MedAustron – a case study

Austrian Centre for Ion Therapy and Research

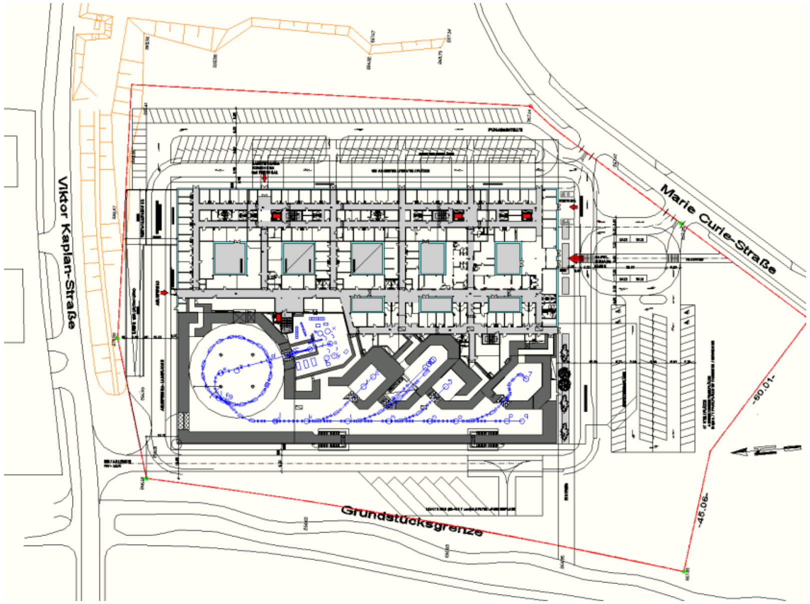
oPAC 3rd Topical Workshop
on Beam Diagnostics

Dr. Fadmar Osmić
Accelerator Manager
Operations and Accelerator Technology Lead
http://www.medaustron.at

MedAustron located in the north of Wiener Neustadt, 40 km south of Vienna

Applications:

- **Medical Treatment**
  - Tumour treatment
  - Clinical research
- **Non-clinical Research (NCR)**
  - Medical Radiation Physics
  - Radiation biology
  - Experimental physics
- **Accelerator operates 24/7**
- Beam time split Treatment:NCR about 50:50



Non-clinical research

- **Medical Radiation Physics and Radiation Biology**
  - Research close to medical application
- **Experimental physics**
  - Proton acceleration to 800 MeV for optimum usage (250 → 800 MeV)
- **One dedicated NCR irradiation room additionally to the three medical**
- **Combination of Clinic-Research provides unique research opportunity in international competition**
  - Ion therapy – Medical Radiation Physics – Radiation Biology
  - Experimental Physics for completing the research program
  - MedAustron accelerator optimized for the requirements of the versatile applications

Conventional tumor therapy

Klinikum Bielefeld-Bethel

Courtesy of Varian

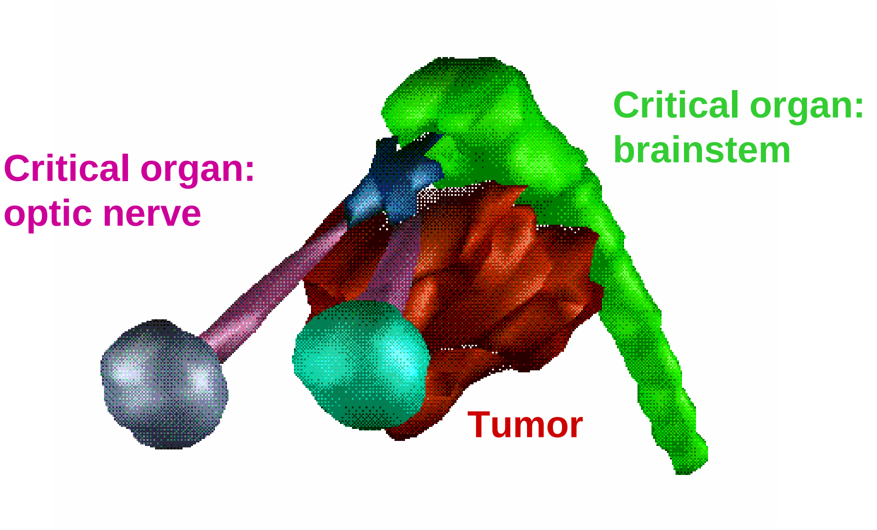
Radiotherapy

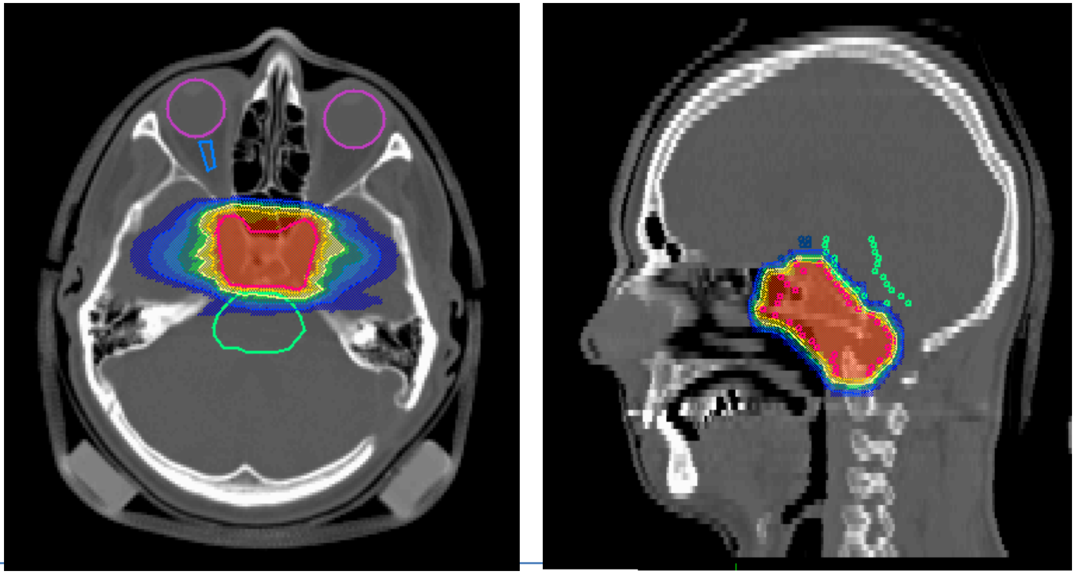
Goal

- A high dosis in the target volume to destroy the tumor cells.
- Sparing the healthy tissue and critical organs.
- Dose distribution adapted to the tumor size and shape.

Types of radiation

- Conventional therapy: photons, electrons
- Hadron therapy: protons, light ions

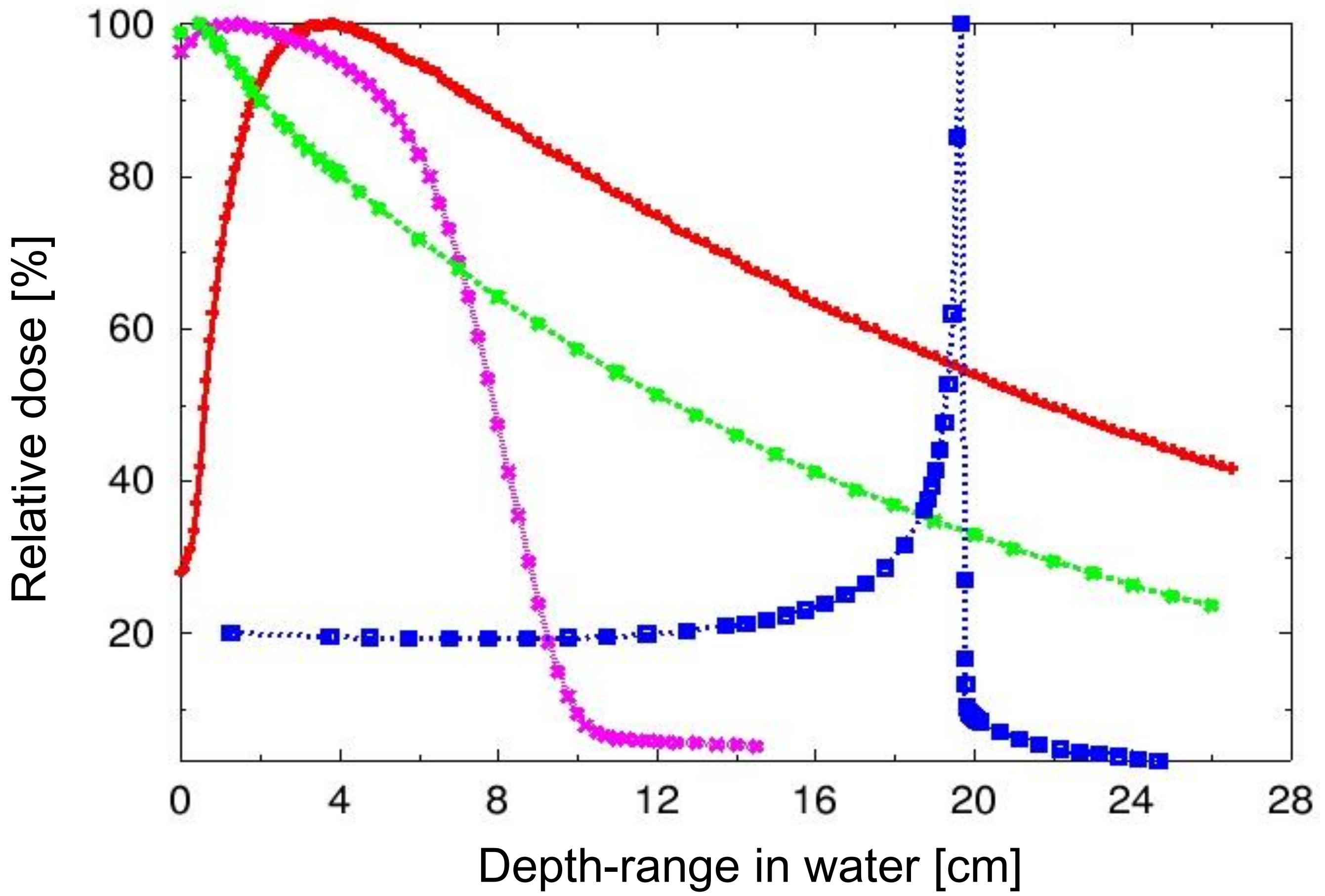




Courtesy GSI

Depth dose curves – “Bragg-peak”

Measurements in water phantom (~tissue equivalent)



Cobalt 60 (γ, ~1.2 MeV)

Electrons 21 MeV

Photons 25 MeV

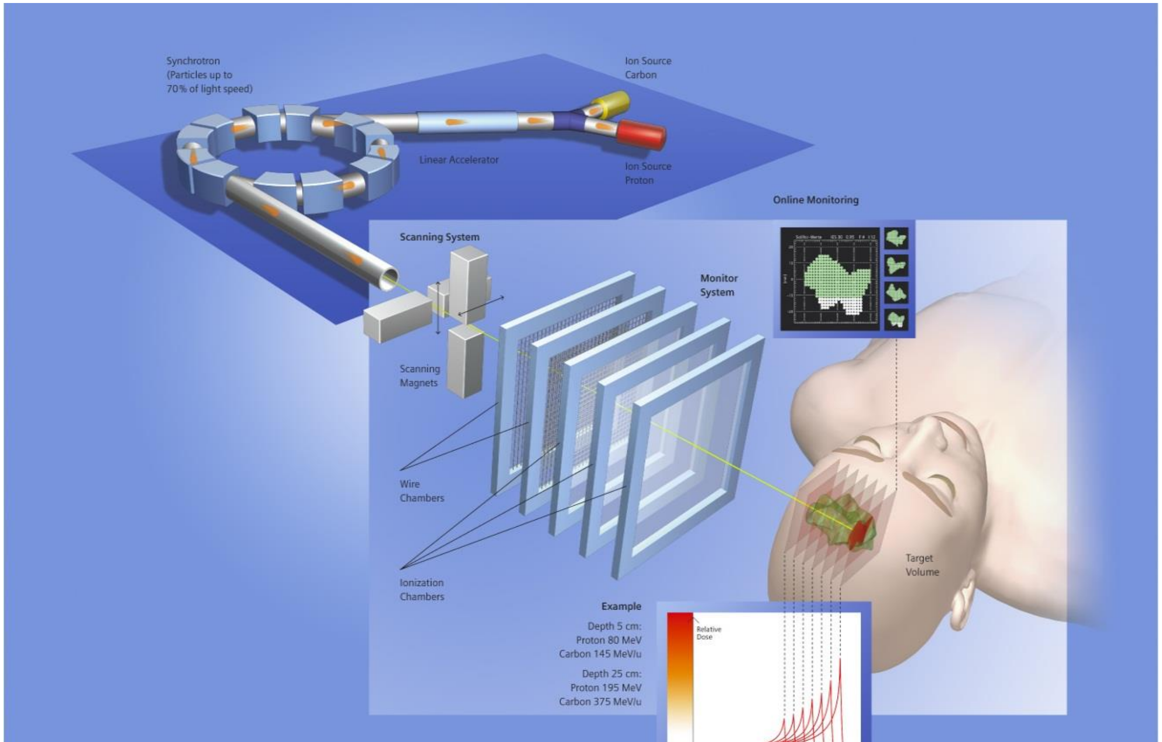
C-ions 330 MeV/u

Data:

Photons and electrons:
University Clinics Vienna

C-ions:
GSI Darmstadt

Active energy selection and scanning system.



Courtesy of GSI

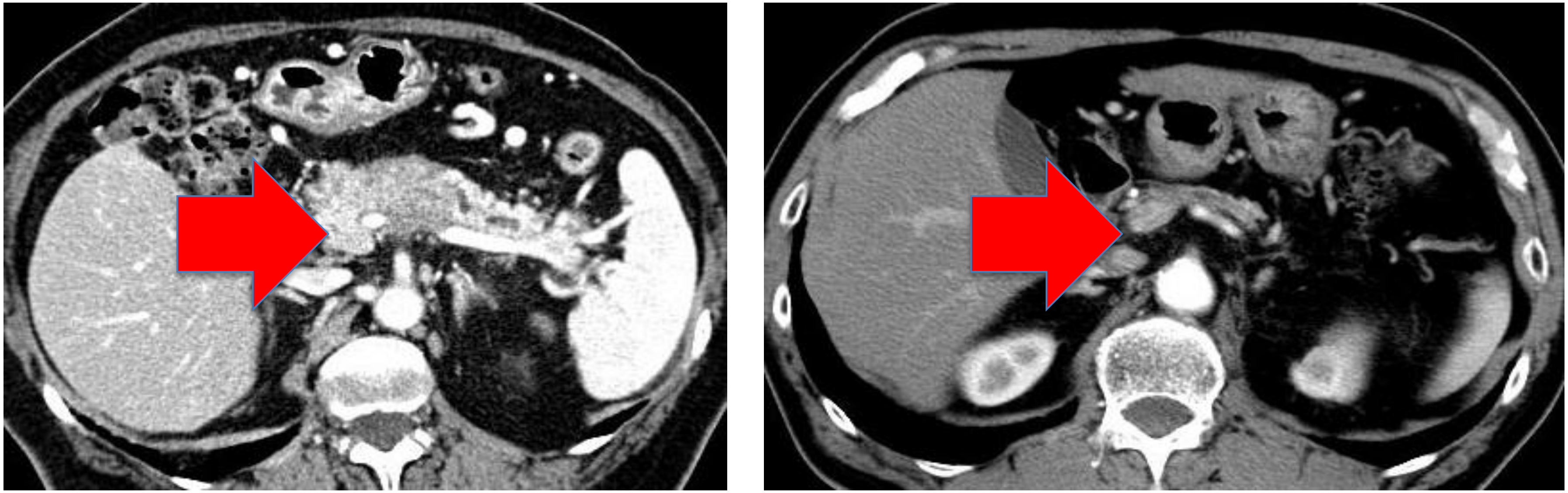
Schematics of accelerator and monitoring system. Does not represent MedAustron layout.

- **Active energy selection** (for longitudinal beam positioning)
- **Transverse beam scanning**

MedAustron: Carbon hadron therapy

Pancreatic cancer:

40 months after treatment, 64 months still alive
(status summer 2012)



Building Layout

We are providing beams in 4 irradiation rooms.

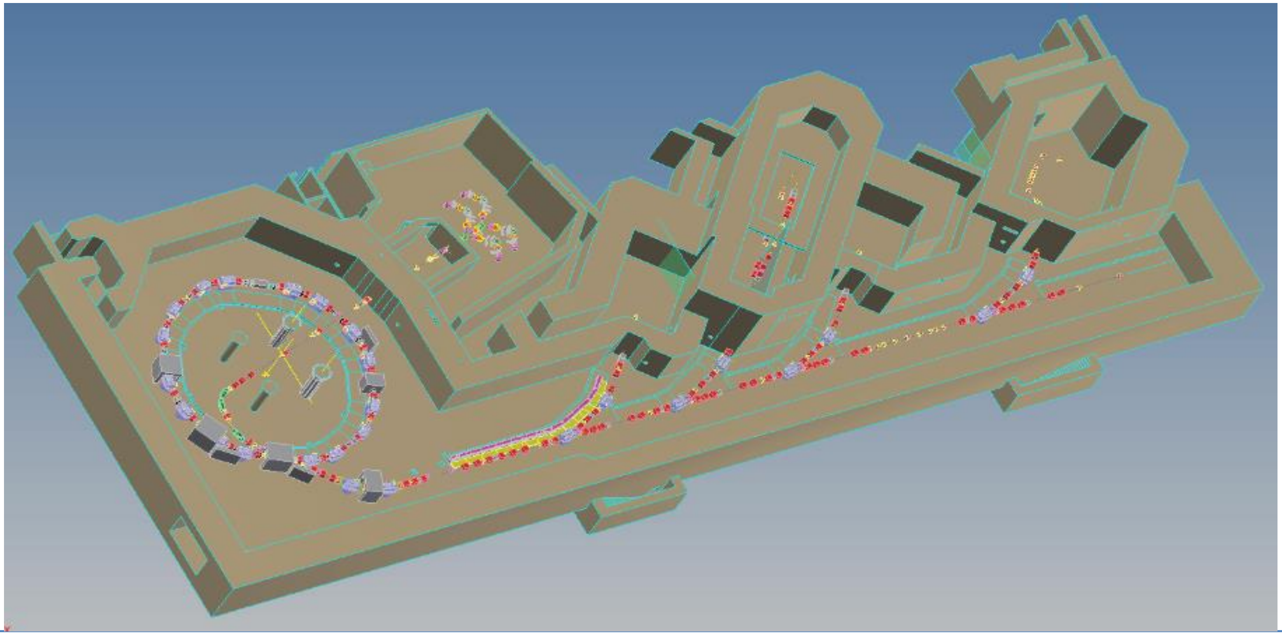
Irradiation rooms:

IR 1: non clinical research: horizontal beam outlet, protons and carbon ions

IR 2: medical use: horizontal & vertical beam outlet, p and C

IR 3: medical use: horizontal beam outlet, p and C

IR 4: medical use: **proton**-gantry, no C!



Beam Parameters in IRs I

Beam Energy

- Protons: 60-250 MeV (medical), up to 800 MeV (for non clinical research room)
- C-ions (C^{6+}): 120-400 MeV/u
- 255 different energy levels

energy translates into penetration depth (about 3-30 cm in human tissue)

Intensities in irradiation rooms

- Protons: $\leq 1*10^{10}$ /pulse
- C-ions: $\leq 4*10^{8}$ /pulse
- Dose build-up: ~ 1 minute to deliver 2 Gray in 1 liter
- 4 different intensity levels (degrader options)

Beam Parameters in IRs II

Beam delivery – active scanning

- Scanning field size: 20 x 20 cm² (IR 1 to 3), 12 x 20 cm² (Gantry)

Beam size at iso-centre

- 4 to 10 mm FWHM (neglecting scattering in air)

Beam position accuracy

- +/- 0.5 mm

Medical Treatment Capacity

- **24.000** single irradiations (fractions) per year
- Patient treatment typically requires **20** fractions.
- Patient receives one fraction/day during **~4** weeks.
- MedAustron capacity up to **1400** patients per year
- About **100** patients/day

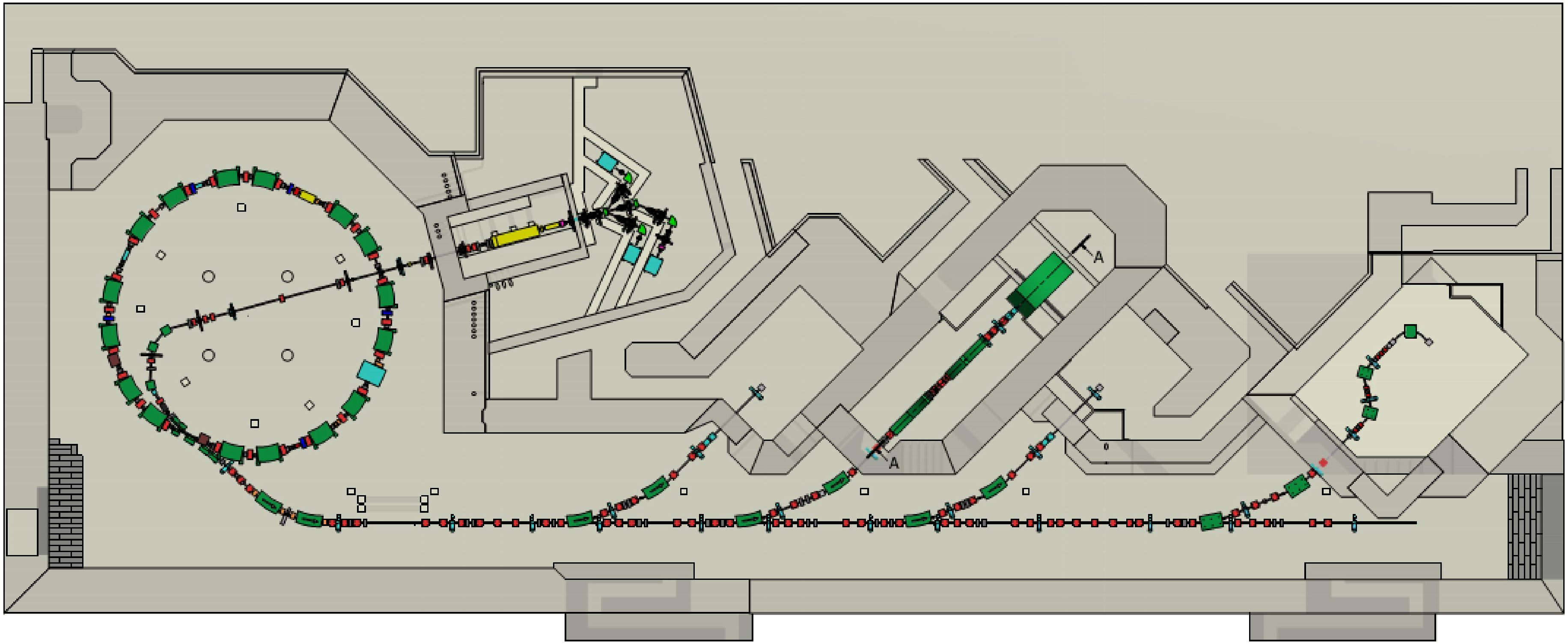
- **Optimizing medical usage of accelerator availability**

- **3** medical irradiation rooms
- **2+1** fixed beams and one proton gantry
- About **25** minutes per treatment room and patient

Accelerator layout

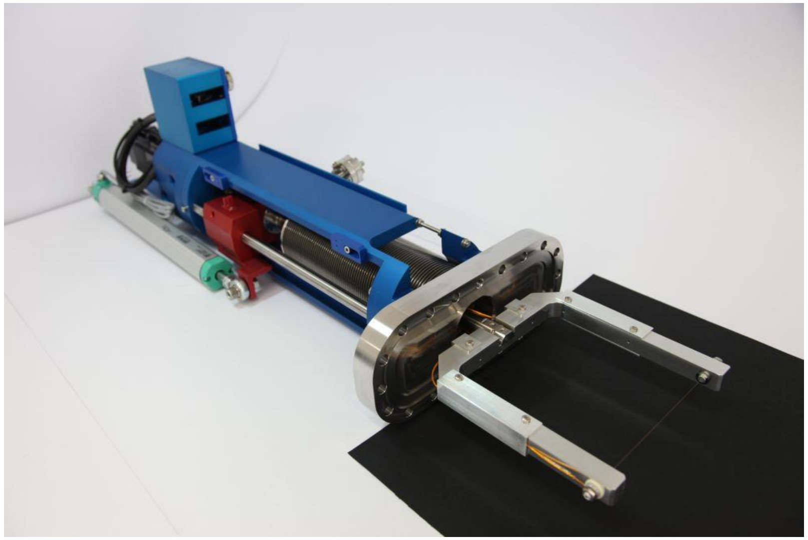
MA Accelerator consists of:

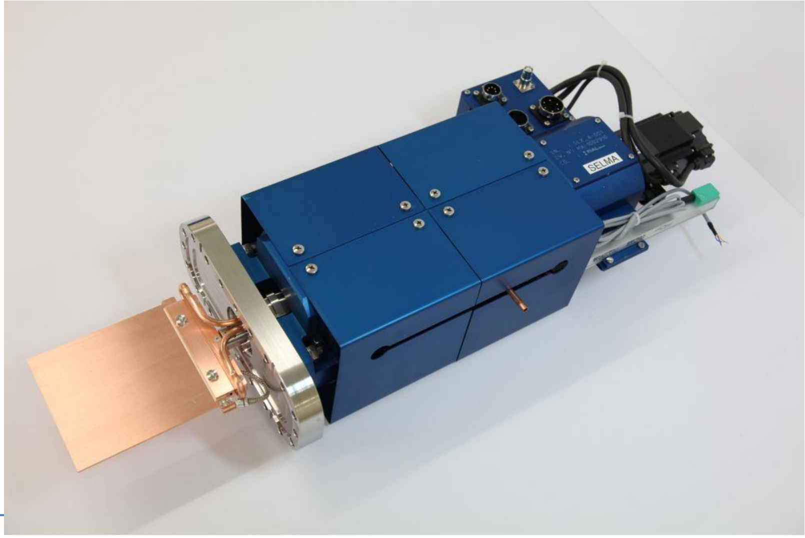
- **> 1000 components** (almost **300** magnets and power converters, **153** beam diagnostic devices, about **400 m** of vacuum pipes, a not neglectable number of special magnets, ion sources, RF devices, etc,..), which need to be controlled!
- From **220** suppliers from **23** different countries



MedAustron: Beam Diagnostics

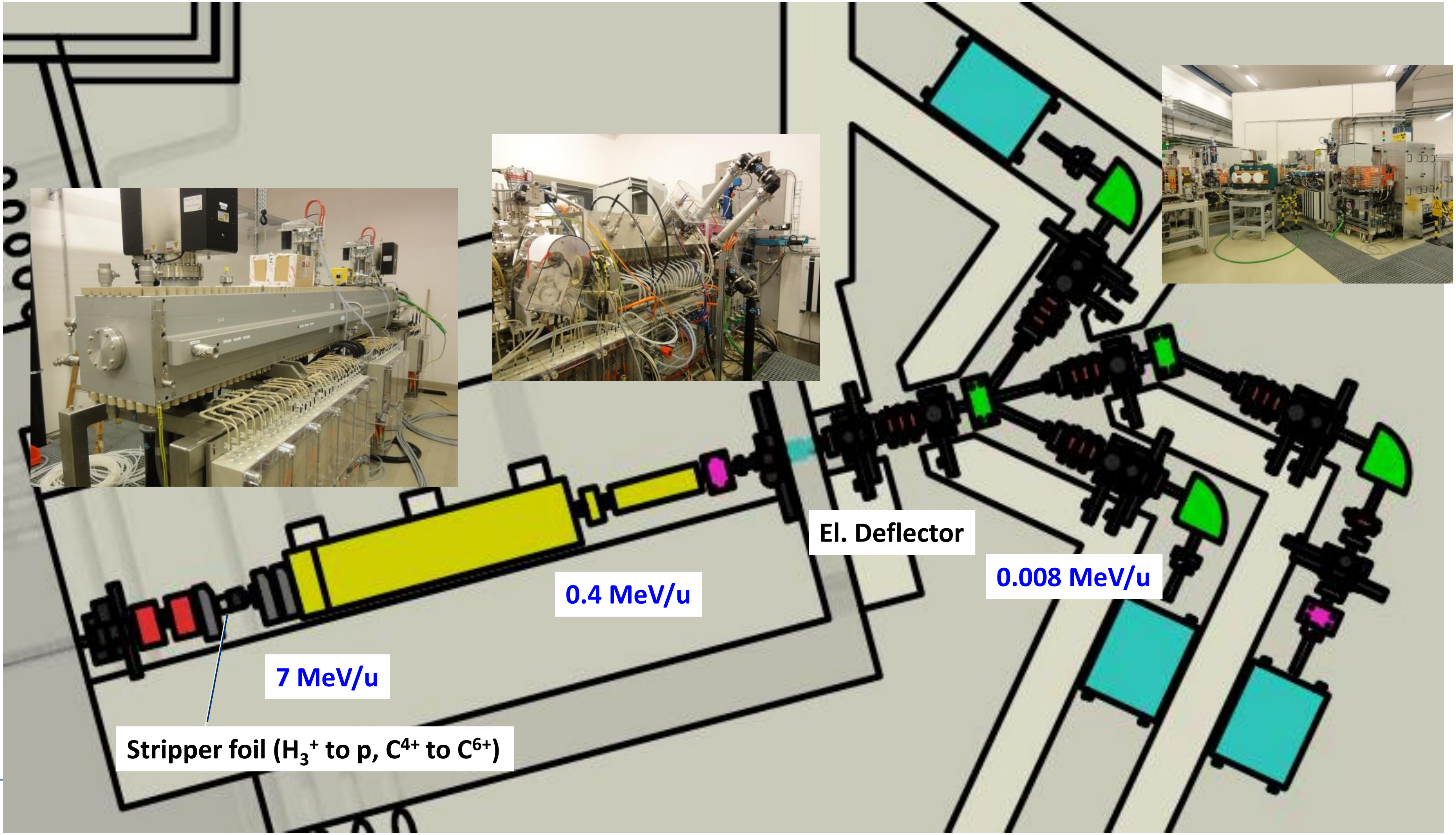
- Design partly based on CNAO BD
- Full in-house development
  - 16 different beam monitor types
  - 26 different beam monitors
  - 153 beam monitors
  - 2 test benches
- BD responsible for the full read-out chain
  - Mechanics (2 FTE)
  - Electronics (2 FTE)
  - FEC (LV) (2 FTE)
  - Physics (1 FTE)





The Injector

Main task: Accelerate the beam to 7 MeV



El. Deflector

0.008 MeV/u

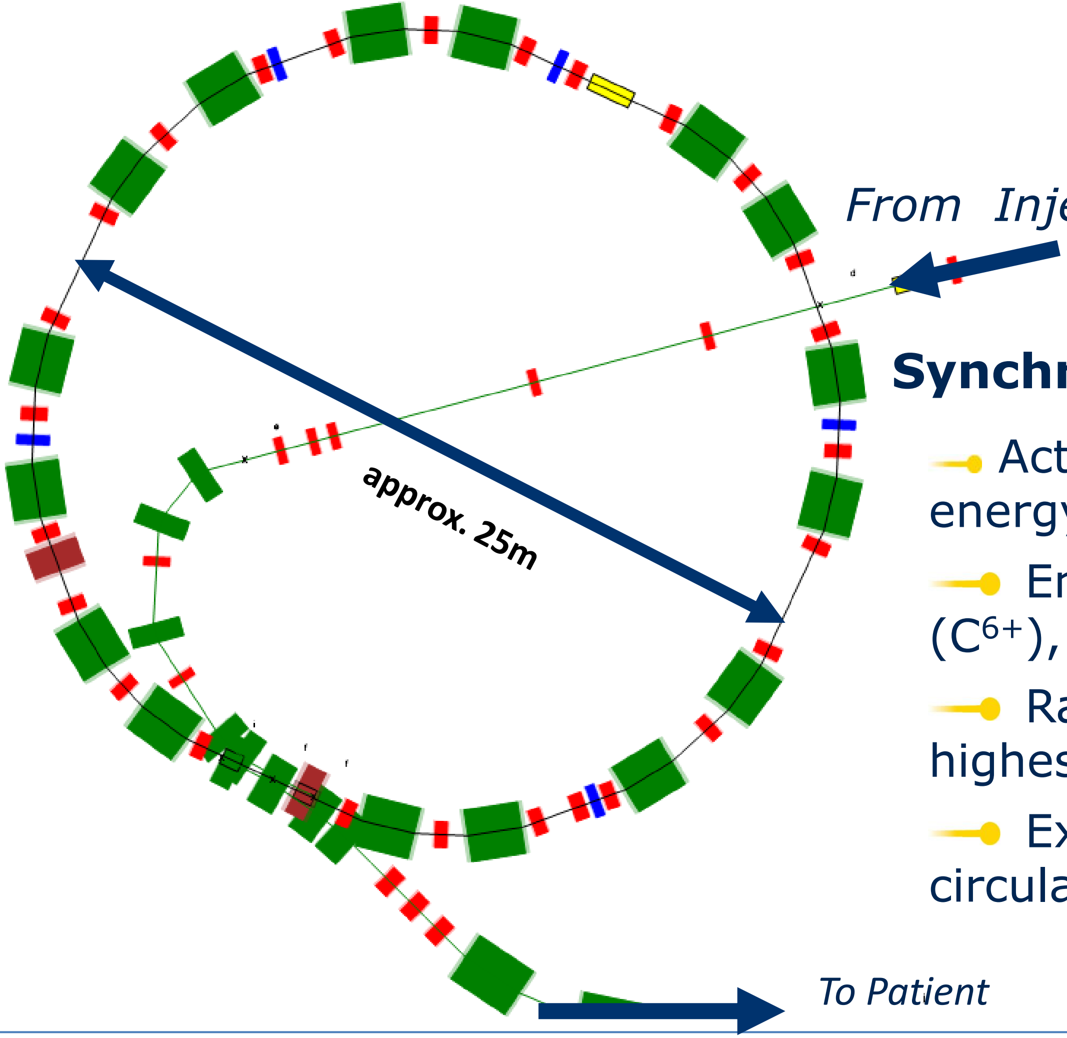
0.4 MeV/u

7 MeV/u

Stripper foil (H_3^+ to p, C^{4+} to C^{6+})

The Synchrotron

Main task: Accelerate a 7 MeV/u beam to the desired extraction energy



From Injector (7 MeV/u)

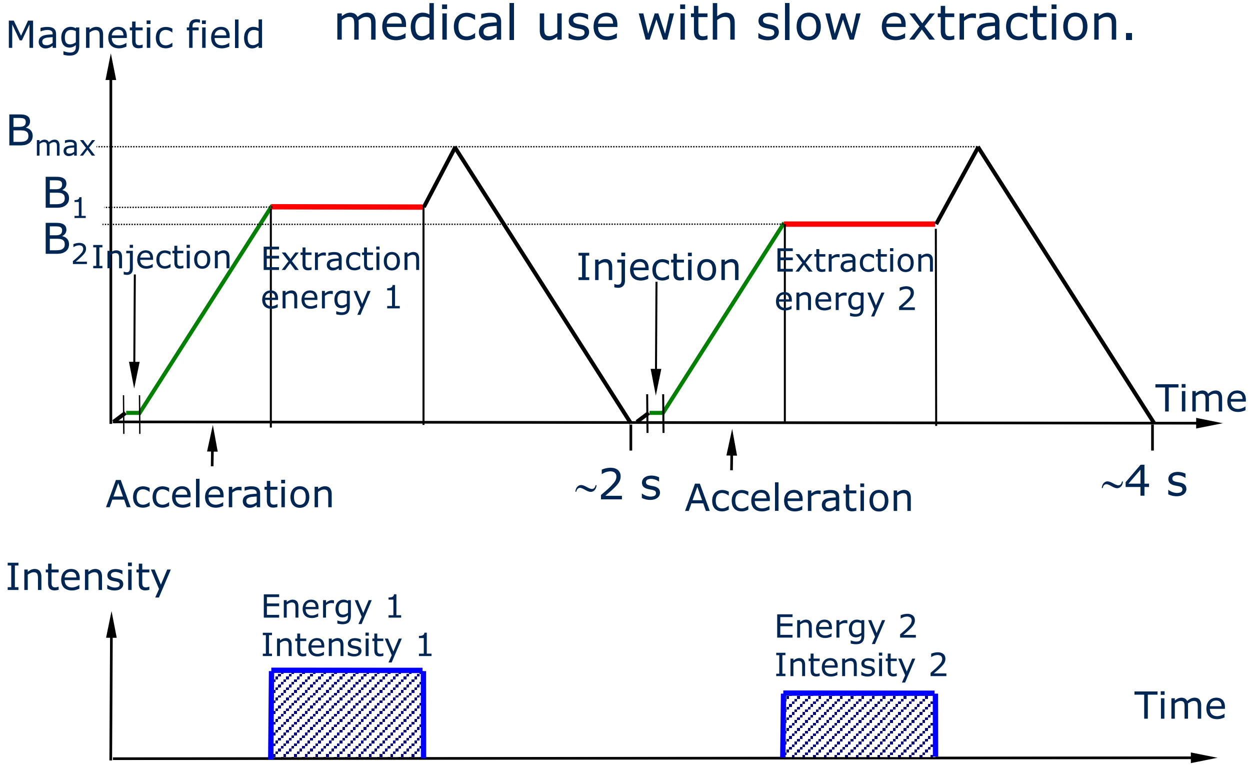
To Patient

Synchrotron – key parameters:

- Active energy selection, 255 energy steps/ion species
- Energy: 120 - 400 MeV/u (C^{6+}), 60 – 800 MeV (p)
- Ramp speed: 0.5 s (to highest carbon extraction energy)
- Extraction time: 1 – 10 s, circulation time up to 120 s

Typical Synchrotron Cycle

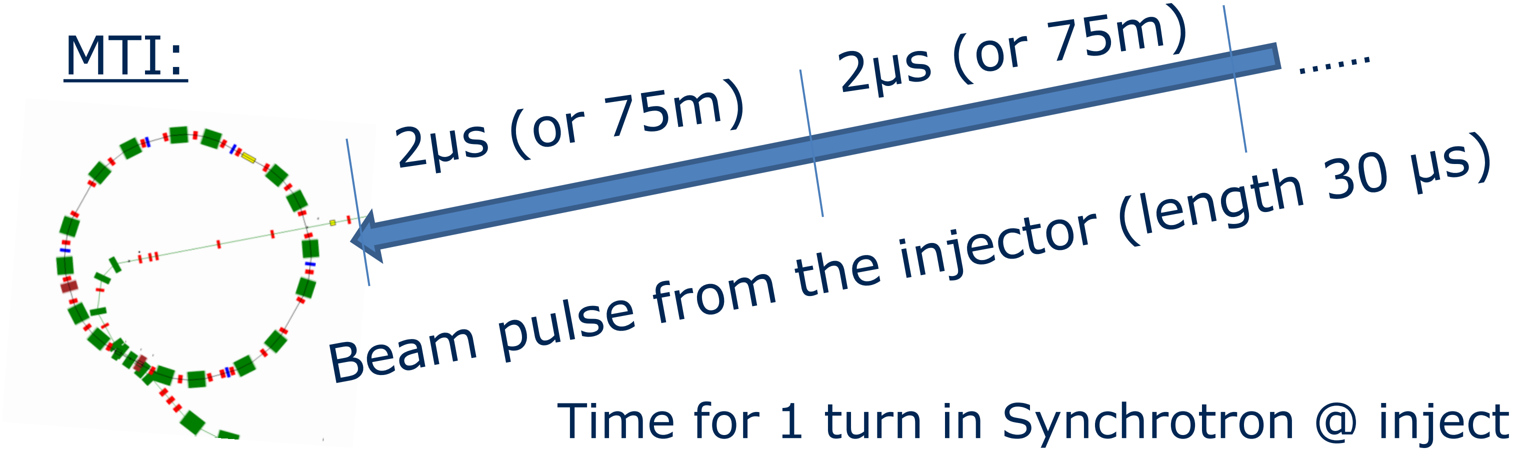
Typical cycle for a synchrotron for medical use with slow extraction.



- Beam structure: pulsed, energy and intensity variable

Multi Turn Injection and Slow Extraction

MTI:



2μs (or 75m)

2μs (or 75m)

……

Beam pulse from the injector (length 30 μs)

Time for 1 turn in Synchrotron @ injection level: about 2 μs

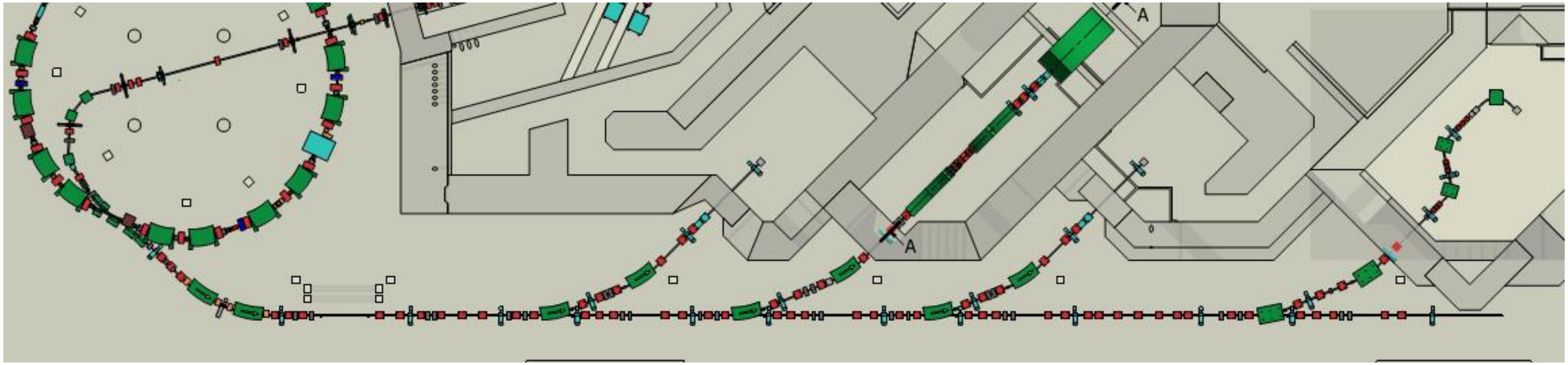
Beam pulse from injector of about 30 μs (chopped with the electrostatic deflector)

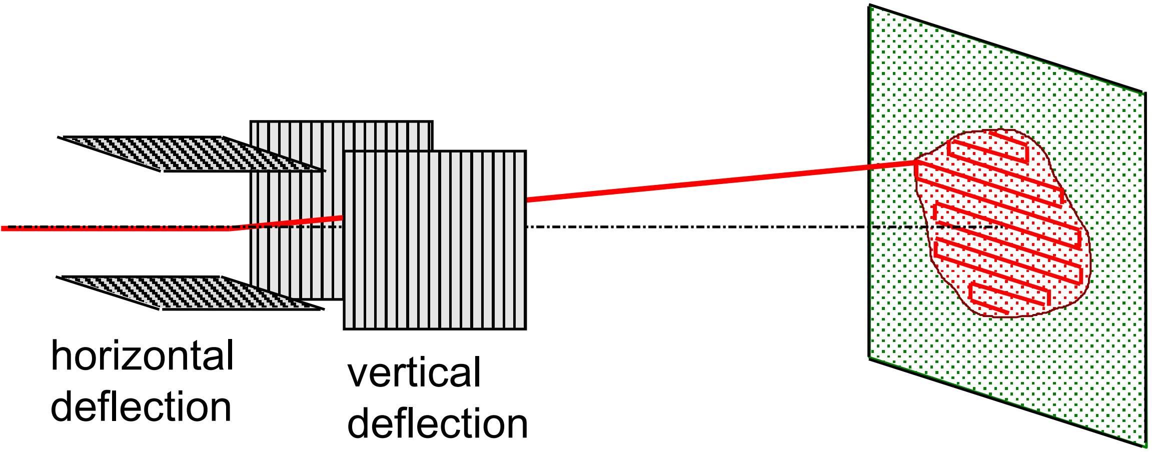
- Injection over 15 turns (multi-turn)
- Special, synchronized equipment needed for this operation
  (injection kickers)

Extraction:

Third order resonance slow extraction using a betatron.

Beam Distribution and Scanning





- Transverse "scanning" with small beams
- Beam sizes variable from 4 to 10 mm (in steps, FWHM in vacuum).
- Fast magnetic deflection (20 m/s).
- One slice is about one pulse (spill), 1-10 s.

A million of beam combinations…

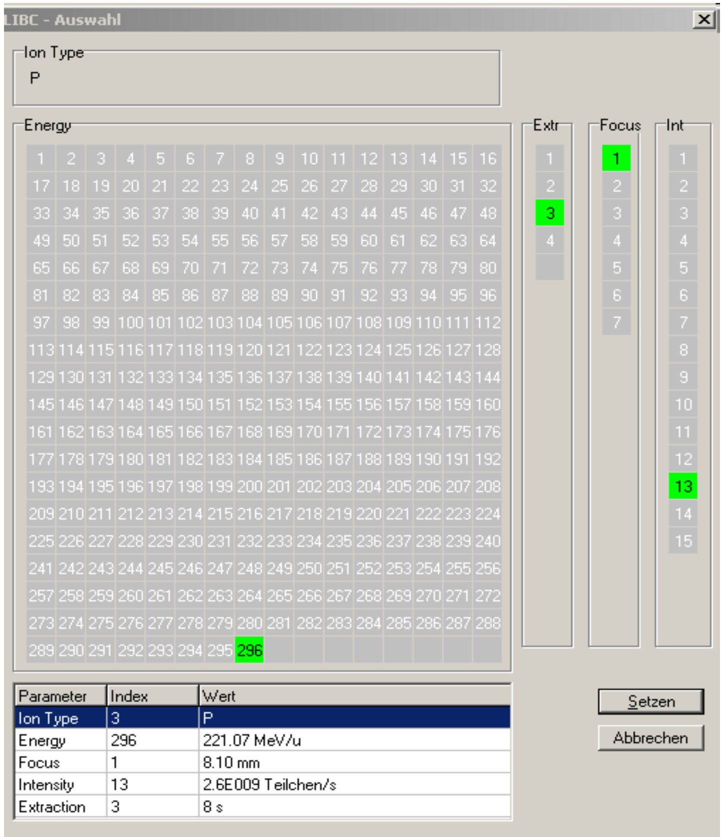
MedAustron

Accelerator is able to generate:

- Number of ion species: **2**
- Number of different energies: **255**
- Number of beam sizes: **5**
- Number of intensities: **4**
- Number of extraction times: **8**

- Beam combinations per beam line: **81600**
- Gantry: different angles needs to be considered
- None clinical research: extended energy range

- Requires a huge amount of commissioning work.
- Most of the combinations obtained by interpolation.
- Stepwise release for medical use.



Parameter	Index	Wert
Ion Type	3	P
Energy	296	221.07 MeV/u
Focus	1	8.10 mm
Intensity	13	2.6E009 Teilchen/s
Extraction	3	8 s

Example for table to select a beam combination

The Medical Front-End

Main task: Serves as a mitigation measure for hazards caused by the accelerator in order not to harm the patient.

Realized by online monitoring of beam properties during the entire patient treatment. (mainly done by Dose Delivery System (CNAO)).

Monitored beam characteristics by the DDS:

- Intensity
- Beam position
- Beam size

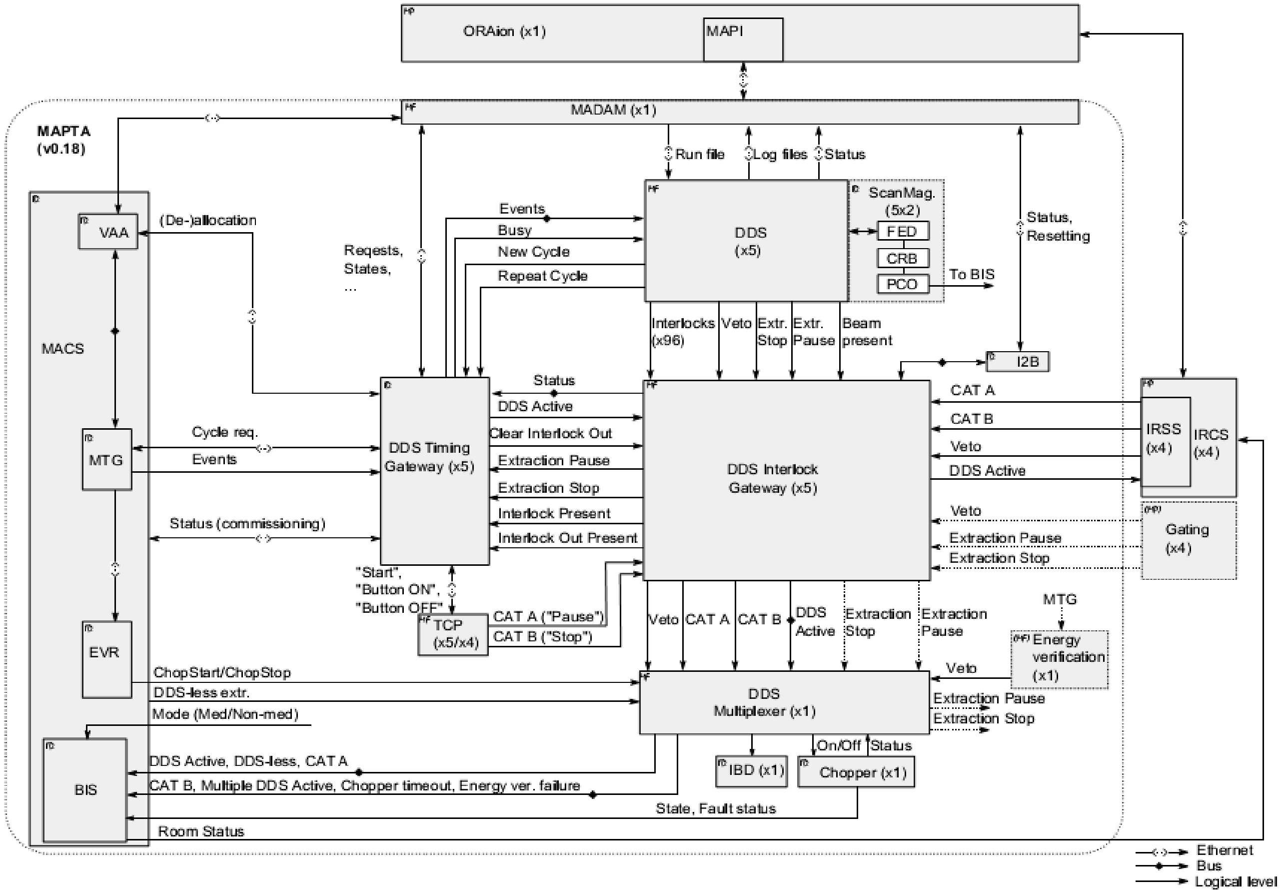
In case of deviations:

- Triggers an interlock
- Switches off beam within very short time (few hundred µs).

The Medical Front-End II

Architecture of Medical Front-End:

- Integrated into the overall system architecture.
- Interfaces to other Medical Devices, Accelerator and Infrastructure.
- TCP: Start and stop irradiation.
- Energy verification.
- Independent beam termination system.
- etc…



Accelerator + Medical Front-End

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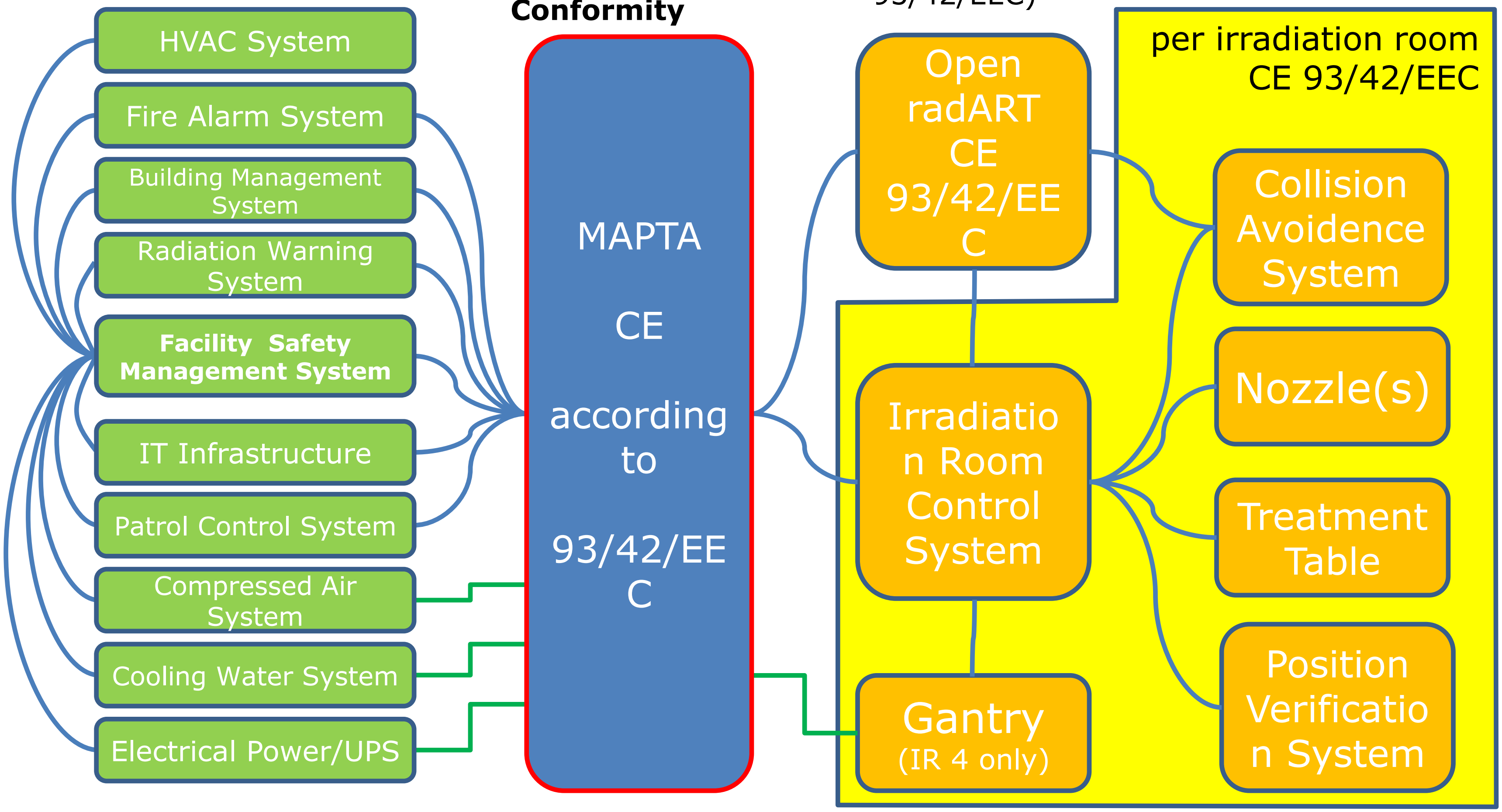
Therapy Accelerator

Interface overview MAPTA

Interface to technical infrastructure (industrial standards)

Declaration of Conformity

Interfaces to Medical Products (**Declaration of Compatibility**, Art. 12, 93/42/EEC)



— mechanical oder electrial connections

∼ Communication or interlock connection

Integration of Industrial Devices into the Medical Device

The Concept for the Accelerator (Industrial Device integration into the Medical Device) is based on three pillars:

- **Risk Management (according to DIN ISO 14971)**
- **Standards (Safety and EMC)**
- **Functional Safety (hazards and risks w.r.t the intended use – patient treatment)**

Current Status

- LINAC commissioned with p$^+$
- Synchrotron installed and commissioning ongoing
- First turn achieved recently – 7th April 2014

Luminescent Screen Device Control

MR-00-000-SLU

v0.2.1.535

Control Values

Trigger Mode*: Mode0 / Mode0

Exposure Time [s]*: 1m / 1m

☐ Enable Lamp*

Lamp Enabled

Readback Values

No. of Acquired Images: 24

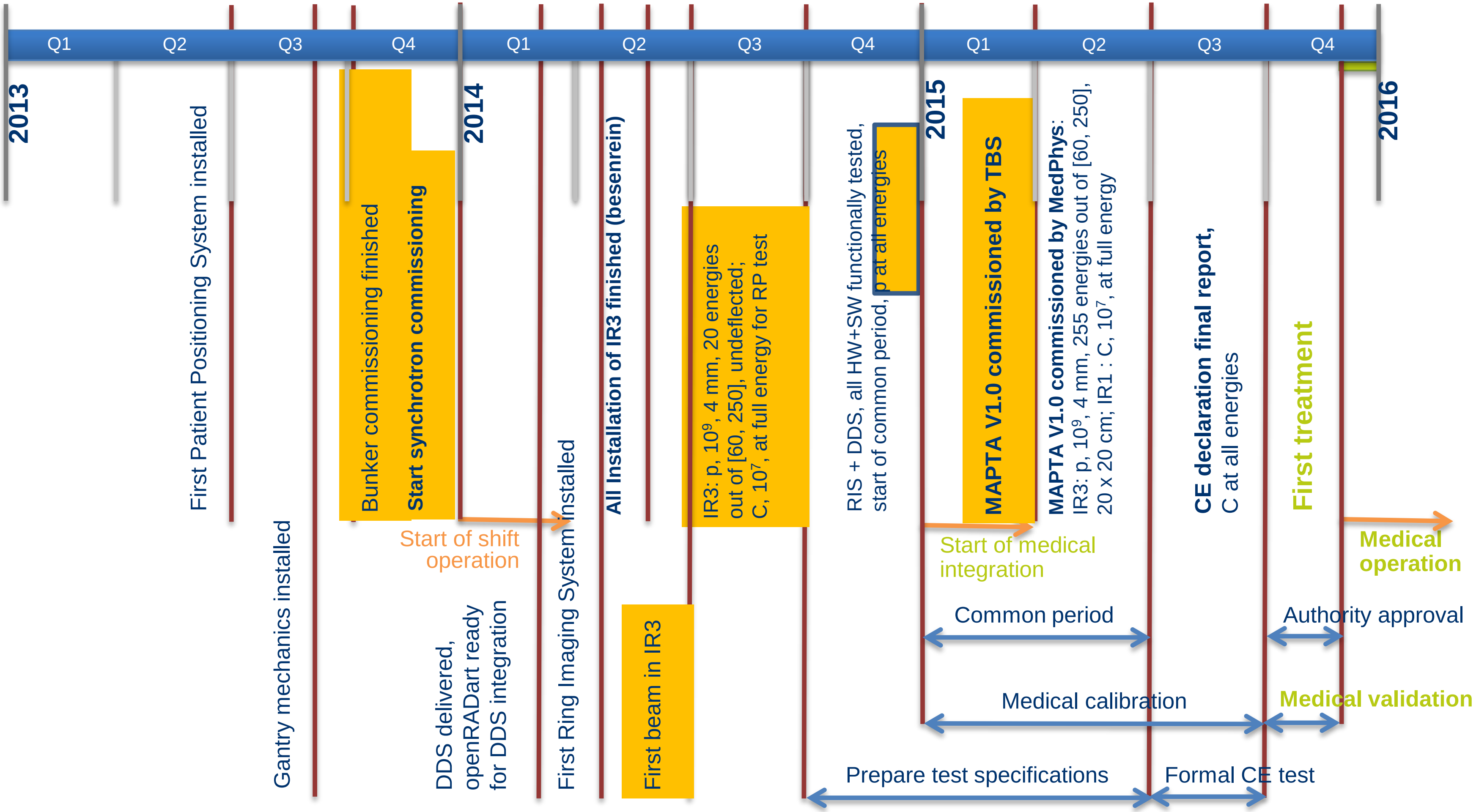
No. of Decoded Images: 24

Pneumatic Motion System

Monitor Position: IN

780x582 1.11X Unsigned 16-bit image 2304 (222,0)

Long term schedule - Timeline 1st Patient



Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

2013

First Patient Positioning System installed

Gantry mechanics installed

Bunker commissioning finished

Start synchrotron commissioning

2014

Start of shift operation

DDS delivered, openRADart ready for DDS integration

First Ring Imaging System installed

All Installation of IR3 finished (besenrein)

First beam in IR3

IR3: p, 10^9, 4 mm, 20 energies out of [60, 250], undeflected; C, 10^7, at full energy for RP test

RIS + DDS, all HW+SW functionally tested, start of common period, p at all energies

2015

MAPTA V1.0 commissioned by TBS

Start of medical integration

MAPTA V1.0 commissioned by MedPhys: IR3: p, 10^9, 4 mm, 255 energies out of [60, 250], 20 x 20 cm; IR1 : C, 10^7, at full energy

CE declaration final report, C at all energies

First treatment

2016

Medical operation

Common period

Authority approval

Medical calibration

Medical validation

Prepare test specifications

Formal CE test

Thank you for your attention!

MedAustron: Gantry

Grundlage ist die PSI-2-Gantry

Weiterentwicklung durch MedAustron

- Gesamtgewicht: 220 t
- Durchmesser: 7,5 m
- Präzision: < 0,1°
- Isozentrum: < 0,3 mm

Finanzierung

Republik Österreich

- € 41 Mio. für die Errichtung
- € 5.5 Mio. p.a. für Betriebskosten und für nichtklinische Forschung

Land Niederösterreich

- Beteiligt sich an den Errichtungskosten für nichtklinische Forschung mit € 3,7 Mio.€
- Errichtet und betreibt die Anlage durch die EGB MedAustron GmbH
- Gesellschaft im 100%-Einfluss des Landes 30 Mio.€ Eigenkapitalausstattung
- Übernimmt Haftung für 120 Mio.€

Stadt Wiener Neustadt

- Stellt Grundstück (3,2 ha) zur Verfügung
- zahlt 1.6 Mio. € Errichtung für nichtklinische Forschung

Gesamtinvestitionskosten: 184 MEURO