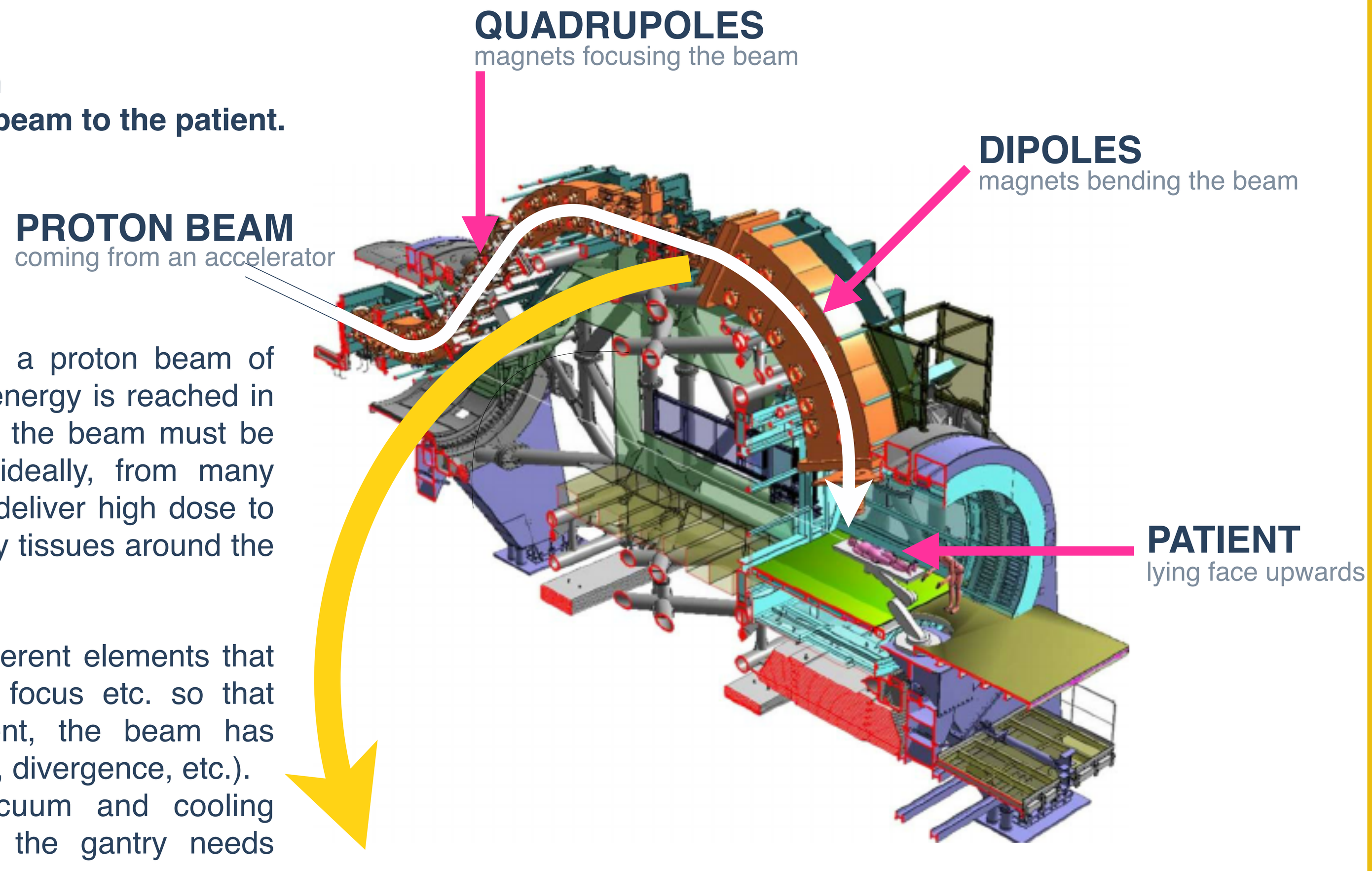
SUPERCONDUCTING GANTRY DESIGN FOR PROTON COMPUTED TOMOGRAPHY

Ewa Oponowicz

University of Manchester/Cockcroft Institute, Manchester, UK

GANTRY

Gantry is a rotating system delivering the accelerated beam to the patient.



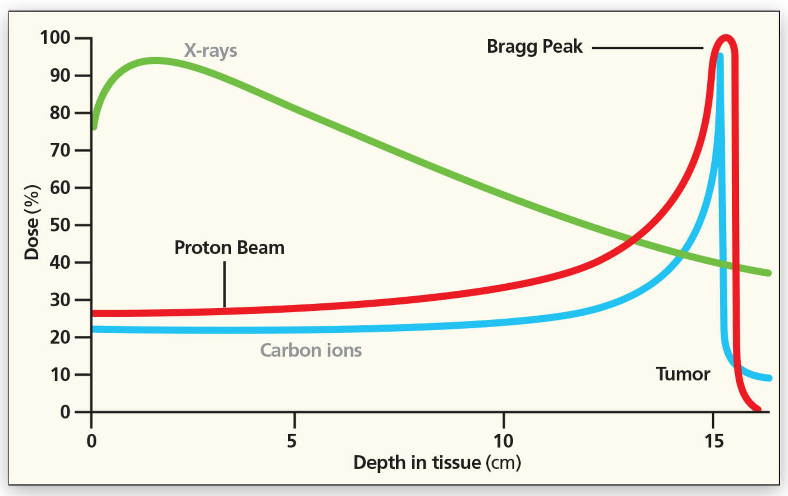
For the treatment purposed a proton beam of 70-250 MeV* is used. This energy is reached in a circular accelerator. Then, the beam must be directed onto the patient: ideally, from many different angles. This helps deliver high dose to the tumour and spare healthy tissues around the tumour at the same time.

Gantry consists of many different elements that control the beam, bend it, focus etc. so that when it reaches the patient, the beam has required parameters (its size, divergence, etc.). Additionally, there are vacuum and cooling systems incorporated, and the gantry needs heavy mechanical support.

Conventional gantries for proton beams in use around the world are up to 9 m long, of 3-4 m radius and weigh 200 tons.

*1 MeV = 1000000 eV
1 eV (electron-volt) is the energy gained by an electron which travels a potential difference of 1V.

PROTON THERAPY

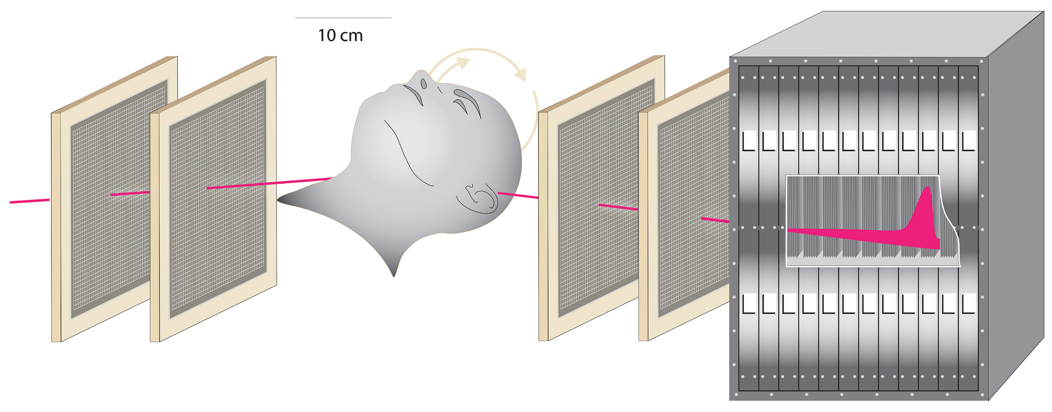


The main advantage of protons is that they stop in the body: for treatment we want them to stop exactly where the tumour is. The higher is the energy of the beam, the deeper in the body these particles stop. The maximum kinetic energy usually used for treatment is up to 250 MeV (protons will stop at 37.7 cm in a tissue equivalent).

PROTON COMPUTED TOMOGRAPHY

In order to prepare a treatment plan for proton therapy, a precise imaging must be performed in order to specify location of the tumour in the patient's body. Nowadays, the conventional technique is computed tomography (CT): performing X-ray imaging from many different angles. X-rays (photons) however interact with the traversed tissue in the different way than protons that are later used for the treatment.

Could we then use the same particles (protons) for both: imaging and treatment?
Yes, but..

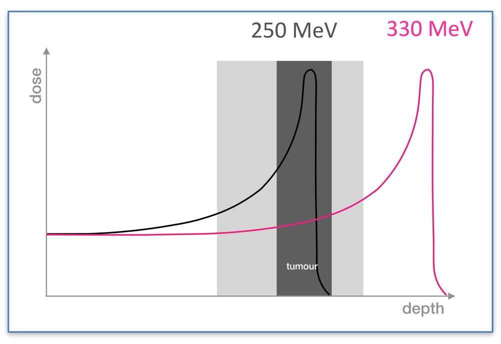


For tomography, protons *stop outside* of the patient's body, so that the dose delivered during imaging is minimised. For an adult patient this would require energy of around **330 MeV**.

The challenge is to design a gantry for so high energy. Why?
Because the higher the energy is, the harder it is to bend the beam.
There are two solutions for this:

- **larger magnets** or
- **stronger magnets**.

In order to have stronger magnets we are choosing superconducting technology.

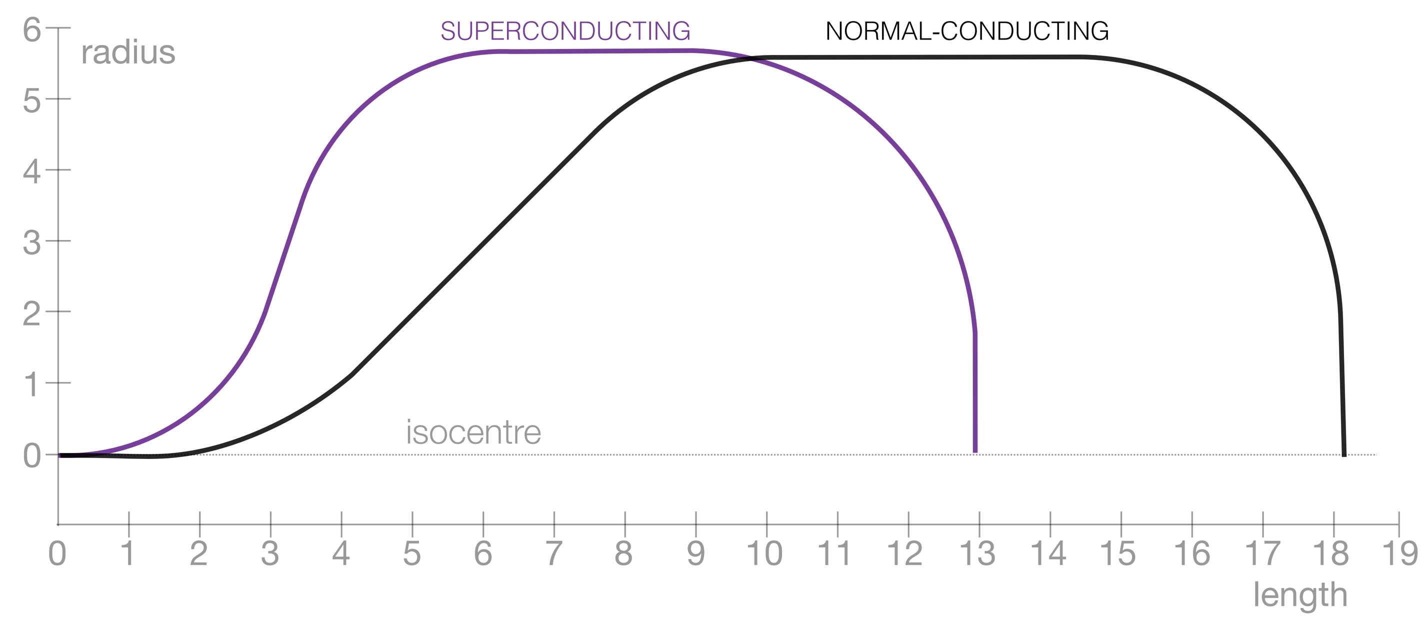


SUPERCONDUCTIVITY

Superconductivity (first observed in 1911) is a phenomenon, occurring in certain materials, in which the electrical **resistance drops to zero** below so called critical temperature.

How the beam is bent?
The higher is the energy, the more difficult it becomes to bend the beam. According to Lorentz' law it is magnetic field that bends the beam. We therefore need stronger magnets.

Why do we use superconductivity in a gantry?
For this application we use electromagnets: magnets, in which the electric current produces the magnetic field. If a superconducting technology is used and there is no electrical resistance, the higher current can be used (meaning higher magnetic field).

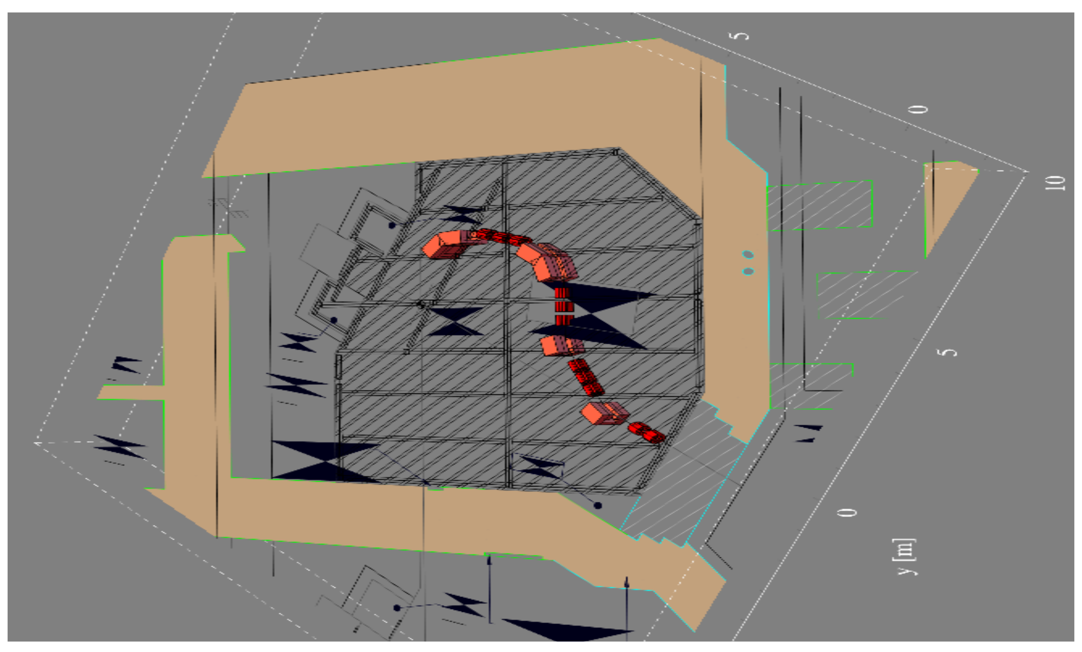


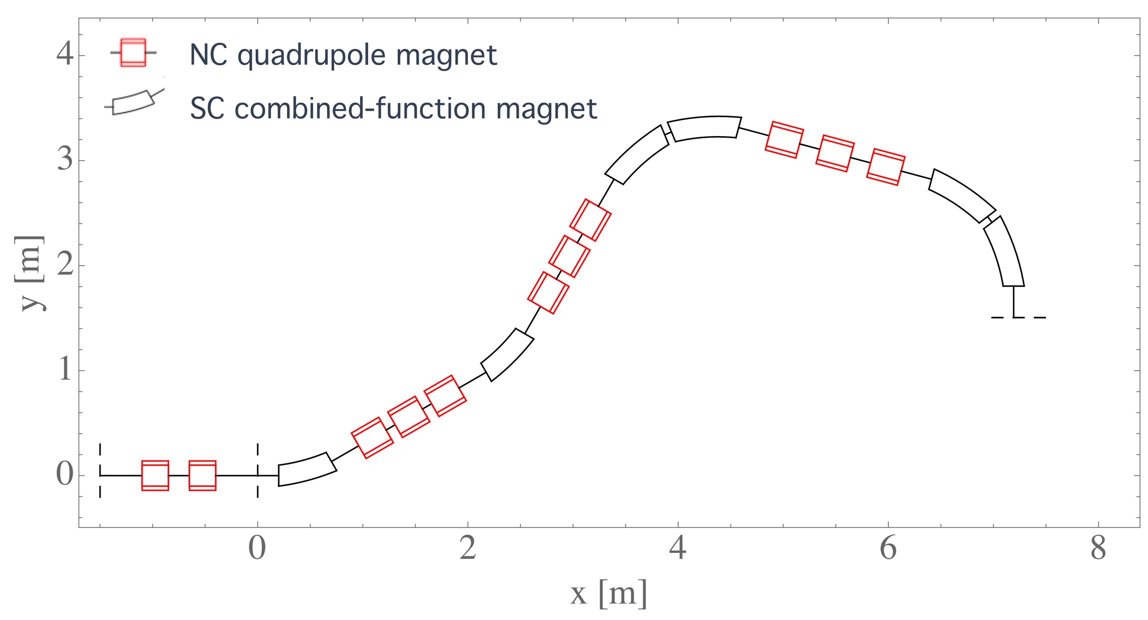
As an example the way travelled by a beam in two gantries used for the same kind of cancer treatment (carbon ion therapy) is schematically presented: In grey a normal-conducting gantry in Germany (600 tons) and in pink a superconducting gantry in Japan (200 tons). One can clearly see a large decrease in the gantry length in case of the superconducting one.

Are there any disadvantages of applying superconductivity?
There are multiple technological challenges related to superconducting magnets.
Firstly, it is an expensive technology. In order to be in the superconducting state the material has to be cooled down to very low temperatures (i.e. 4.2 K). This requires high power. Additionally, this cooling system has to be mounted on a rotating structure of the gantry.
Also, possible quenches (the magnet enters back the normal-conducting state) that could disturb the operation of the medical centre.

GANTRY DESIGN

This gantry is designed such that it could transport a beam of the kinetic energy suitable for proton computed tomography. At the same time, thanks to superconducting magnets (magnetic field in superconducting dipoles is 2.8 T) it is not too large and fits into the research room in the Proton Therapy Centre at the Christie Hospital in Manchester, UK.





PROTON THERAPY CENTRE IN MANCHESTER, UK

In 2011 the UK government has confirmed that there would be two new proton therapy centres in:

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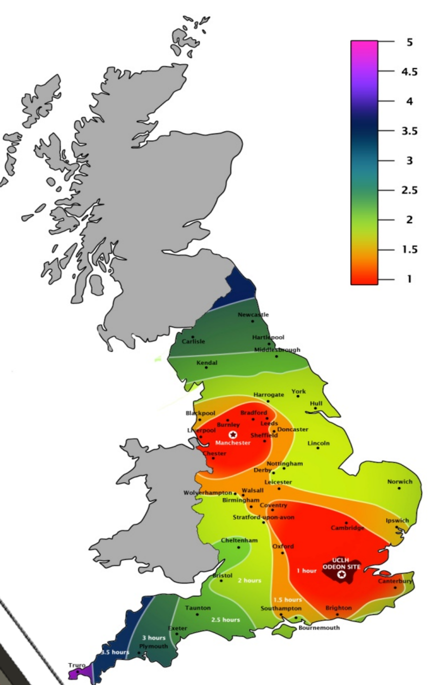
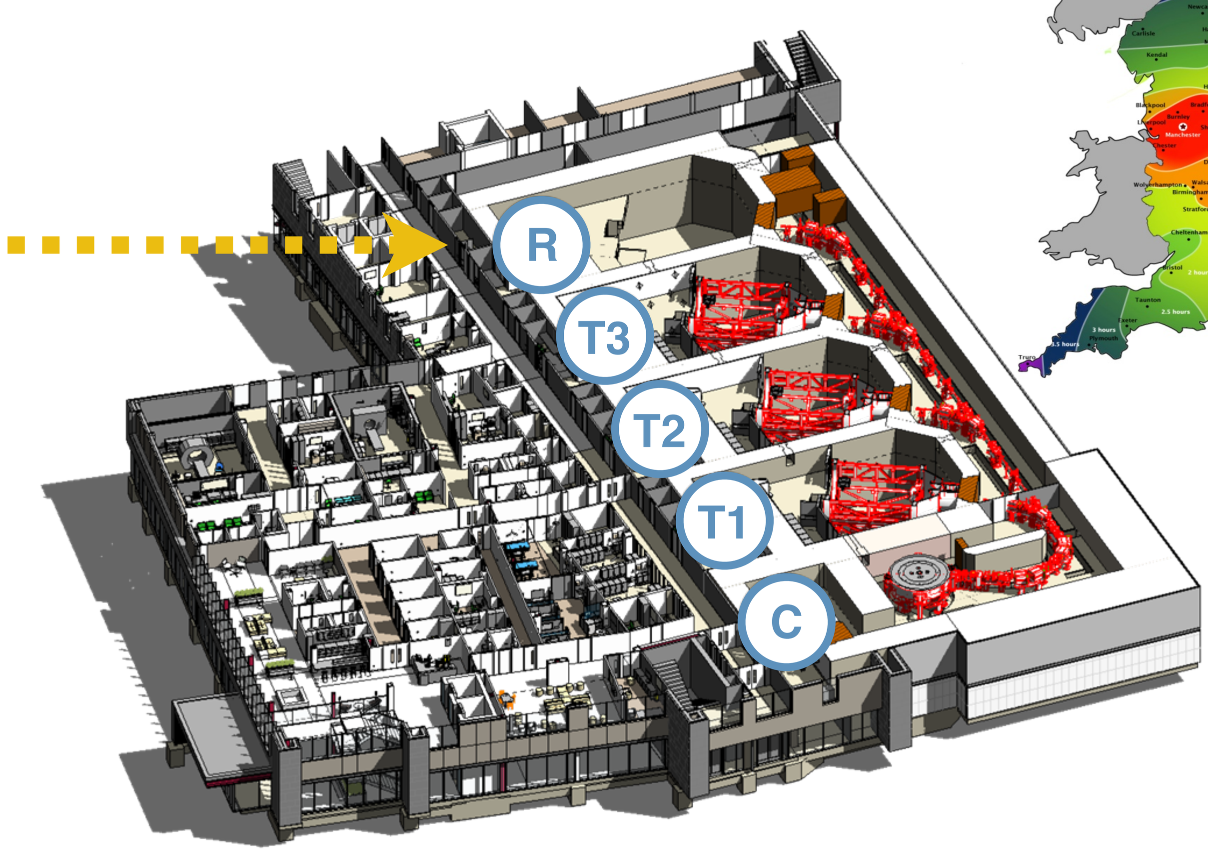
- the Christie Hospital in Manchester (in 2018).

Both centres, when fully operating, will treat in total approximately 1500 patients per year.





The proton beam is delivered by a superconducting cyclotron (C), accelerating the beam up to the kinetic energy of 254 MeV. The beam is then transported into one of the 3 treatment rooms (T1, T2, T3). The 4th room (R) is dedicated for technical, biological and clinical research. This room is also the location at which eventually the superconducting gantry for proton tomography would be installed.

REFERENCES:
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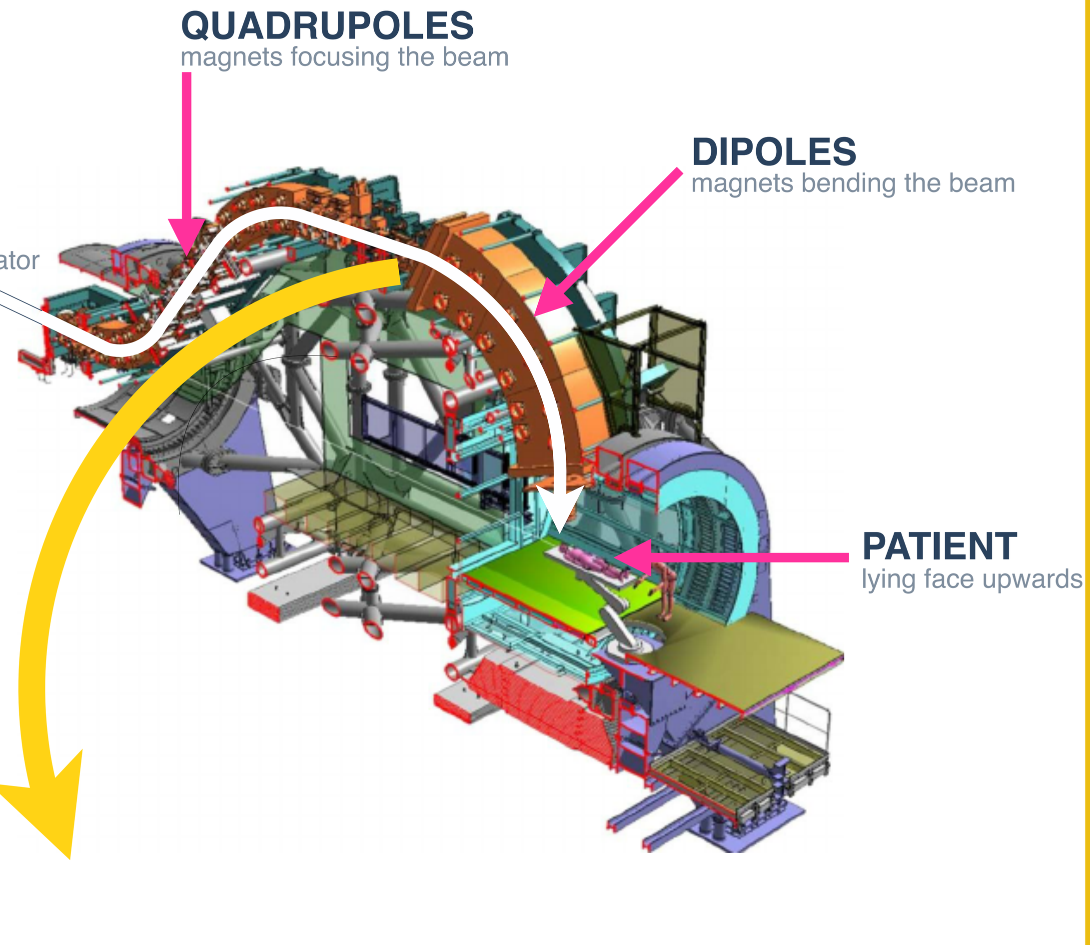

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Gantry consists of many different elements that control the beam, bend it, focus etc. so that when it reaches the patient, the beam has required parameters (its size, divergence, etc.). Additionally, there are vacuum and cooling systems incorporated, and the gantry needs heavy mechanical support.

Conventional gantries for proton beams in use around the world are up to 15 m long, of 3-4 m radius and weigh 200 tons.

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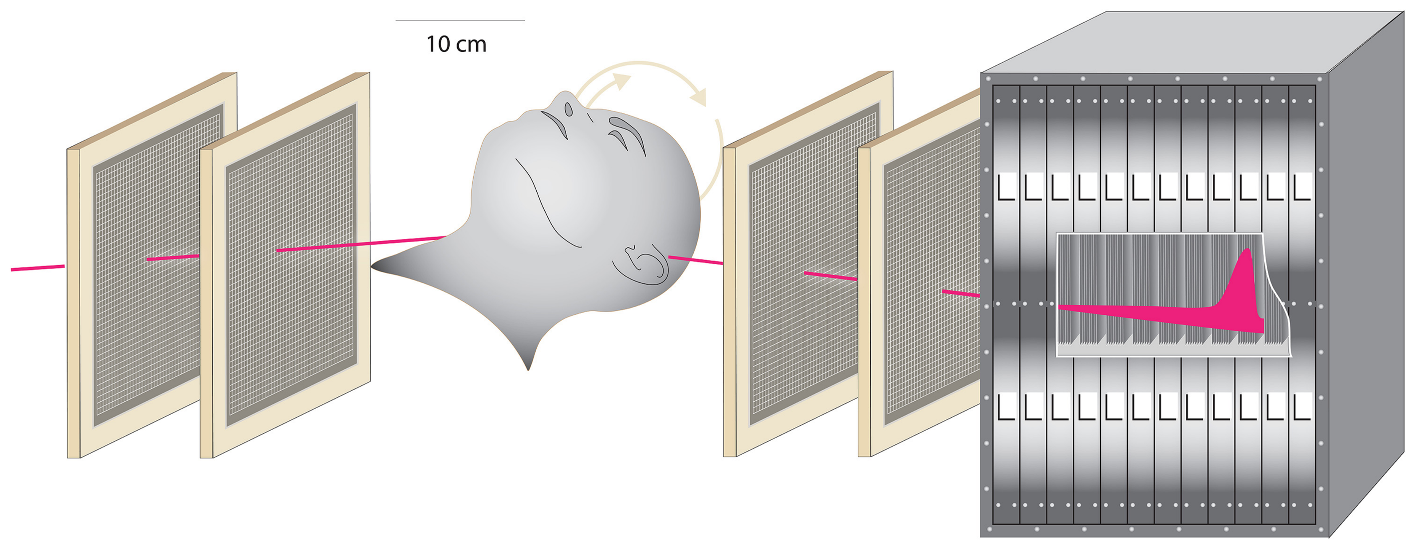

The main advantage of <u>protons</u> is that they <u>stop</u> in the body: for treatment we want them to stop exactly where the tumour is. The higher is the energy of the beam, the deeper in the body these particles stop. As mentioned above, the energy usually used for treatment is up to 250 MeV.
For tomography, however, they should <u>*stop outside*</u> of the patient's body, so that the dose delivered during imaging is minimised. For an adult patient this would require energy of around **330 MeV**.

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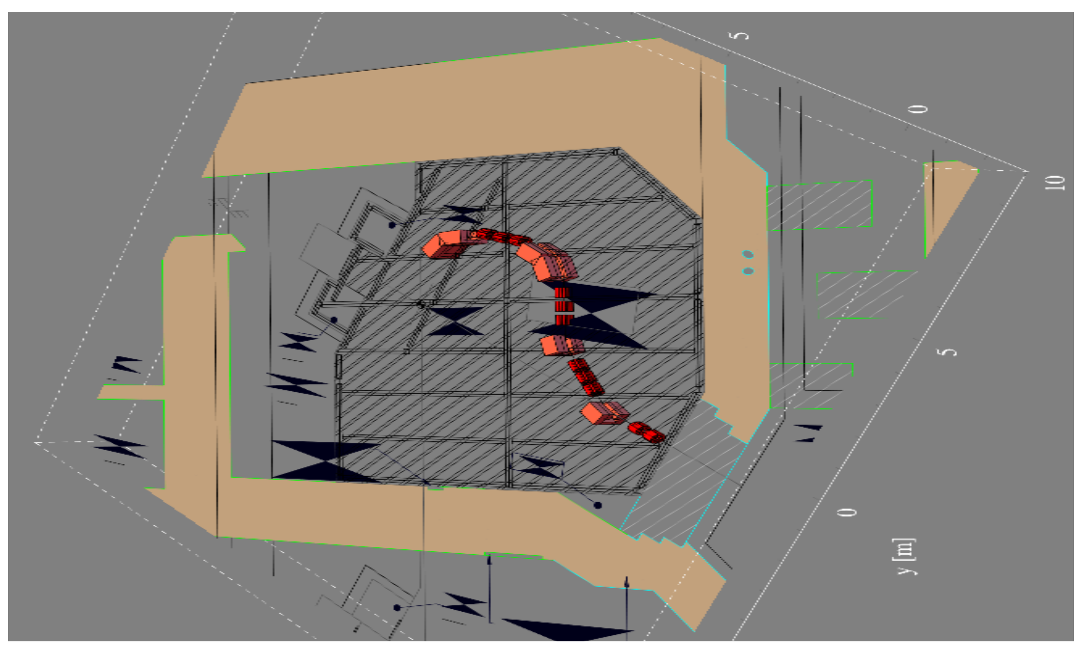

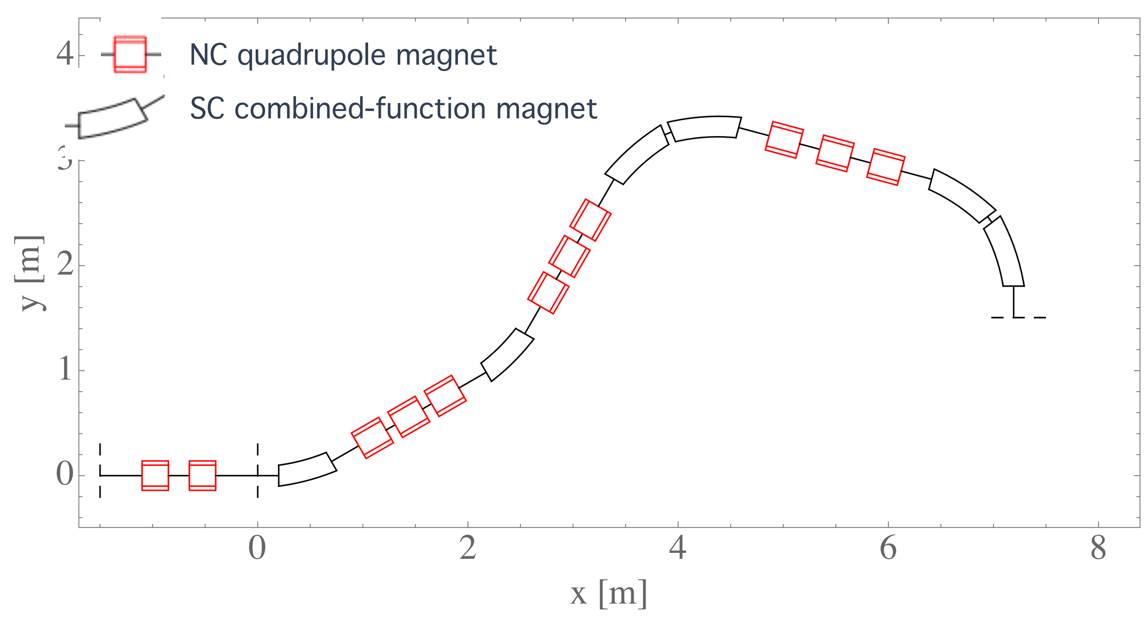

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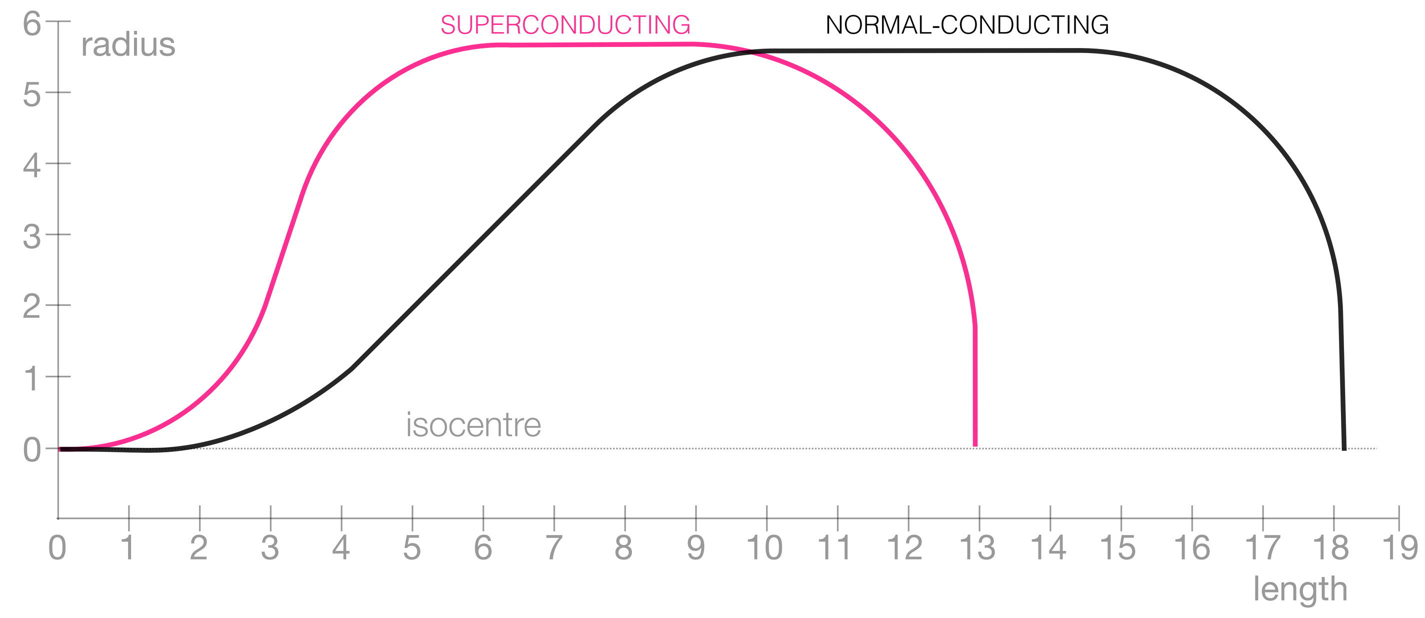

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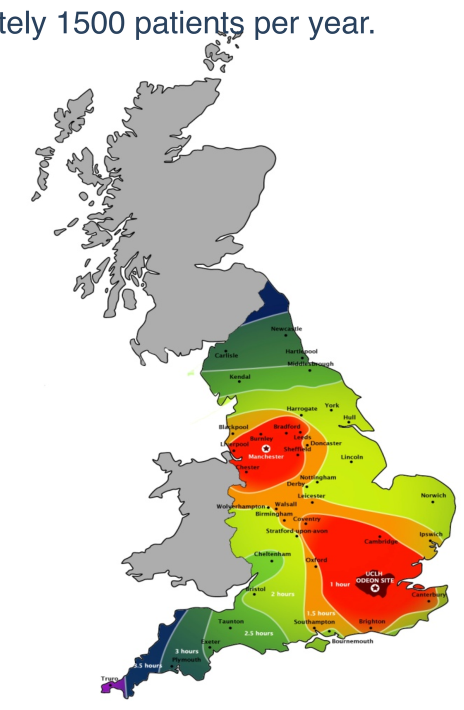
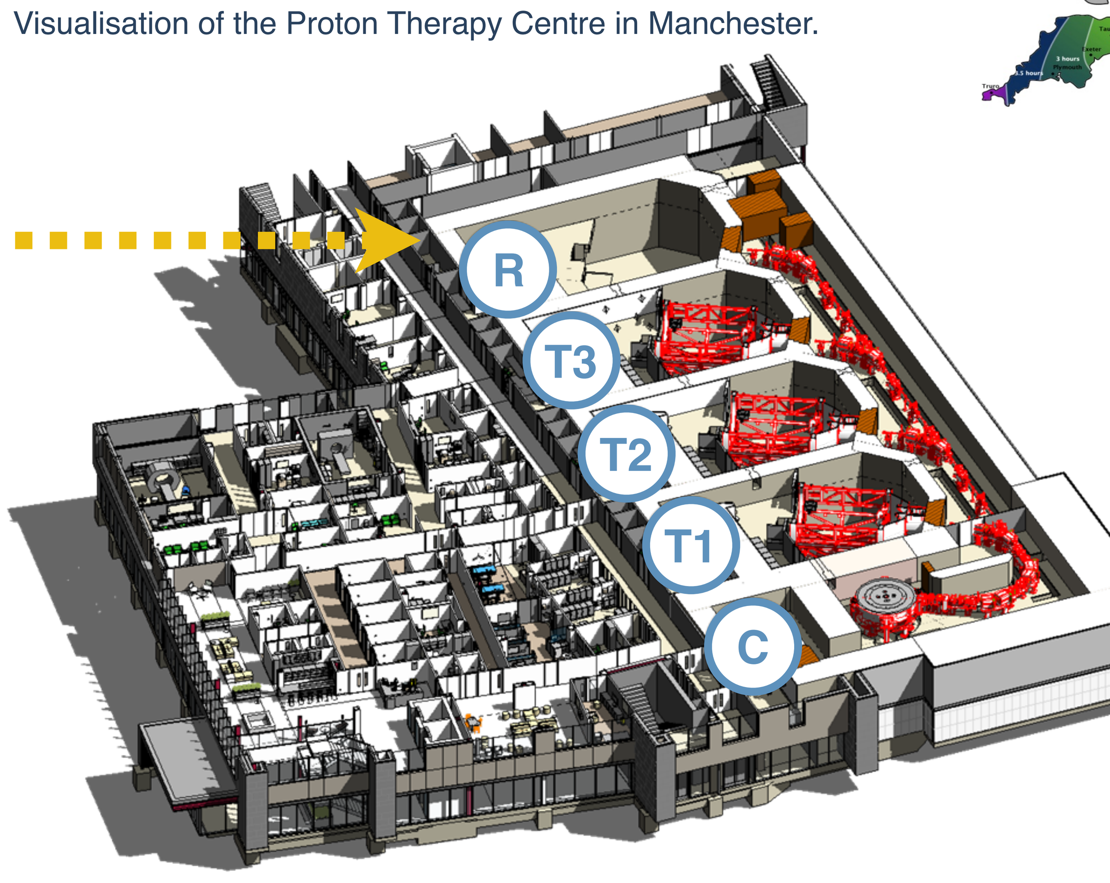
Visualisation of the Proton Therapy Centre in Manchester.





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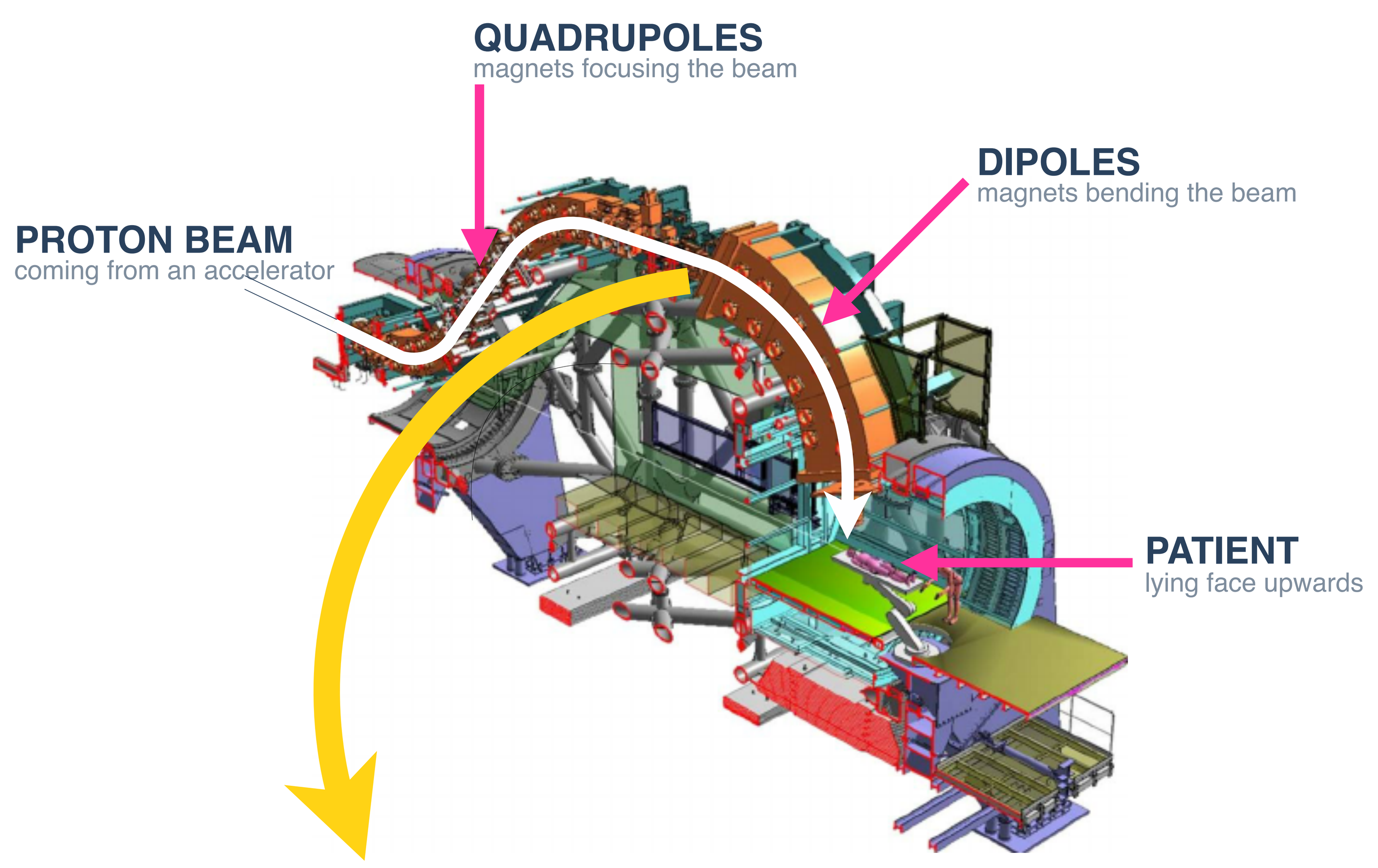

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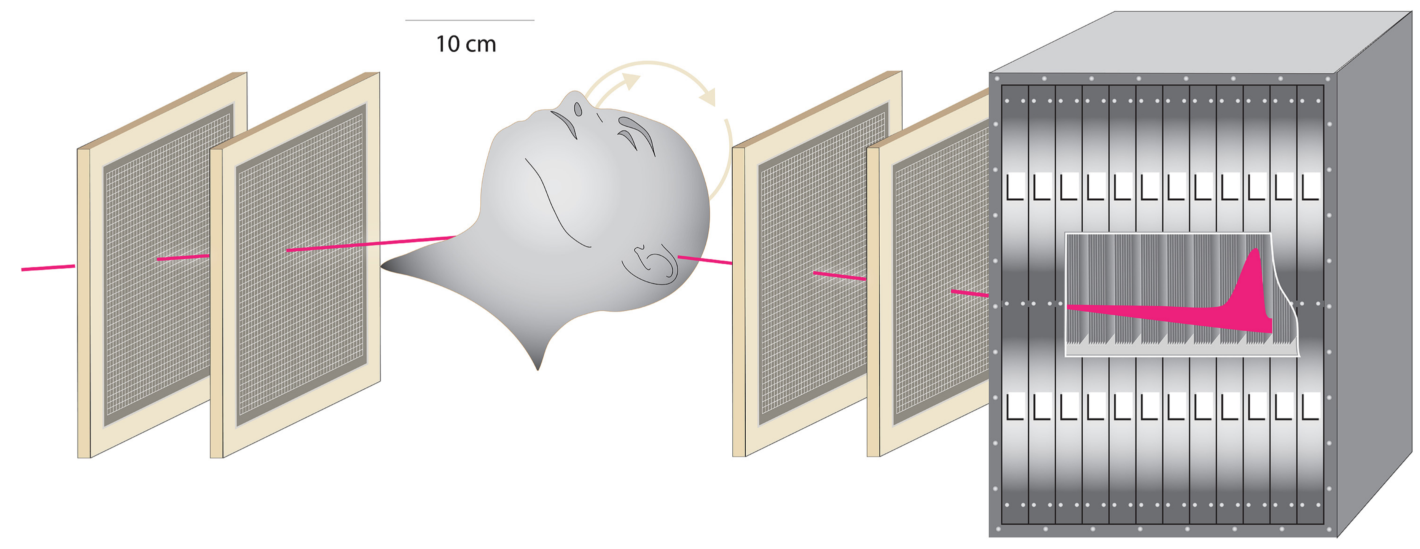

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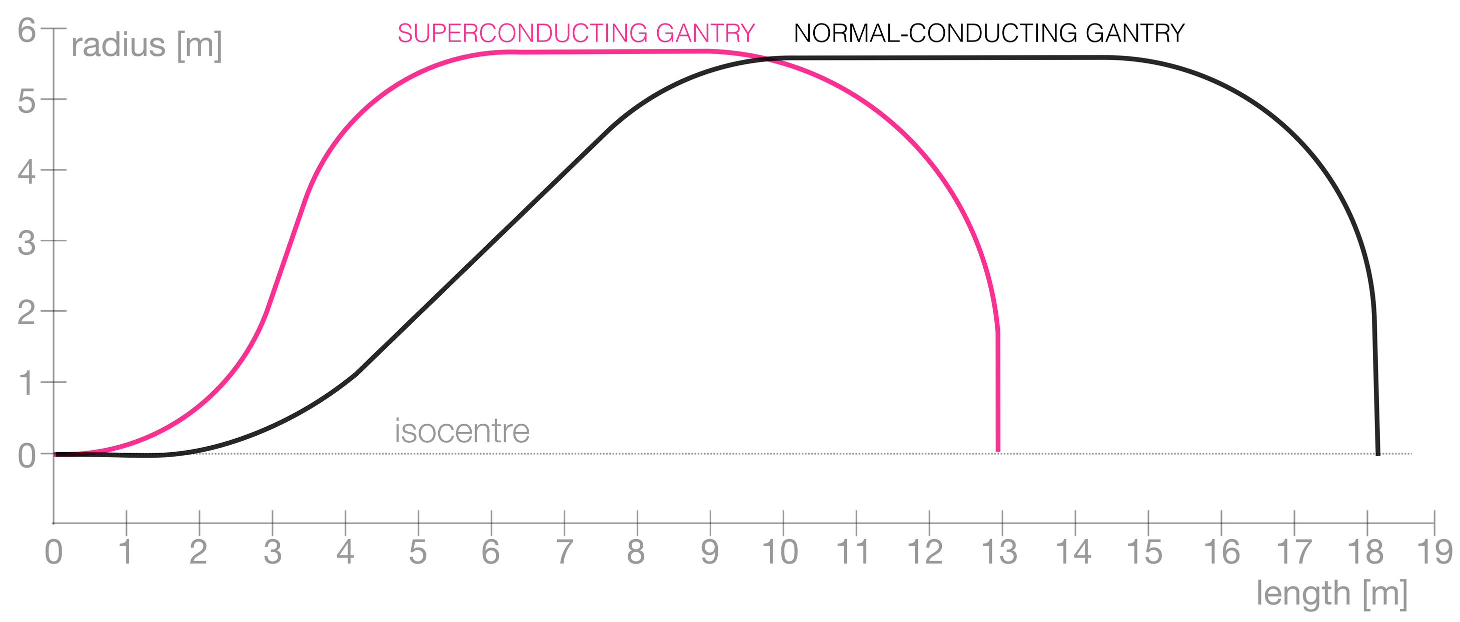

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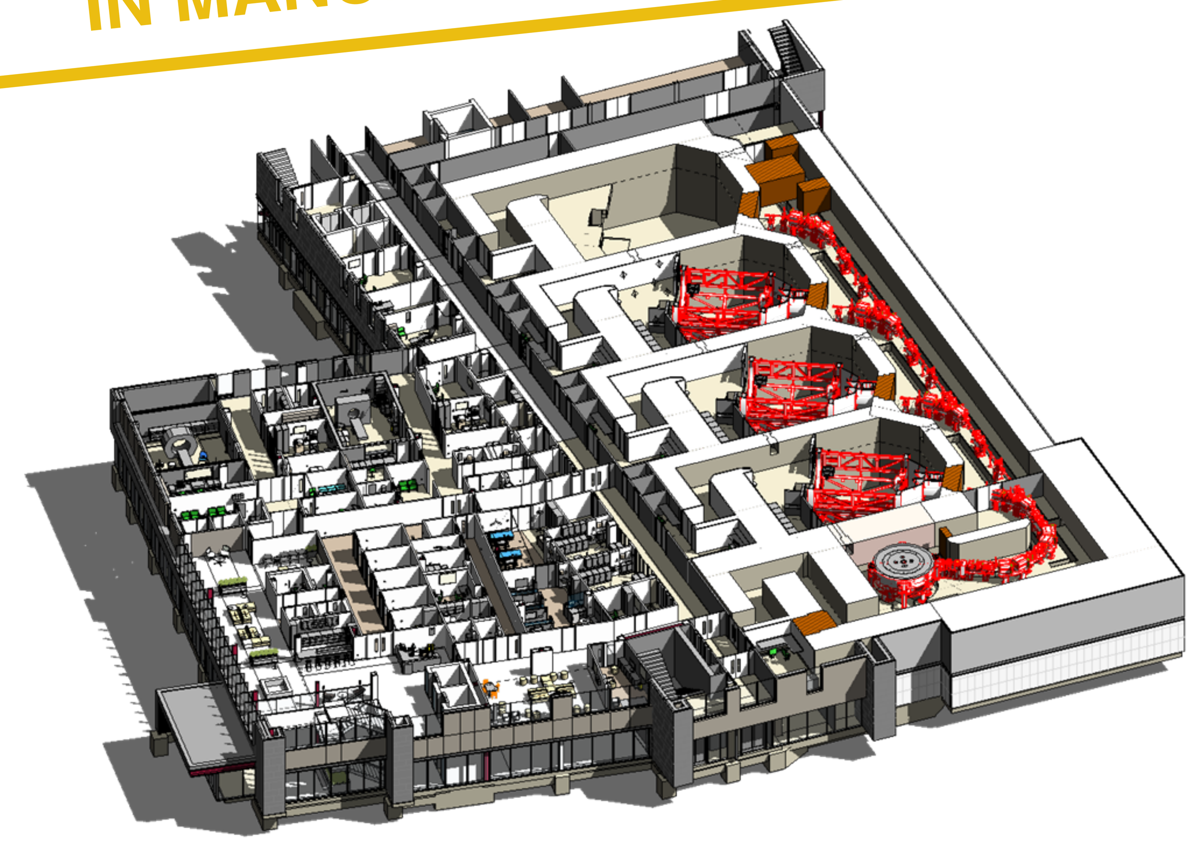

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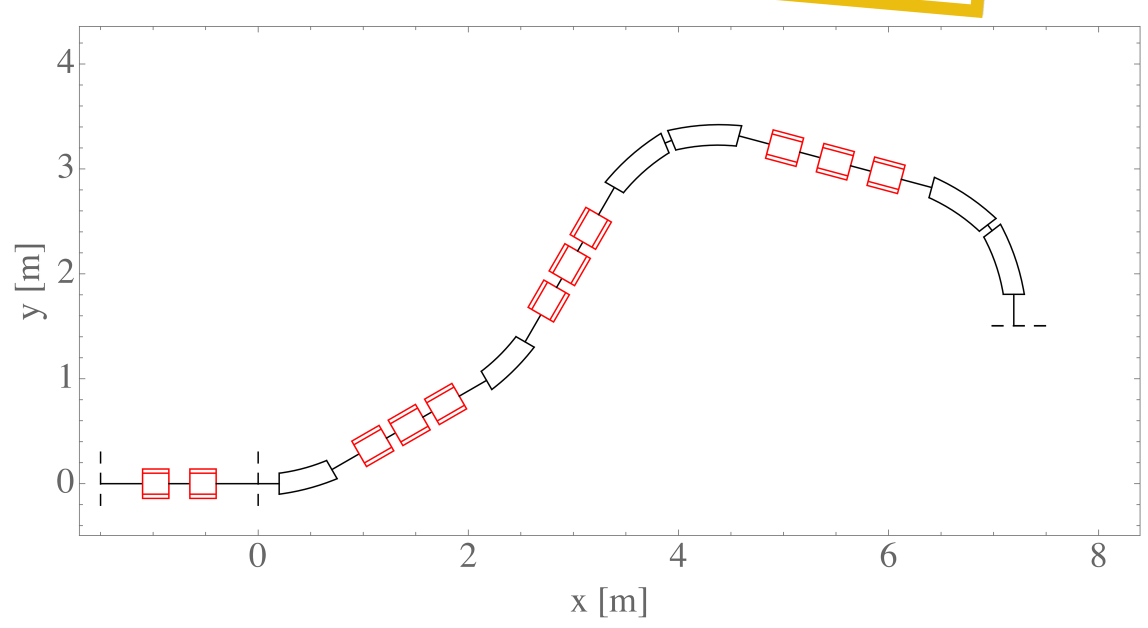

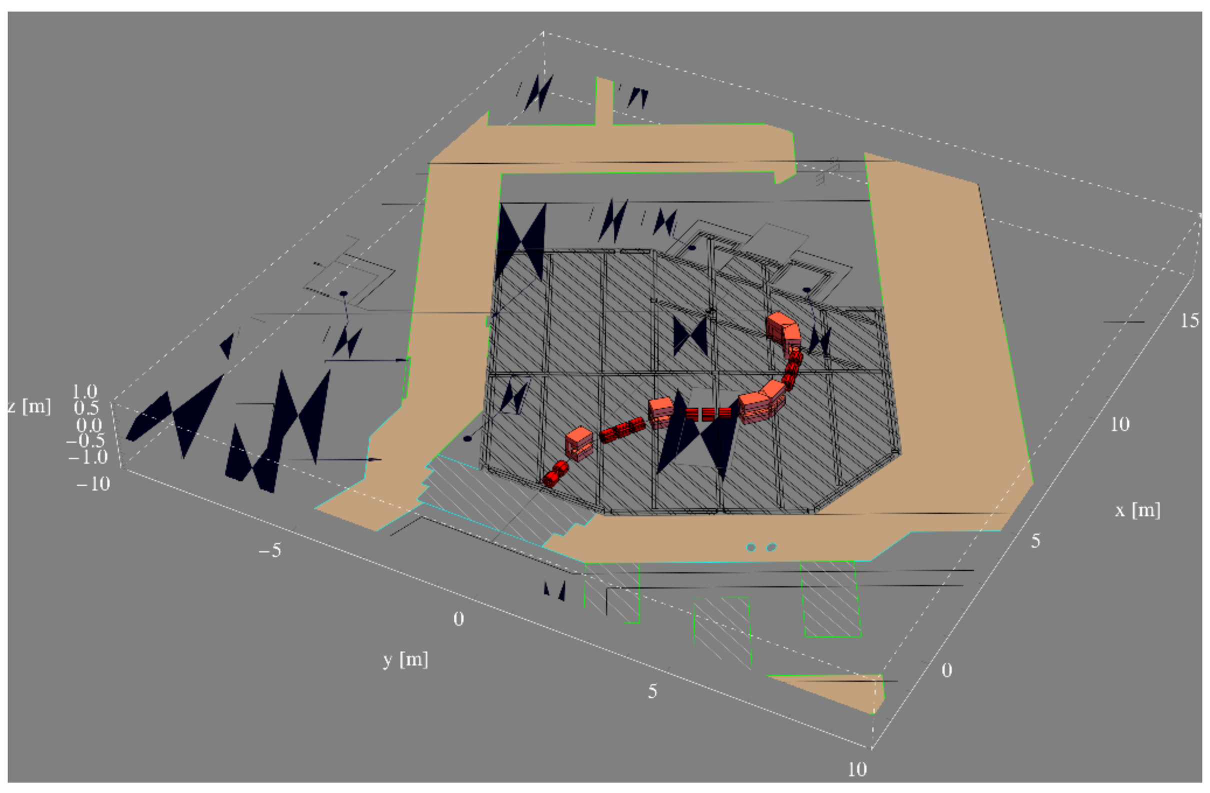

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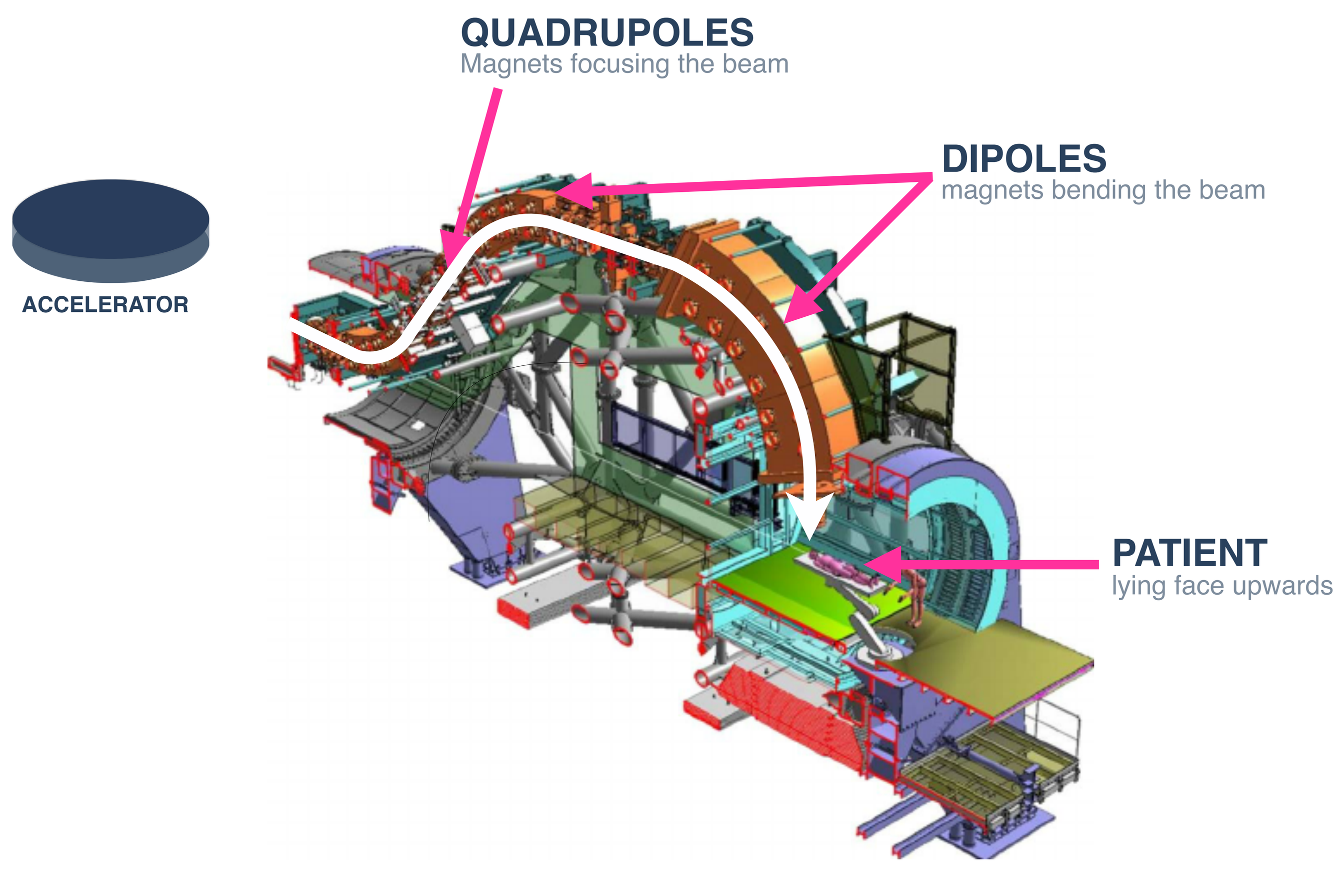
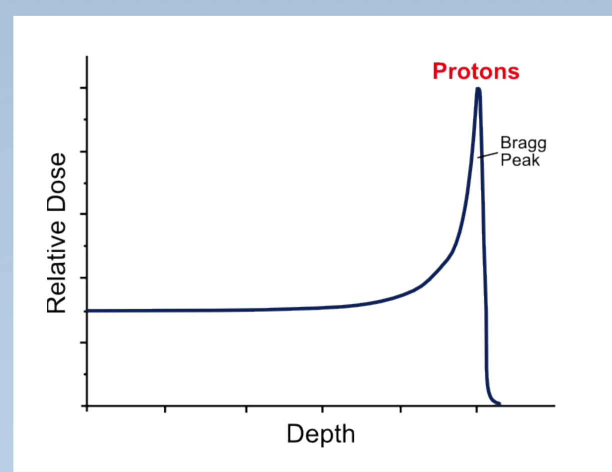
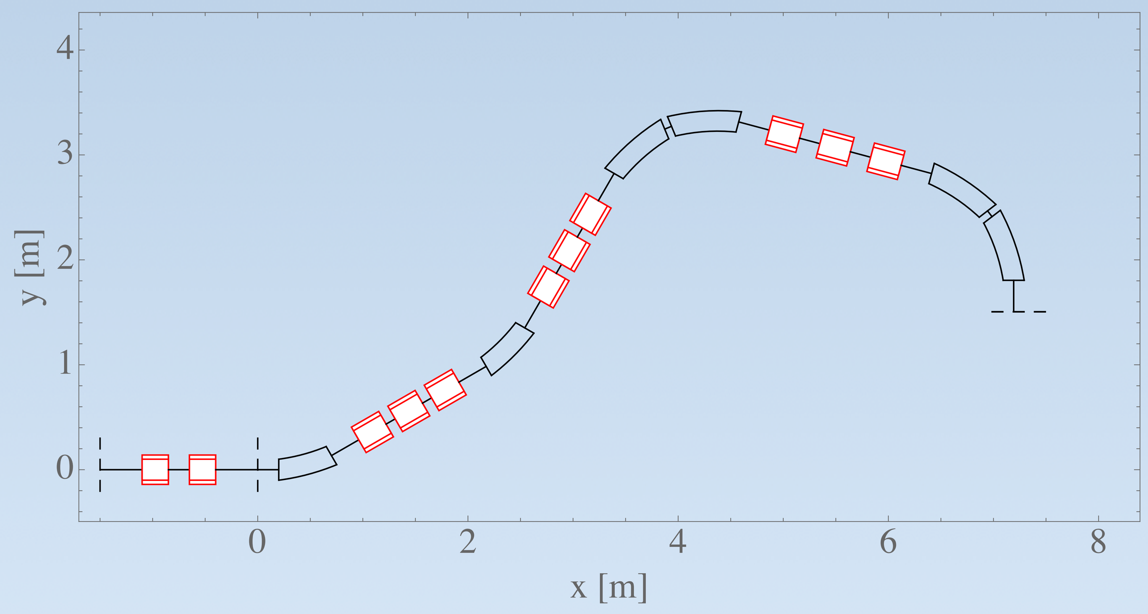


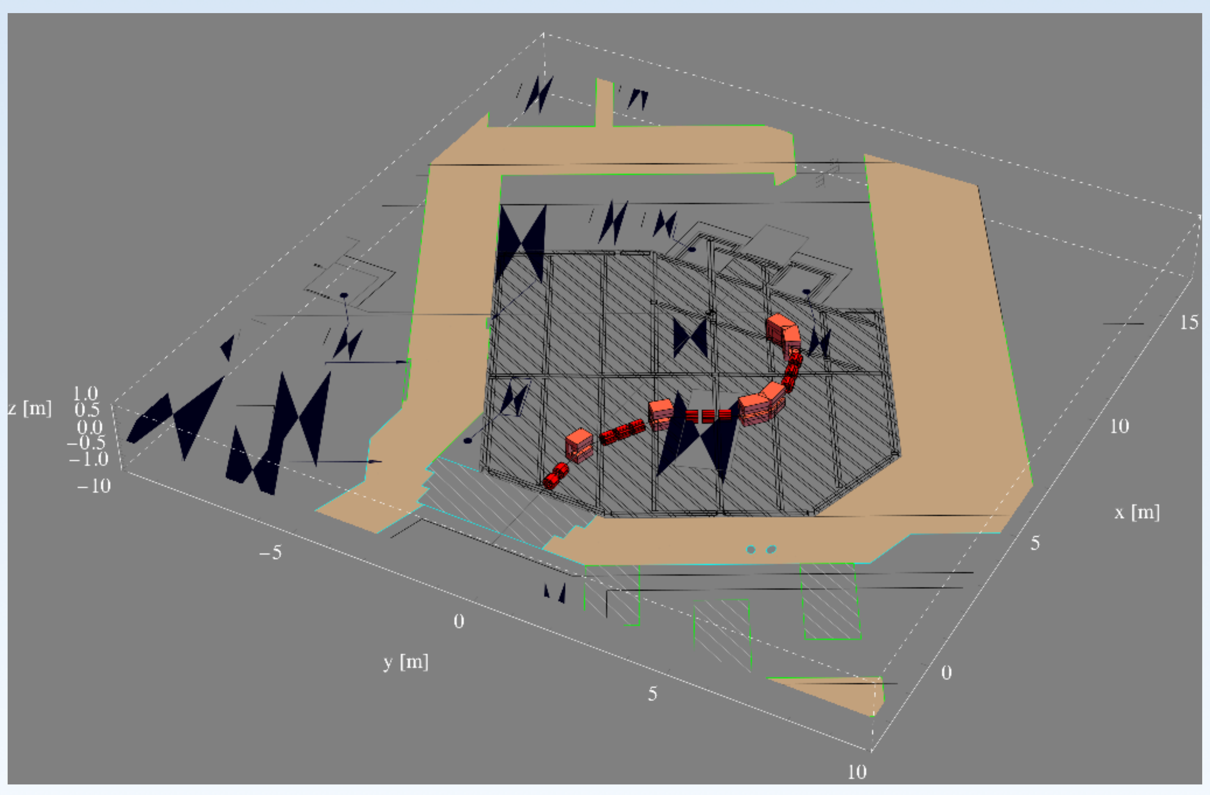
WHY SUPERCONDUCTING?

WHY DO WE NEED PROTON CT?

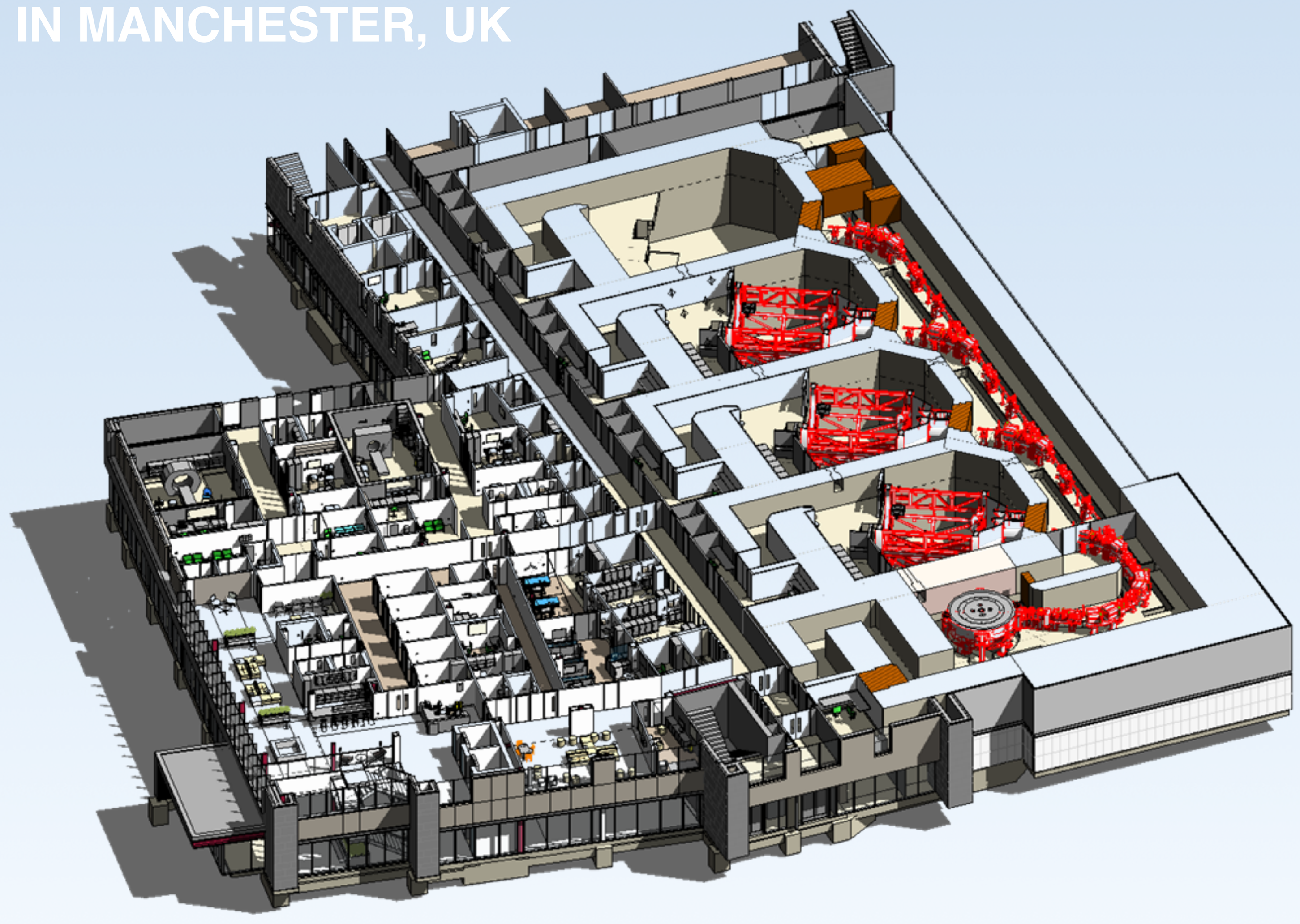


FIRST DESIGN





LAYOUT OF THE PROTON THERAPY CENTRE IN MANCHESTER, UK



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