Joint Universities Accelerator School

JUAS 2016

Archamps, France, 22nd -26th February 2016

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

Case study – Tutorial – Mini Workshop

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Introduction

- The goal is to practice elements learned during the lectures
- Students are invited to design and specify 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 short written report

Programme

- 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)

Deliverables

Students are expected to deliver a short written 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
- Note: the reports will be evaluated and contribute (3 points out of 20) to the total score together with the results of the exam

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

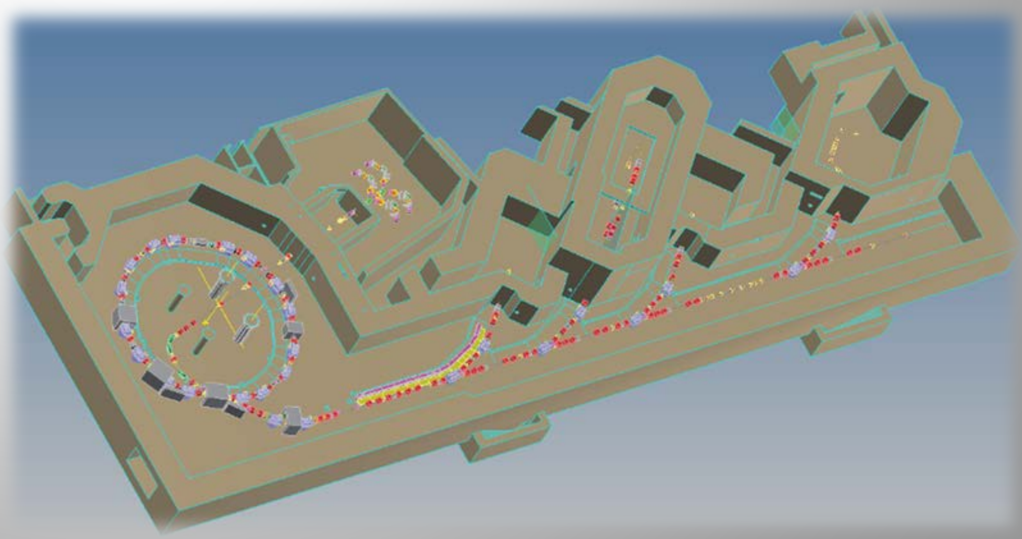
- Tumour treatment
- Clinical research

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



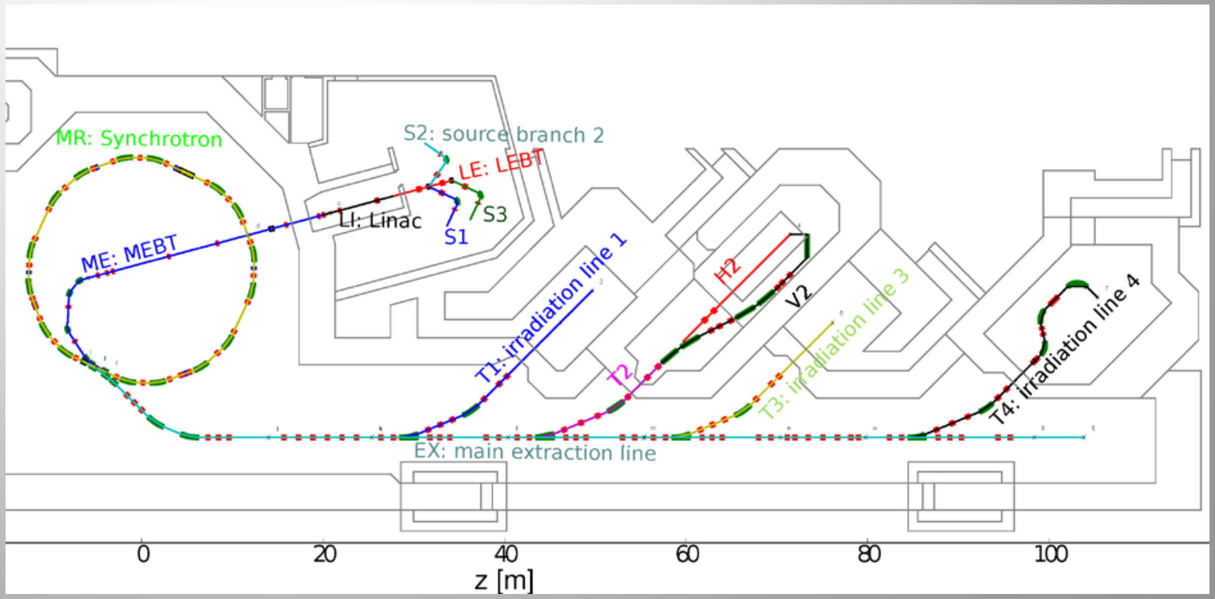
Irradiation rooms

Medical facility:

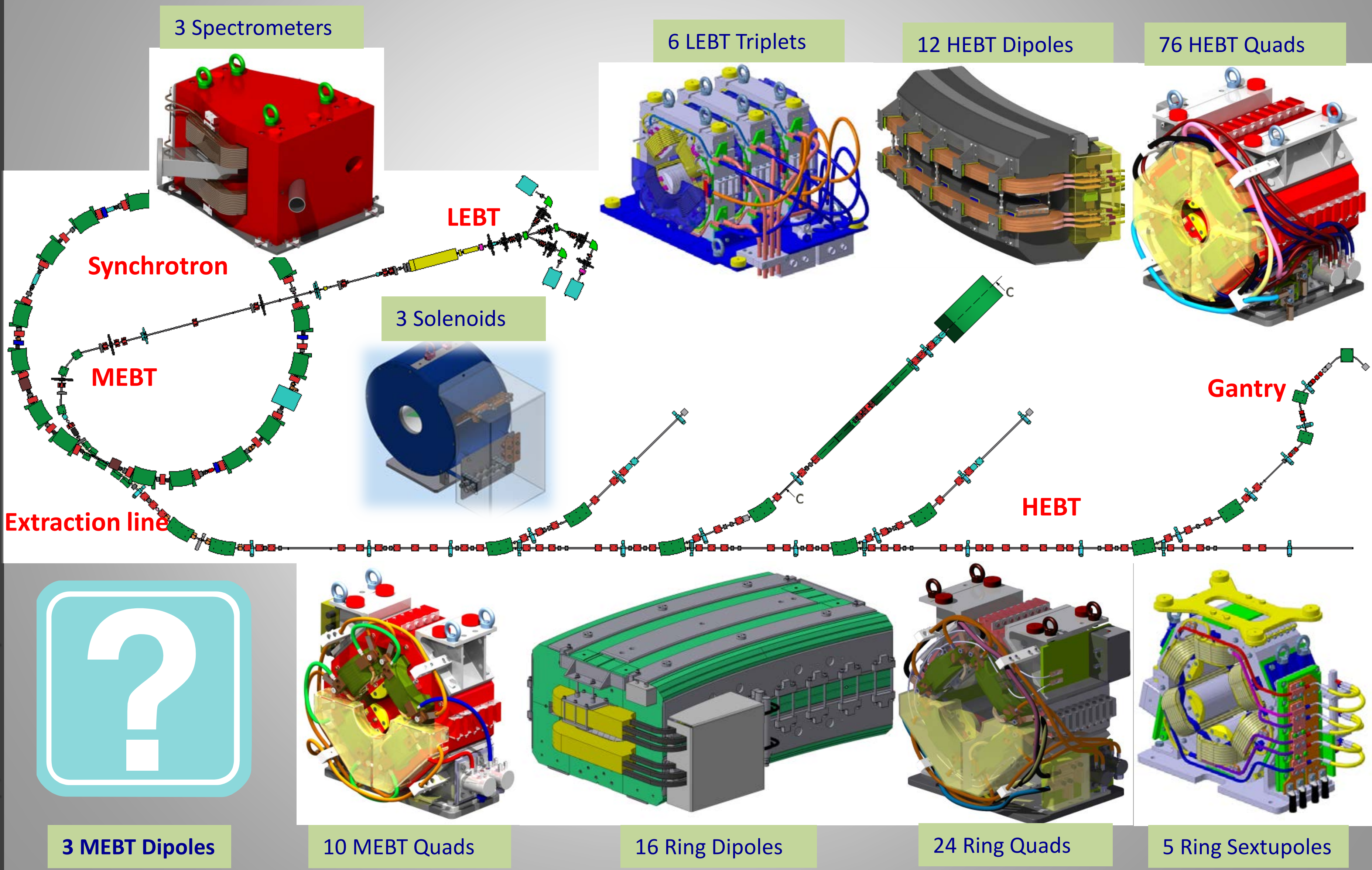
- IR2
  - Horizontal and vertical beam
  - Protons and carbon ions
- IR3
  - Horizontal beam
  - Protons and carbon ions
- IR4
  - Gantry
  - Protons

Non-clinical research facility:

- IR1
  - Horizontal beam line
  - Protons (up to 800 MeV) and carbon ions

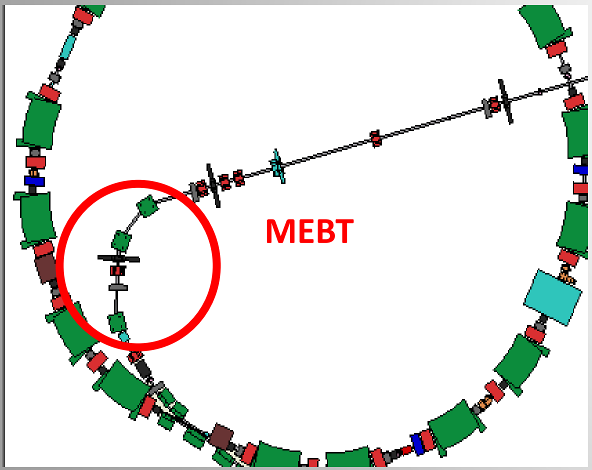


Magnet families



Beam parameters

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



Parameter	Value	Unit
Particle type	Protons, C^{6+}	
Beam energy	7	MeV/u
Operation mode	quasi DC	
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

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Functional specification

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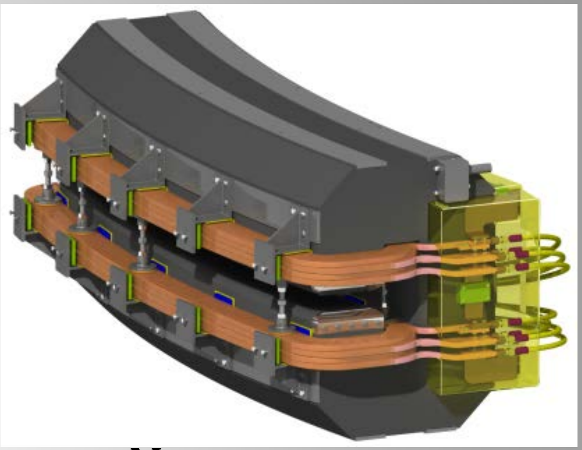
Parameter	Value	Unit
Number of magnets	3	
Bending angle	36	deg
Beam entry/exit angle	18	deg
Operation mode	quasi DC	
Ramp rate	0.3	T/s
Horizontal good field region	+/- 20	mm
Vertical good field region	+/- 23	mm
Field quality inside GFR $\Delta B/B_0$	< $\pm 1\cdot10^{-3}$	
Max. overall magnet length	0.8	m
Max. available water pressure drop	0.8	MPa
Inlet water temperature	25	°C
Max. converter current	650	A
Max. converter voltage	160	V

Exercise 1: Analytical design

The following parameters should be defined or derived:

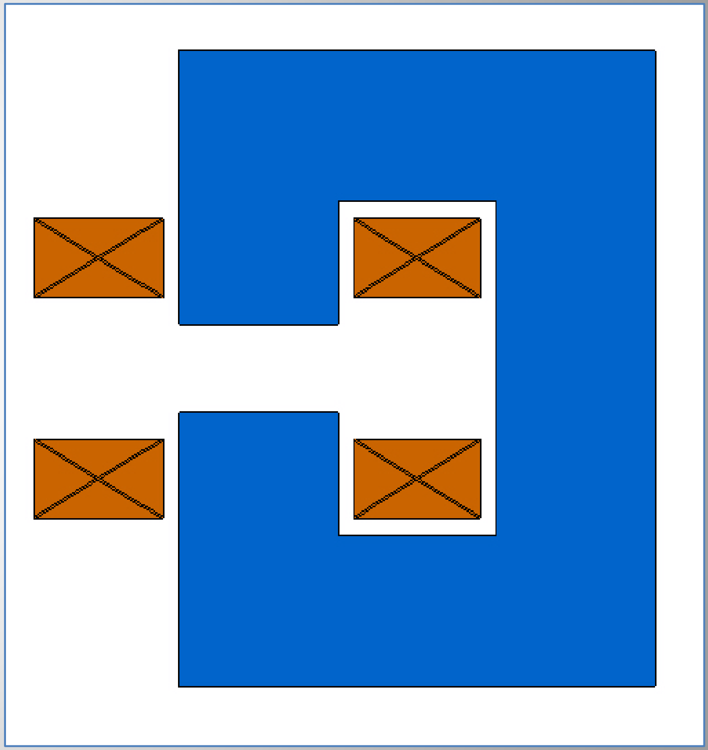
- Magnet shape (straight/curved)
- Flux density B
- Aperture height h
- Excitation current NI (ampere-turns)
- Magnetic length l_{mag} and iron length l_{iron} ($k = 0.55$)
- Pole width and yoke thickness
- Current density j, nominal current I and number of turns N
- Dissipated power P, coil resistance 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



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 wrt to beam axis
- Coil excitation (ampere-turns)



Hint: prepare a sketch with key-point coordinates

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