# Helium Synchrotron Optics Design

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**15.1.2024**

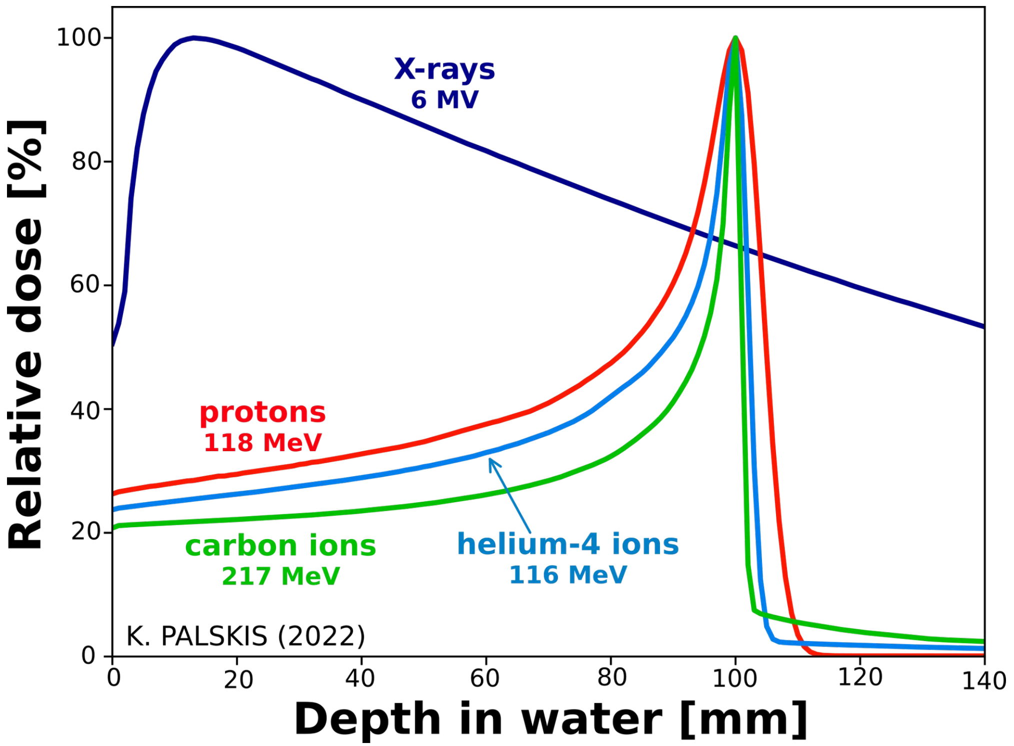
# Outline

- **Introduction**
- **Beam optics**
- **Outlook & Conclusions**

# Introduction

## Hadron therapy

- High-precision radiotherapy for tumours
  - surgically inoperable
  - resistant to traditional radiotherapy
- Utilises charged particle beams
  - characteristic Bragg peak
- Particle species:
  - protons
  - carbon
  - **helium**




Sharper Bragg peak compared to protons

Reduced fragmentation compared to carbon ions

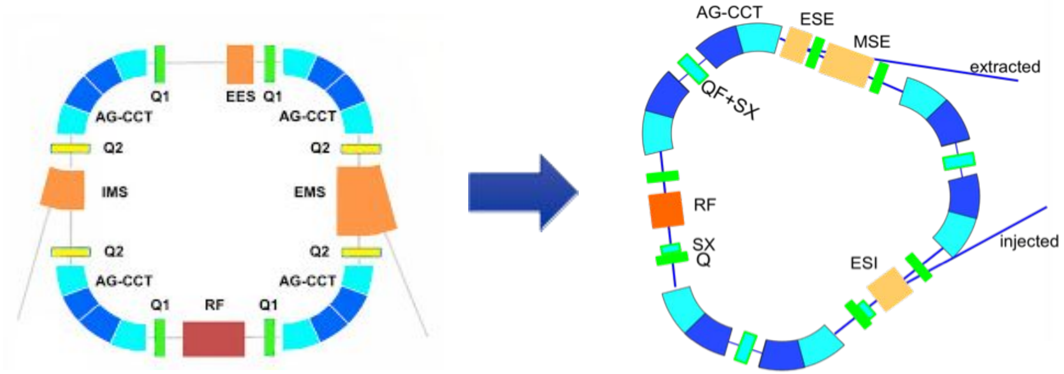
Increased RBE and reduced OER to protons

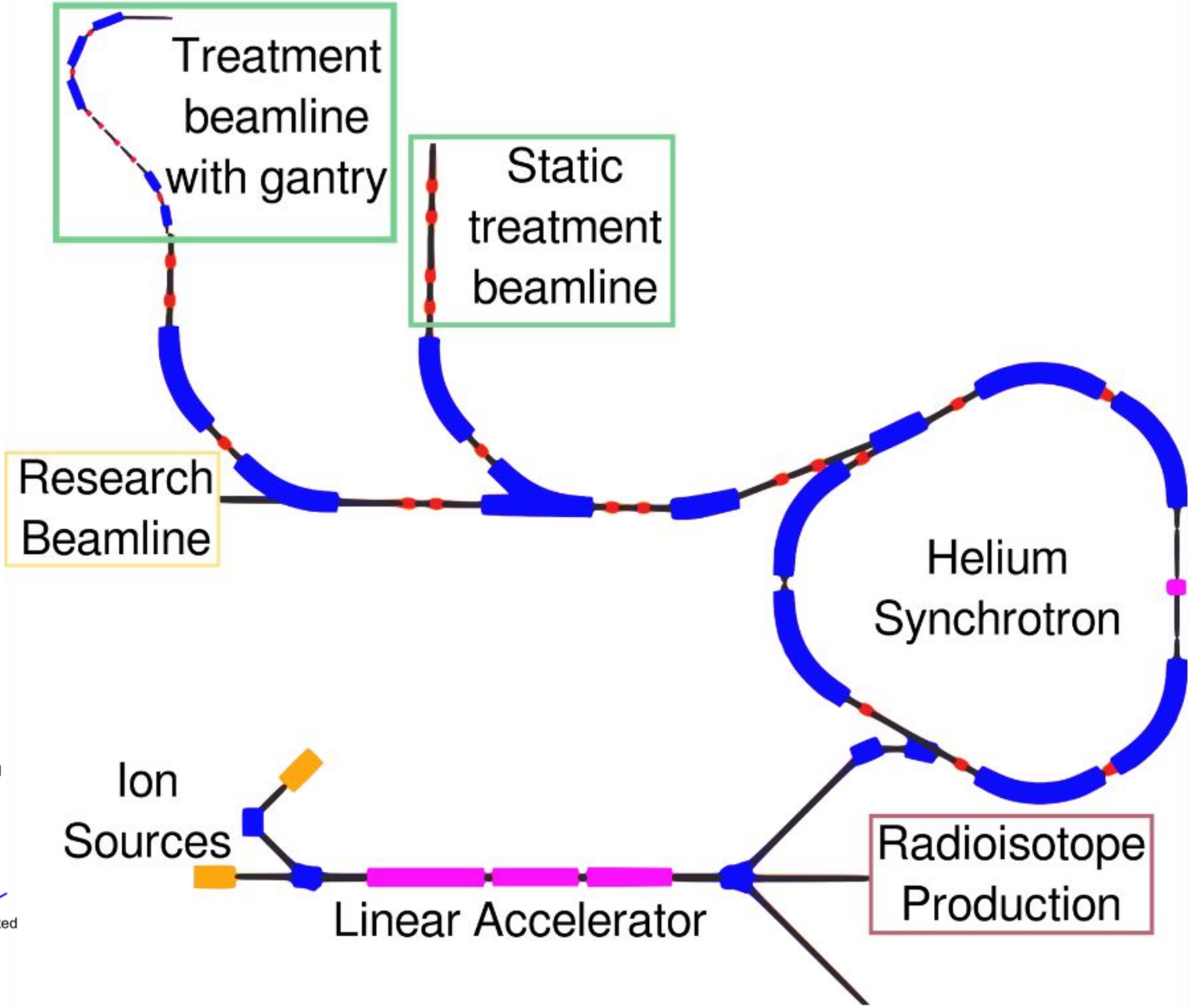
Reduced neutron risk compared to carbon ions

# Introduction

## Helium synchrotron

- Compact triangular design
  - 30 m circumference
- Particle species: protons and helium ions
- Relatively low energy accelerator
  - 5 - 220 MeV/u
- Multiturn injection
- Slow extraction

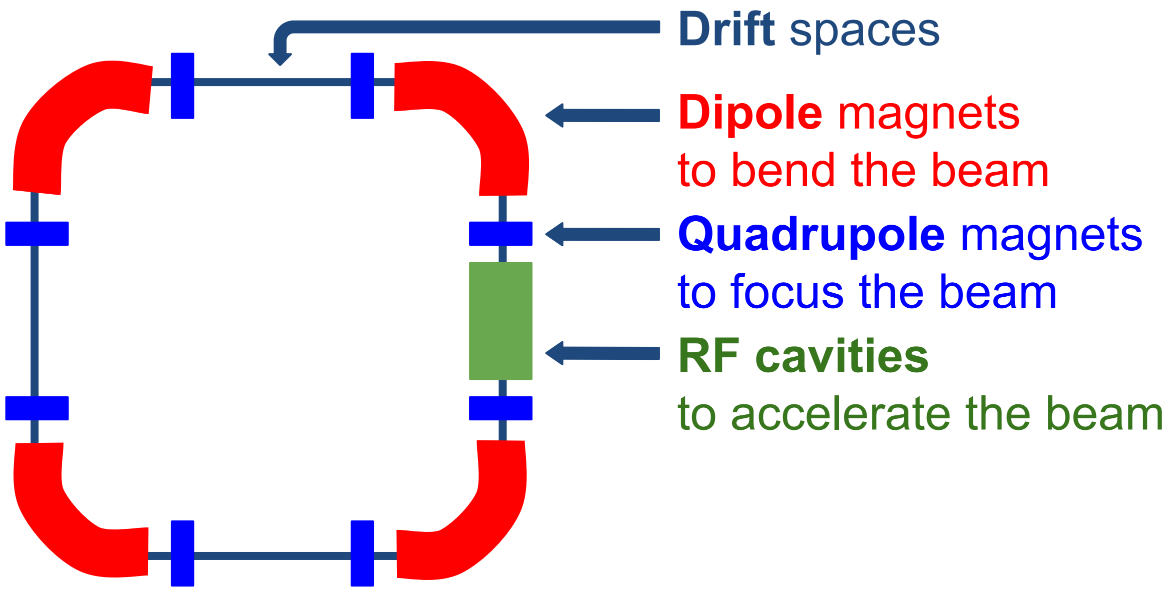


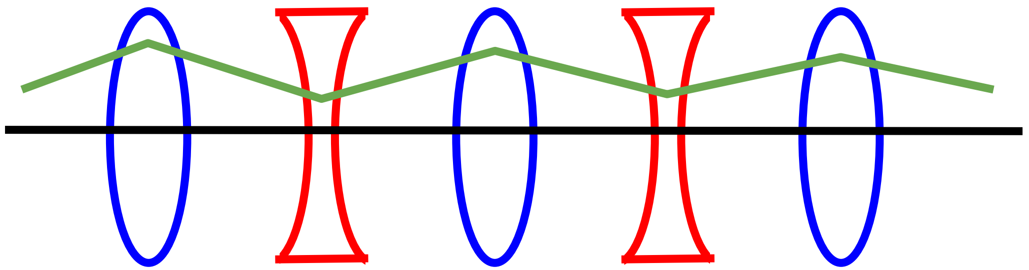
# Introduction

## Accelerator physics

- From a particle's point of view, an accelerator is a sequence of
  - drifts: no external fields, particles go straight
  - magnetic fields: modify trajectory of the particles
    - dipoles and quadrupoles
  - electric fields: change the particle's energy
    - RF-cavities
- Synchrotron - a type of circular accelerator
- Lattice - a sequence of principle elements

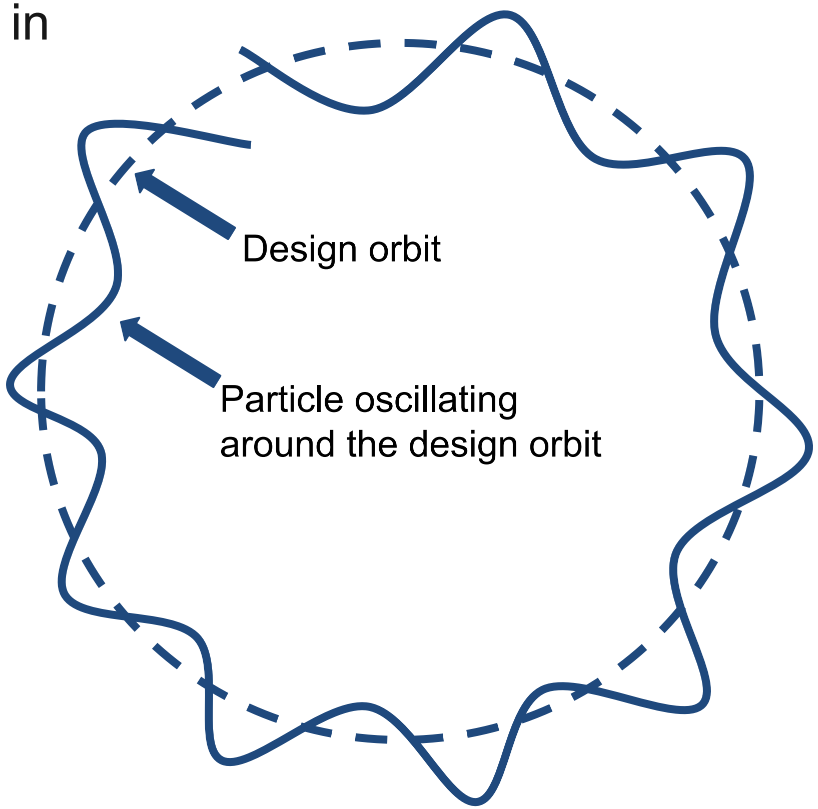


# Introduction



## Beam optics

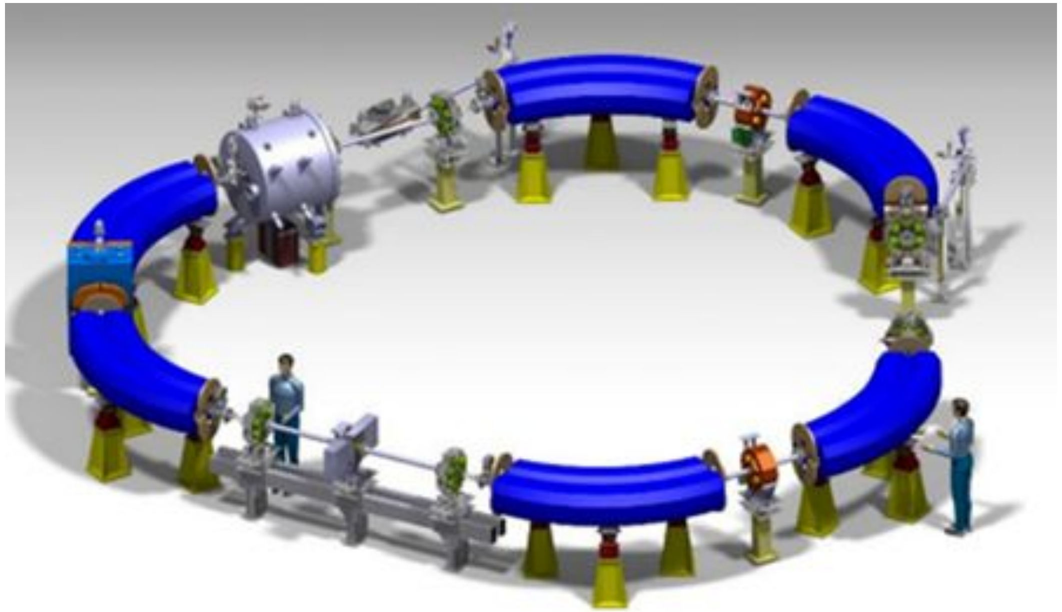
- Focusing magnets work like lenses in optics
  - focusing and defocusing elements are quadrupoles focusing in one plane while defocusing in the other
- Particles oscillate around a design orbit
- Tune = number of oscillation per one revolution
- Beta function
  - describes oscillations of the particle beam
  - relates to the aperture of the beam



# Beam optics

## What we need?

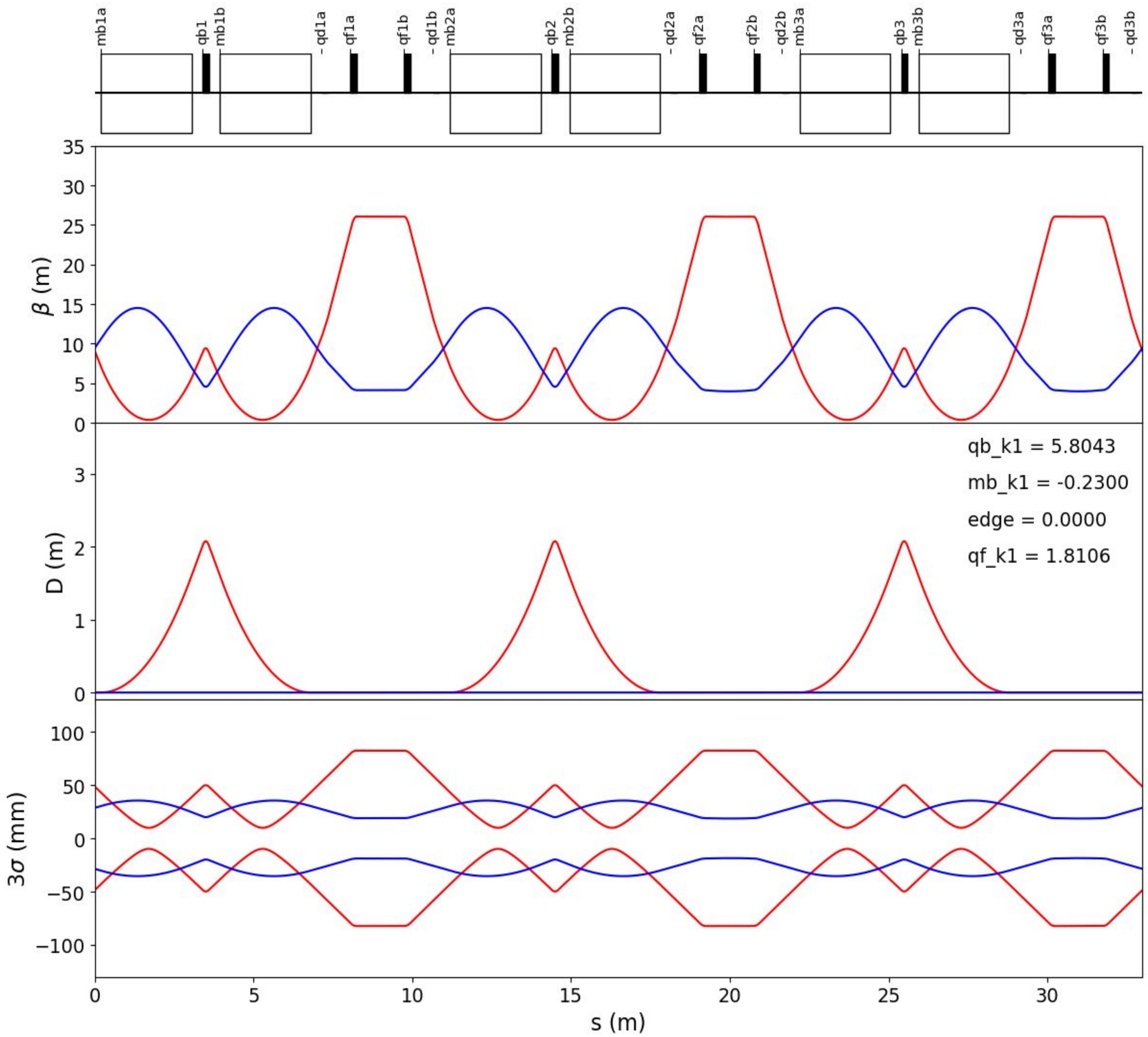
- A tune that produces an integer number if multiplied by 3
  - requirement for slow extraction
- Beam that fits the aperture
  - **beta functions relate directly to the beam size!!**
  - $\beta_{x,max} < 20$ m, $\beta_{y,max} < 10$ m
- Flexibility with use
- Cost-effective design



# Beam optics

## What we have?

- Simple linear design
- Tune: Qx = 2.67 ✔
- $\beta_{x,max} \approx 26$ m, $\beta_{y,max} \approx 15$ m (too big!) ✘
- No flexibility ✘
- Complex bending magnets ✘



# Beam optics

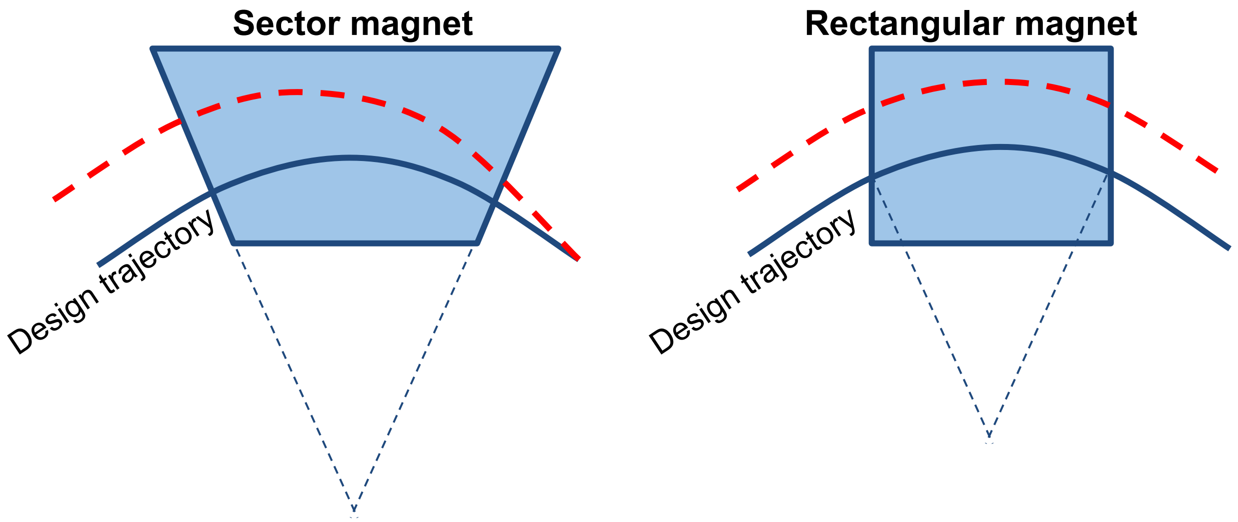
## What can we do?

- Optimise drift spaces between elements
- Change the magnet design
    - switch to less complex magnets
- Add flexibility with defocusing quadrupoles

# Focusing effects on dipole magnets

## Edge focusing

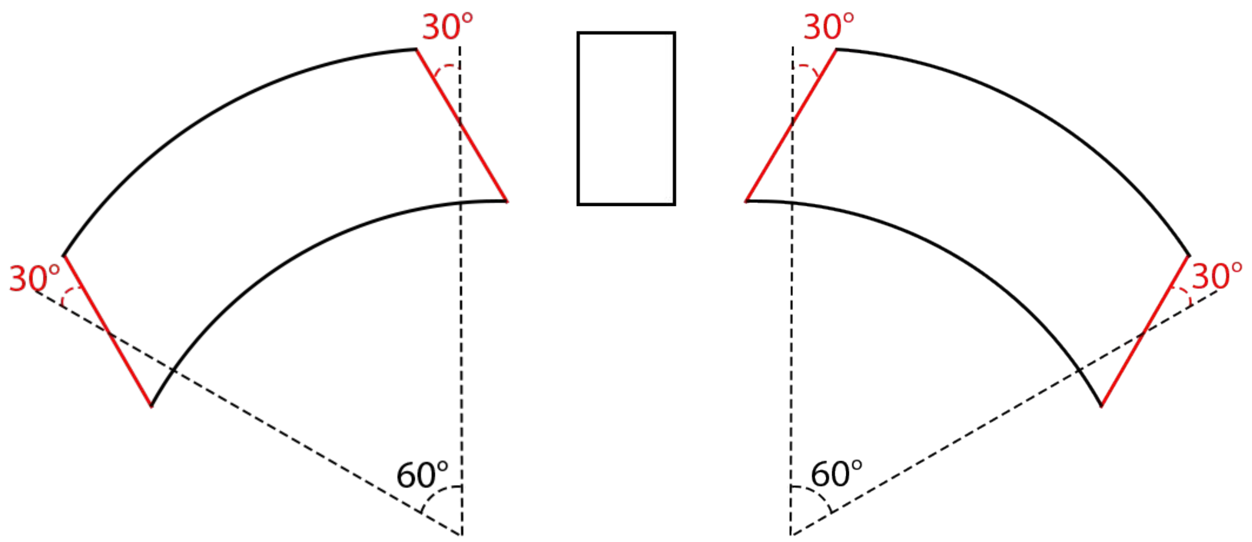
- At the ends dipoles can be either sector or parallel edge
  - different focusing effect on the beam
- Rectangular magnets easier to manufacture




## Combined function magnets

- Combined dipole and quadrupole field
- Generated by shaping of the poles
  - introducing a gradient to a regular dipole
- Expensive to manufacture

# Optics optimization




## Changes

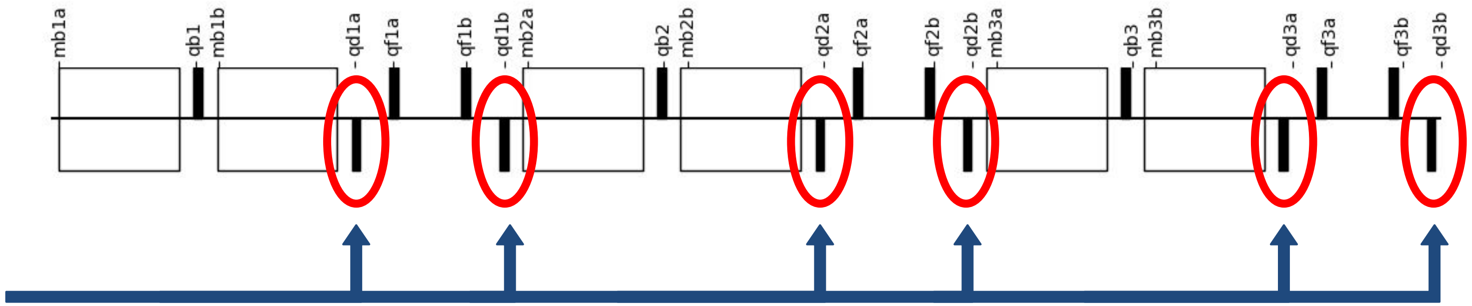
- Rectangular bending magnets
  - additional beam focusing ✔
  - easier/cheaper manufacturing ✔
- Smaller gradient or no gradient in bending magnets
  - better field condition ✔
  - easier/cheaper manufacturing ✔

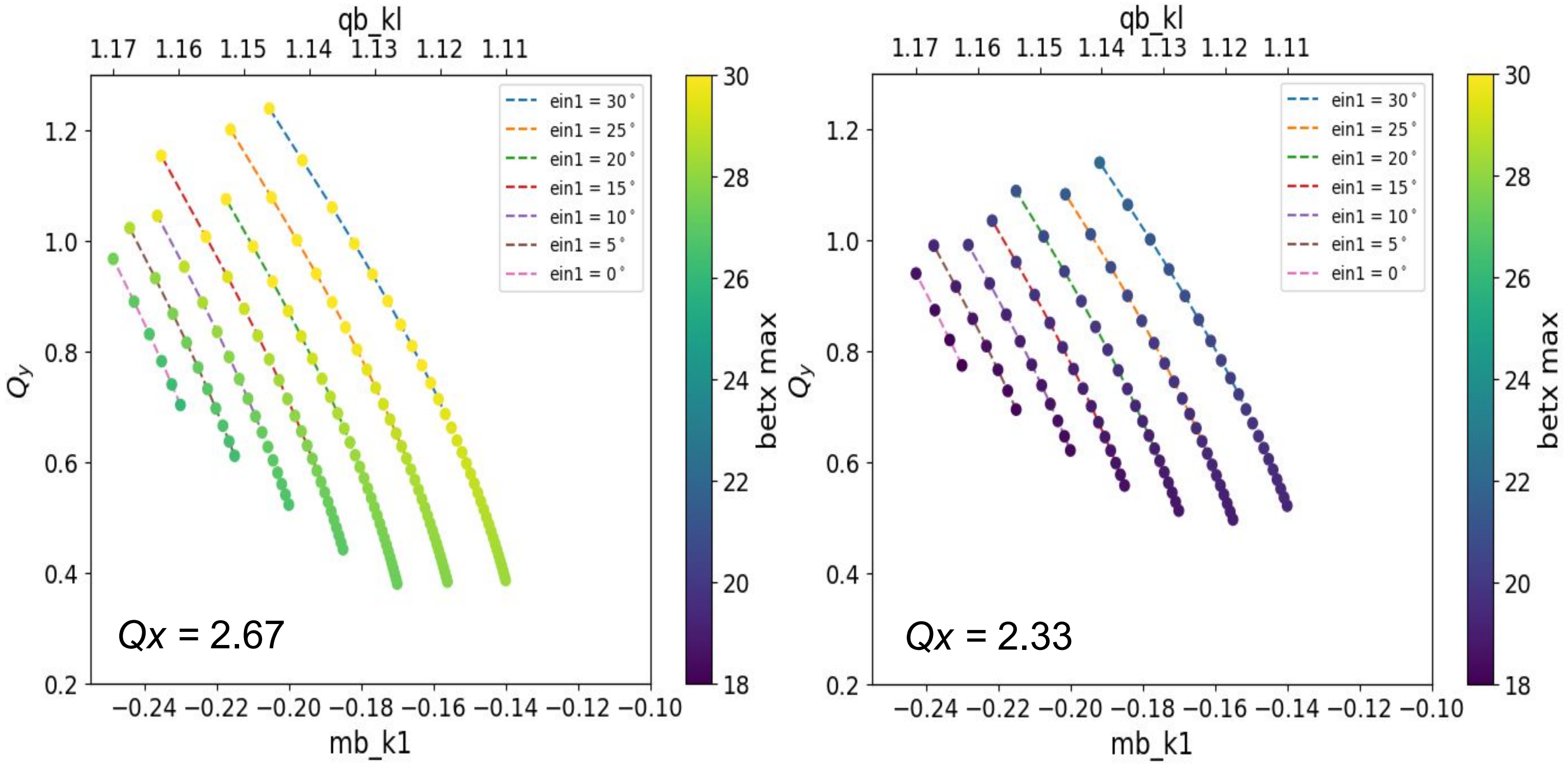
# Optics optimization

## Changes

- Defocusing corrector magnets
  - additional beam focusing ✔
  - more flexibility with use ✔
- Change to tune $Qx = 2.33$ ✔
- $\beta_{x,max} \approx 20$ m, $\beta_{y,max} \approx 8$ m ✔
  - reduced by >20% and >45%

    in x and y respectively

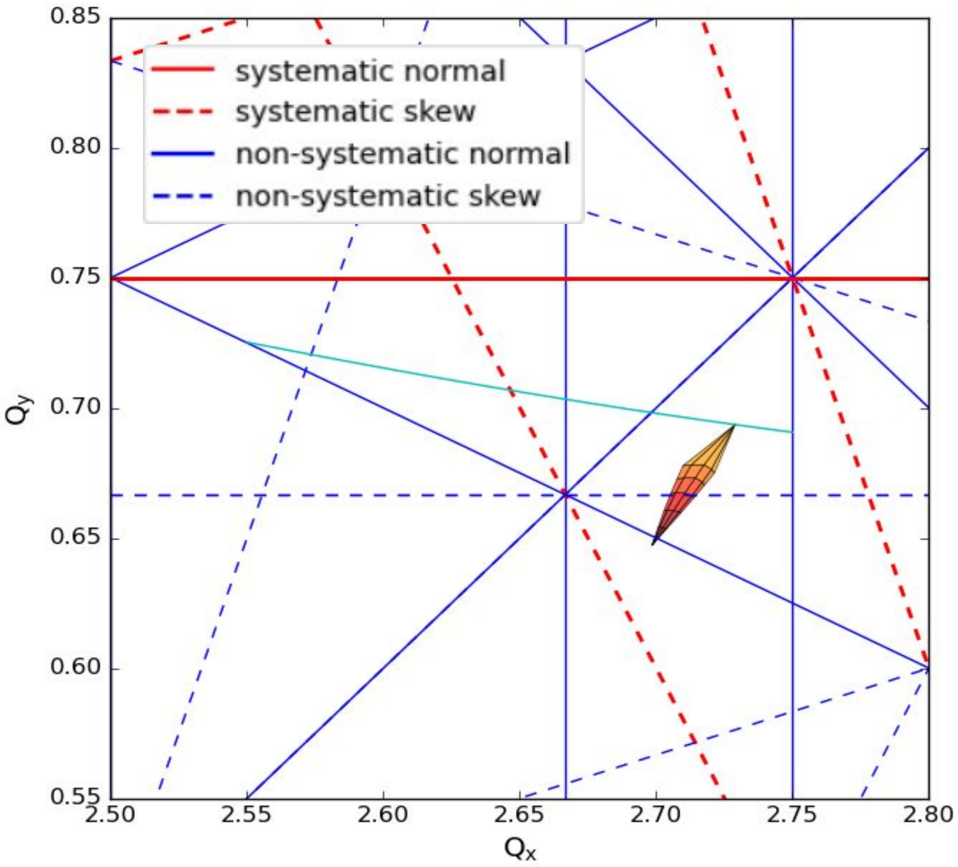


# Outlook

## So what next?

- **Looking into higher order effects**
- Finalising of the triangular lattice design and identifying potential limitations (magnet errors, collective effects etc.)
- Comparing different particle species - protons and helium ions
- Exploring different layout geometries, for example the rectangular one



# Conclusions

## What to take home?

- Designing a facility optimised for helium beams is important in the development of hadrontherapy
- This project offers a perfect opportunity to build connections and introduce hadron therapy into Finland

# Thank you!