STATUS OF THE CARBON COMMISSIONING AND ROADMAP PROJECTS OF THE MEDAUSTRON ION THERAPY CENTER ACCELERATOR

IPAC 2019 – Melbourne, Australia

Mauro Pivi, L. Adler, A. De Franco, F. Farinon, N. Gambino, G. Guidoboni, G.Kowarik, C. Kurfürst, H. T. Lau, S. Myalski, C. Schmitzer, I. Strasik, P. Urschütz, A. Wastl, on behalf of all Therapy Accelerator Division MedAustron, Austria

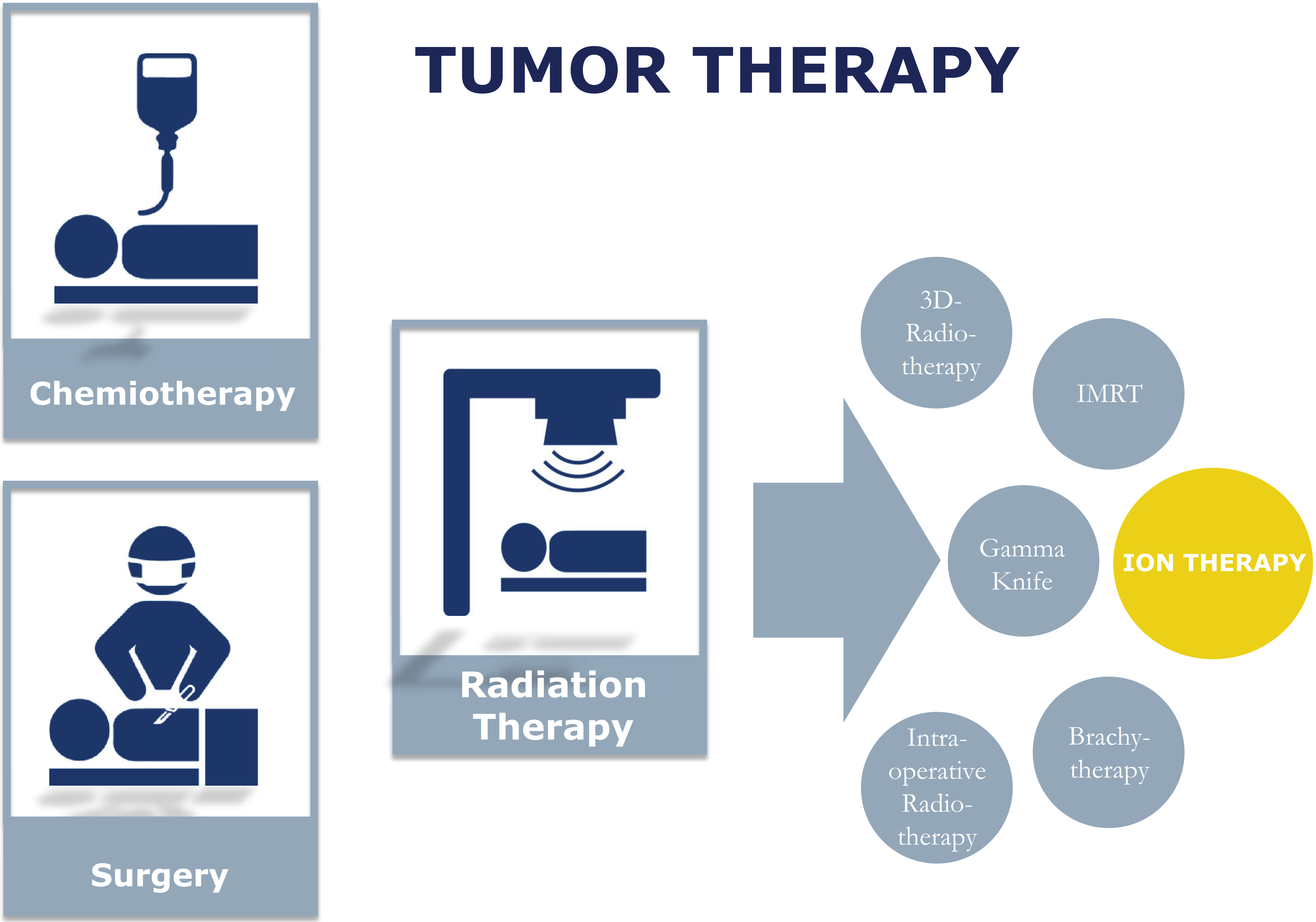
L. Penescu, Abstract Landscapes, Montpellier, France

MedAustron

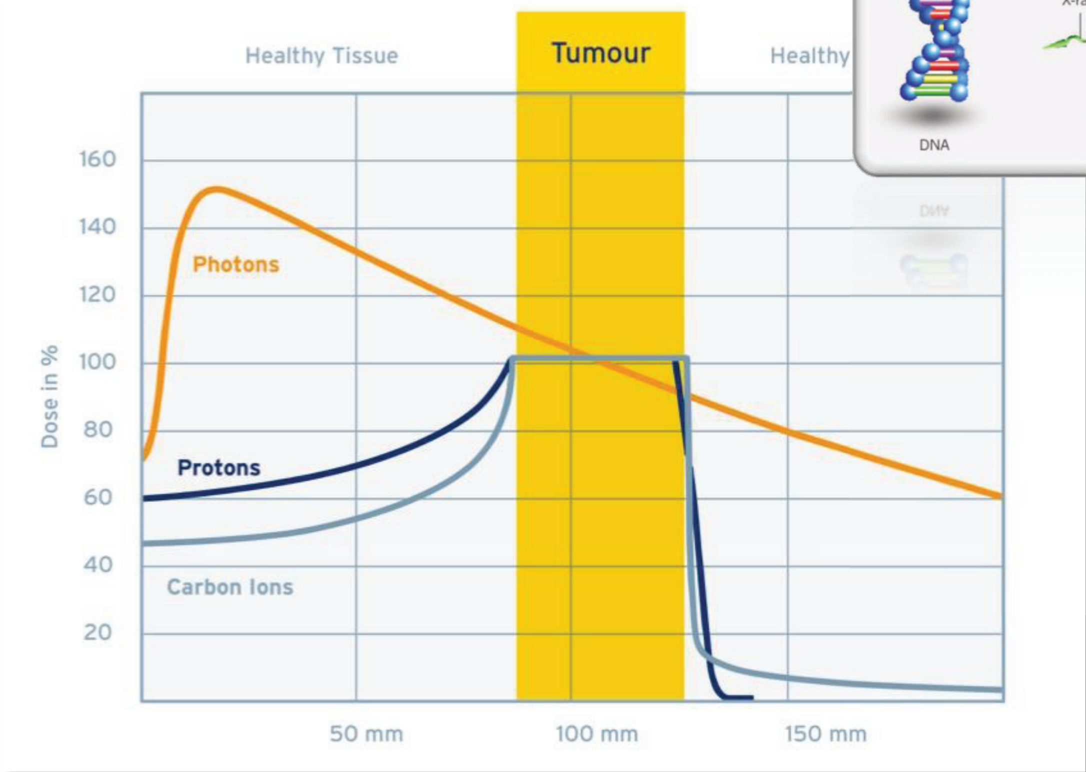
OVERVIEW

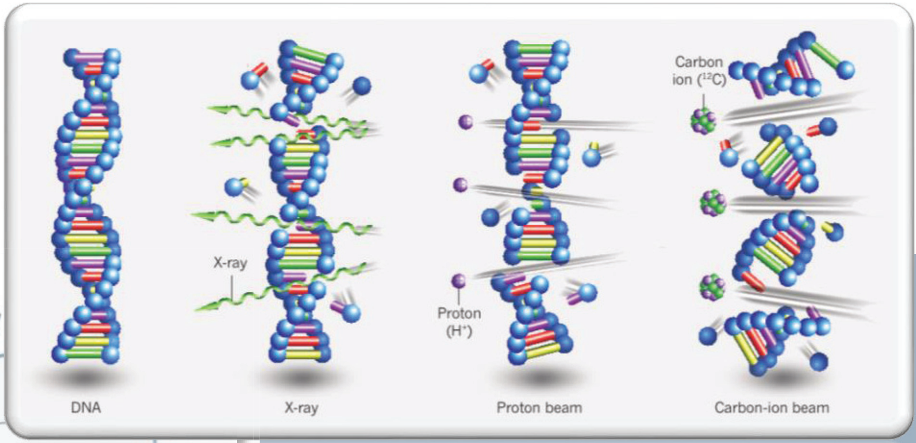
- MedAustron Center overview & Status
- Beam Commissioning with Carbon Ions
- Machine Accuracy, Stability and Robustness
- Future Commissioning Projects

TUMOR THERAPY



ION BEAM THERAPY





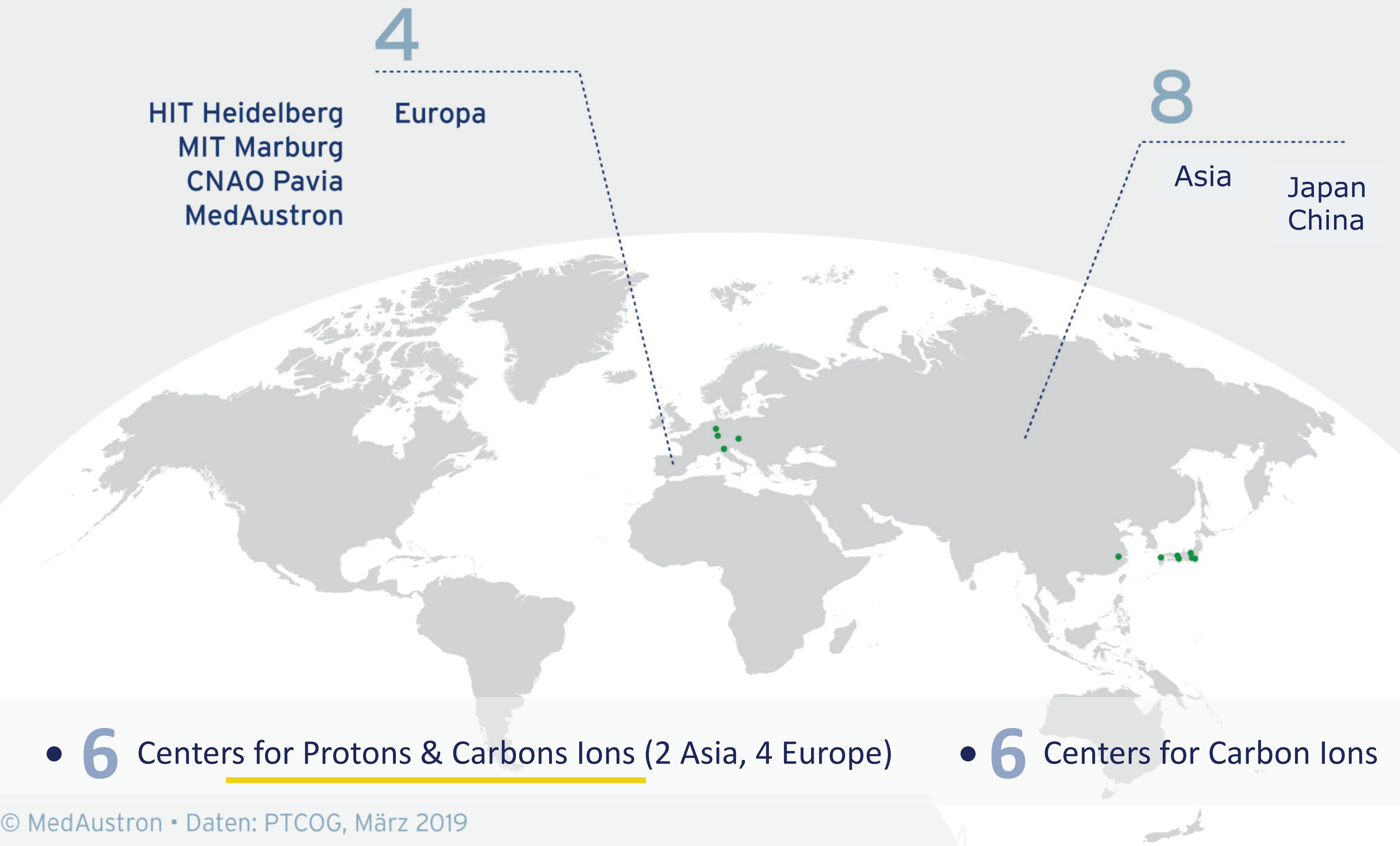
Lower exposure
to radiation of healthy tissue

Reduction
of side effects and long-term damages

Photons:
„Conventional"
Radiation Therapy

Protons,
Carbon Ions:
Ion Beam Therapy

Carbon Ion Therapy Centers Worldwide: 12
(in operation by March 2019)



- **6** Centers for Protons & Carbons Ions (2 Asia, 4 Europe)
- **6** Centers for Carbon Ions

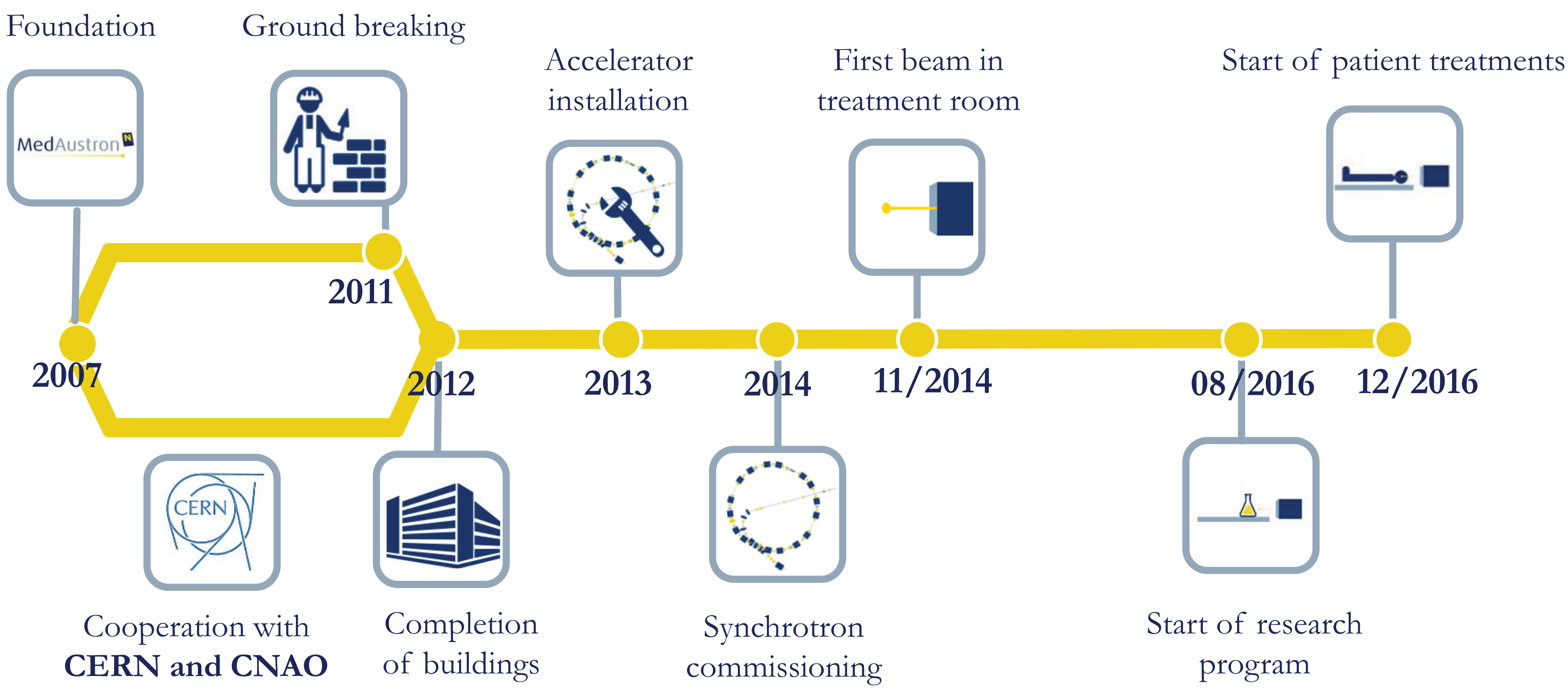
MedAustron in Austria

MedAustron Center

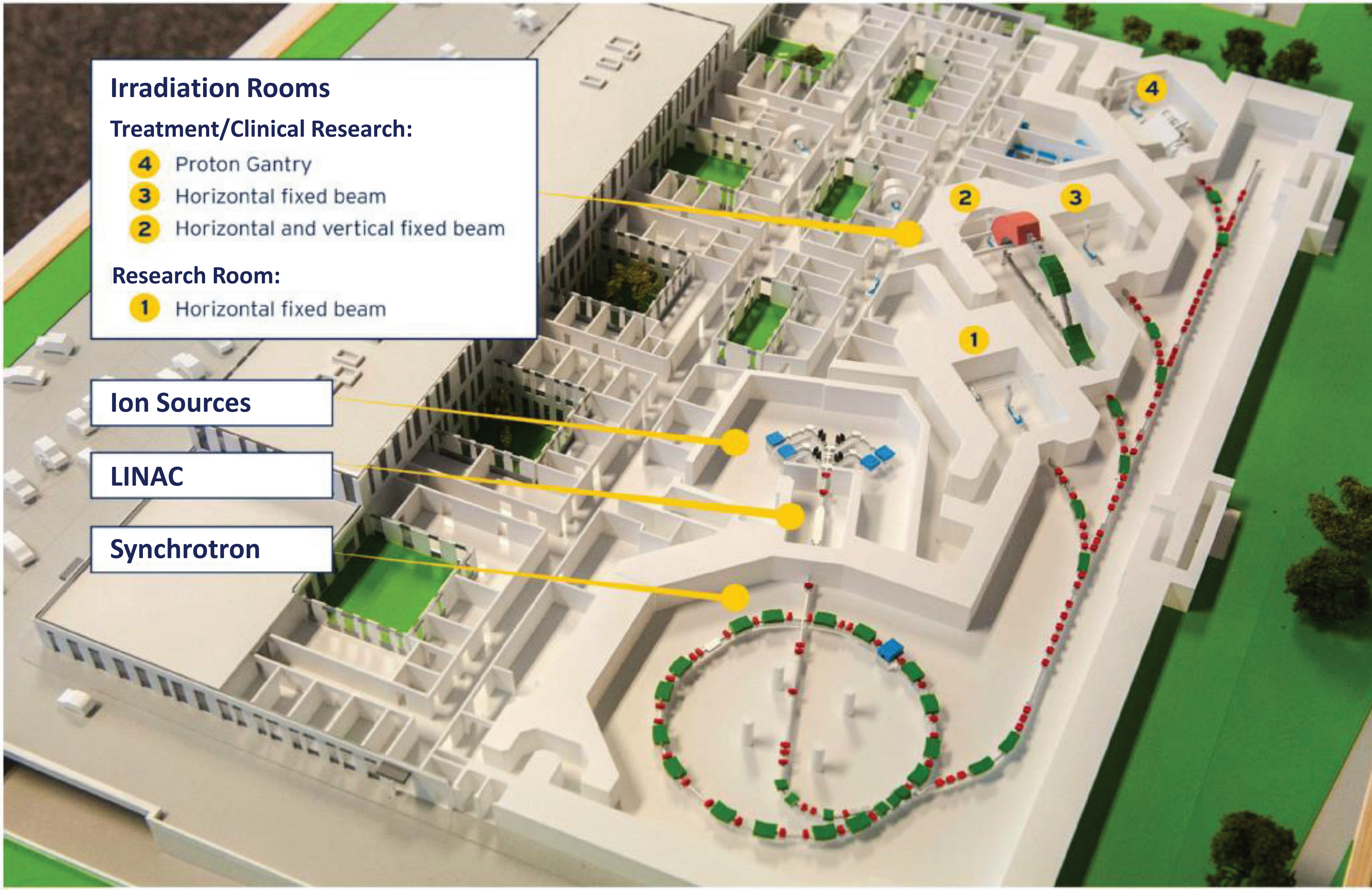
Wiener Neustadt

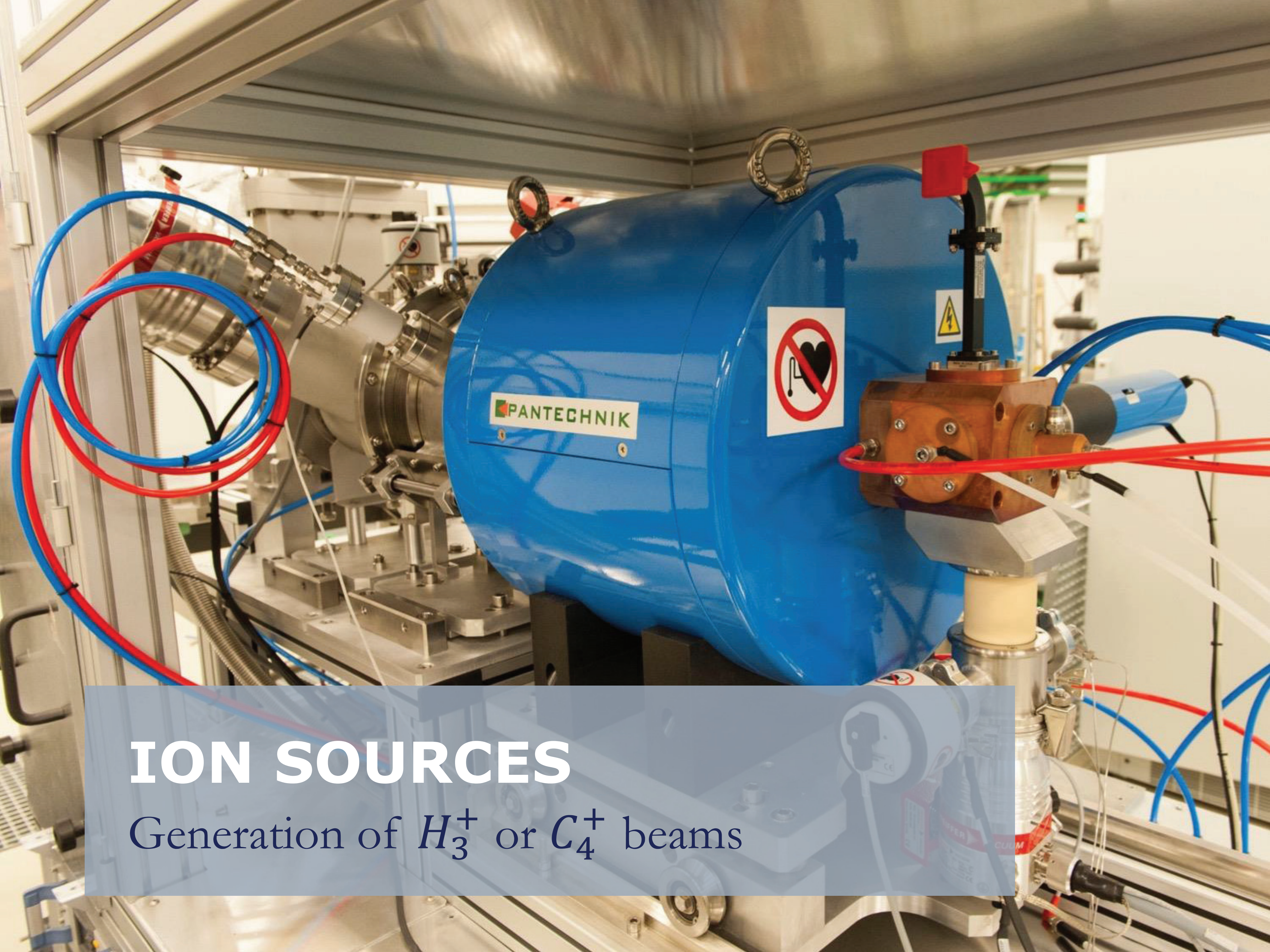
MedAustron

MedAustron HISTORY



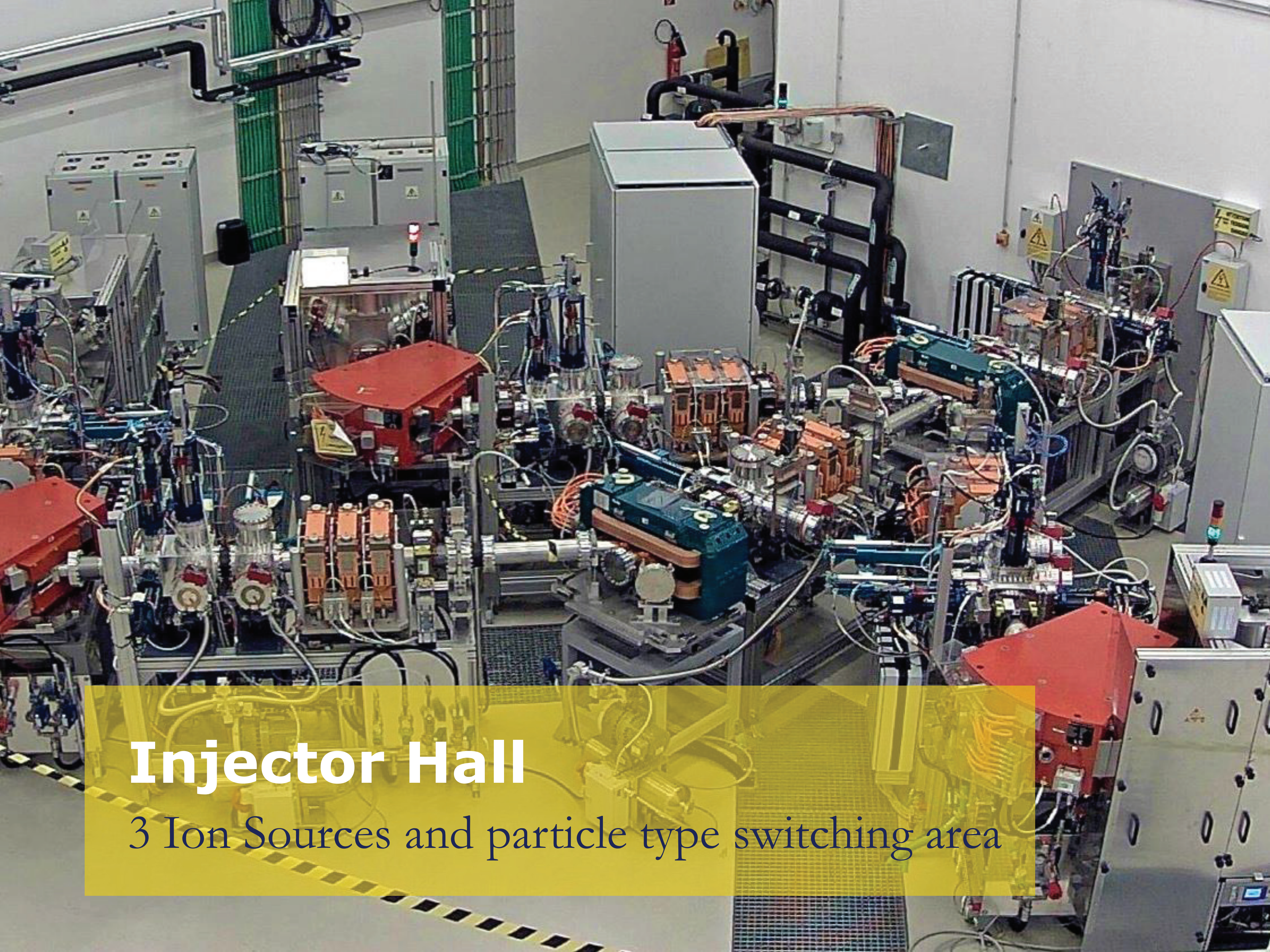
THE FACILITY





ION SOURCES

Generation of H_3^+ or C_4^+ beams



Injector Hall

3 Ion Sources and particle type switching area

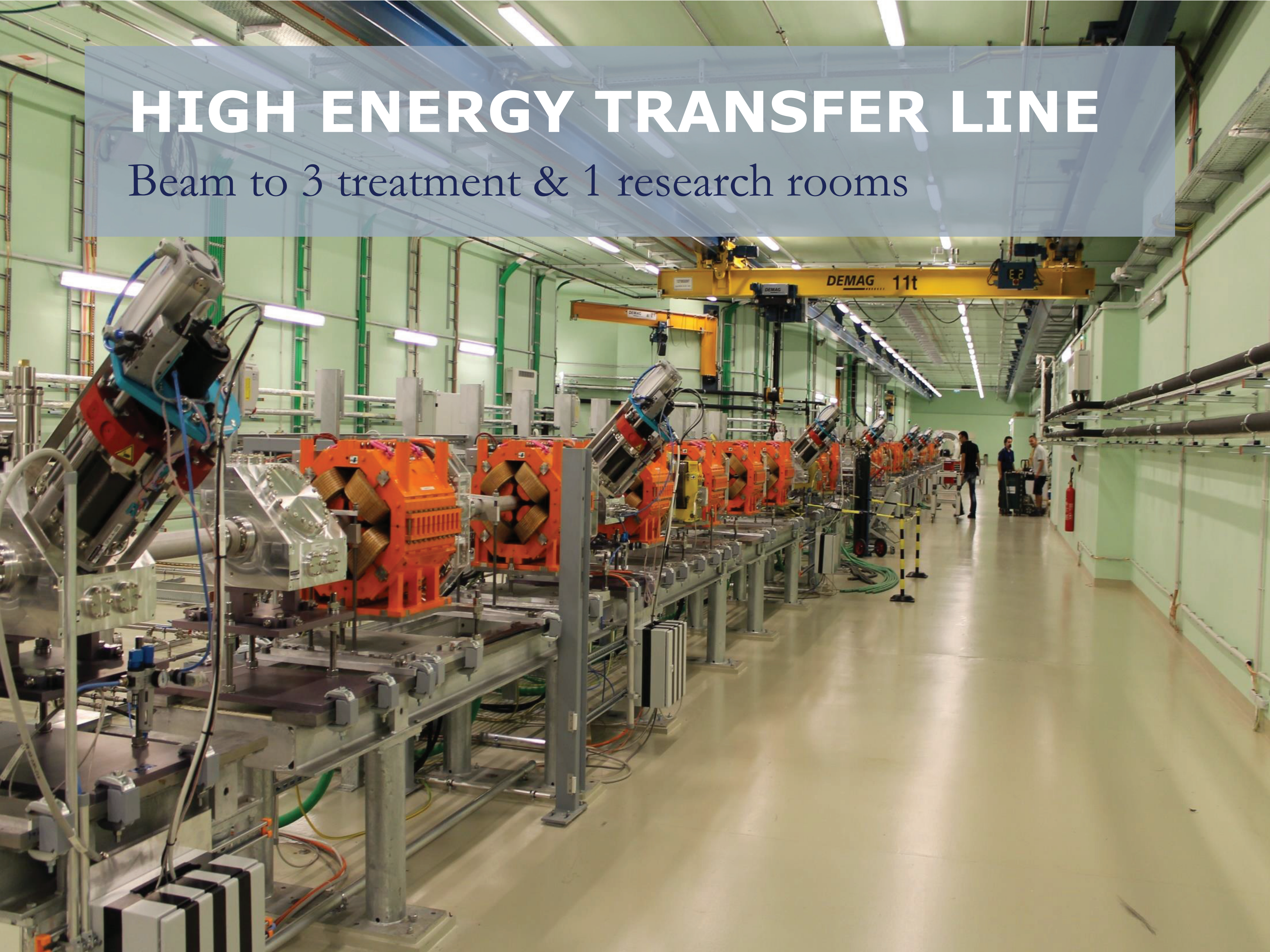
LINEAR ACCELERATOR

Solenoid, RFQ, IH tank, acceleration to 7 MeV/n


SYNCHROTRON
Proton 60-250 (800) MeV, carbon 120-400 MeV/n

HIGH ENERGY TRANSFER LINE

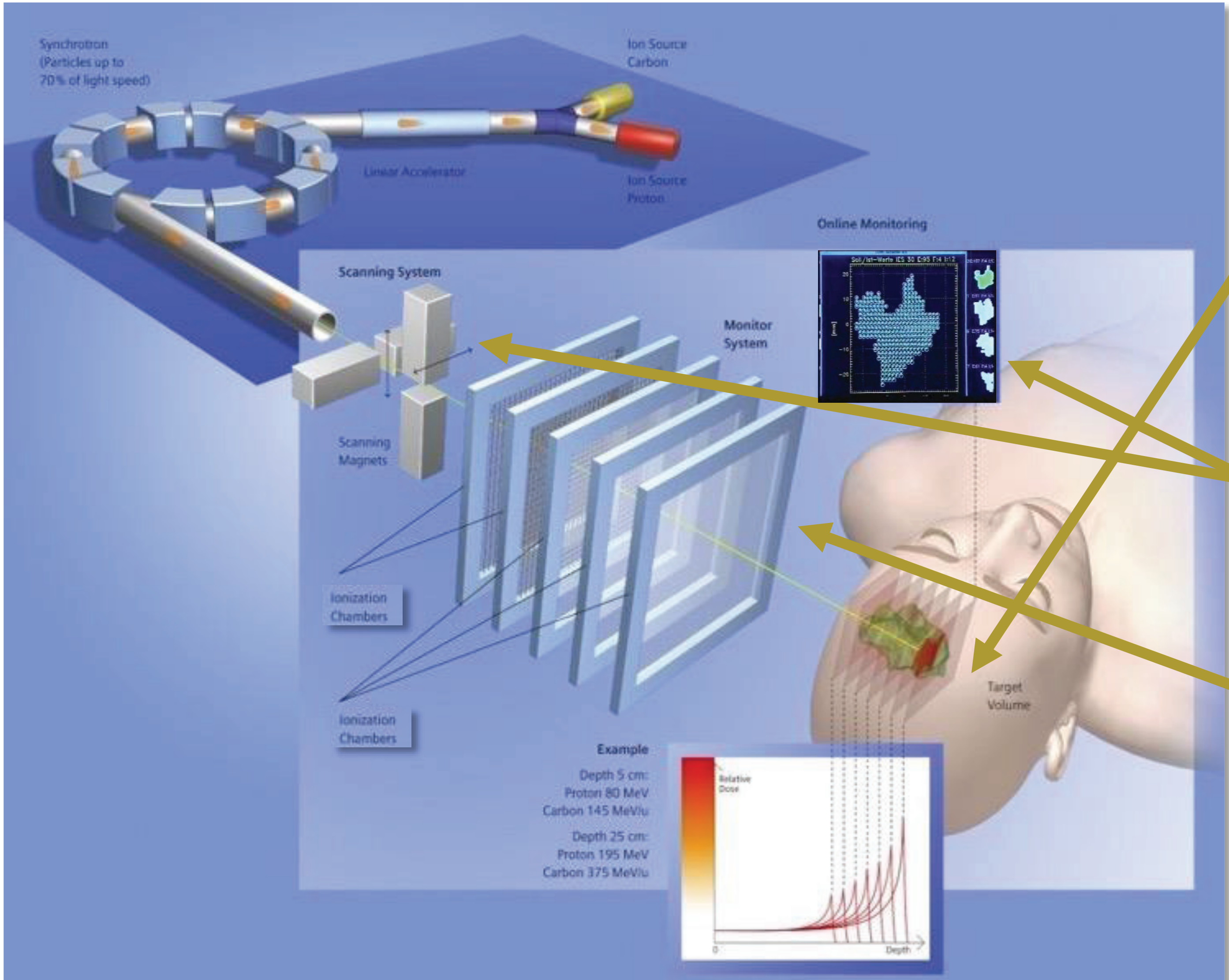
Beam to 3 treatment & 1 research rooms



PATIENT ROOM

Patient positioning in the sub-millimeter scale

BEAM CONTROL



Active

Energy selection (Penetration depth)

Active

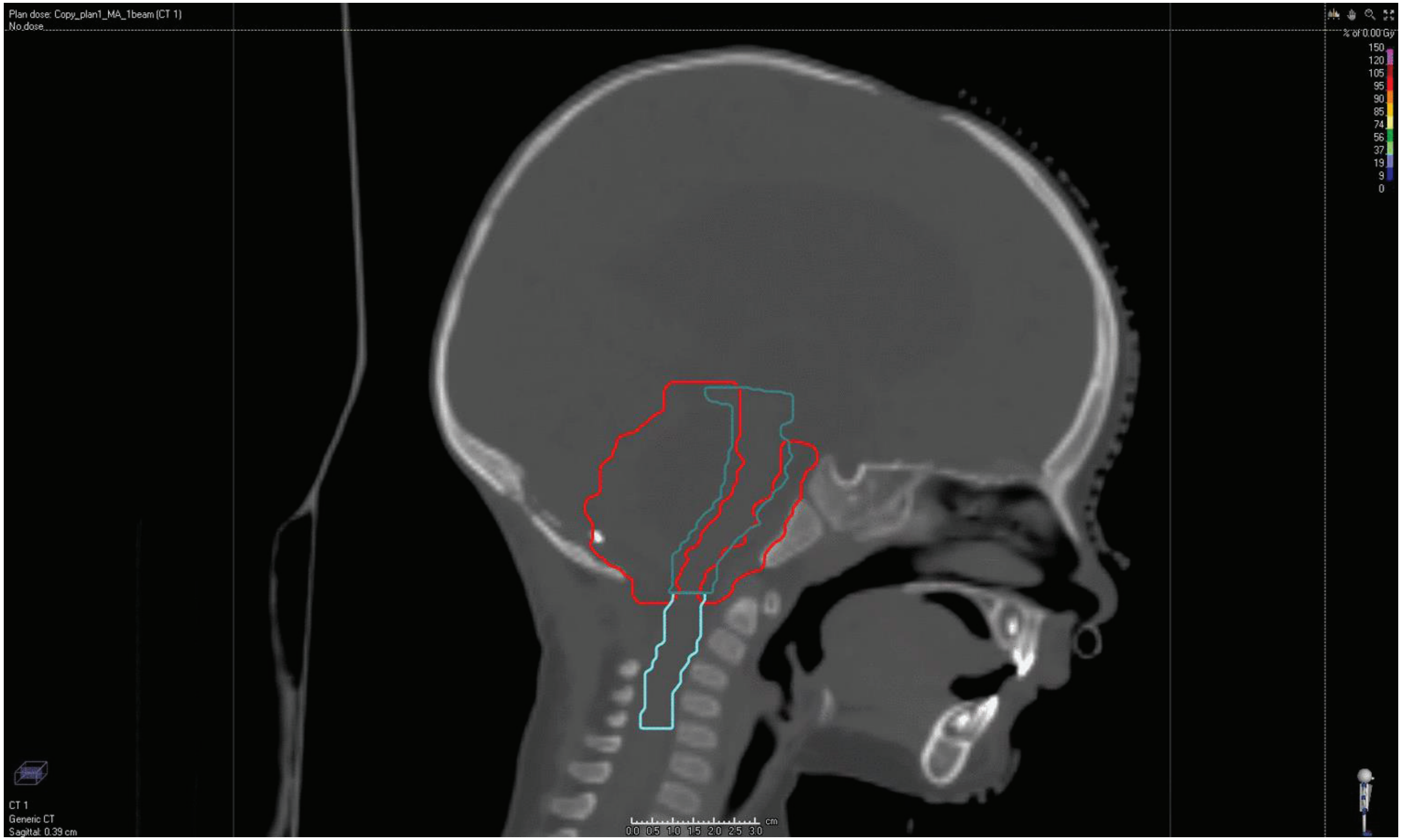
Transverse scanning

Online

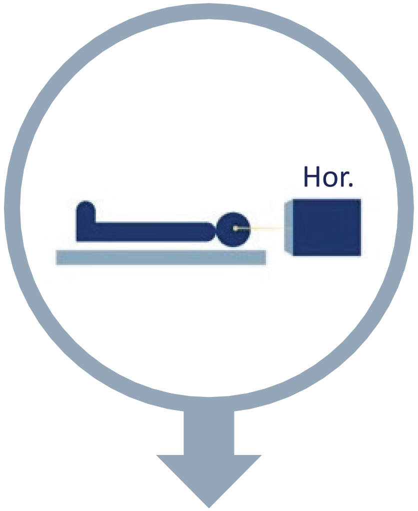
Monitoring of beam parameters

DELIVERY TECHNIQUES

ACTIVE ENERGY MODULATION



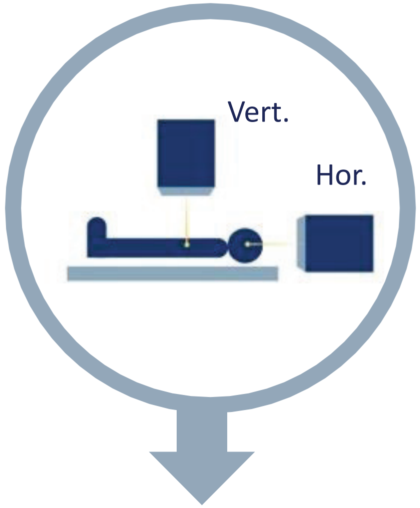
ROOMS & MODALITIES
STATUS



1 Room
Horizontal

p

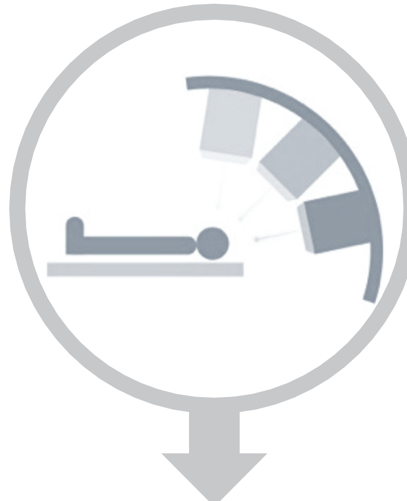
C → 2020



1 Room
Horizontal & Vertical

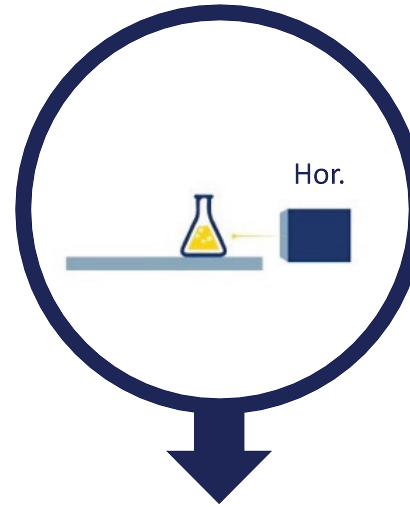
p C → Jul 2019

C → 2020



1 Room
Rotational Gantry

P



1 Research Room

p

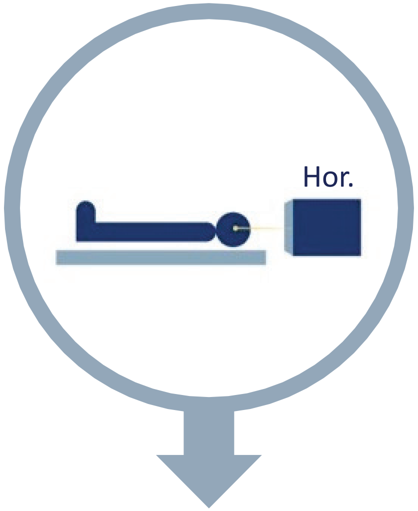
C P_{800} → 2019

Dates when room/particle will be operational

Patient Treatment

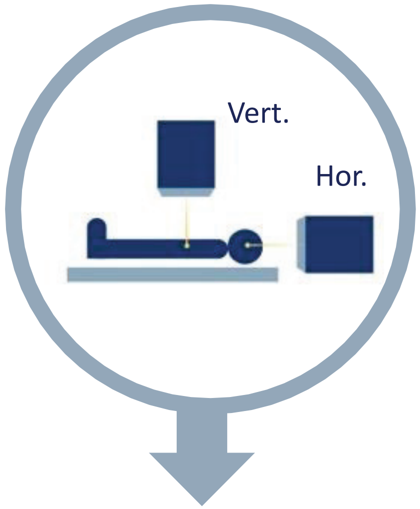
Research

ROOMS & MODALITIES IN FULL OPERATION



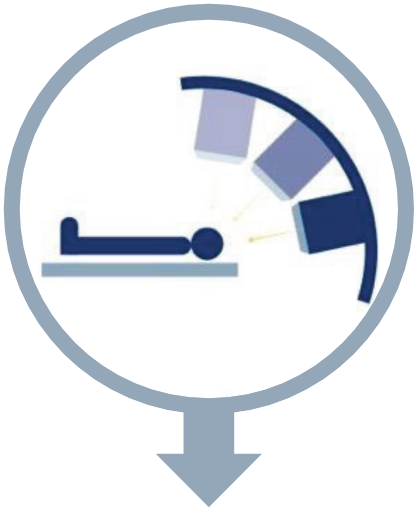
1 Room
Horizontal

p C



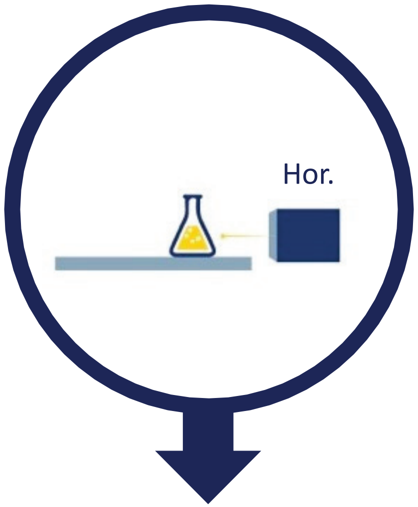
1 Room
Horizontal & Vertical

p C



1 Room
Rotational Gantry

p



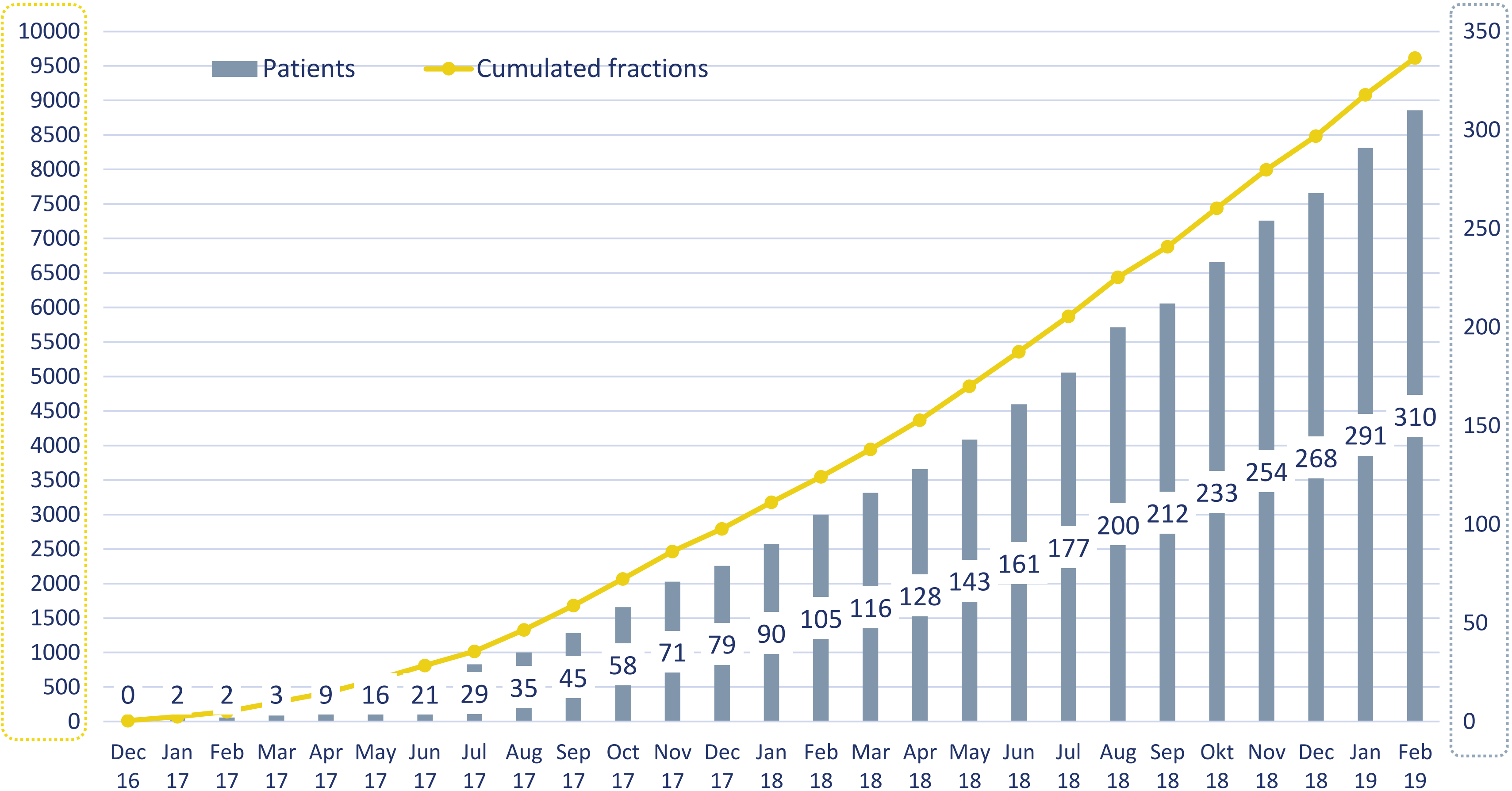
1 Research Room

p C

Patient Treatment **Research**

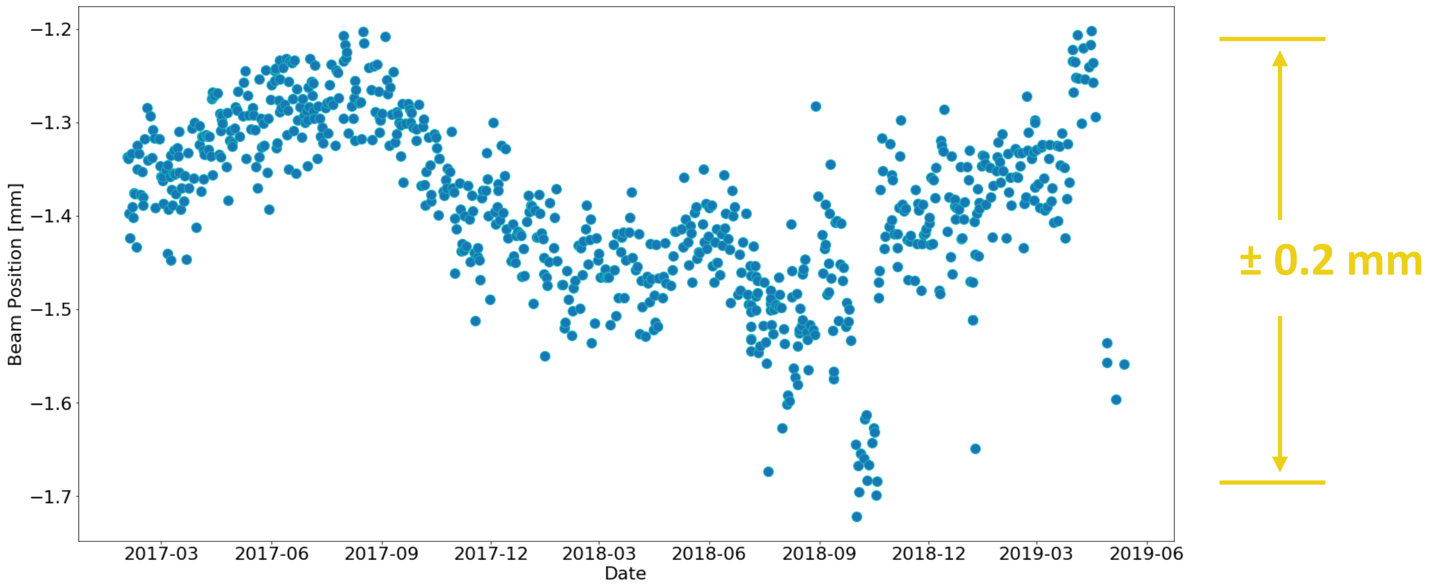
PATIENTS TREATMENT
ACTUAL

- 30 patients / day: protons in 2 irradiation rooms
- > 310 patients treated, applied 10,000 individual fractions
- Goal in full operation: > 1000 patients/year



MACHINE STABILITY AND ROBUSTNESS

- High machine stability:
  - Rigorous internal process for changes implementation
  - Magnetization cycles & Field stabilization under control
  - 2 × Quality Assurance daily



Hor. Proton Beam position at BPM, monitored > 2 years: ±0.2mm

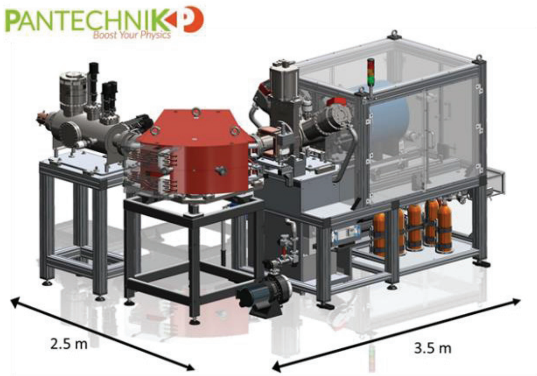
REQUIREMENTS ON CARBON ION BEAM FOR CLINICAL TREATMENT

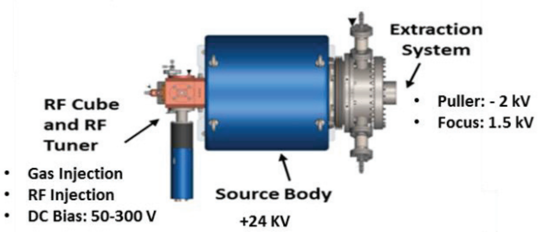
Main Parameters	Requirement
Penetration depth in water "Range"	30 - 270 mm
Beam Energy*	120-400 MeV/n
Beam size	6 - 10 mm
Beam size symmetry	± 10%
Beam alignment precision	< 500 μm
Intra-beam Bragg peak variation	< 300 μm

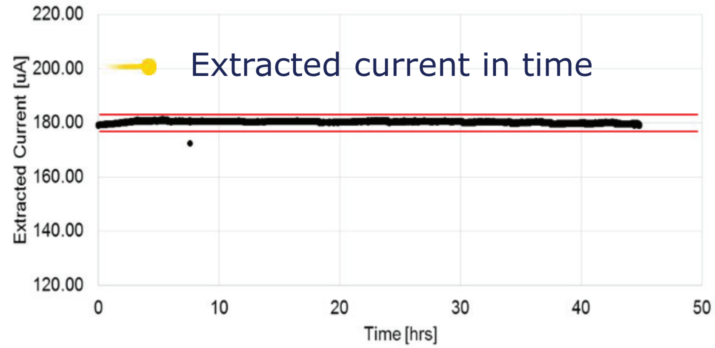
*Energy ≡ Penetration depth in water

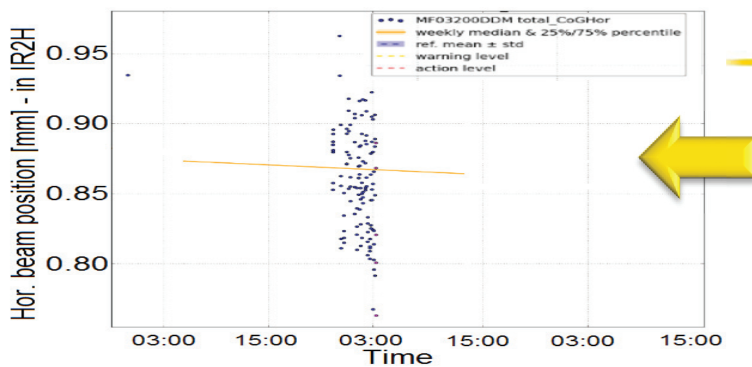
- Must meet requirements at 2 "iso-centers": design and -50cm (!)

CARBON COMMISSIONING: ION SOURCE 2



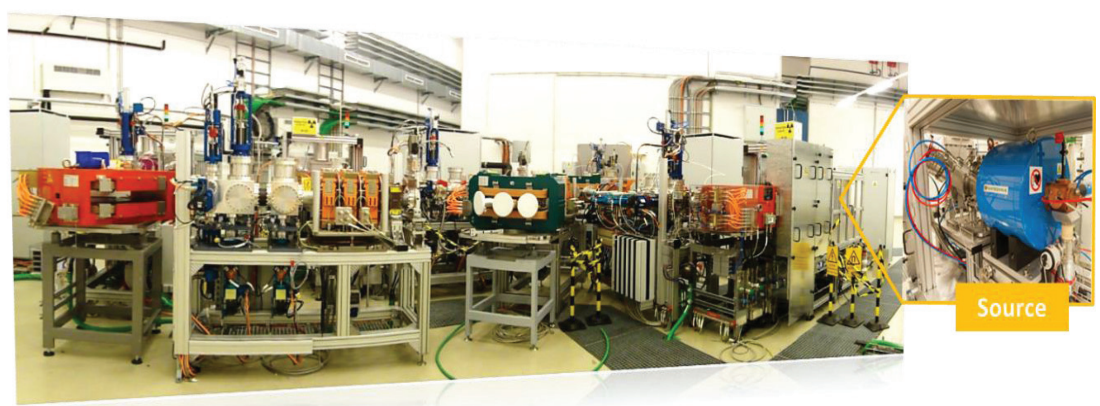






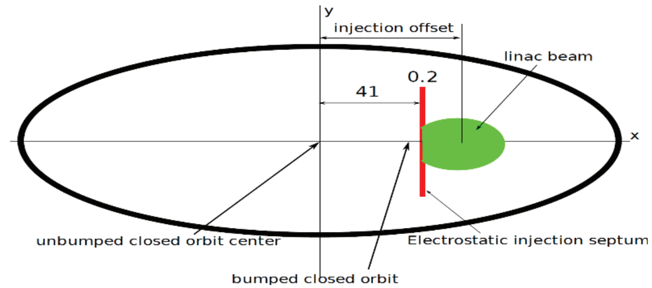
- Successful carbon ion source commissioning in terms of extracted beam intensity and stability
- RF power variation over full operating range: → ±0.1mm at room iso-center

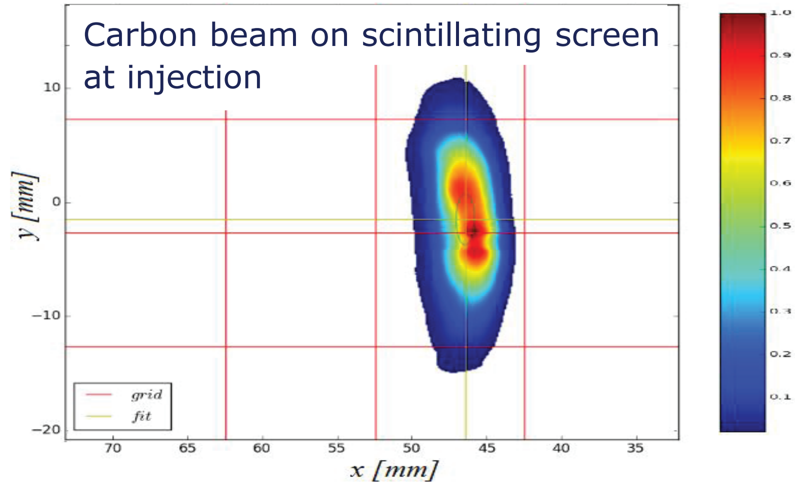
Typ. Parameters	H^+ Source	C^{4+} Source
RF Frequency (GHz)	14.451	14.455
RF Power (W)	8-10	100-200
B_{ECR} (T)	0.5	0.5
Gas Mix	H_2	CO_2+He
Ex. current	670 uA	150 uA

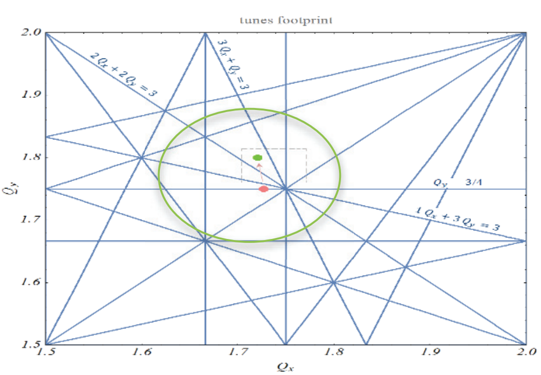


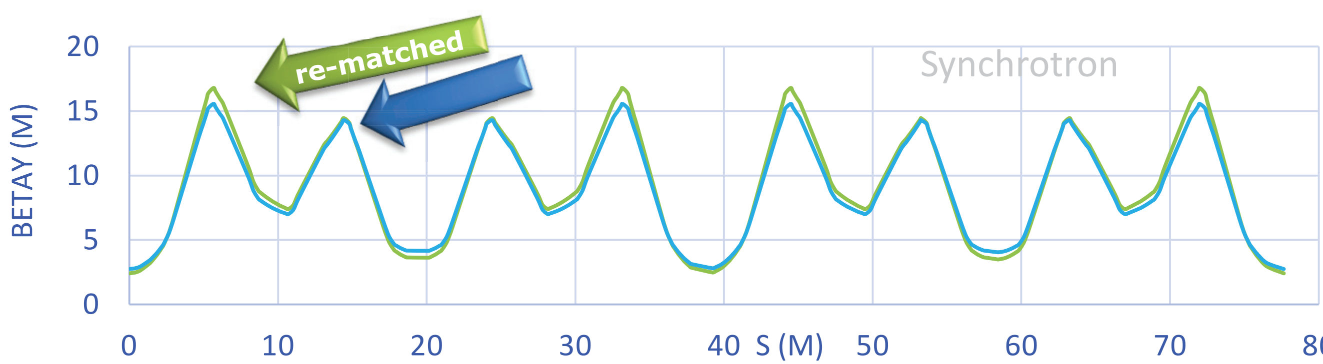
MULTI-TURN INJECTION INTO SYNCHROTRON

- Multi-turn injection painting in the Hor. plane
- Inject 26us beam pulse (13 turns) during 80us decay time of synchrotron correctors bump
- Multi-parameter space (ESI, MST, H & V corr., Pulse, Bump) optimization for beam intensity [1.5e9 ions] & Hor. emittance [at design]
- Initially large Vert. emit: moving tunes working point & re-matching synchrotron to injector optics reduced Vert. emittance by a factor ~4

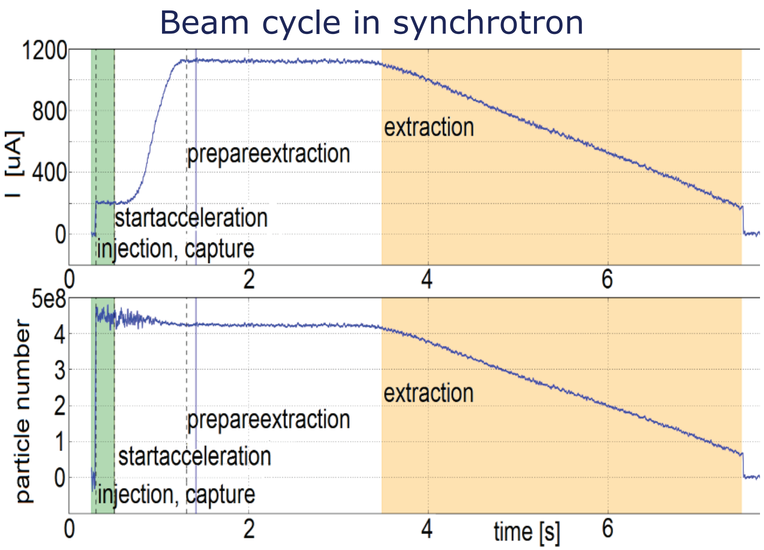






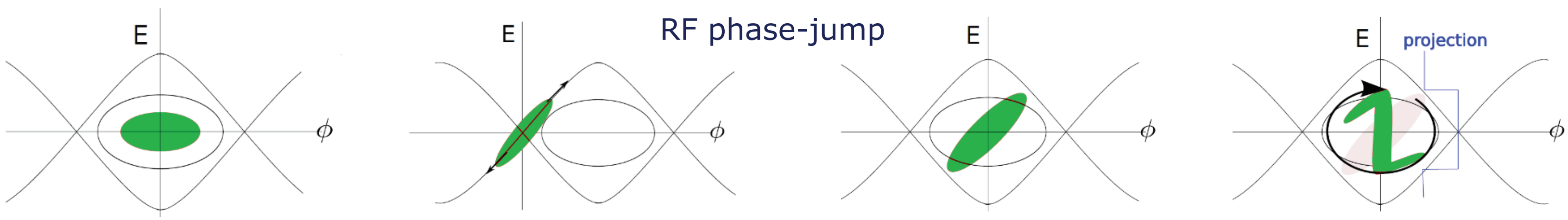


MAIN RING: RF CAPTURE ACCELERATION AND RF PHASE JUMP



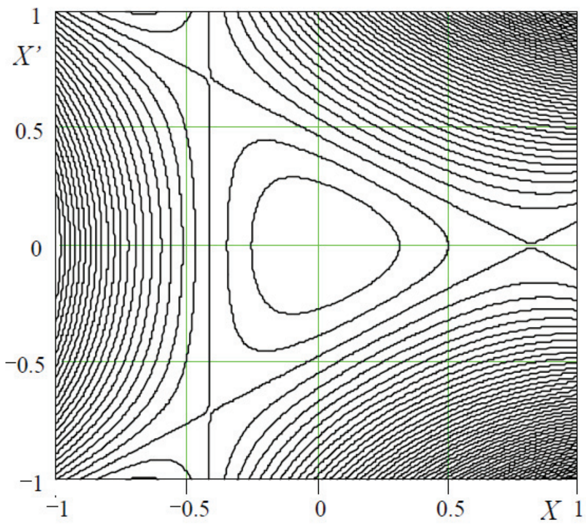
Transmission efficiencies			
Particle Type	LINAC	Injection	Acceleration
Proton	43%	27%	79%
Carbon	60%	32%	95%

- Beam injected and kept at +20 mm from closed orbit
- RF capture & acceleration at rate ~3 T/s up to 400 MeV/n with small beam losses.
- Carbon beam stable during ramp: "Btrain" not necessary (Bfield info → to synchrotron RF).
- Up to 2×10^9 carbon ions at flattop.
- RF phase-jump performed to elongate momentum spread to dp/p → 0.4%

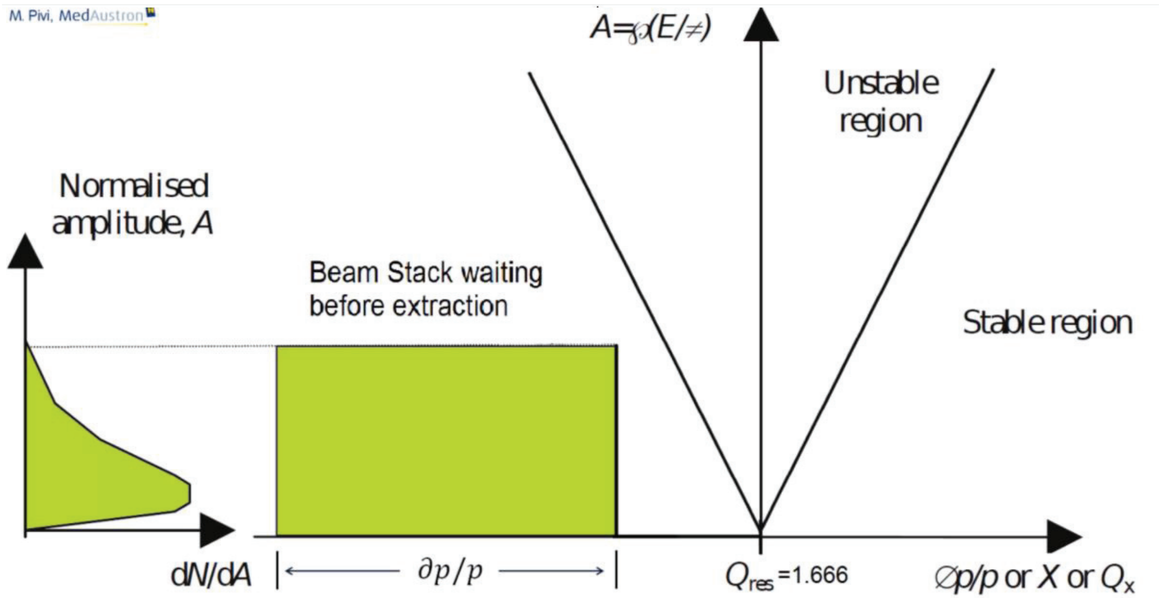


0. matched to bucket 1. phase jump + dp/p elongation 2. Back to bucket 3. Rotation

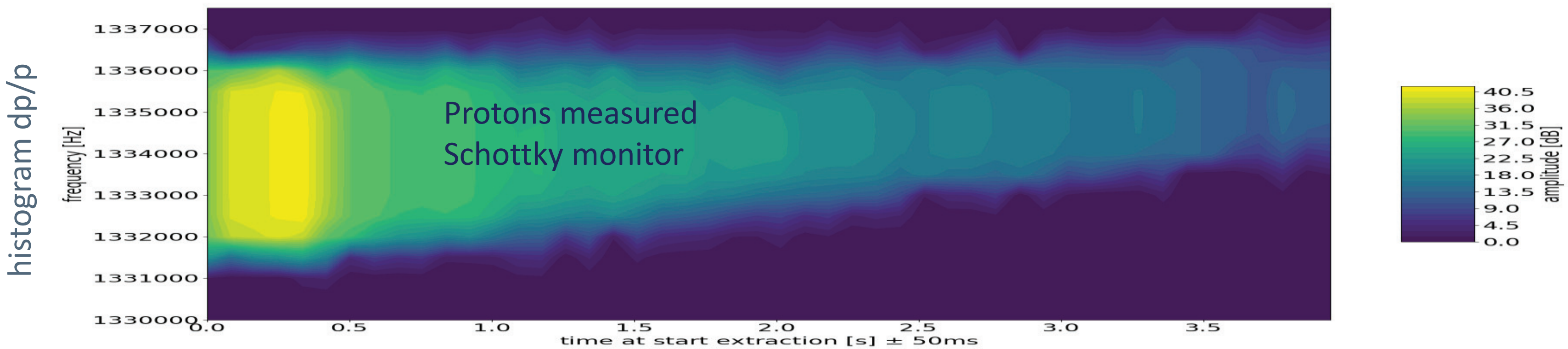
3RD ORDER RESONANCE SLOW EXTRACTION FROM SYNCHROTRON



Hor. phase space after resonance sextupole is turned ON

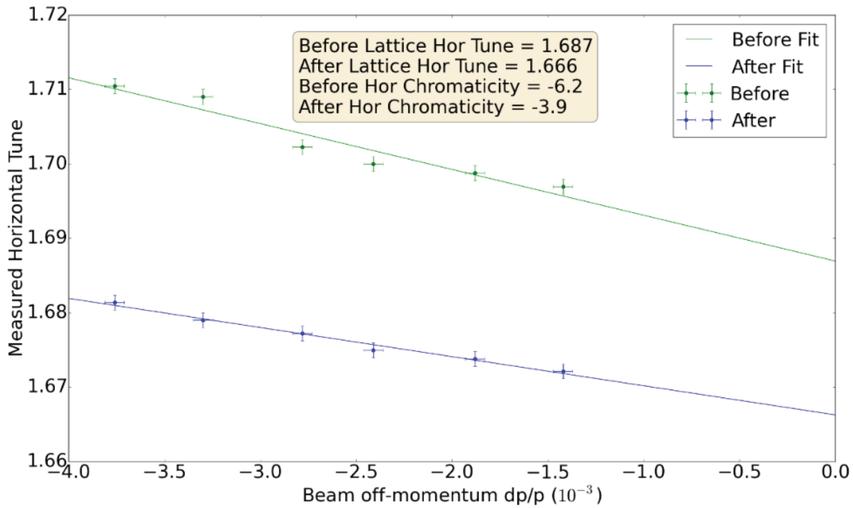


Slowly increase momentum spread to move beam into resonance Q_x=1.6666



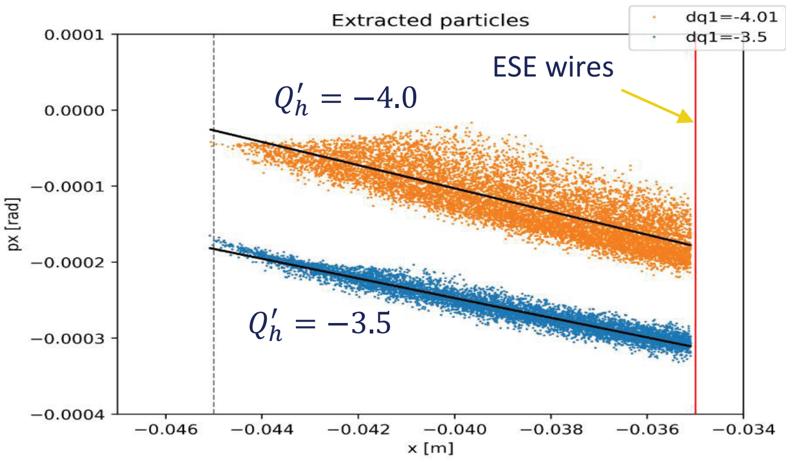
SLOW EXTRACTION: TUNE AND CHROMATICITY

- Precise control of tune and chromaticity via Response Matrix for optimal extraction
- Horizontal chromaticity for optimal extracted intensity



- Measured tune and chromaticity before/after optimization

- Simulated extraction for different Chromaticities



- Tune & Chromaticity Response Matrix

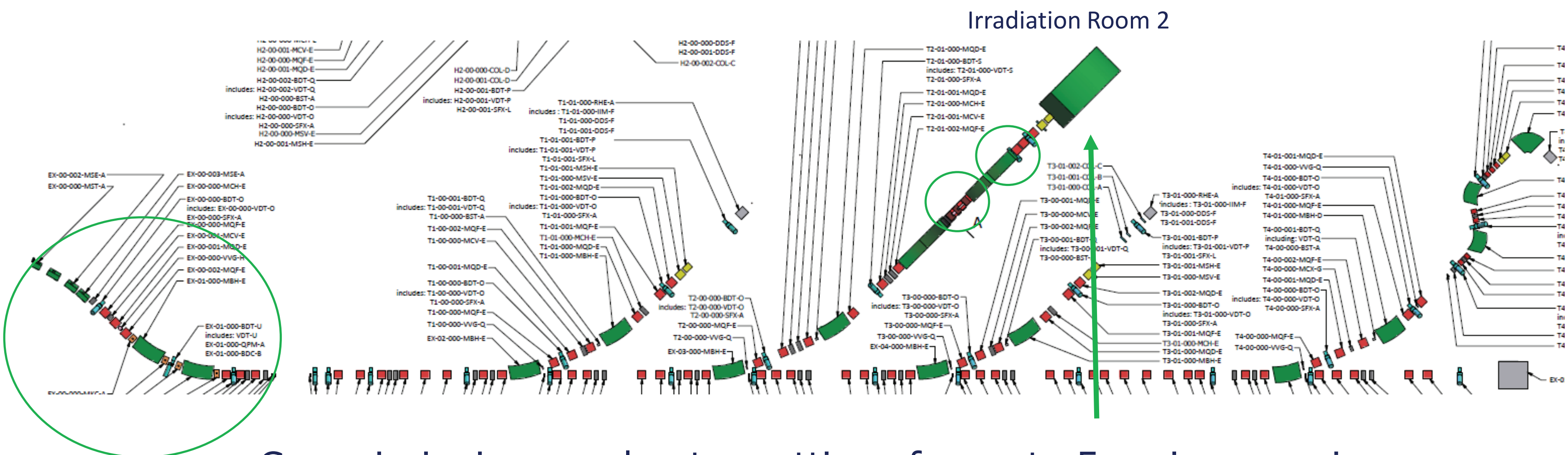
$$Q_h = Q_{h0} + \frac{\partial Q_h}{\partial K1_{MQF1}} \Delta K1_{MQF1} + \frac{\partial Q_h}{\partial K1_{MQD}} \Delta K1_{MQD} + \frac{\partial Q_h}{\partial K1_{MQF2}} \Delta K1_{MQF2}$$

$$Q_v = Q_{v0} + \frac{\partial Q_v}{\partial K1_{MQF1}} \Delta K1_{MQF1} + \frac{\partial Q_v}{\partial K1_{MQD}} \Delta K1_{MQD} + \frac{\partial Q_v}{\partial K1_{MQF2}} \Delta K1_{MQF2}$$

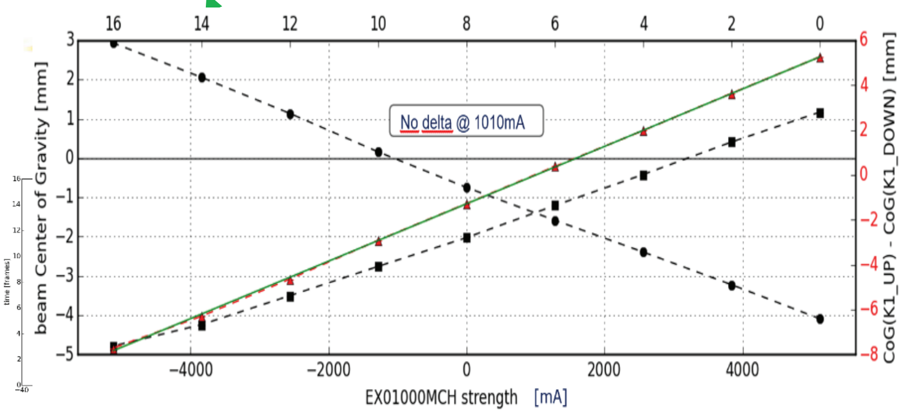
$$Q'_h = Q'_{h0} + \frac{\partial Q'_h}{\partial K2_{MXF}} \Delta K2_{MXF} + \frac{\partial Q'_h}{\partial K2_{MXD}} \Delta K2_{MXD}$$

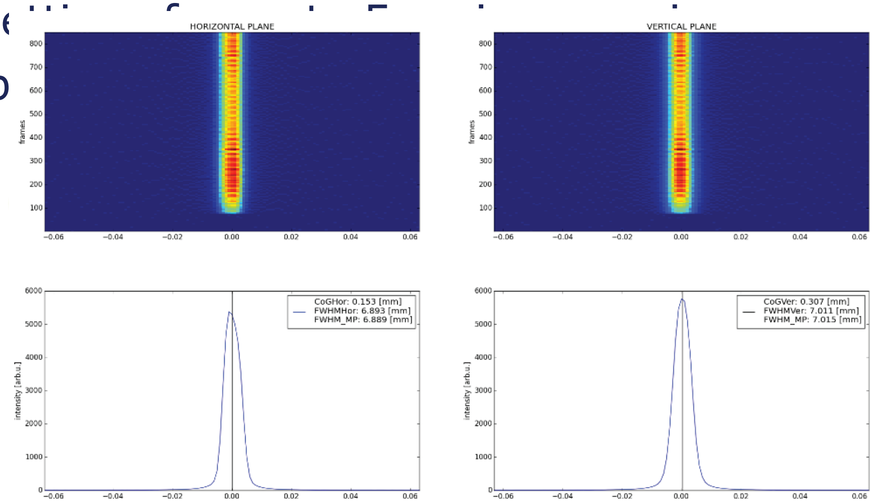
$$Q'_v = Q'_{v0} + \frac{\partial Q'_v}{\partial K2_{MXF}} \Delta K2_{MXF} + \frac{\partial Q'_v}{\partial K2_{MXD}} \Delta K2_{MXD}$$

HIGH ENERGY TRANSFER LINE



- Commissioning accelerator se





CLINICAL TREATMENT REQUIREMENTS ON CARBON

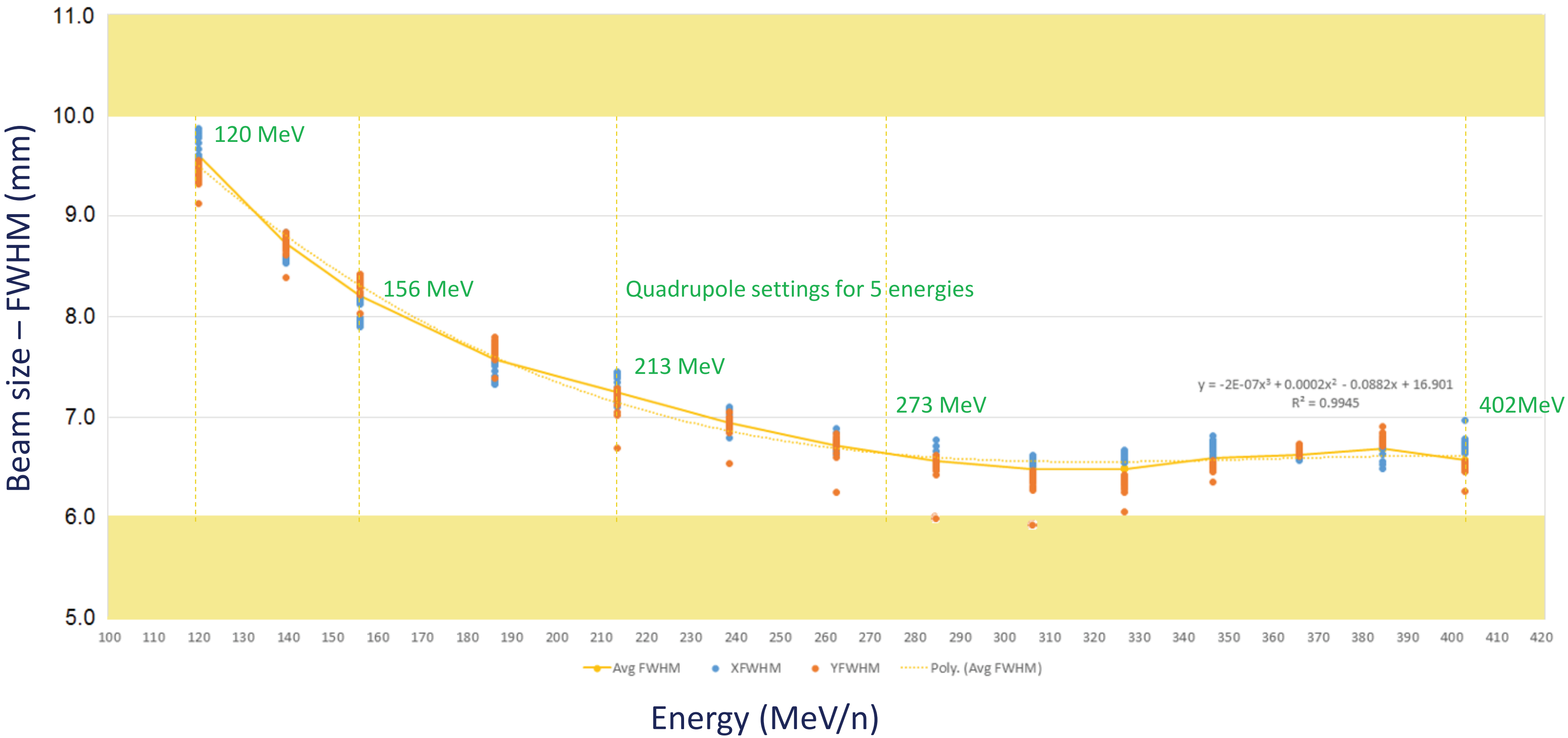
Parameter	Requirement
Energy*	120 - 400 MeV/n
Penetration depth in water "Range"	30 - 270 mm
Beam spot size	6 - 10 mm
Beam symmetry	± 10%
Beam position	< 500 µm
Bragg Peak variation intrabeam	< 300 µm

*Energy ≡ Penetration depth in water

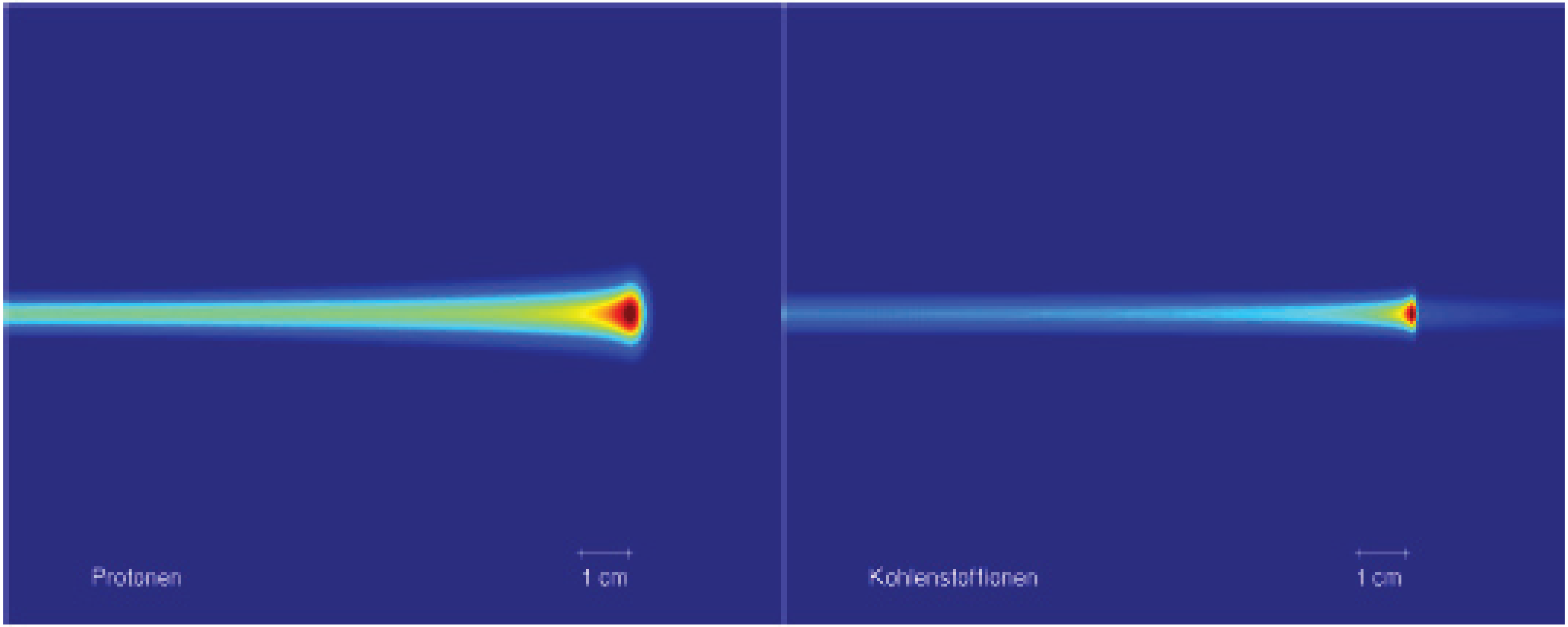
- Met requirements at 2 "iso-centers": design and -50cm

MEDICAL PHYSICS ACCEPTANCE: BEAM SIZE

- Size as function of energy at isocenter

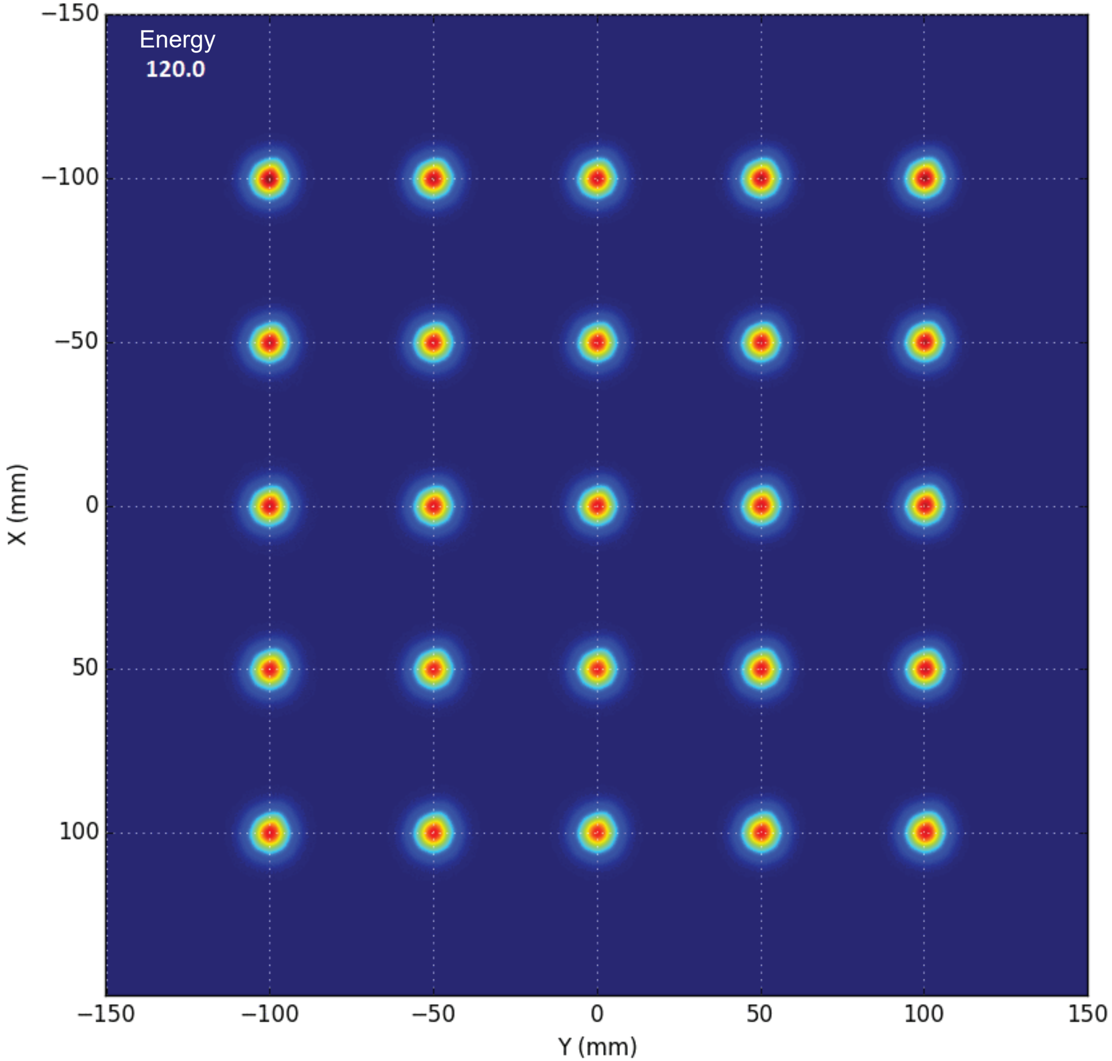


SINGLE PB PROTONS VS CARBONS



Slide courtesy Markus Stock, Medical Physics

ACCEPTANCE: SPOT MAP @ ISO-CENTER

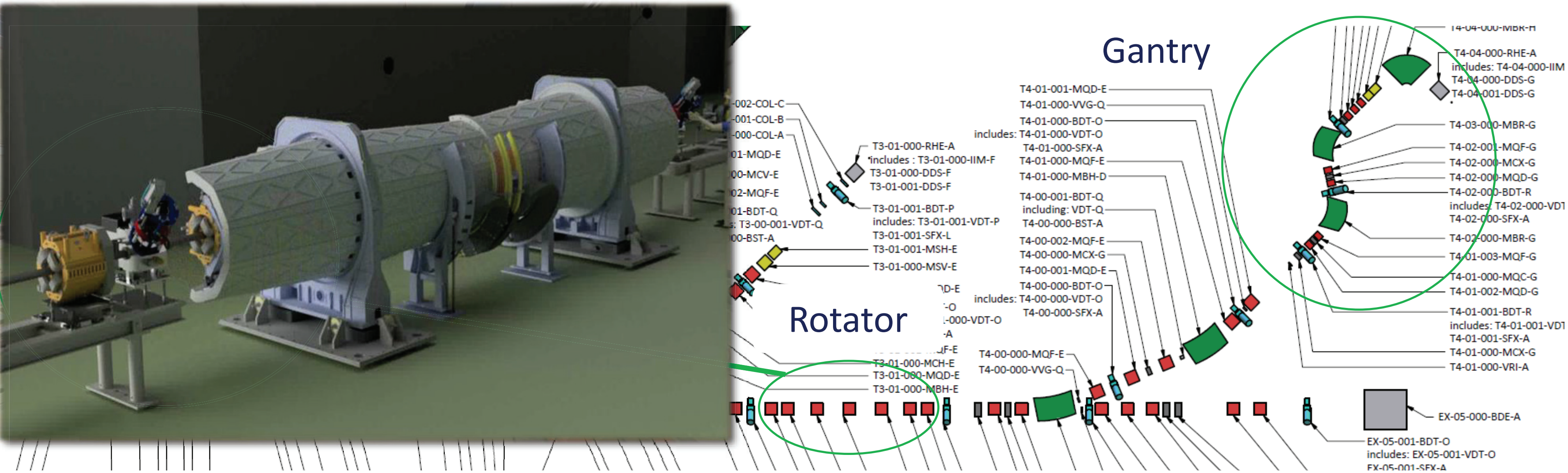


Slide courtesy Markus Stock, Medical Physics

GANTRY & ROOM 4

Proton beam line rotation 210 degree

THE ROTATOR: A NEW OPTICS CONCEPT



- The rotator is a 1:1 module of 7 quadrupoles, which are physically rotated <u>by half</u> of the Gantry rotation angle
- To match the optics into the rotated coordinate system of the Gantry
- The optics inside Gantry is independent of the Gantry rotation angle

Collaborators: M. Pullia, CNAO and M. Pavlovic, Bratislava University

BUILDING A NEW FACILITY

SUMMARY

- MedAustron is a synchrotron based center for ion therapy for cancer treatment and research, one out of six centers in the World
- Presently 30 patients/day treated with protons
- Provider of ion beams for research purposes
- Completed beam commissioning with Carbon for the first beam line. Operative in July
- Ongoing Carbon and proton 800 MeV commissioning for all other beam lines
- Next, Gantry beam line commissioning
- Same MedAustron facility being built in Iran

BEAM COMMISSIONING TEAM MEDAUSTRON