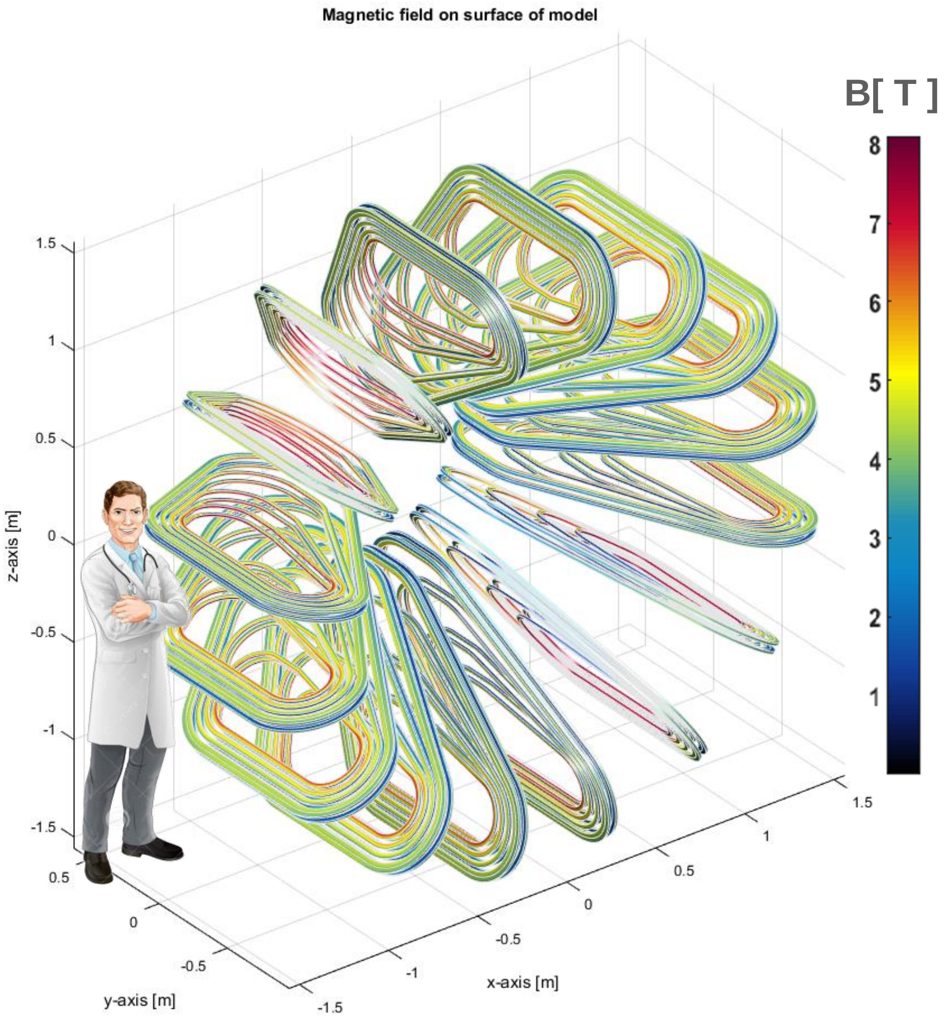
100 000 particles tracking in 3D magnetic field map:

$$m\frac{d\boldsymbol{v}}{dt} = q(\boldsymbol{v} \times \boldsymbol{B})$$

- Random Gaussian distribution in [x, xp, y, yp ,E]

E. Felcini *et al.*, “Particle Tracking and Beam Optics Analysis on Toroidal Gantry for Hadron Therapy”, to be submitted to phys. rev. accel. Beams, 2020

GaToroid for Protons



- Number of Coils: 16 (-)
- <u>Peak Field on Coil: 8.2 (T)</u>

- Coil Dimension: ~1.5 x 1 (m x m)
- **Torus Dimensions: ~1.5 x 3 (m x m)**
- Bore: ~ 0.8 m (MRI-like)
- **Estimated Mass: 12 (tons)**

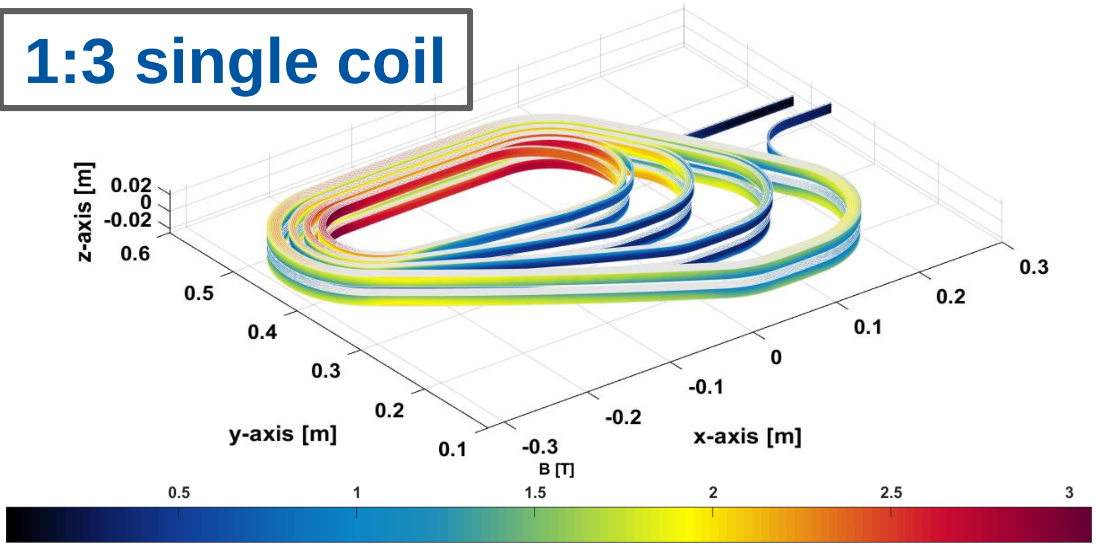
- Total Stored Energy: 30 (MJ)
  (LHC dipole ~7 MJ)

- Operating Temperature

4.5 K → Low Temperature Supercond. (LTS)
20 K → High Temperature Supercond. (HTS)

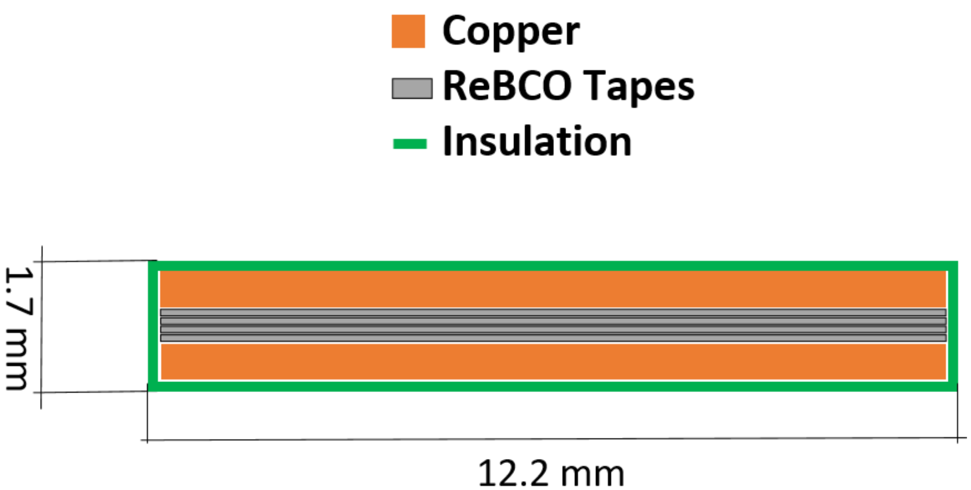
GaToroid Demonstrator

1:3 single coil

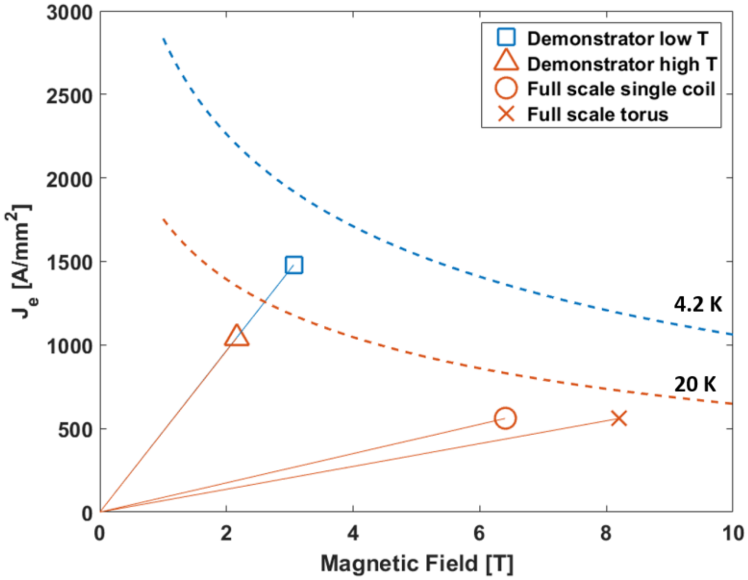


Demonstrator Parameters		
Parameter	Unit	Value
Number of Grades/Layer		5
Number of Layers		2
Size	[m x m]	0.6 x 0.4
Scale		1:3
Cable Length	[m]	50
Inductance	[mH]	0.64

HTS Demonstrator - Cables Parameters		
Parameter	Unit	Value
Conductor		ReBCO
Cable Topology		Non-Twisted Stack
N of SC tape		4
N of Cu tape		2
Cable Width	[mm]	12.2
Cable Thickness	[mm]	1.7
Cu: Non-Cu ratio		5.3



GaToroid Demonstrator

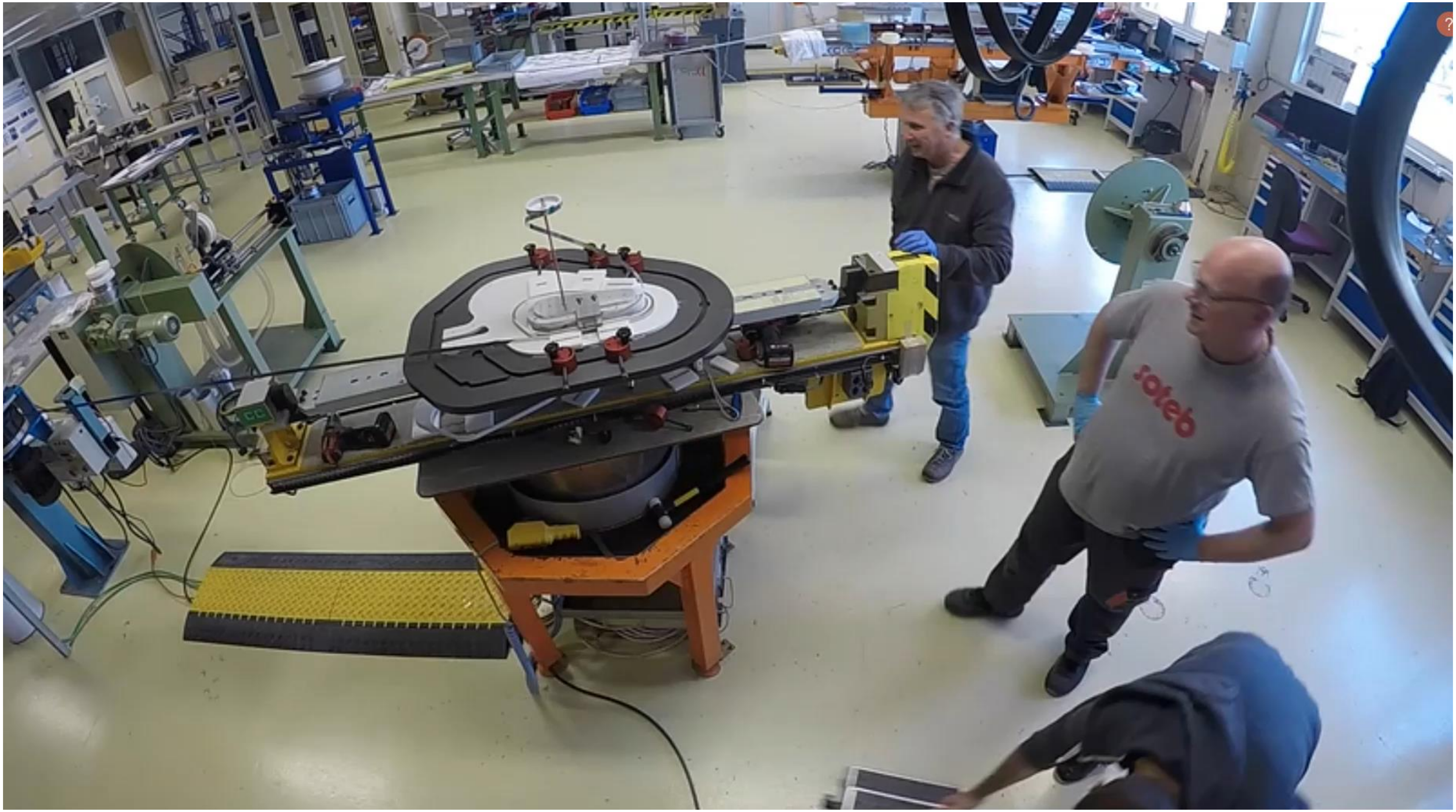


Conductor performance scaled from Bruker tape[1]: 670 A/mm^2 at 4.2 K, 20 T

HTS Demonstrator - Operating Conditions			
Parameter	Unit	High T | Low I	Low T | High I
Operating Current - I_{op}	[kA]	5.0	7.1
Operating Temperature - T_{op}	[K]	20	4.2
Peak Magnetic Field - B_{op}	[T]	2.16	3.06
Eng. Current Density (Tape) - J_e	$[A/mm^2]$	1042	1479
Eng. Current Density (Cable) - J_{eC}	$[A/mm^2]$	241	342

[1] M. Danial and J. van Nugteren, "Parametrization of the critical surface of REBCO conductors from Bruker," CERN - Internal Report, 20 July 2017

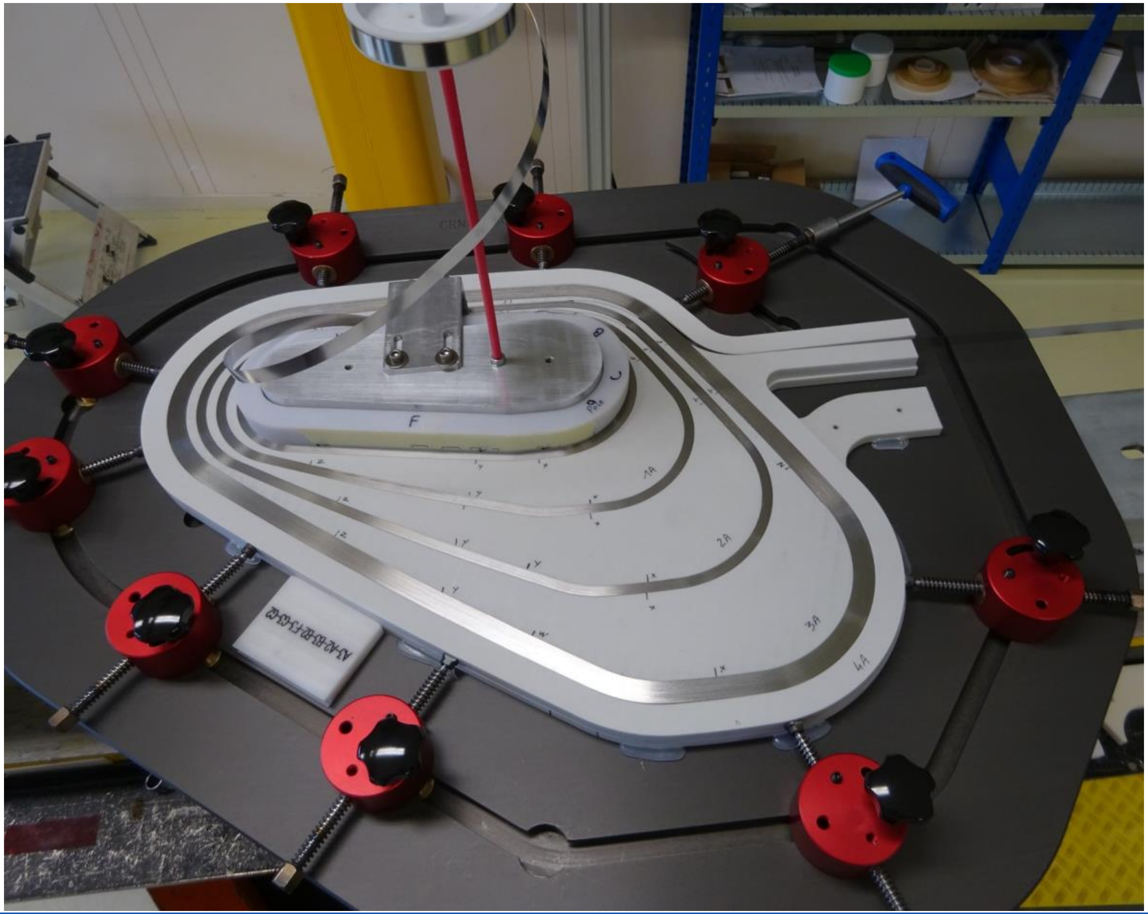
GaToroid Demonstrator



Thanks to Jacky Mazet, Frederic Garnier, Sebastien Clement,
Jeremie Massard and Juan Carlos Perez from TE-MSC-MDT

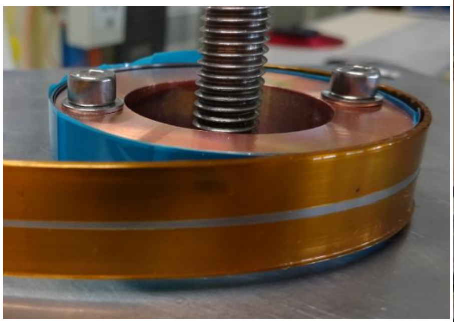
GaToroid Demonstrator

1^{st} dummy in stainless steel tape
and 3D printed spacers



Work in Progress

Winding
Insulation
Impregnation



Thanks to all the people in 927 (TE-MSC-MDT) for the hard work and patience!

Mechanical Concept
Modelling
Drawings

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(EN-MME-DI)

Tuukka Lehtinen
(EN-MME-EDS)

…under the wise supervision of Diego Perini (EN-MME-DI)