Joint Universities Accelerator School

JUAS 2018

Archamps, France, 26th February – 2nd March 2018

Analytical & numerical design of a normal-conducting, iron-dominated electro-magnet

Case study – Tutorial – Mini Workshop

Thomas Zickler

CERN

Introduction

- The goal is to practice elements learned during the lectures

- Students will design, specify and optimize a ‚real' magnet

- Sample case: Bending magnet for the MedAustron medium-energy beam transfer line

- Work in groups of 3 persons during 2 half-days

- At the end, students are expected to deliver a written magnet design report

- Short introduction to MedAustron

- Magnet input parameters, requirements and constraints

- Excercise 1:
  – Analytical design (paper & pencil) to derive the main parameters
  – Expected results: detailed parameter list, magnet cross-section (yoke & coils) ready for entering the model in FE-code

- Excercise 2:
  – Numerical field computations and optimization of the pole profile
  – Expected results: optimized magnet cross-section (pole profile)

Introduction to MedAustron

MedAustron is located in Wiener Neustadt (50 km south of Vienna) next to the future site of the new hospital

Medical Treatment

- Tumour treatment
- Clinical research

Non-clinical Research (NCR)

- Medical Radiation Physics
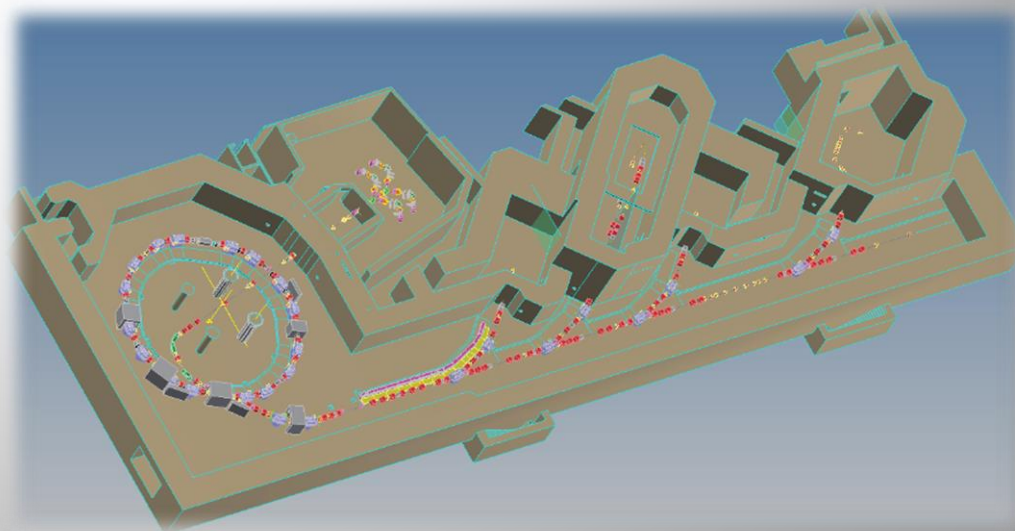- Radiation biology
- Experimental physics

Accelerator Main Parameters

- Synchrotron based (circumference 76 m)

- Ion species: protons and carbon ions
    - Optionally and at a later stage other ions with q/m>1/3 are possible

- Energy range
    - Proton: 60-250 MeV (medical)
        - Higher proton energy provided for experimental physics: up to 800 MeV
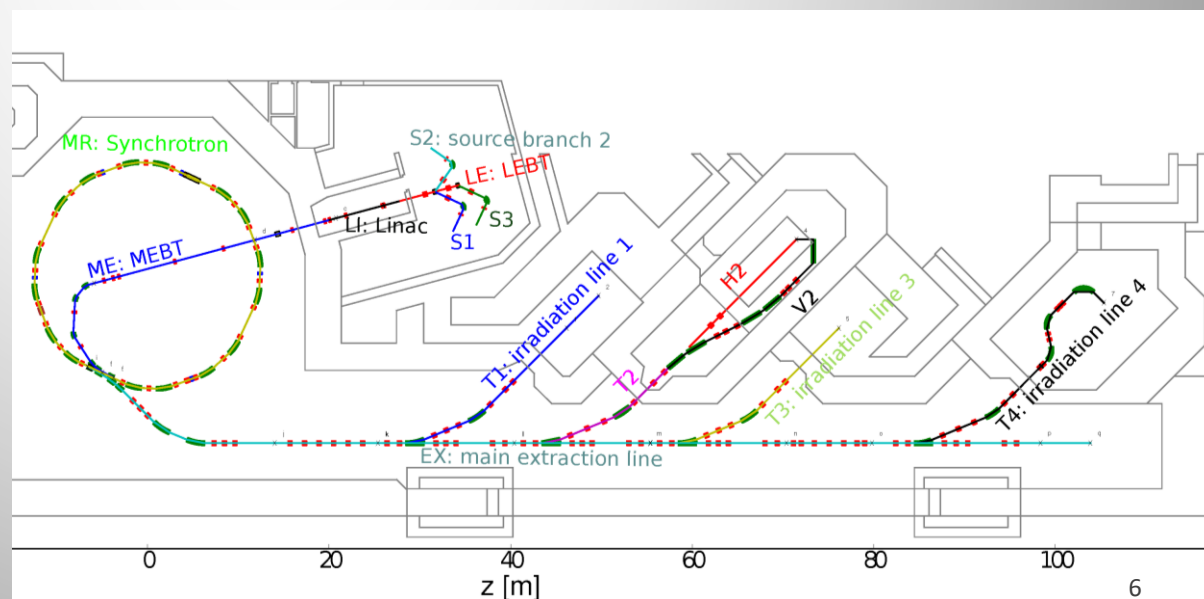   - Carbon: 120-400 MeV/n

- Cycle time > 1 second

Irradiation rooms

Medical facility:

- IR2

  - Horizontal and vertical beam

  - Protons and carbon ions

- IR3

  - Horizontal beam

  - Protons and carbon ions

- IR4

  - Gantry

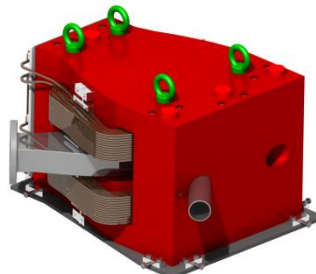 - Protons

Non-clinical research facility:

- IR1

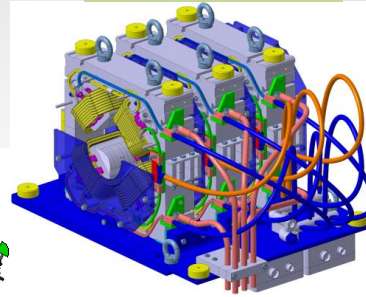 - Horizontal beam line
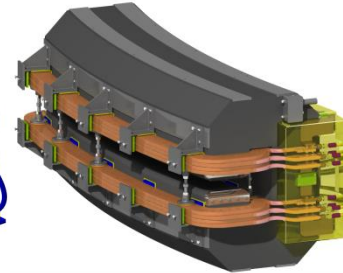
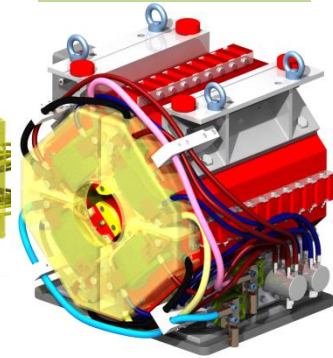 - Protons (up to 800 MeV) and carbon ions
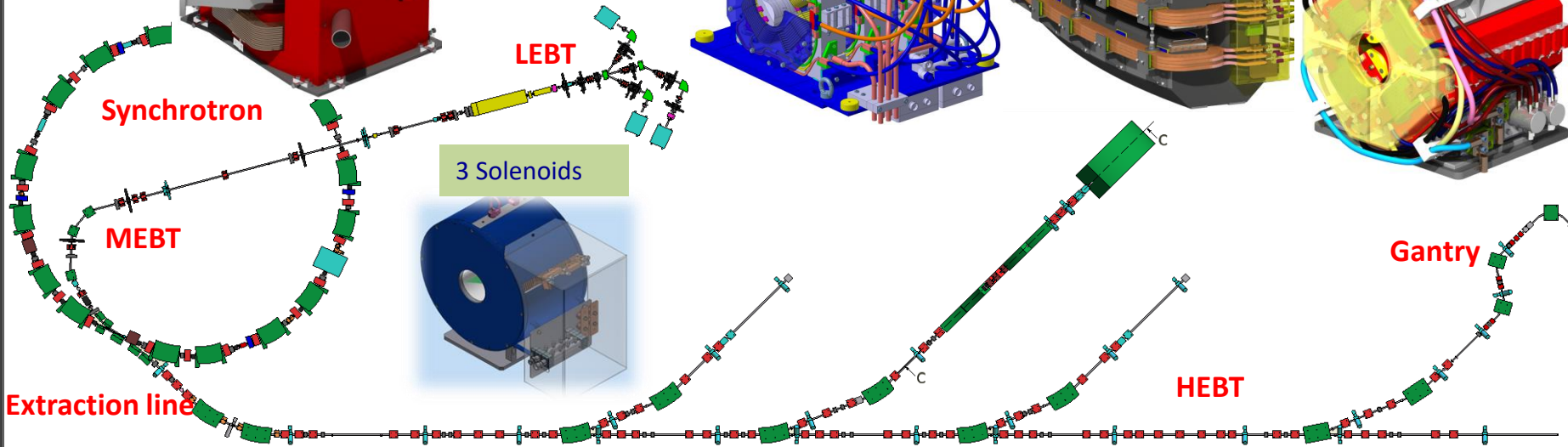
Magnet families

3 Spectrometers

6 LEBT Triplets

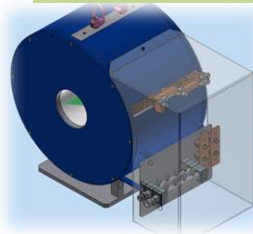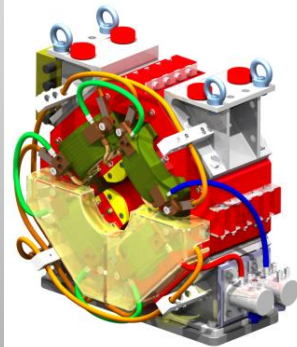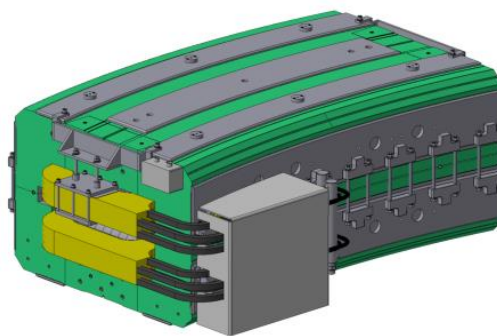12 HEBT Dipoles

76 HEBT Quads

LEBT

Synchrotron

3 Solenoids

MEBT

Gantry

Extraction line

HEBT

3 MEBT Dipoles

10 MEBT Quads

16 Ring Dipoles
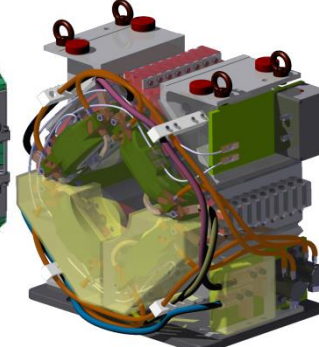
24 Ring Quads
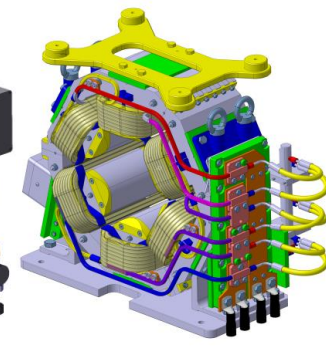
5 Ring Sextupoles

Beam parameters

Required: Three bending magnets for the medium-energy beam transfer line between the Linac and the Synchrotron

MEBT
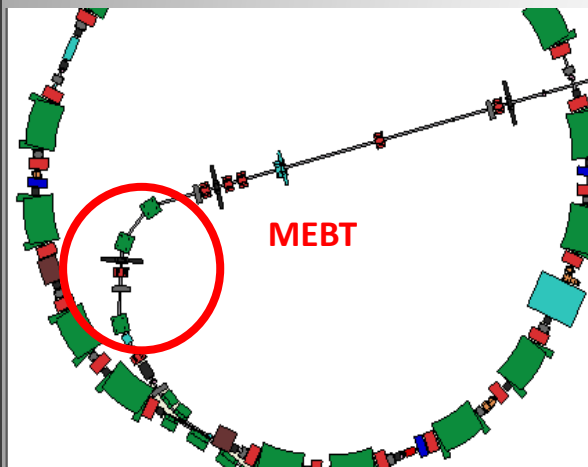
Parameter	Value	Unit
Particle type	Protons, C^{6+}	
Beam energy	7	MeV/u
Length of beam line	40.9	m
Beta function β_x, β_y	~10	m
Beam size σ_x, σ_y	+/- 10	mm
Margin for closed orbit distortions	+/- 10	mm

Functional specification

Parameter	Value	Unit
Number of magnets	3	
Bending angle	36	deg
Beam entry/exit angle	18	deg
Operation mode	quasi DC	
Ramp rate	0.3	T/s
Horizontal good-field region	+/- 20	mm
Vertical good-field region	+/- 23	mm
Field quality inside GFR $\Delta B/B_0$	< +/- $1 \cdot 10^{-3}$	
Max. overall magnet length per magnet	0.8	m
Max. available water pressure drop	0.8	MPa
Inlet water temperature	25	°C
Max. converter current	650	A
Max. converter voltage (3 magnets in series)	160	V

Exercise 1: Analytical design

The following parameters should be defined or derived:

- Magnet shape (straight/curved)
- Flux density B
- Aperture height h
- Excitation current NI (ampere-turns)
- Magnetic length l_{mag} and iron length l_{iron} (k = 0.55)
- Pole width and yoke thickness
- Current density j, nominal current I and number of turns N
- Dissipated power P, coil resistance R, dc voltage V
- Coil size (width, height) and conductor material
- Pressure drop Δp, Temperature rise ΔT
- Conductor size (height, width, cooling hole diameter) and insulation thickness
- Coolant flow Q and flow velocity u_{avg}, Reynolds number Re
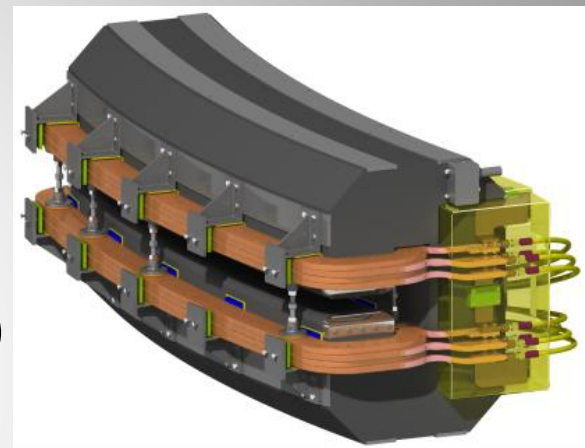
Hint: reasonable assumptions are not forbidden!

Exercise 1: Analytical design

For the computer work with FEMM, you will need the following magnet parameters:

- Aperture height
- Pole width
- Yoke dimensions (horizontal and vertical)
- Coil window width and height
- Coil dimensions (width and height)
- Coil position
- Coil excitation (ampere-turns)
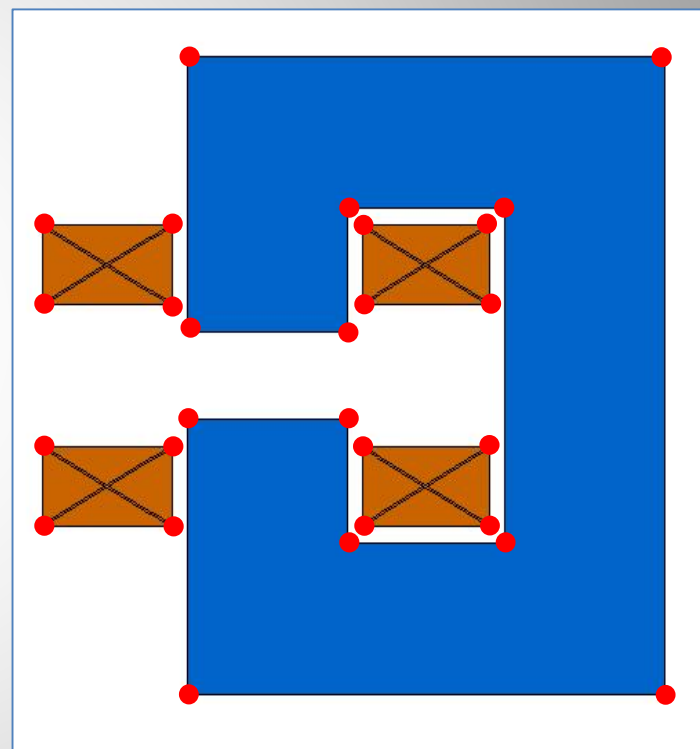
Hint: prepare a sketch identifying the key-point coordinates (x/y) wrt the beam axis

Exercise 2: Numerical design

2D Numerical calculations with FEMM:

- FEMM: 2D FE code for magnetics, electrostatic, heat flow and current flow problems with graphical pre- and post-processors

- Licensed under the terms of the Aladdin Free Public License

- Input via GUI or scripts (LUA scripting engine)

- More info (wiki) and download from the web:

- http://www.femm.info/wiki/HomePage

Exercise 2: Numerical design

The goal of this exercise is:

- Download, install and get familiar with FEMM (→ homework)

- Enter a simple dipole geometry (yoke + coils) using nodes, segments and block labels

- Define and set the neccessary material parameters

- Apply the correct boundary conditions

- Analyze the results:

  – field lines, flux distribution, central field, field along the axis and the GFR, current density, etc...

- Optimize the pole profile to improve the field quality

Design report

Students are expected to deliver a written magnet design report which should include at least:

- detailed magnet parameter list summarizing the outcome of the analytical design

- explanation for your design choice

- magnet cross-section based on analytical calculations with yoke and coil shape

- optimized cross-section (pole profile) based on numerical computations fullfilling the field quality requirements

- <u>Note</u>: the reports will be evaluated and contribute (3 points out of 20) to the total score together with the results of the exam

- Please send the final report (1 per group) in electronic form to the JUAS secretary

- Submission deadline: Monday, 12th March 2018

(Good luck...)

... and it is not forbidden to ask questions!