NHa NORMANDY HADRONTHERAPY

Projet C400 IONS chez CYCLHAD : du virtuel à la réalité

Laurent Maunoury

05/10/2023

Disclaimer

PROPRIETARY INFORMATION

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Due to a continuous research and development program and due to the fact that the Heavy Ion system is under development, IBA and NHa cannot provide a guarantee that every technical specifications given in this document will be in accordance with the developed product. IBA and NHa reserve the right to make changes in design, technical descriptions and specifications of its products without prior notice. The Heavy Ion system is also subject to review by competent authorities (FDA, notified bodies, etc.).

Introducing NHa…

Normandy Hadrontherapy (NHa) located in Caen, France

- 2 main shareholders: **IBA** & **SAPHYN** (Normandy Region).
- Several other industrial and institutional partners joined the project

Owning about **40%** of the shares, **IBA** is:

- (i) the largest equity stakeholder
- (ii) industrial shareholder of NHa.

- Accelerators technology is in IBA DNA
- Design of the C400 heavy ion cyclotron (Based on IBA design – Transfer of IP)
- All the other element(s) of the treatment rooms (IGPT, workflow and integration) using IBA technology
- Largest equity shareholder of NHa and authorized partner to market the new heavy ion system

- Design, produce and market C400 IONS system
- Build a multiple heavy ions particle Radiation Oncology department in Caen with research capacity (Biology and Physics)
- Supported by the Normandy Region (French state) already hosting GANIL to become a leading European center for research and treatment in hadrontherapy

sfpi fpim VINCI Colombe Investment GROUPE TREUIL ÉFINOR SRIW INVESTMENT & GROWTH SIGMAPHI ACCELERATOR TECHNOLOGIES iba RÉGION NORMANDIE Saphyn NORMANDIE SANTÉ

NHa NORMANDY HADRONTHERAPY

Design, produce and market the ion therapy system

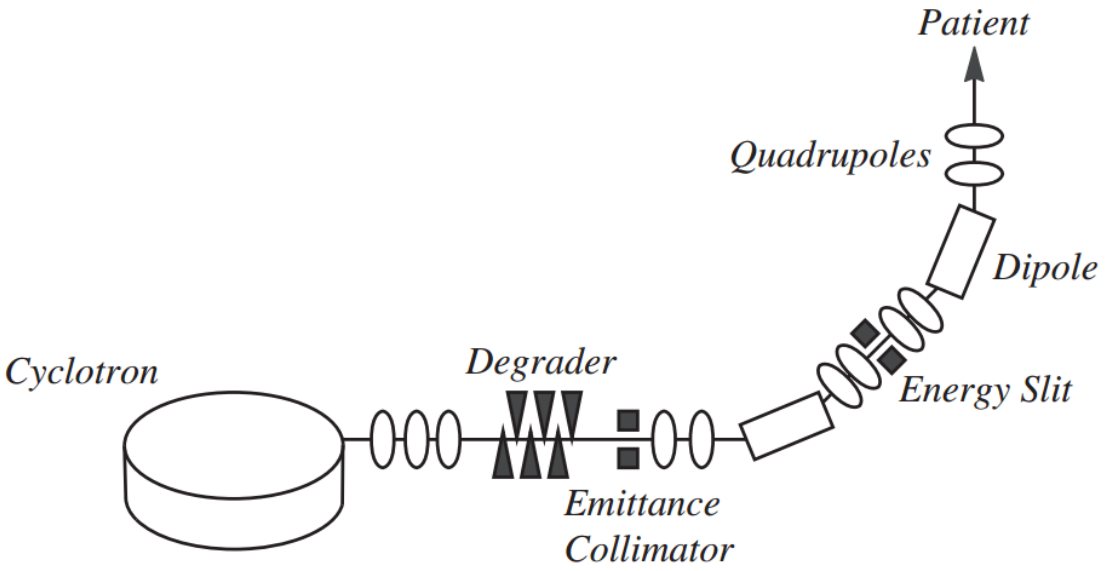
Currently	2023 => 20 employees
Forseen	2024 => 31 employees

The C400 IONS project

Bring all the advantages of the cyclotron-based clinical treatment to hadrontherapy, starting with Carbon and Helium beams

Strong points of cyclotrons technology:

- Continuous beam
  - Easier beam delivery
- Compact layout
- Simple system
  - Less equipment, complex magnet, no injector, etc.
- Cost efficient
- High beam current
  - Interesting opportunity for FLASH and minibeams
- Easy to maintain
  - expect ~15 technicians for site maintenance (3 rooms)
- Technology very well known and mastered
  - C400 developed in close collaboration with IBA (~50% of installed cyclotron-based PT centers worldwide)



First site: CYCLHAD (Caen, France)

Building ready to host the system: cyclotron, injection line, dependencies, etc.

Cyclotron vault

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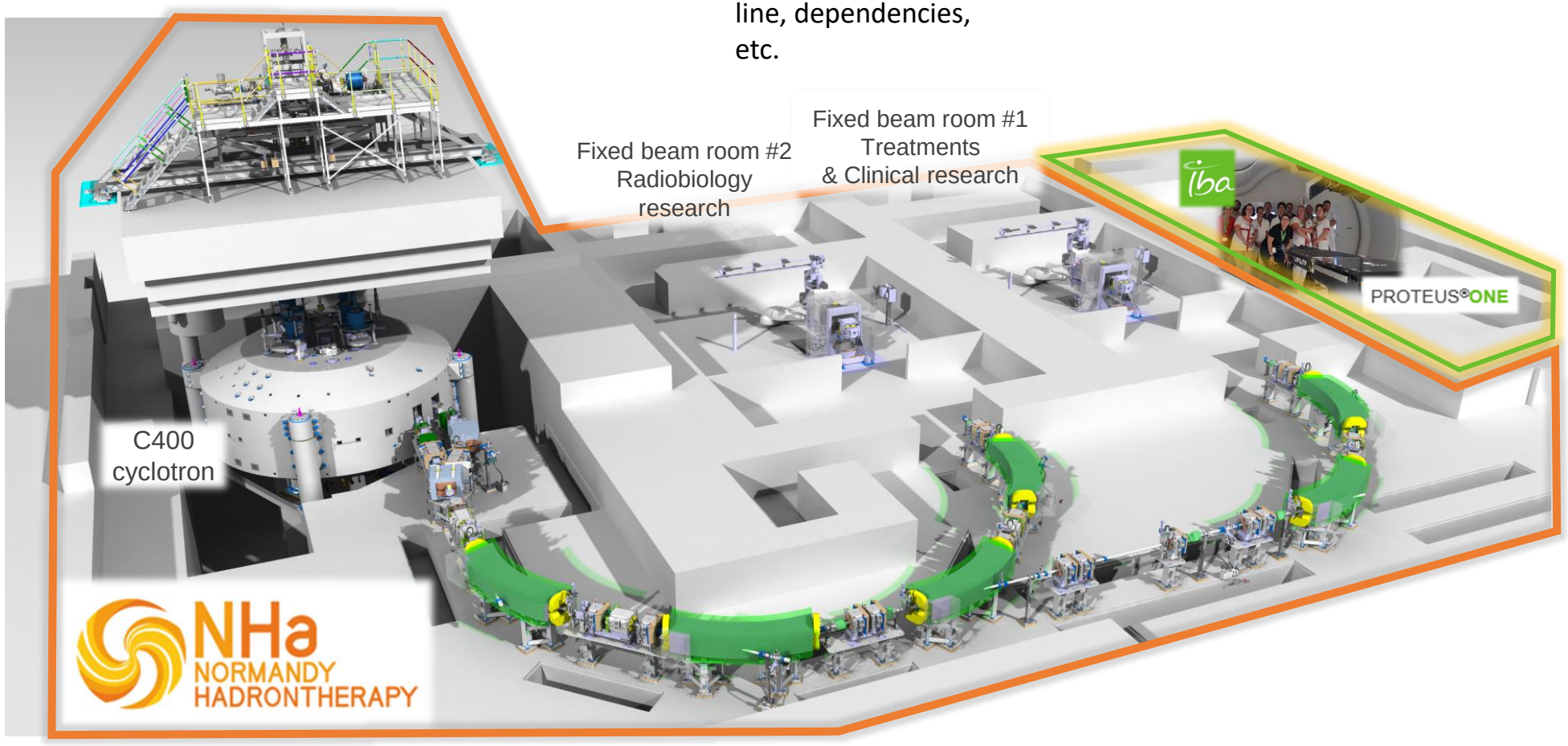
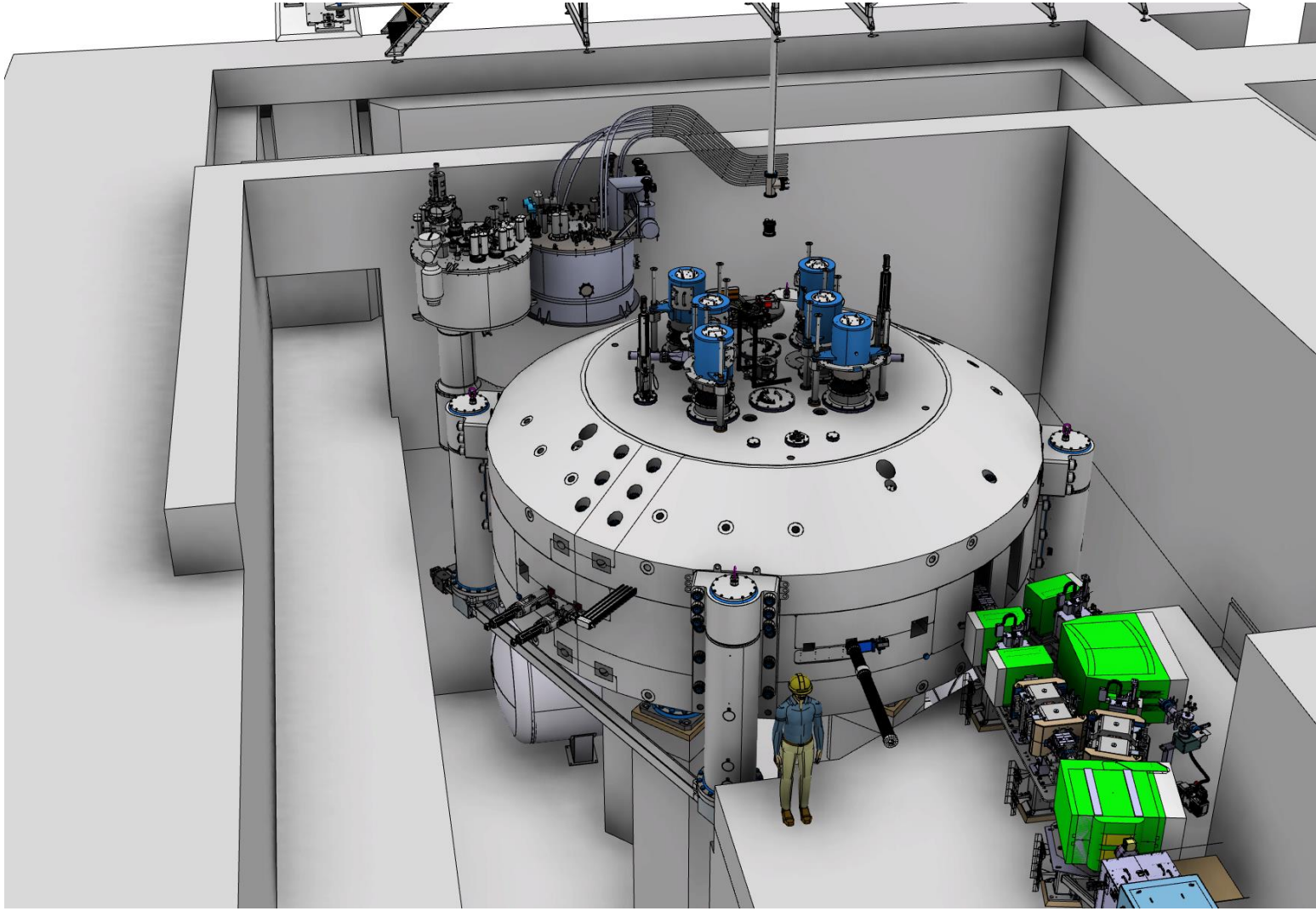


Overview of the C400 cyclotron

Main technical features:



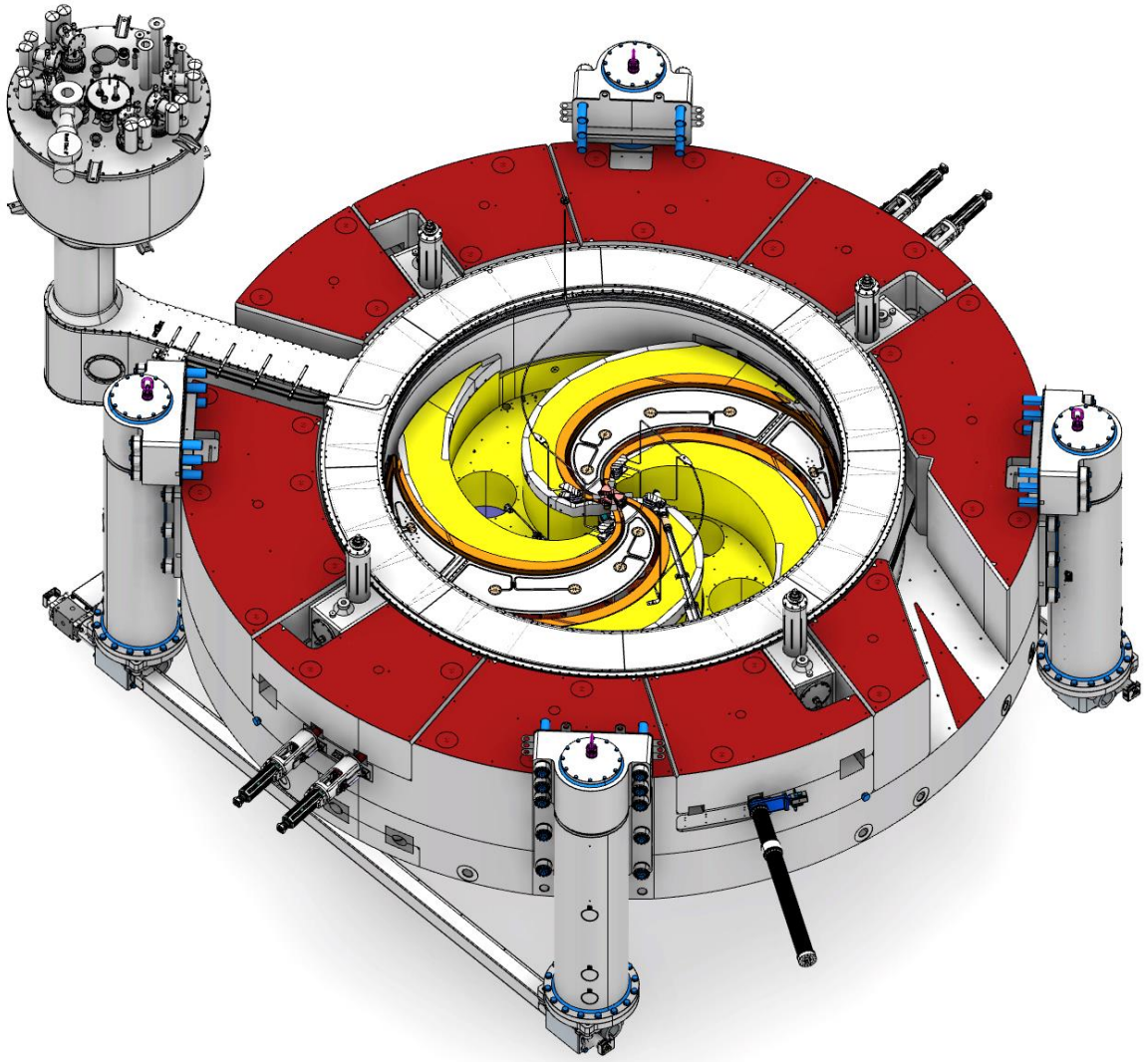
Overview of the C400 cyclotron

Main technical features:

- **"Compact" magnet**

  740 Tons – 7m diameter yoke - pole radius 1.87m
  pole is 4-fold symmetry / Elliptical gap / Spiralized poles
  can accelerate q/m = ½ particles

- **RF: 75MHz for $^{12}C^{6+}$, 75.6MHz for H_2^+, Harmonic #4**



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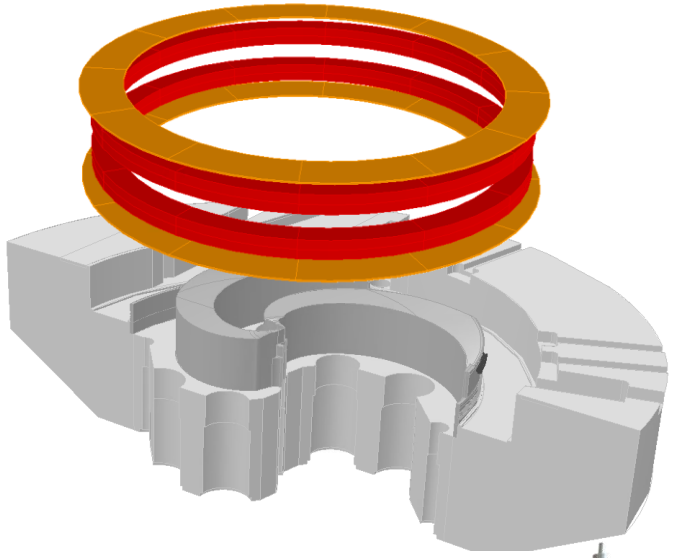
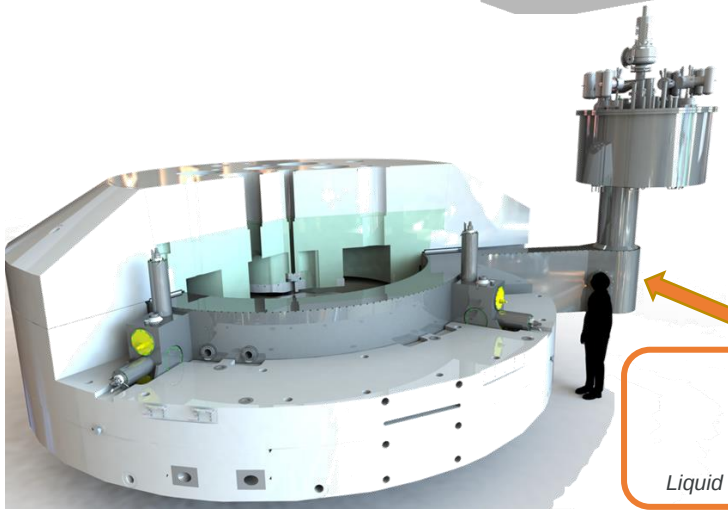
- **Cryogenic coils**
  - **max field 4.5T**
  - **coils in liquid He bath**
  - **2 sub-coils/coil to adapt field to particle masses discrepancies.**





Coils

Ramping time : 2 hours

Time to switch between particles : < 15 min

Stored energy: ~55.6 MJ

turns per coil : 1344

Supra material : NbTi

Critical current: 2800 A @ 4,5 T @ 4,2 K

Cryostat

Outer diameter: 4.8m

Liquid helium bath T°: 4.3 K

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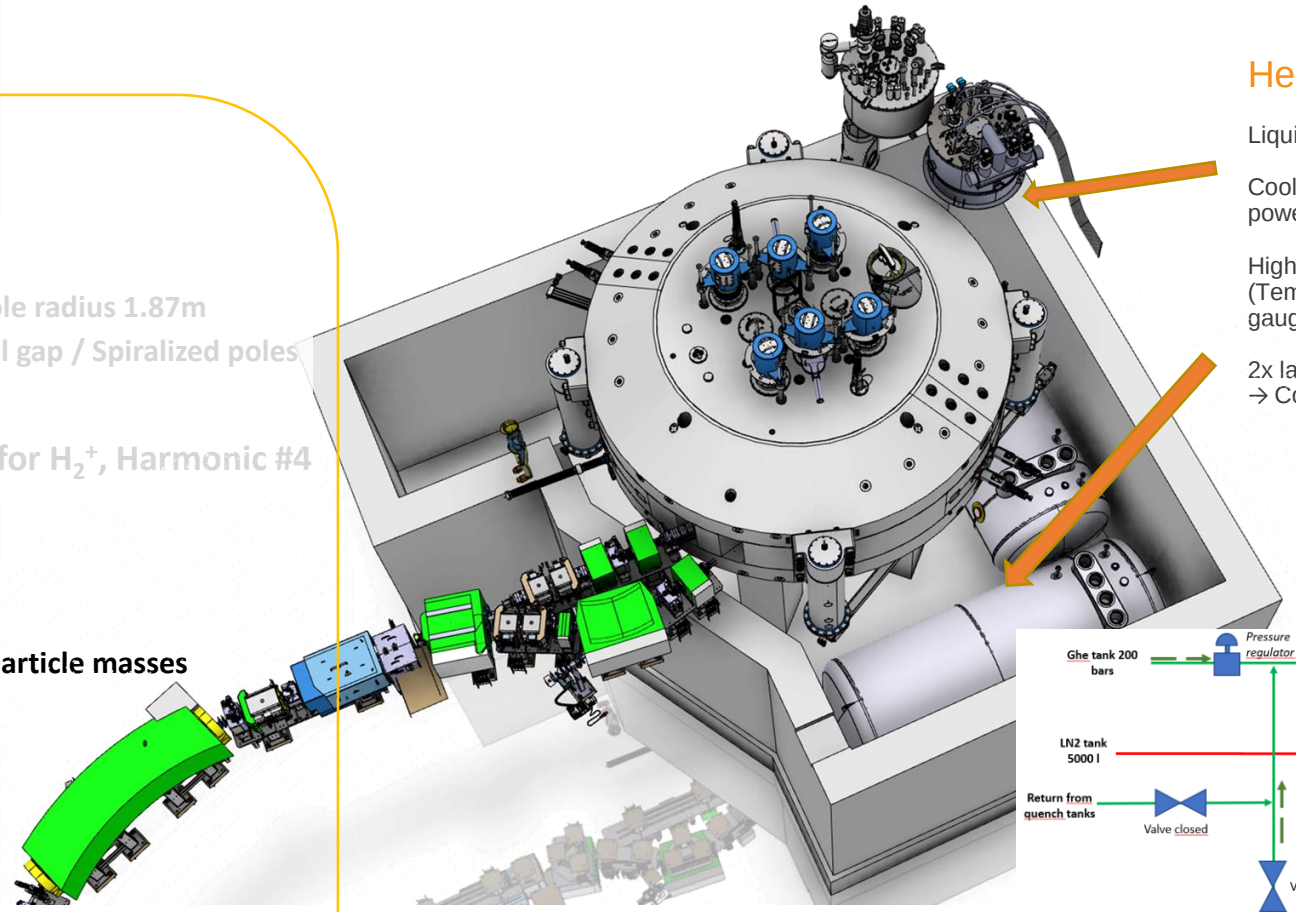


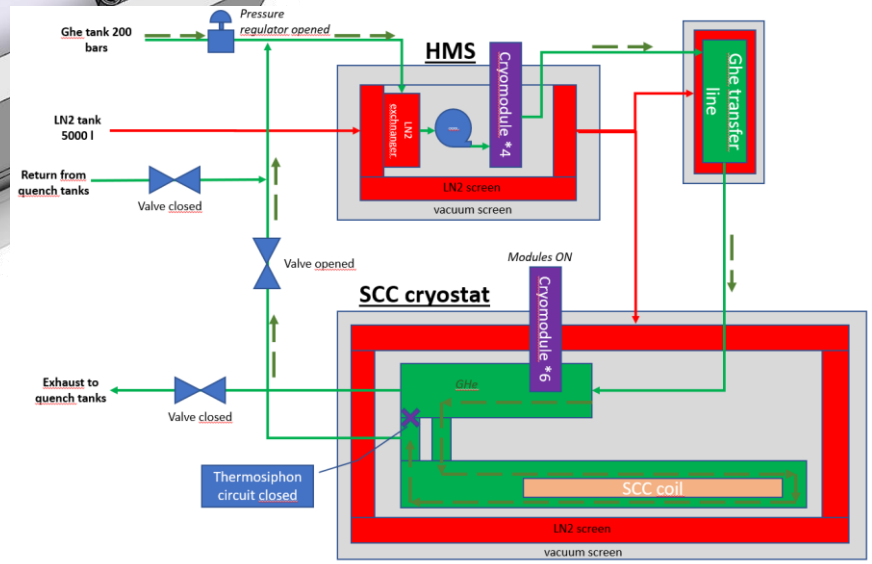
Helium Management System

Liquid helium thermosyphon circulation system

Cooling power : 6 cryocoolers / 14 W cooling power @ 4.3 K

Highly instrumented for quench management (Temperatures / Voltages / pressures, strain gauges, quench heaters)

2x large tanks for complete He recovery
→ Cost saving and environment friendly



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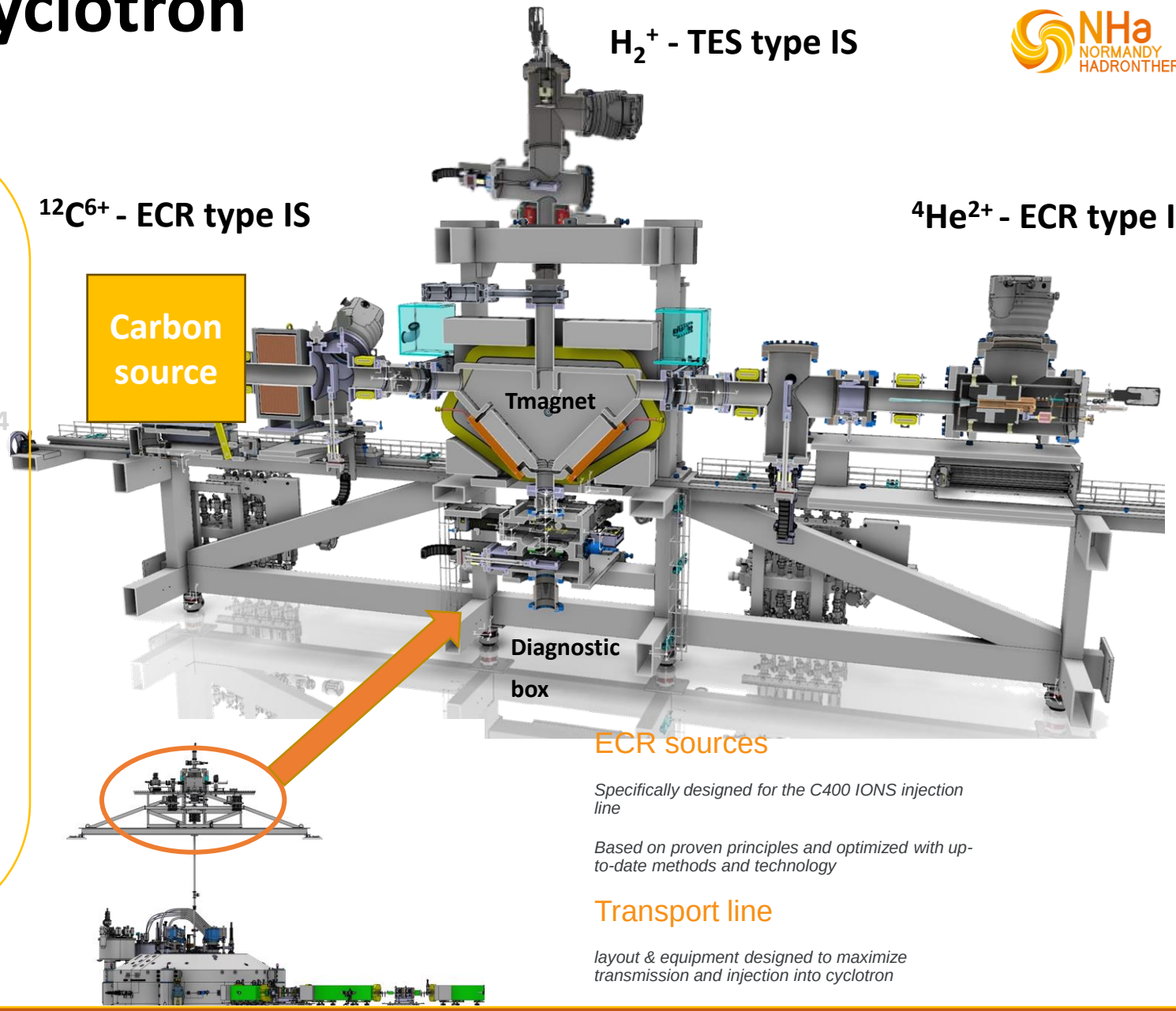
  - 3 sources: H_2^+, $^4He^{2+}$ & $^{12}C^{6+}$
  - **Beam optics controls, buncher & diagnostics**



ECR sources

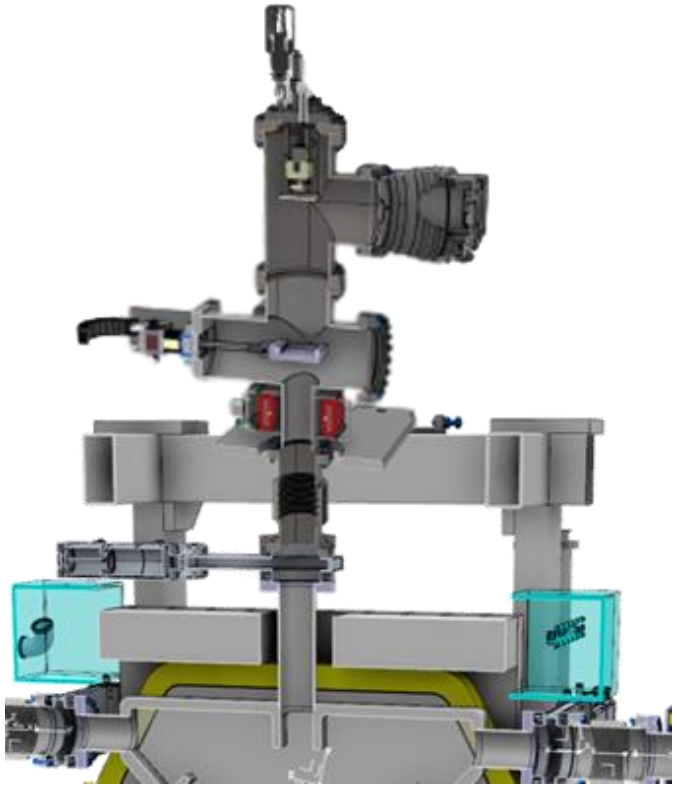
Specifically designed for the C400 IONS injection line

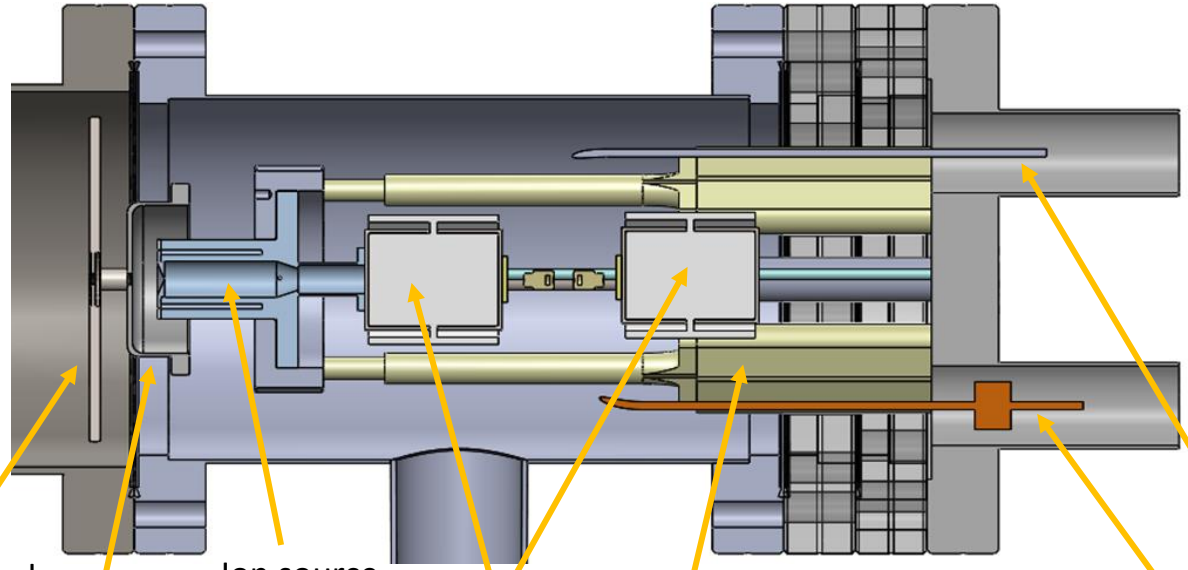
Based on proven principles and optimized with up-to-date methods and technology

Transport line

layout & equipment designed to maximize transmission and injection into cyclotron

TES - H_2^+





Grounded electrode

Focus electrode

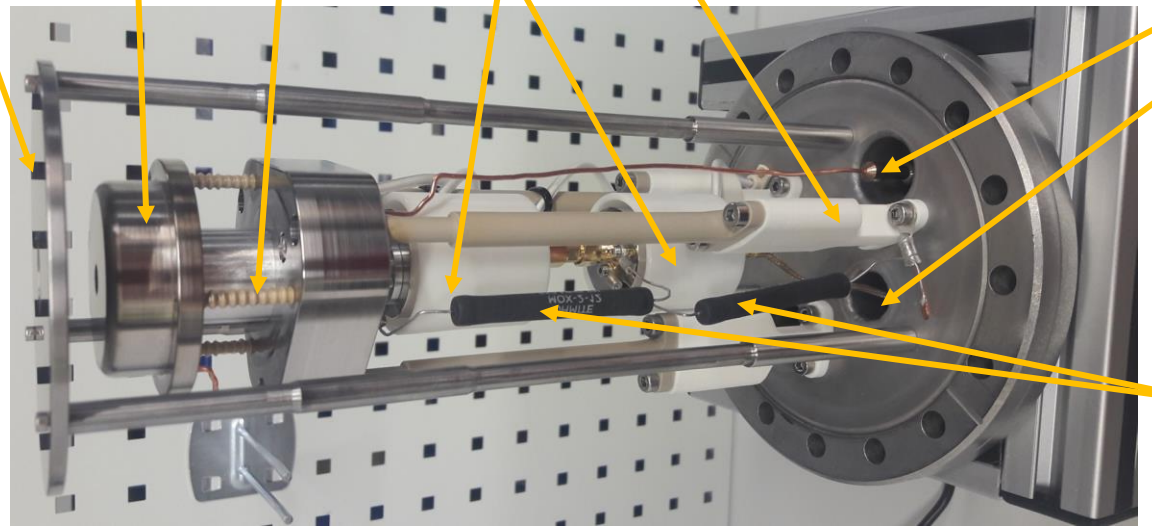
Ion source cavity

RF couplers

Insulator

HV connector

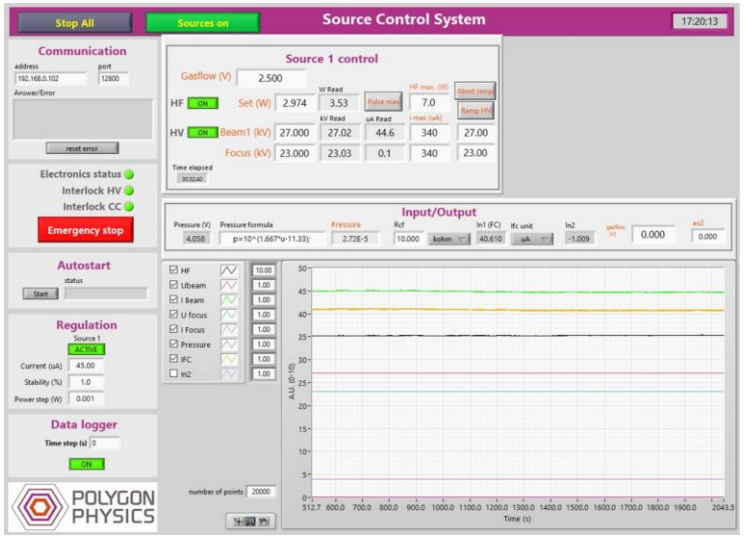
Gas injection



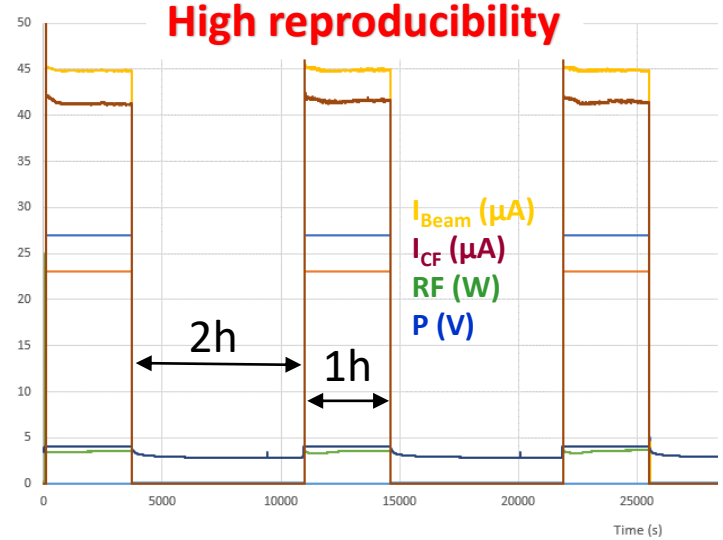
HV resistors

Beam parameters with two coupler-insulator

Extraction 1 mm / 6 mm / 6 mm - 27 kV / 23.5kV

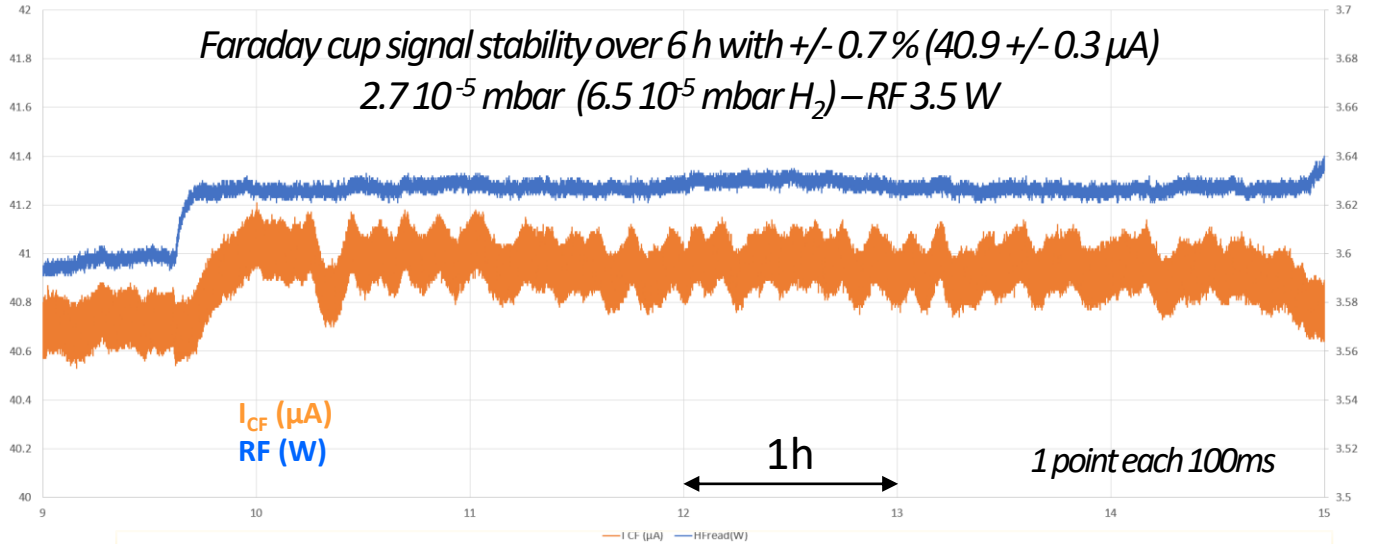


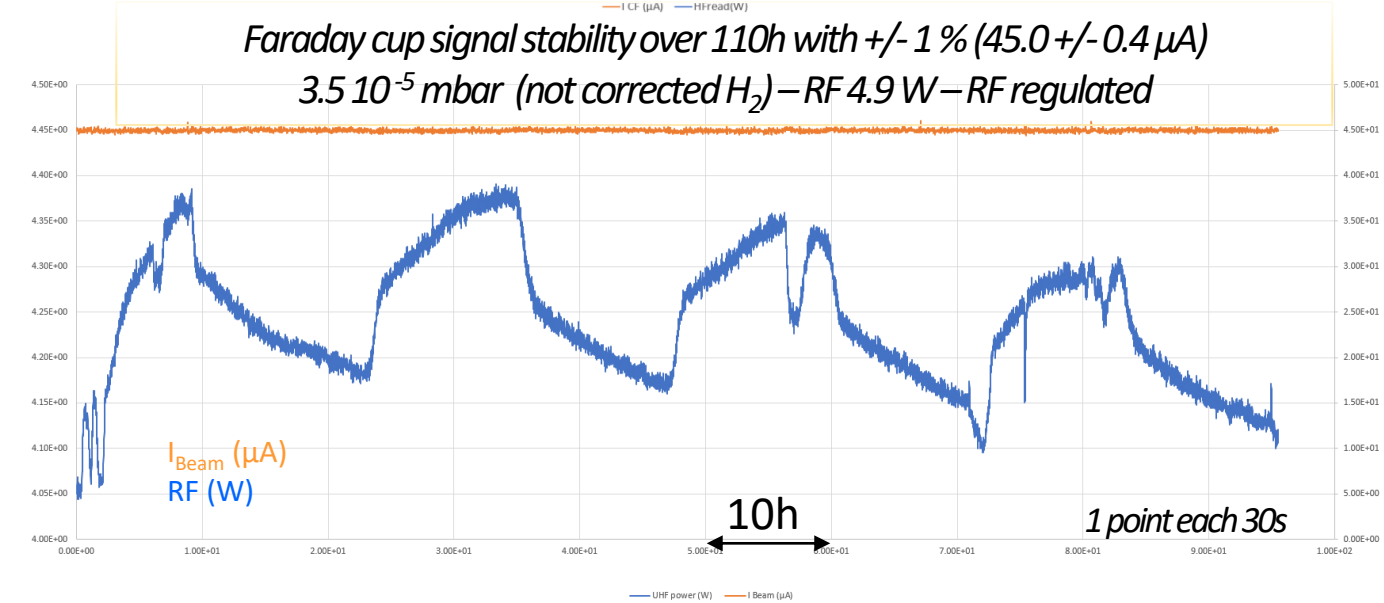
High reproducibility



3.10 $^{-5}$ mbar under operation, 3.10 $^{-7}$ mbar before restart

High stability





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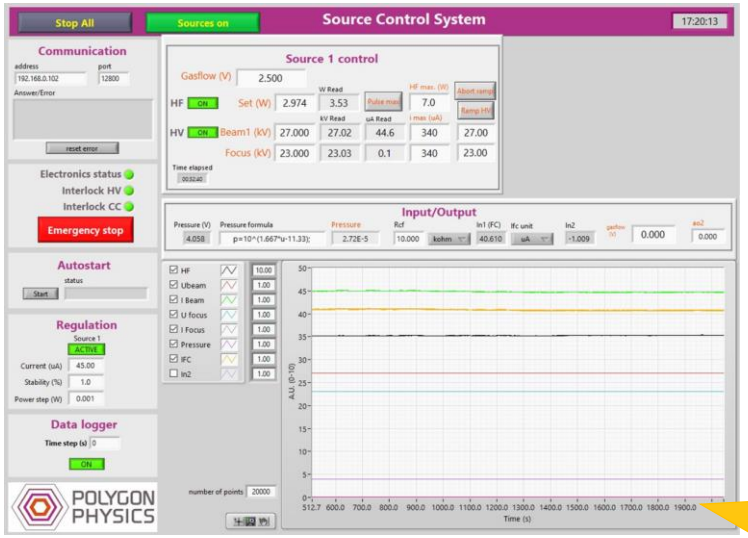

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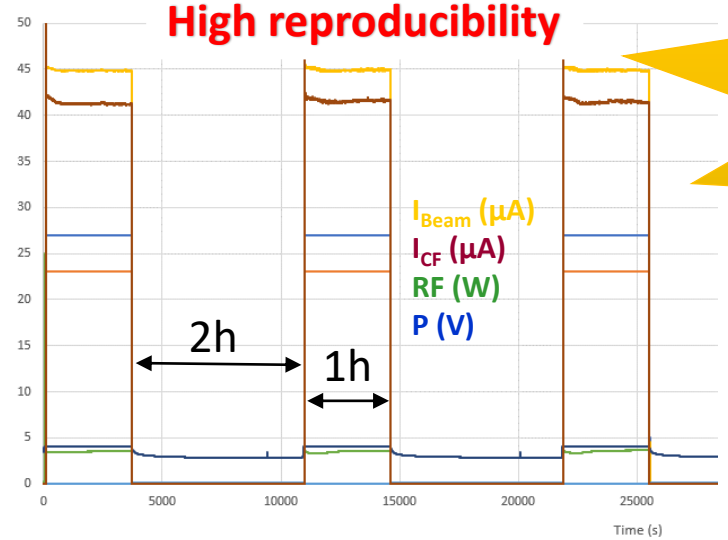

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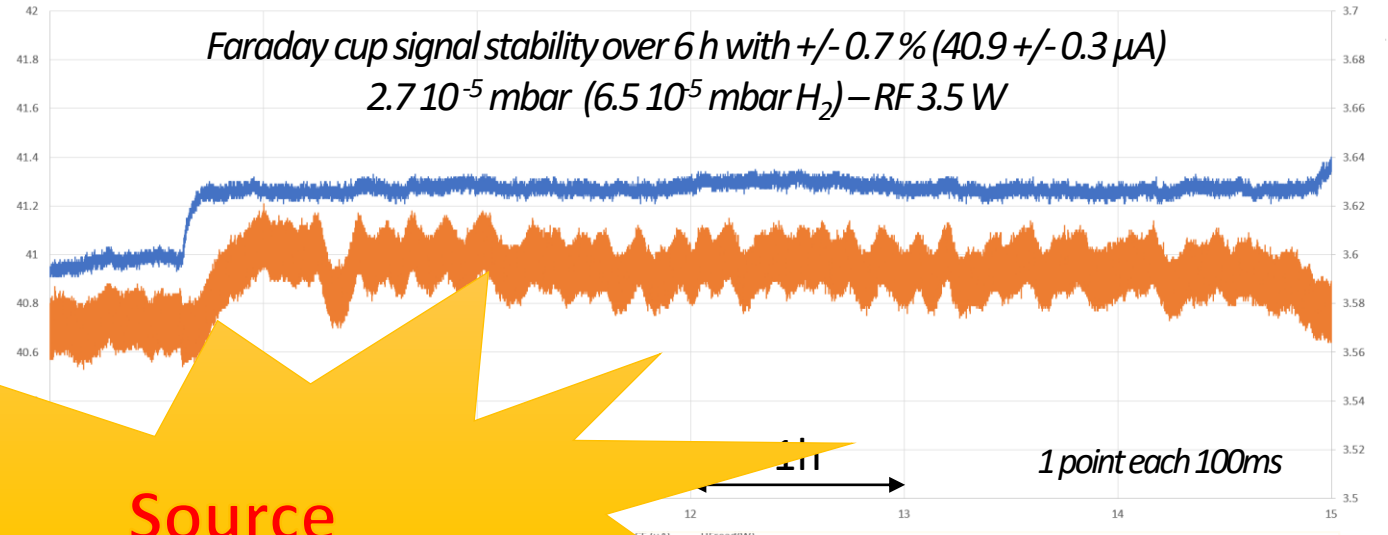
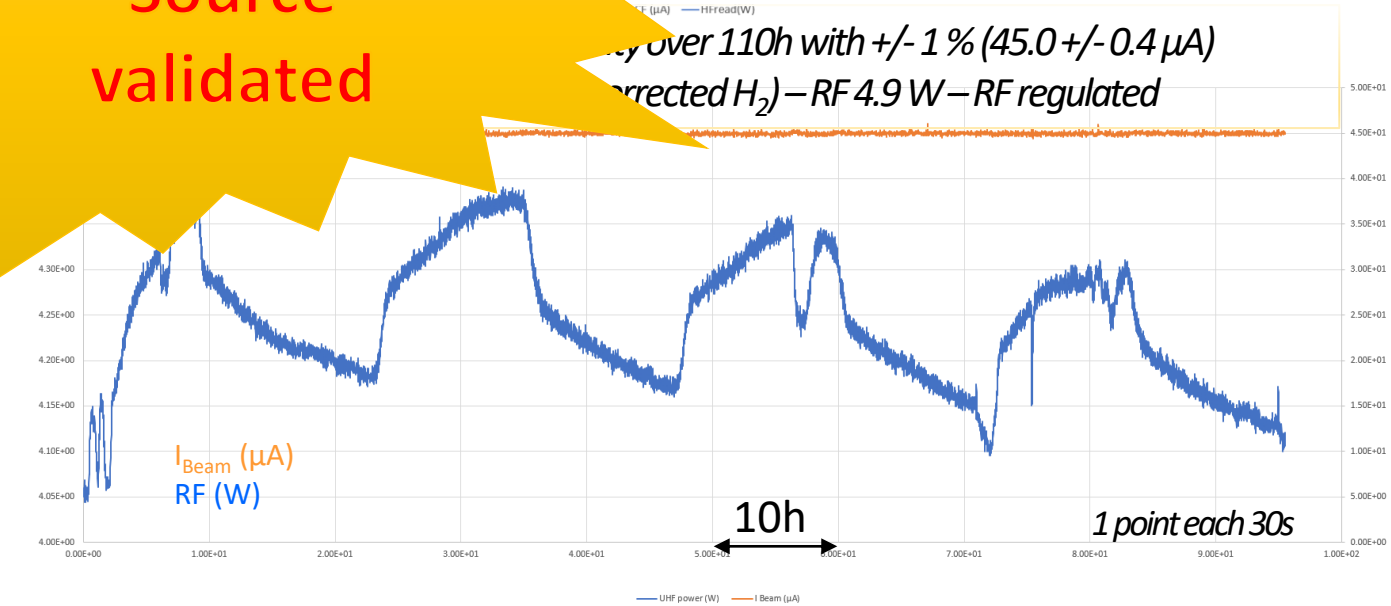
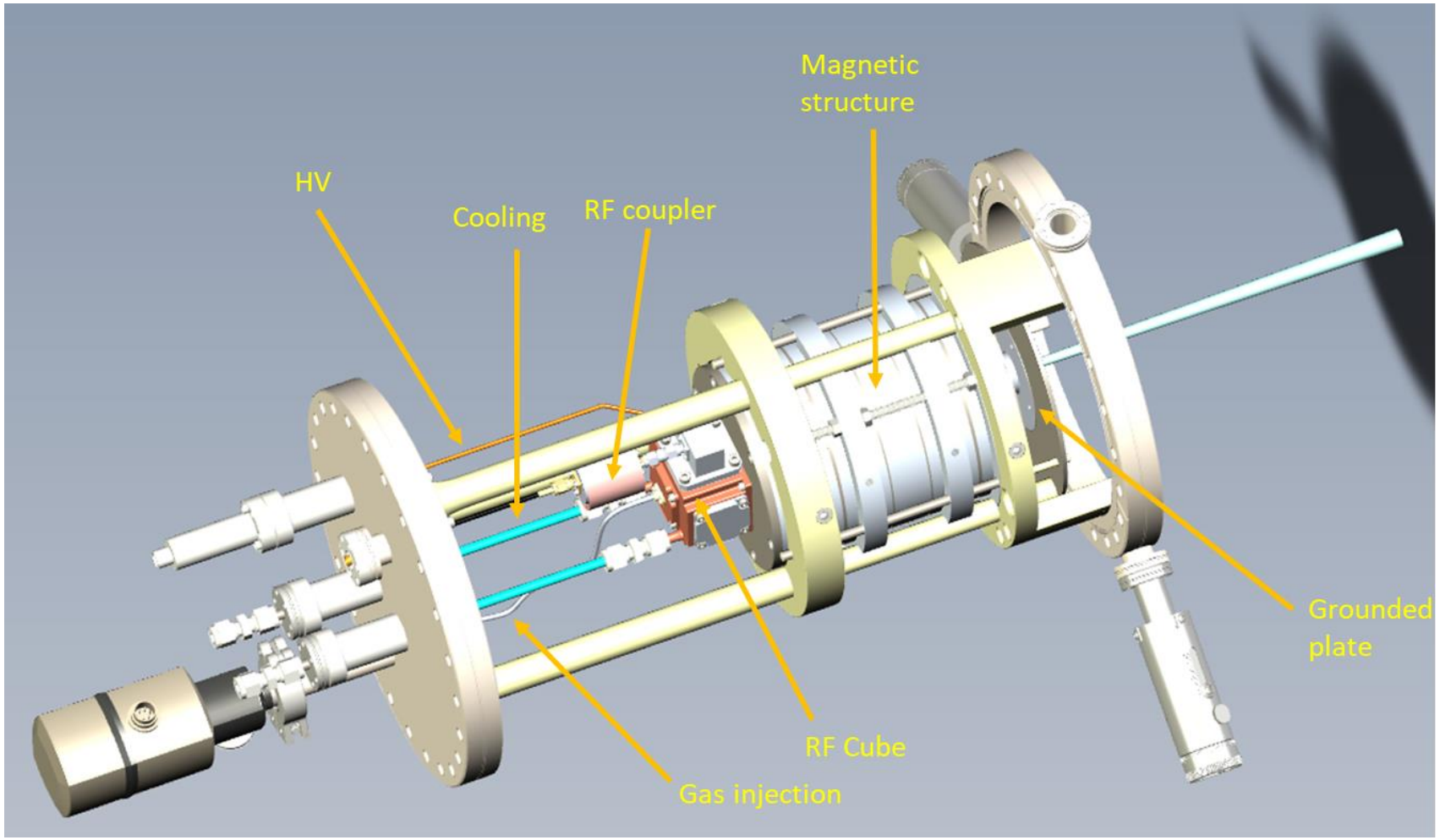
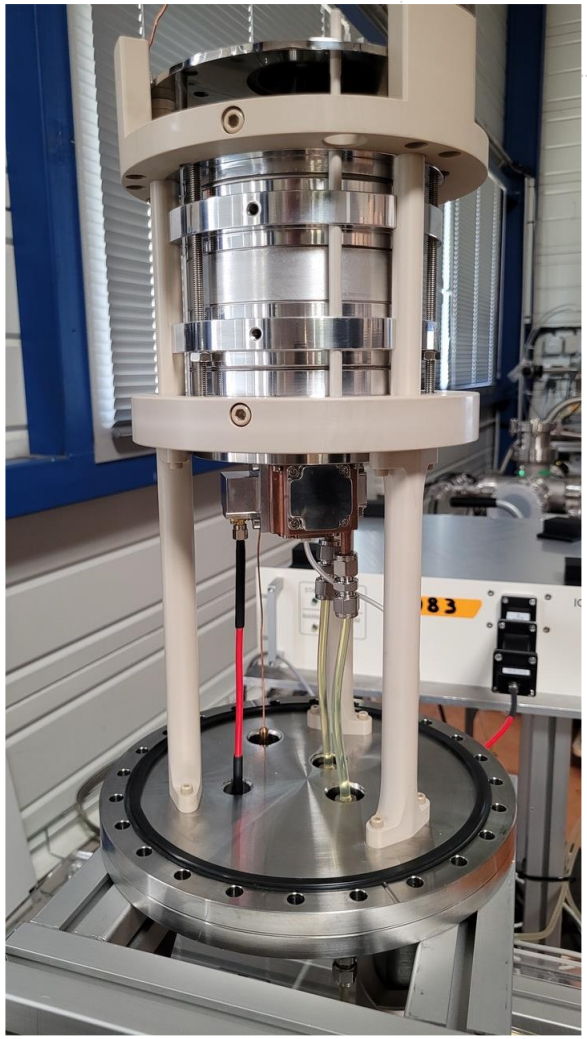


Source validated



NANOVAC - $^{4}He^{2+}$





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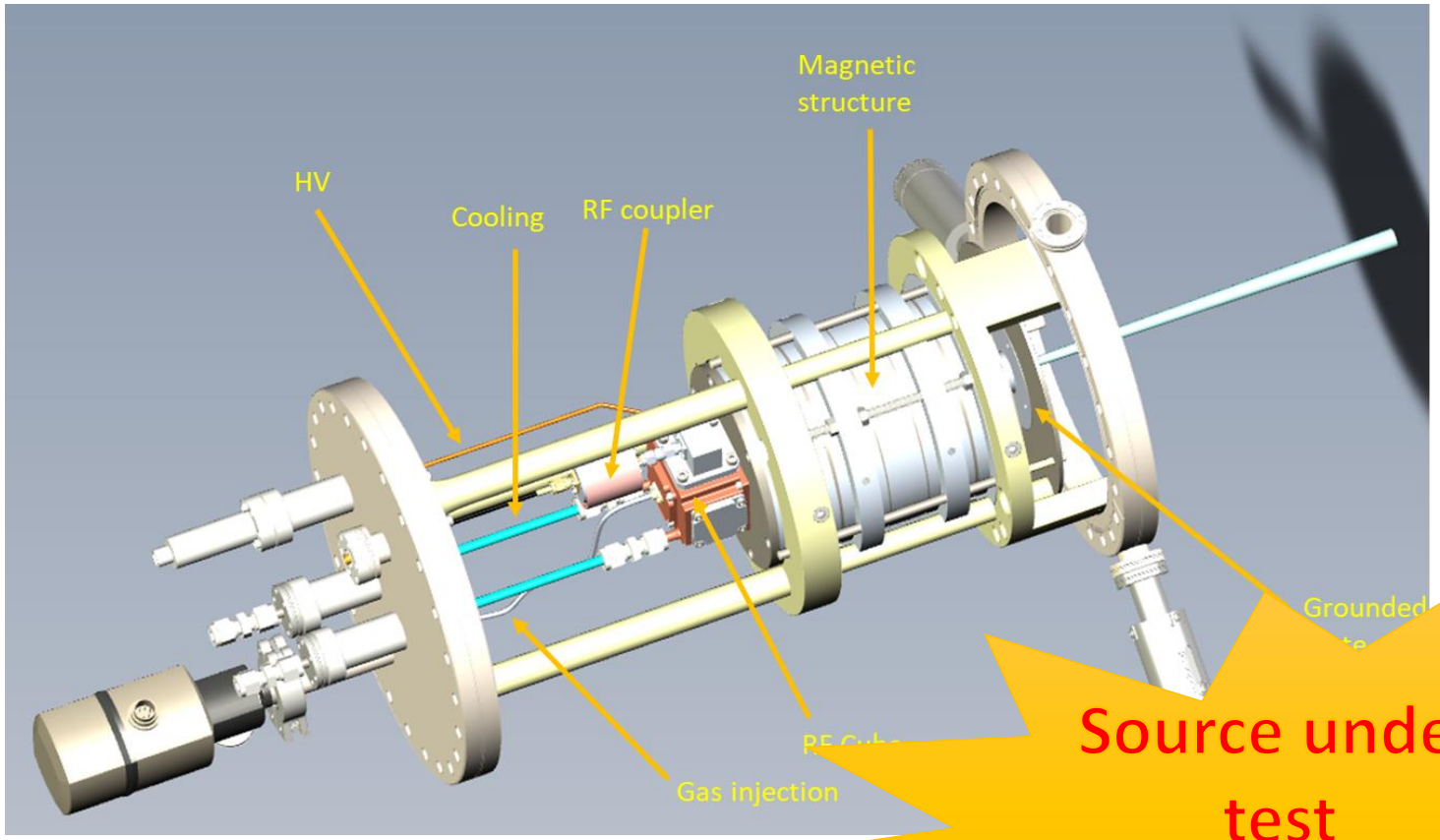


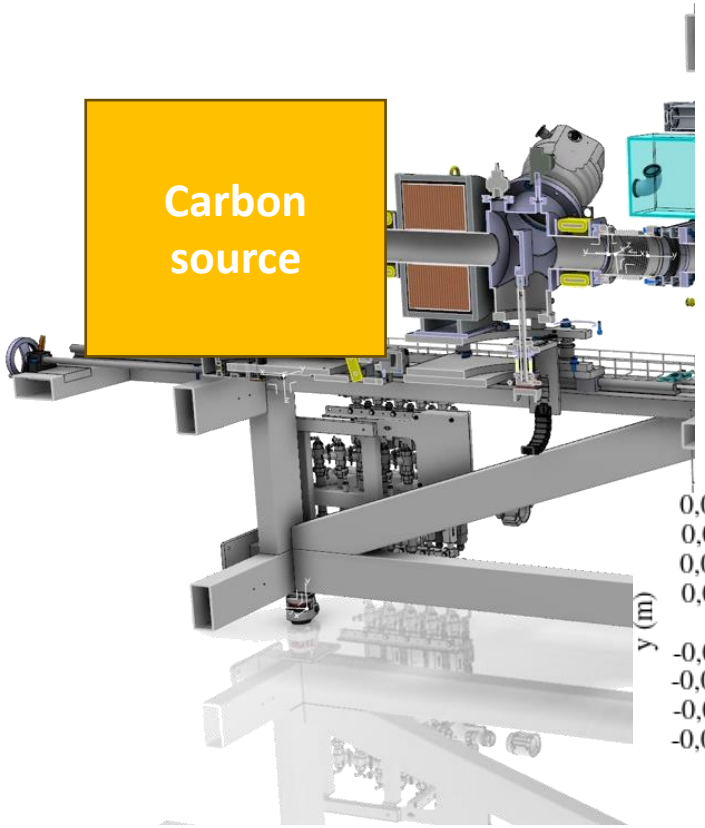
Source under test (Wien filter)

- Good scale with RF power
- 50W => 1.1 mA of total current

Estimation of ~100µA $^4He^{2+}$ => 50µA required

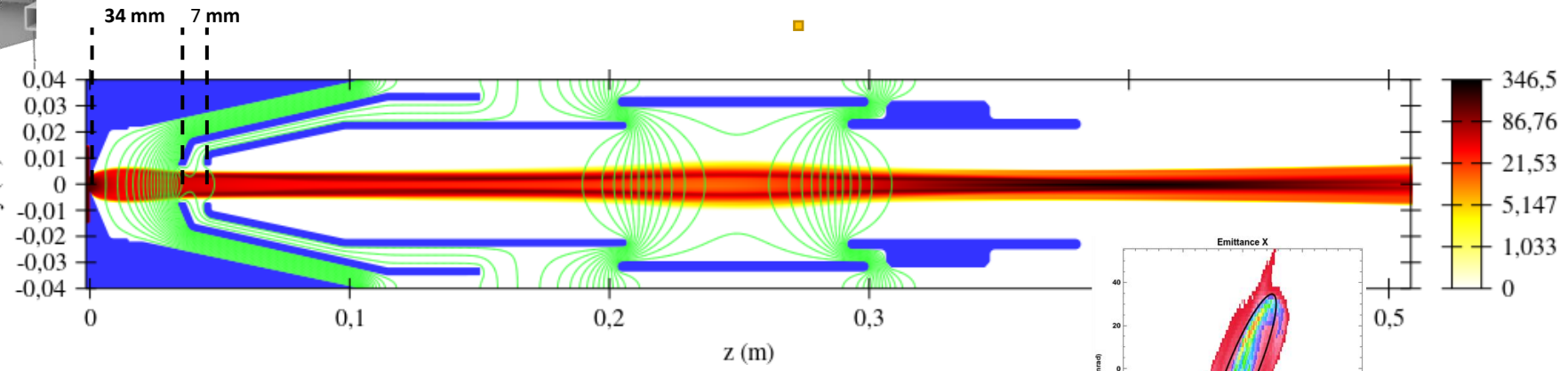
NHAC-ECRIS - $^{12}C^{6+}$

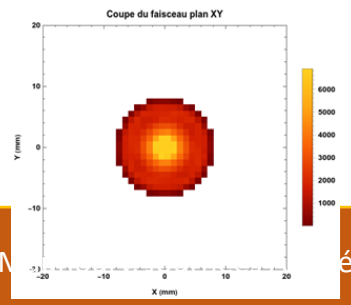
New NHa development realized in close collaboration with IBA and PP

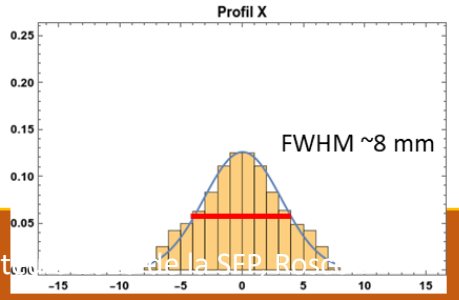


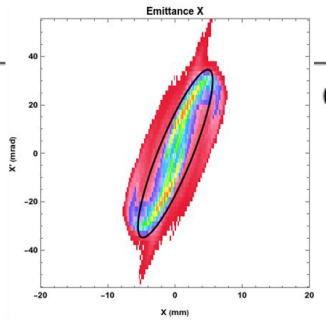
Features:

- *ECR type ion source 14GHz*
- *Full permanent magnet*
- *Multigap extraction*
- *Minimum B + multipole type magnetic structure*
  - ✓ $B_{min}/B_{ecr} \sim 0.84$
  - ✓ $B_{inj}/B_{ecr} \sim 2.36$
  - ✓ $B_{ext} \sim B_{rad}$









ε_{geom} = 95.2 π.mm.mrad
ε_{norm} = 0.376044 π.mm.mrad
80.5% particles inside the ellipse

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New NHa development realized in close collaboration with IBA and PP

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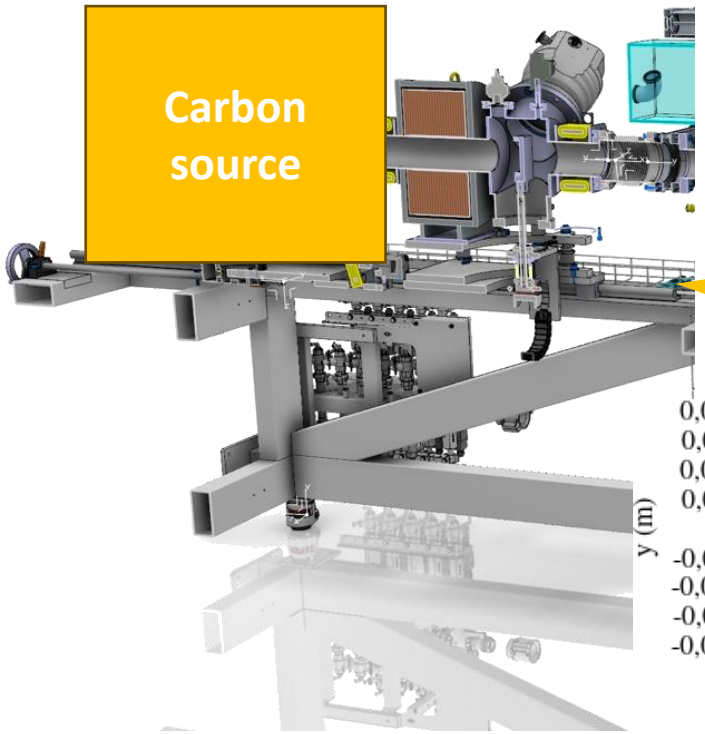
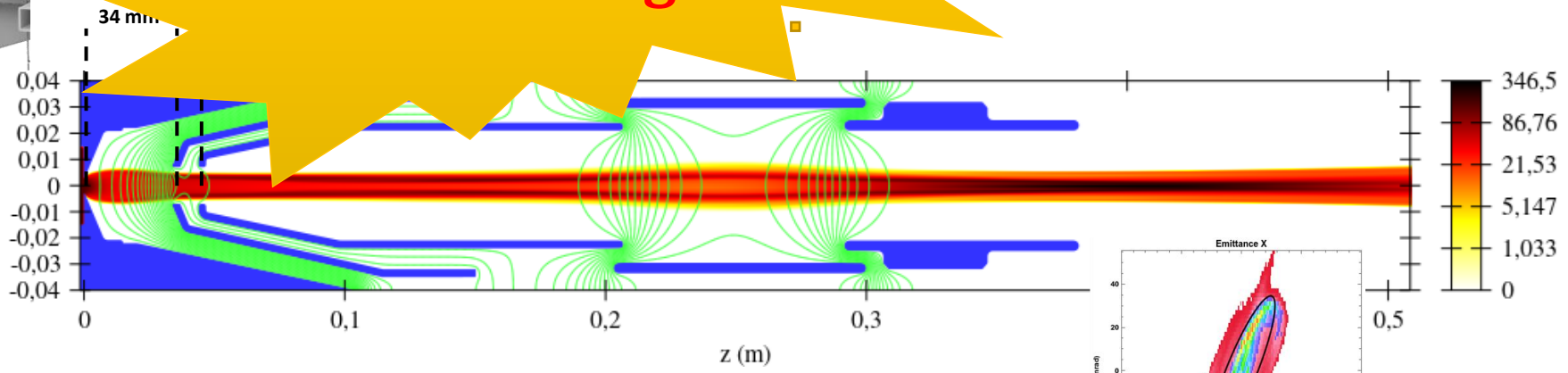
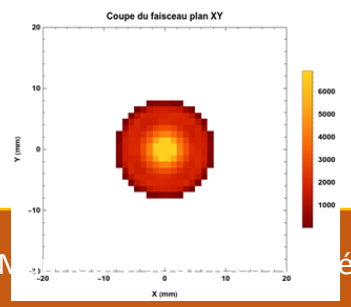
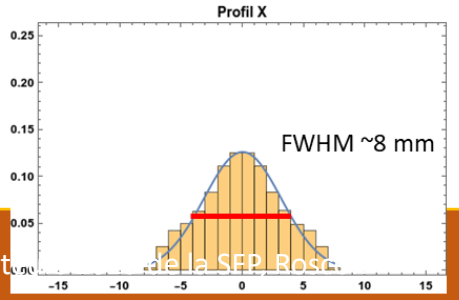
- *Full permanent magnet*
- *Multi gap extraction*
- *Minim[illegible]ucture*

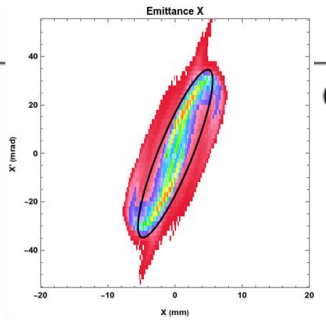


Source under final design









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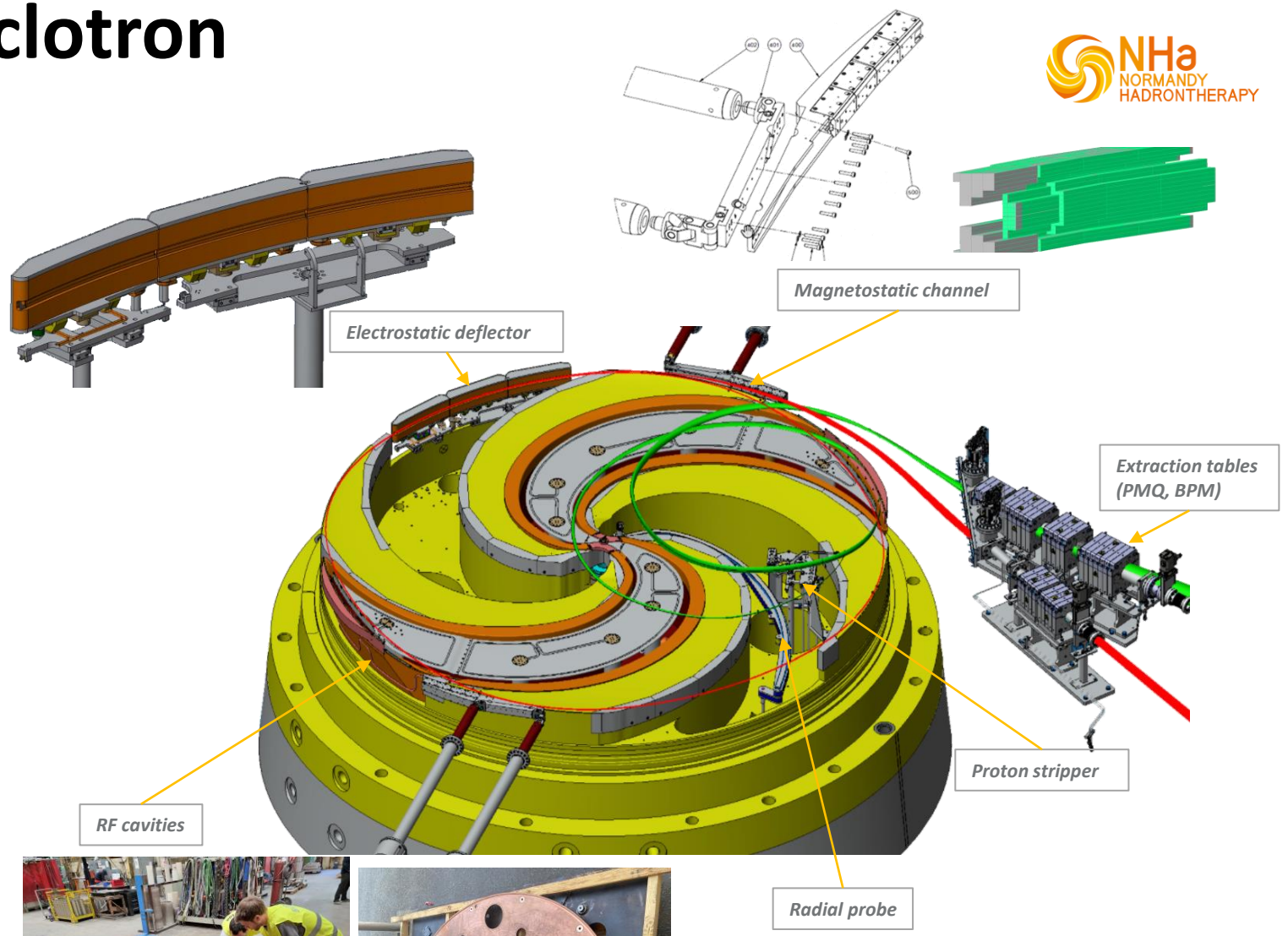
  - 3 sources: H_2^+, $^4He^{2+}$ & $^{12}C^{6+}$
  - Beam optics controls, buncher & diagnostics
- **Dual extraction**:
  - H_2^+ @ ~265 MeV/u: **protons extracted via stripping**
  - $^4He^{2+}$ & $^{12}C^{6+}$ @ 400 MeV/u: **via electrostatic deflector**



Performance of the system

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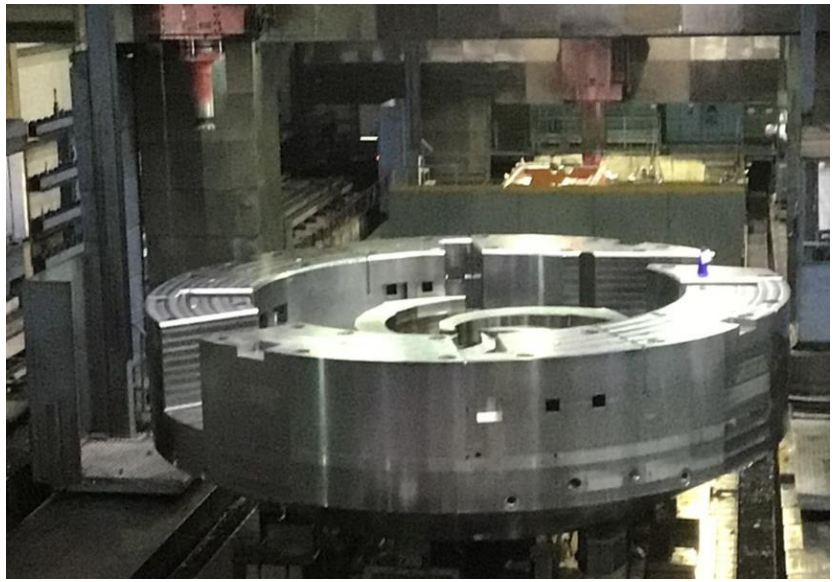
General System performance	
SCC ramping up (hours)	2
Time to switch particles (min)	15
Irradiation time (min) 2Gy in a 10x10x10 cm cube	1

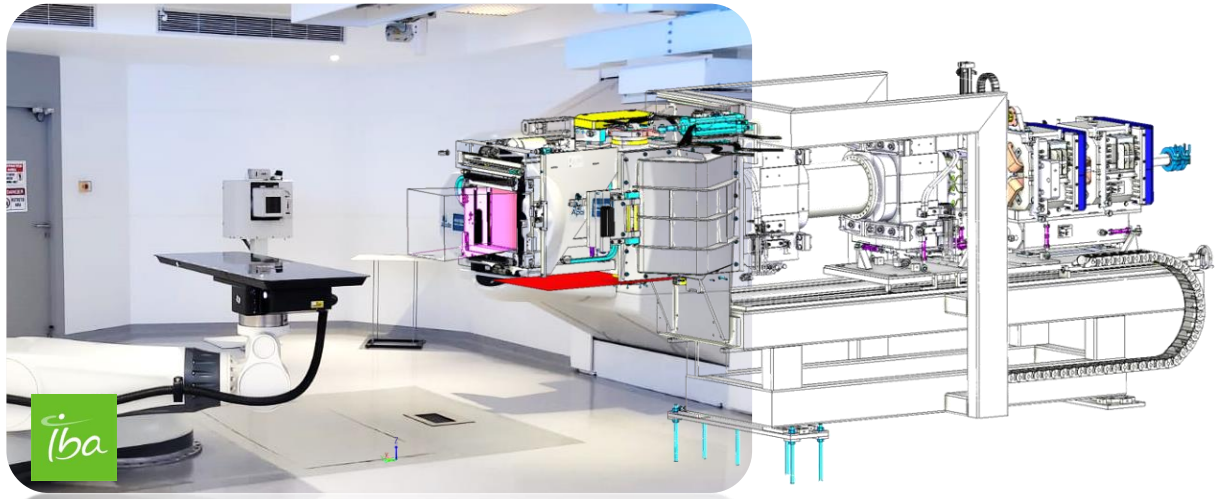
Beam delivery performance	Carbon	Proton	Helium
Maximum clinical range (cm in water)	27	32	32
Maximum range (physics research) (cm in water)	27	32	80
Beam position accuracy at isocenter (mm)	0.5		
Beam spot size @ max range (mm (1σ)) *Tolerance +/- 20%*	3	3	3.6
Beam spot size @ min range (mm (1σ)) *Tolerance +/- 20%*	4	8	6
Max. Field size (cm x cm)	20x20	30x30	26x26
Irradiation time (min) *2Gy in a 10x10x10 cm cube*	1		?

Poles and yokes manufacturing

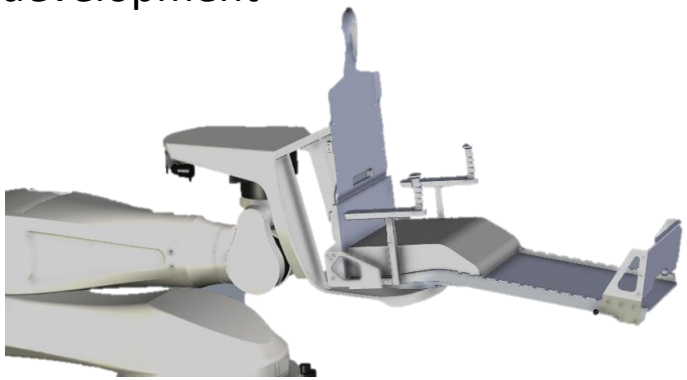


Multi-particles – fixed beam treatment room

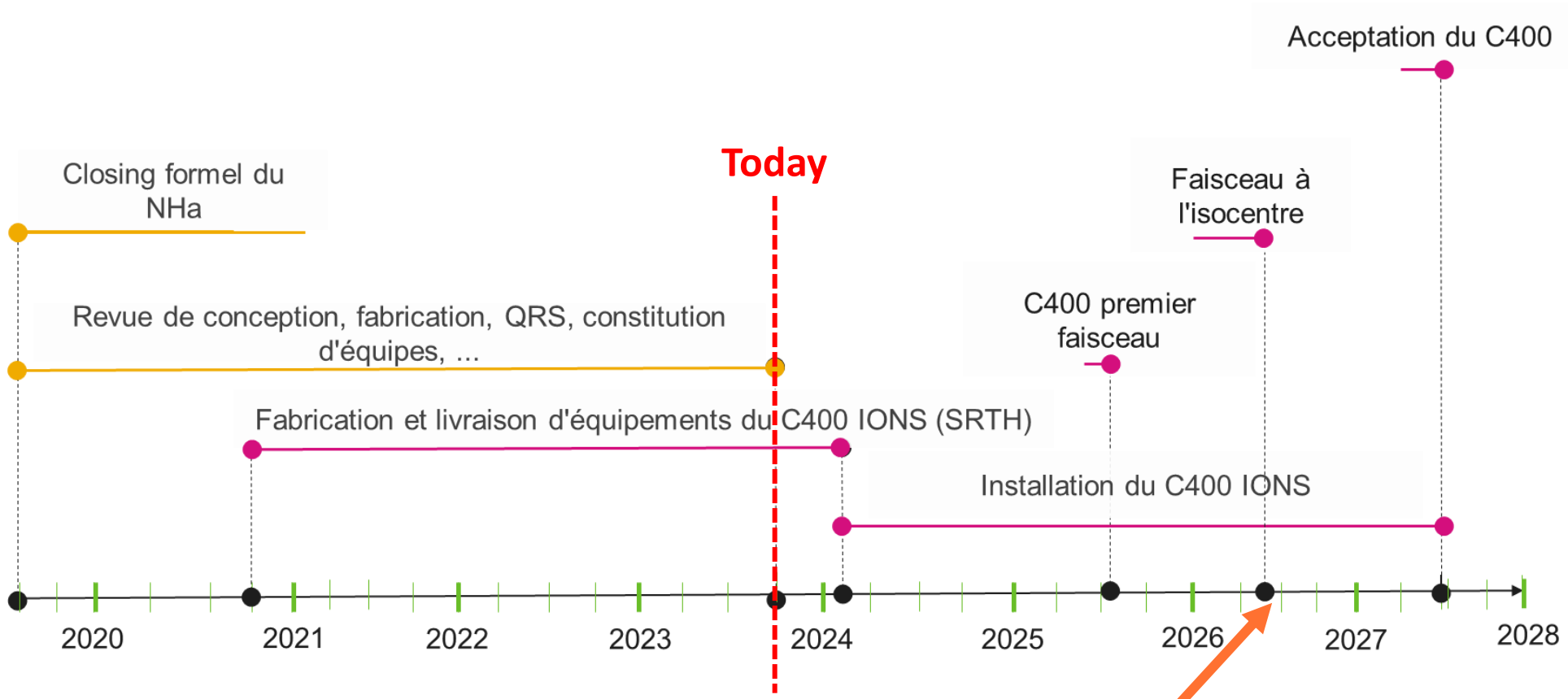
- Taking advantage of know-how and experience from IBA
- High performance beam delivery and dosimetry:
  - Pencil beam scanning technology
  - 6D Patient Postioning robotic system
  - Larger Source Axis Distance / smaller field due to carbon
  - Nozzle bottom clearance improved for a chair
  - Ripple filter to reduce the number of layers
  - Range shifter for ranges < 4cm
- Innovative chair currently in development



Courtesy of IBA: Chennai site, India



Project timetable



International Particle Accelerator Conference, Ganil ***05/2026 Caen***

Particle Therapy Co-Operative Group, François Baclesse

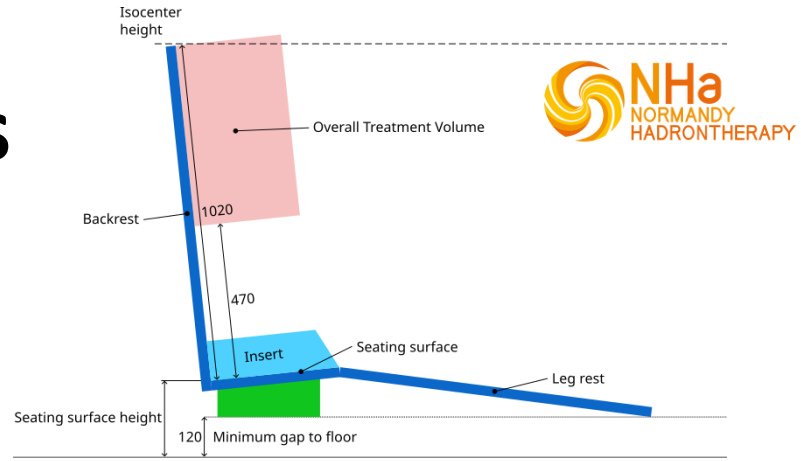
Comprehensive Cancer Center and CYCLHAD, ***06/2026 Caen***

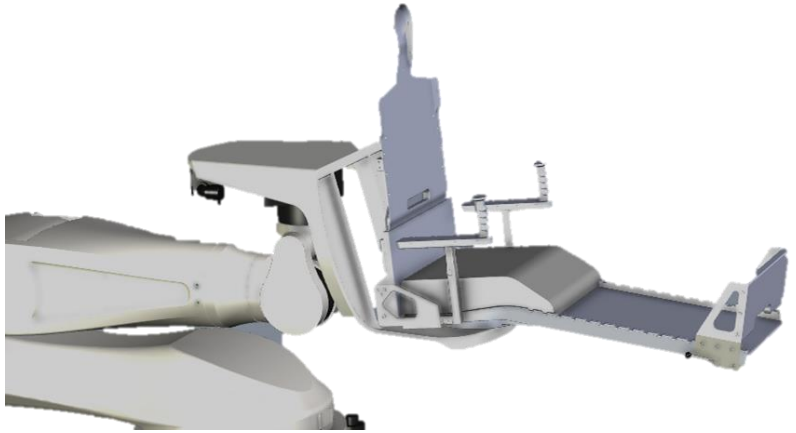
NHa
NORMANDY
HADRONTHERAPY

Thank you for your attention

Patient alignement main specifications

Clinical Design Specifications	Couch	Chair
Accuracy (positionning/angle)	< 0.75mm / 0.1°	
Positioning reproducibility	≤ 0.5 mm for 67% of the cases < 1 mm for every case	
Prescription angles - Yaw	± 9 °	± 180 ° (3 positions)
Prescription angles - Roll	± 10 °	± 10 °
Prescription angles - Pitch	± 10 °	0° to +10
Seat angle	-	6°
Leg rest angles	-	3 positions
Back rest angle	-	1 position (90,95,100°)
Additional correction angles (yaw/roll/pitch)	± 5 °	
Treatment volume	1000 × 500 × 400 mm³	320 × 230 × 550 mm³
Carbon Couch top / Backrest ecosystem	Qfix kVue	?
Trolley	no	yes



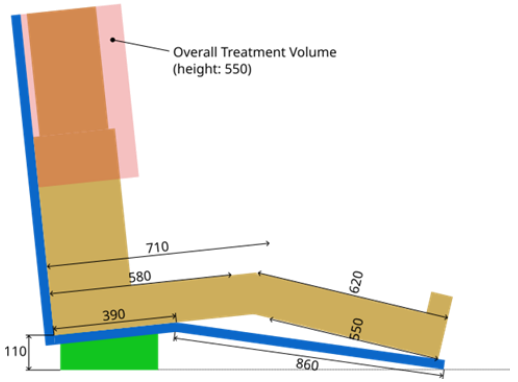


visuel non contractuel

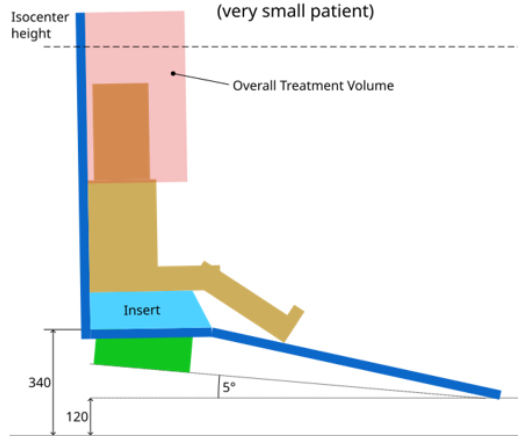
Ongoing developments - Chair

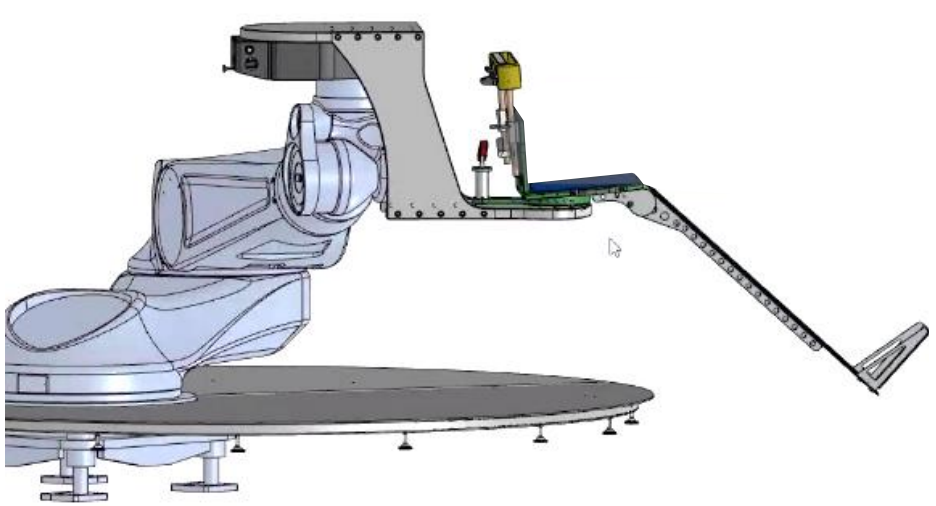
Anthropometric Dimensions to be Considered for Seated Patients (ISO 7250-2)	Minimum Value (mm)	Maximum Value (mm)
Sitting / crown-buttock height (upper limit of treatable volume per patient)	670	**1020**
Shoulder height reduced by safety margin of ~50 mm (lower limit of treatable volume)	360	**630**
Head breadth + positioning uncertainty of ~±25 mm (width of treatable volume)	180	**230**
Head length + positioning uncertainty of ~100 mm	260	**320**
Buttock-popliteal length (seat depth)	340	**580**
Popliteal height (for adjustment of feet rests)	320	**550**
Knee height (for dimensioning of leg rests and adjustment of feet rests)	360	**620**
Buttock-knee length (for dimensioning of leg rests and adjustment of feet rests)	420	**710**

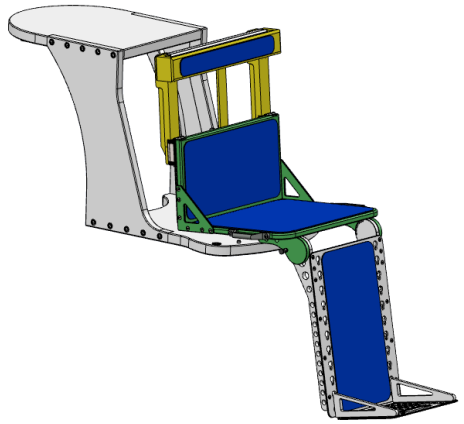
Tallest Patient on Chair



Lowest Chair Position with Pitch
(very small patient)







SC coils & cryostat

Coils

Ramping time : 2 hours

Time to switch between particles : < 15 min

Stored energy: ~55.6 MJ

Cold mass at 4.3K: 14.6 tons

turns per coil : 1344

Supra material : NbTi

Critical current: 2800 A @ 4,5 T @ 4,2 K

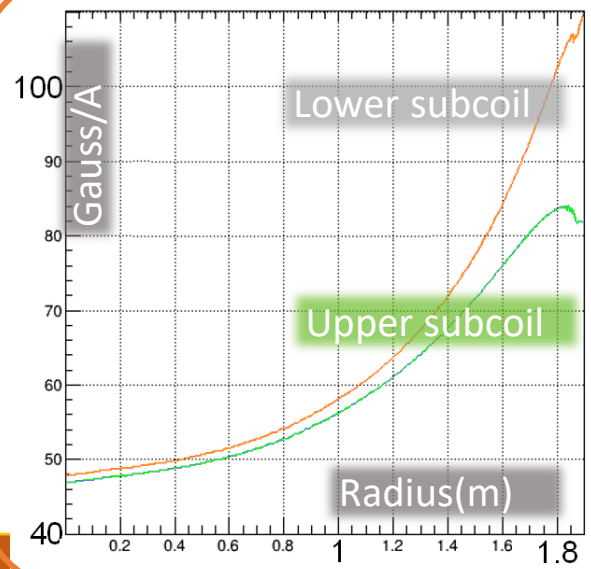
Conductor peak field: 3.9T

Current density : ~31 A/mm²

Coils current:

PS1 ~1034 A (on all 4 sub coils)

PS2 (max 120A) (only on 2 sub coils)



Cryostat

Outer diameter: 4.8m

Liquid helium bath T°: 4.3 K

Liquid helium thermosyphon circulation system

Cooling power : 6 cryocoolers / 14 W cooling power @ 4.3 K

Highly instrumented for quench management (Temperatures / Voltages / pressures, strain gauges, quench heaters)