Development of the new IBA S2C2

Jongen, Mandrillon, Abs, Kleeven, Quets, Verbruggen

Topics of discussion

- The S2C2 put into context.
- S2C2 guided tour:
  - Magnet yoke and yoke lifting system.
  - Superconducting coil.
  - RF system.
  - Ion source.
  - Extraction system.
  - Ancillaries: Vacuum system / Water cooling / Power distribution.
- Ongoing factory tests.

Why an S2C2 ?

Superconducting Synchrocyclotron

Market studies indicate that there is a growing need for smaller and cheaper protontherapy facilities.

IBA superconducting synchrocyclotron is designed to be an alternate proton source for therapy fulfilling new constraints:

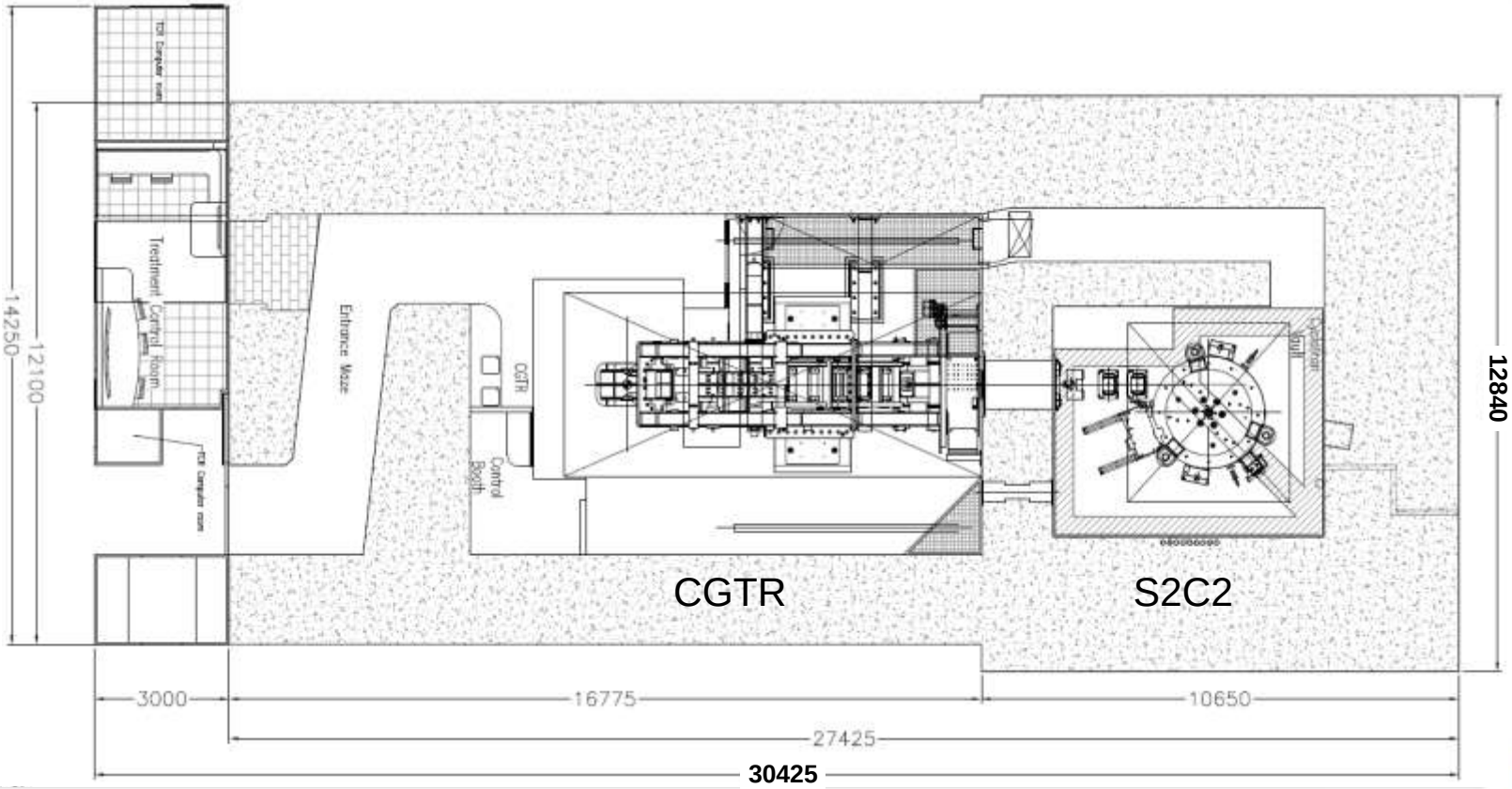
- Compact reliable and operator less system.
- Low recurrent cost.
- Full pencil beam scanning capabilities.
- Short development time.
- Extremely short on-site deployment time.

…and targeted at a new markets, competing with linacs, with a fully integrated standardized product:

The Proteus One®

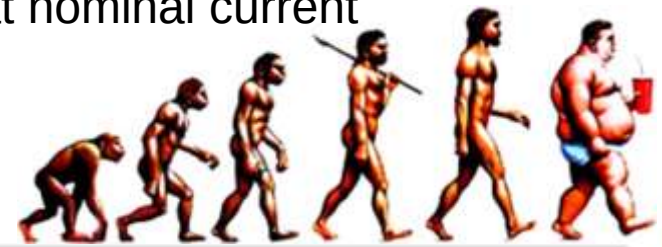
Proteus One® layout

30.4m x 12.8m



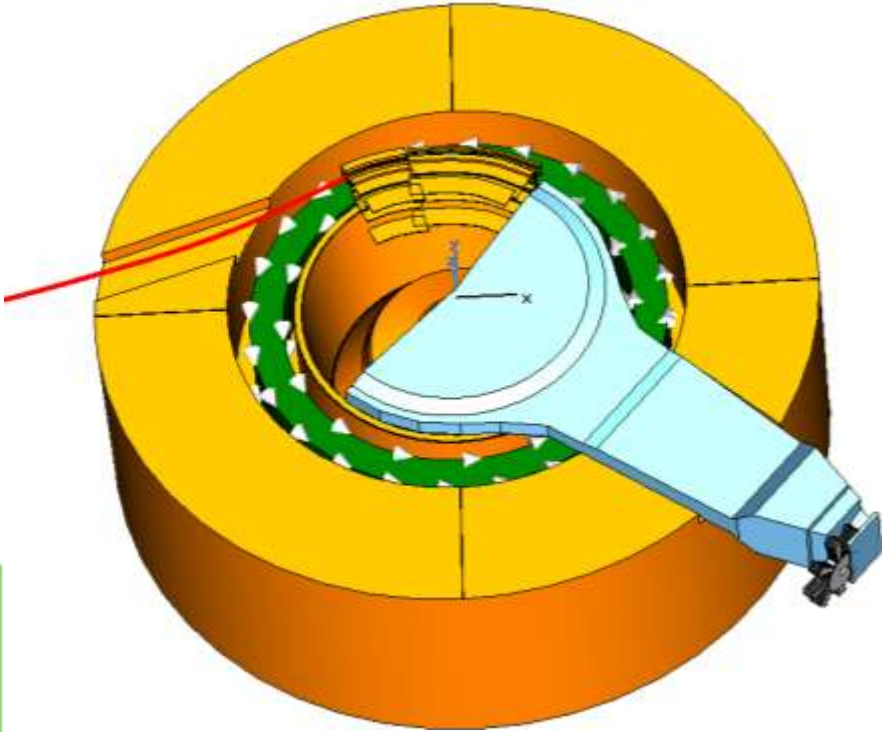
Evolution

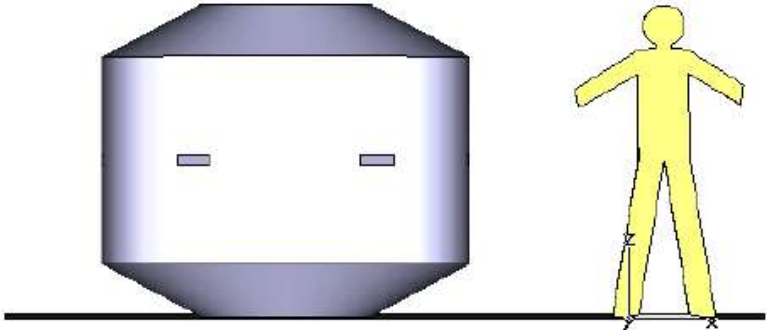
Early 2008	Preliminary studies
May 2009	Workshop to define S2C2
Sept 2009	M0, official kick-off of the S2C2 project
Dec 2009	SCC manufacturer selection
June 2010	Steel for magnet yoke order
Jan 2011	Start of yoke machining
Aug 2011	Delivery of magnet yoke at IBA
Feb 2012	Delivery of superconducting coil at IBA
May 2012	Superconducting coil at nominal current
End 2012	Extracted beam ?



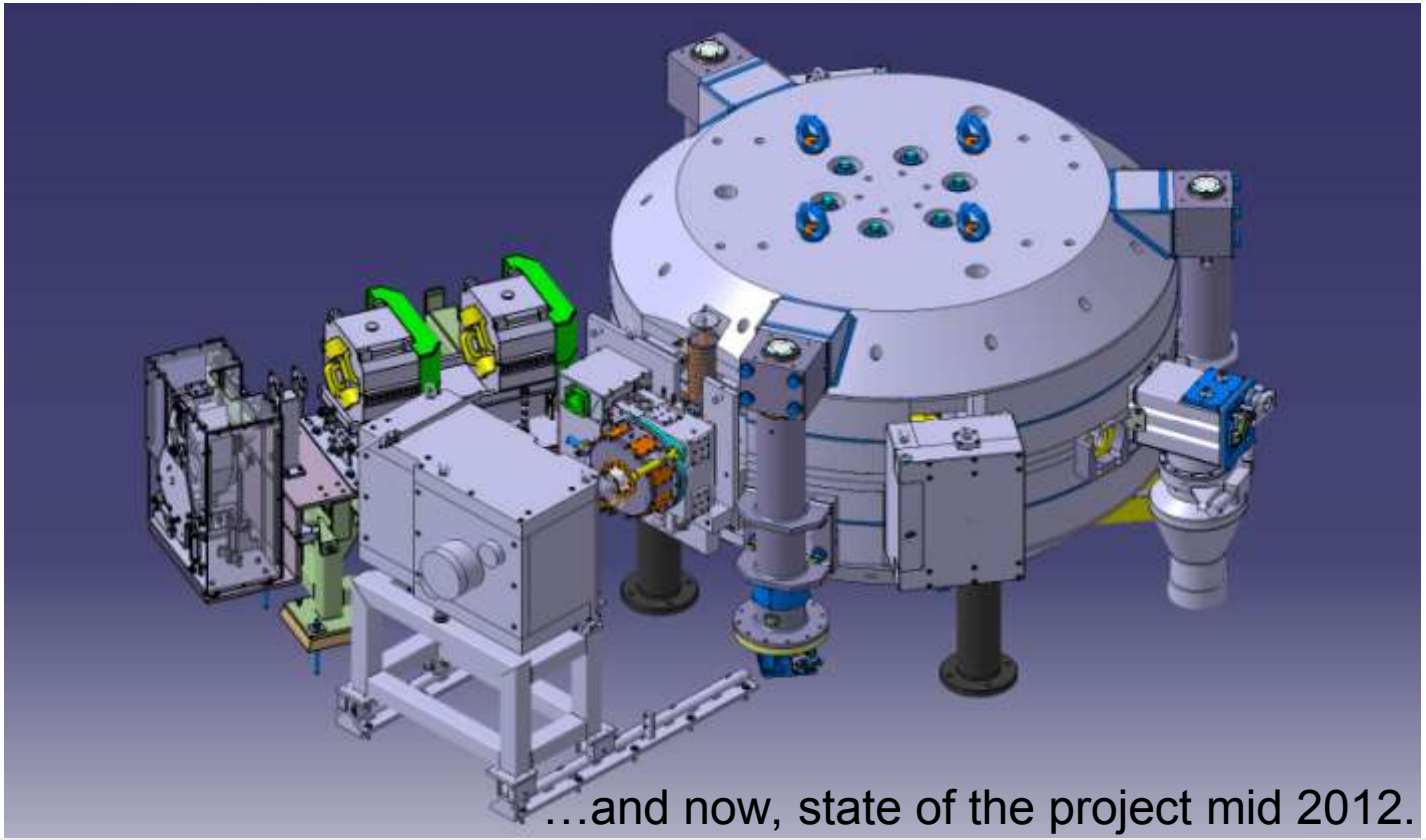
From concept…

The concept, as imagined back in early 2009.





…to project.



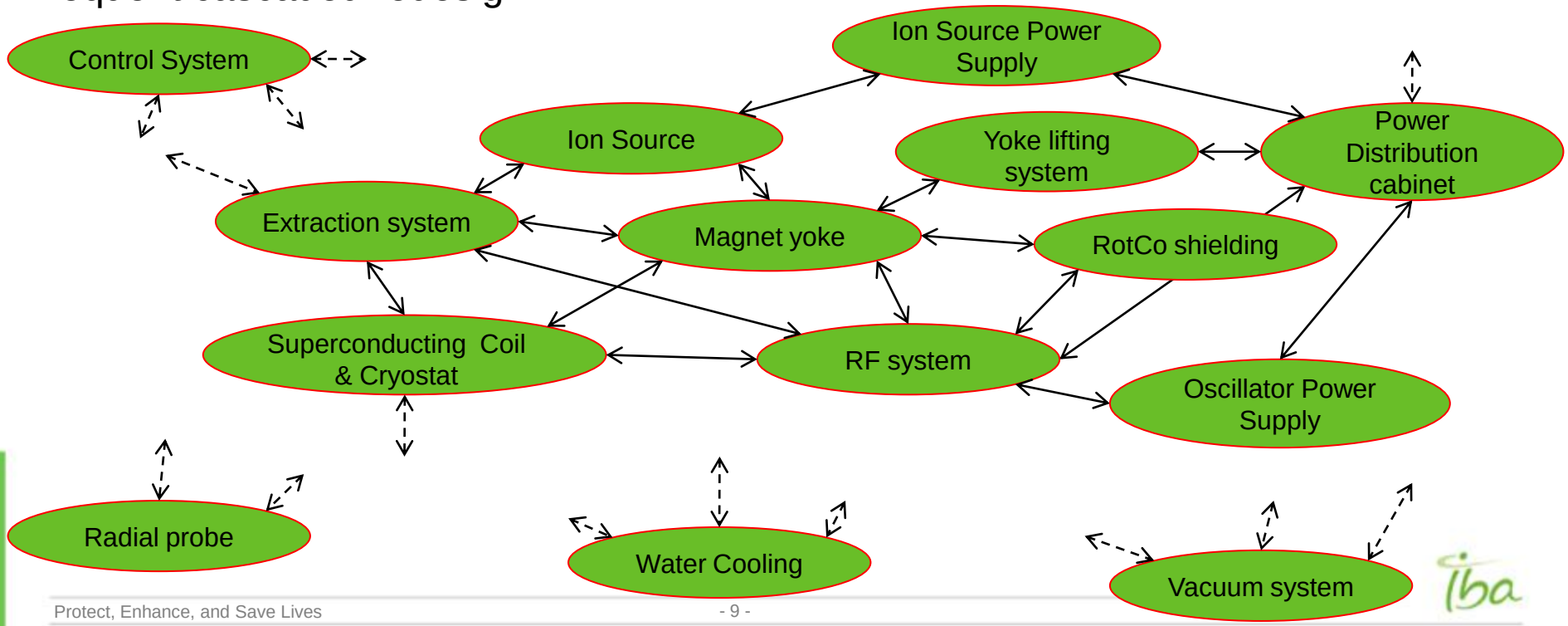
…and now, state of the project mid 2012.

It’s real hardware…

…not just pretty CAD drawings !

Why is it challenging ?

A major difficulty lies in the close interdependance of all sub-systems, leading to frequent cascaded redesign.



Why is it challenging ?

Emphasis has been put on the fact that the integrated system, « Proteus One® », has to be « Operator Free »

- Increase the intrinsic reliability by design (GRA, FMECA, ...).
- Redundancy where necessary, without adding complexity when possible.
- Hot spares: identical equipment can be swapped between critical and non-critical locations in the event of failure.
- Standardization: reduction of number of different items and tool required for maintenance to reduce RSPL and MTTR.
- Diagnostics: add transducers to monitor equipment.
- Complex software: automated operation, morning check and startup script, …
- Robust historian and extensive remote diagnostics possibilities.
- Open and easily expandable control architecture to cover future needs.

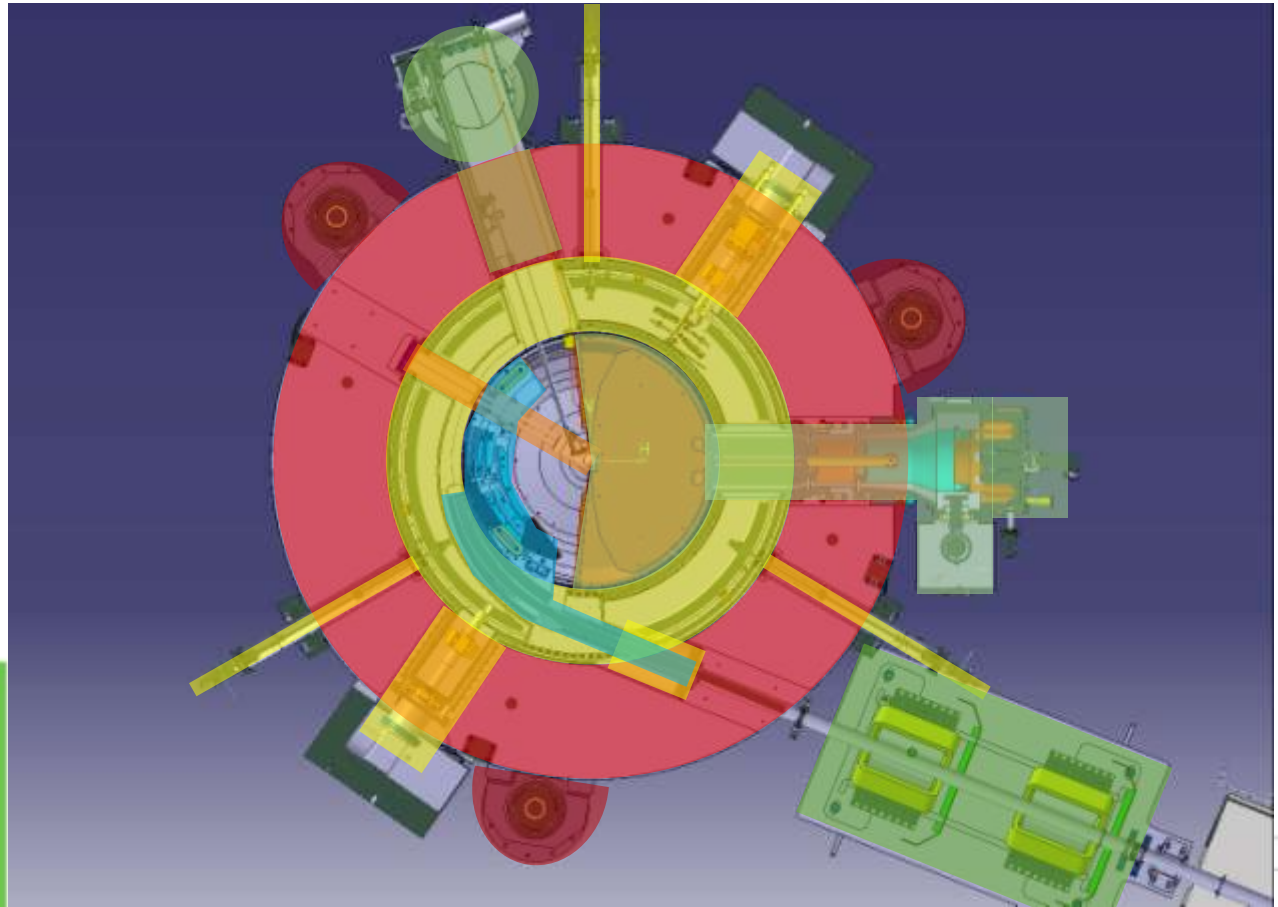
Specifications

Do we still satisfy the initial technical specifications ?

- Compact system: dia.2.5m, height 2m, weight <50T.
- Reliability: NbTi cryogen free coil, passive regenerative extraction…
- Low cost: Censored M€ recurrent cost for prototype.
- 1kHz beam pulse repetition rate for PBS.
- 20nA, 230MeV for PBS.
- Still possible to reach 250MeV with some additional work if required.

S2C2 guided tour

General system layout



Magnet yoke

Super conducting coil

RF system

Ion source

Extraction system

Vacuum system

Yoke lifting system

Extraction beam line

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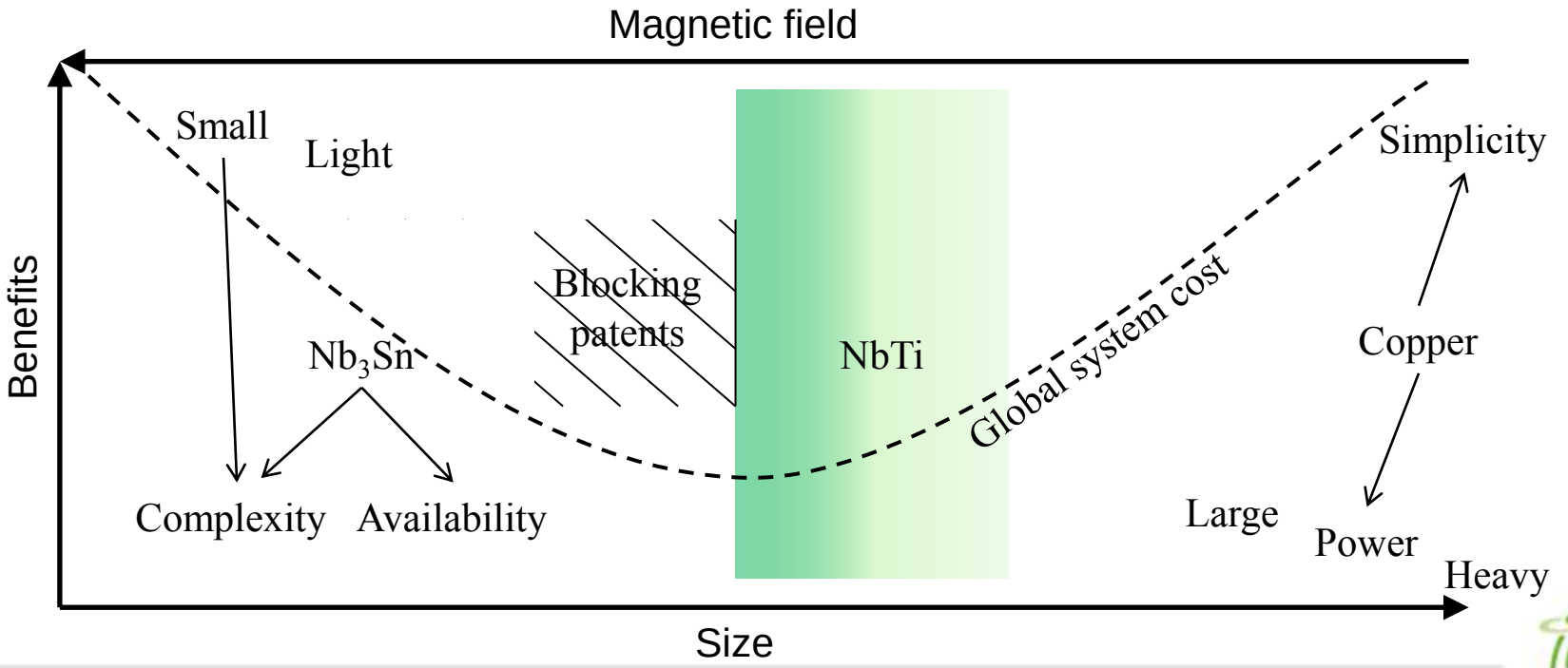
Magnet Yoke

The magnet is a complex compromise…



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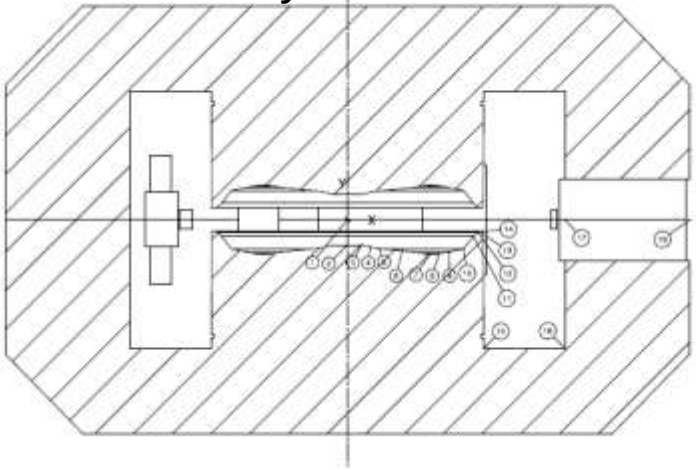
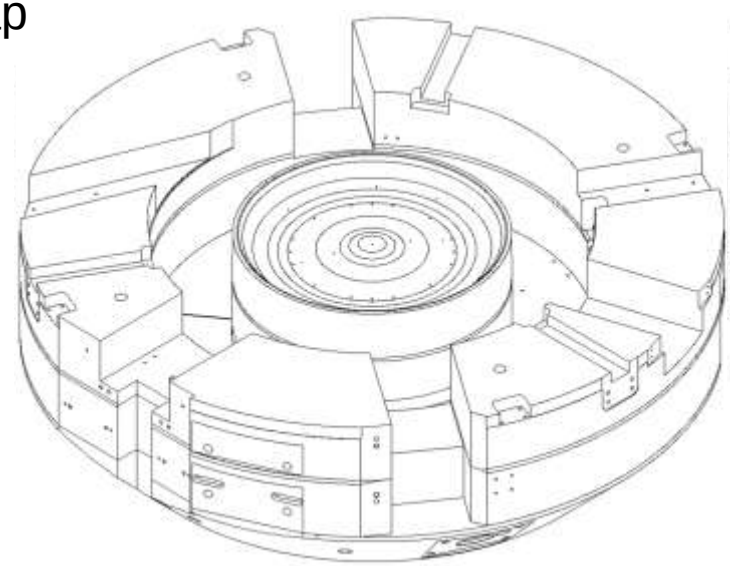
Magnet Yoke

The yoke size is a compromise between coil complexity, peak field, stray field and total weight. Also, it allows to stay away from any patents and use cheap and readily available NbTi.

The pole profile is the result of an optimized extraction system.



REF.	X	Y
1	0	0
2	0	-92
3	50	-92
4	82.5	-99.7
5	115	-104.5
6	200	-113
7	300	-126.5
8	335	-123.9
9	370	-118
10	424	-106
11	460	-61
12	475	-44.5
13	480	-43
14	495	-43
15	497.5	-470
16	794	-470
17	794	0
18	1250	0



Diameter: 2.5m
Iron weight: 41.5tons

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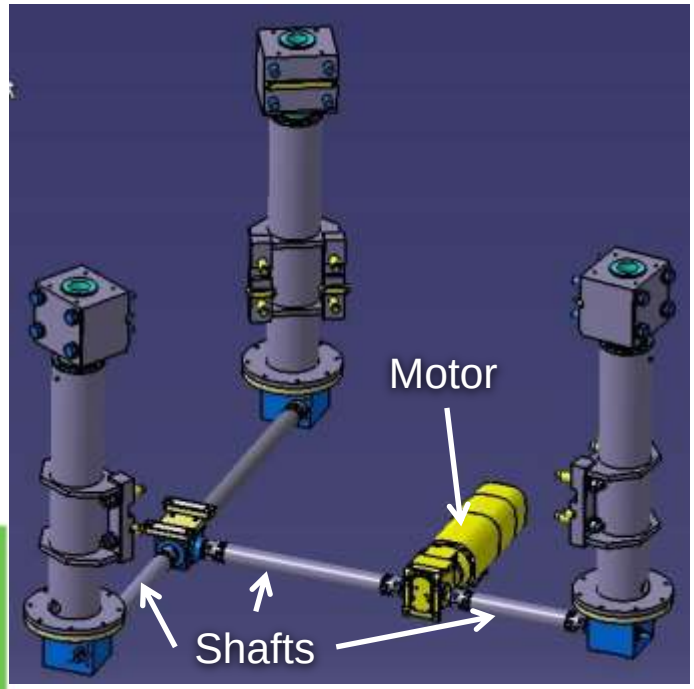
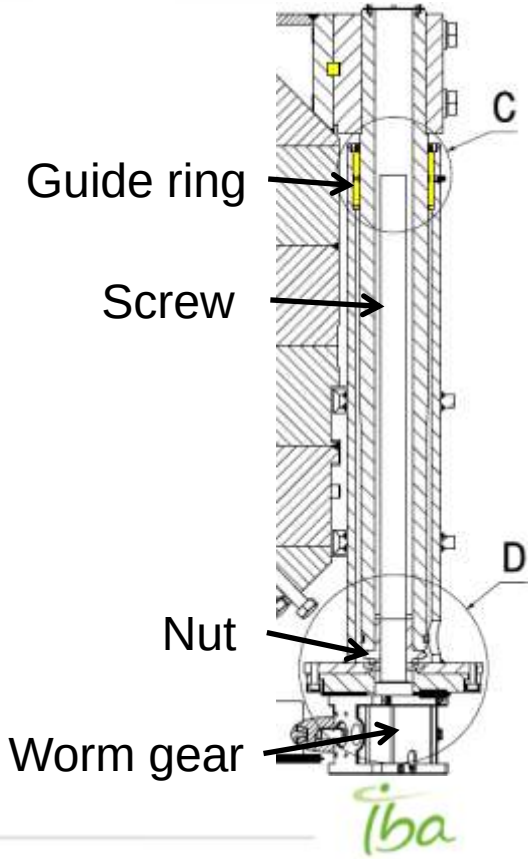
Yoke lifting system

- Three screw jacks ensure a perfect parallelism between the two yoke halves and a rigid guiding to avoid collisions.



- Mechanical dimensions in order to stay in accordance to standard EN13155.
- Resolvers on each screw ensure safe operation.
- On closing, the screws stops on an overtorque to ensure that the yoke is well closed.
- Precision microswiches interlocks the SCC to avoid screw damage.



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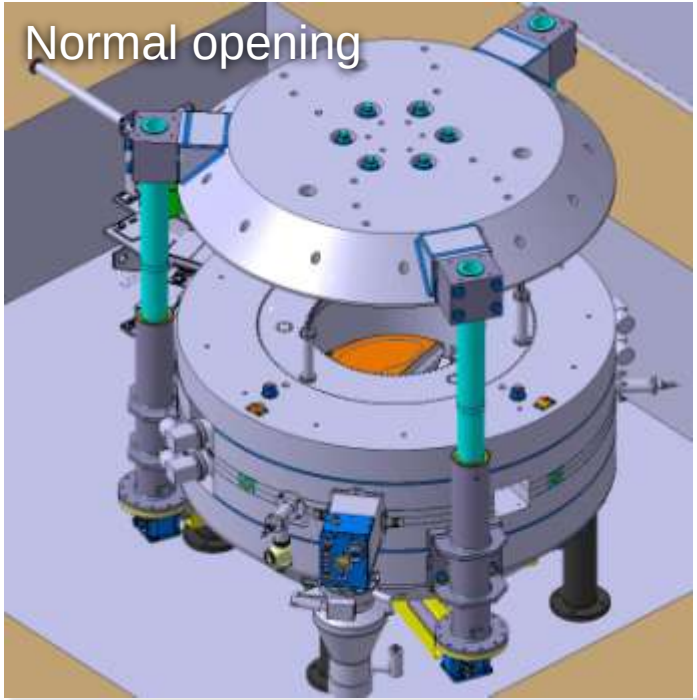
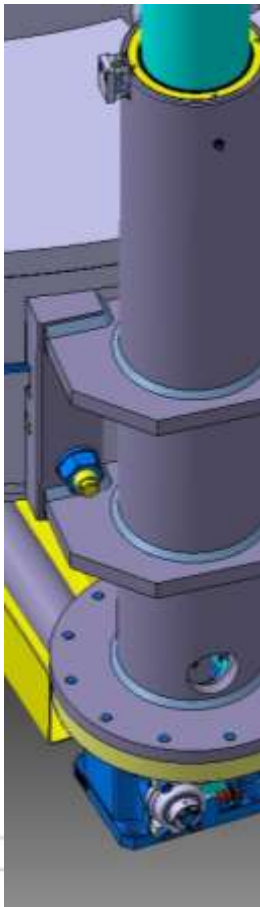
Yoke lifting system

The YLS offers the possibility to open above the cyrostat as well as at the median plane.





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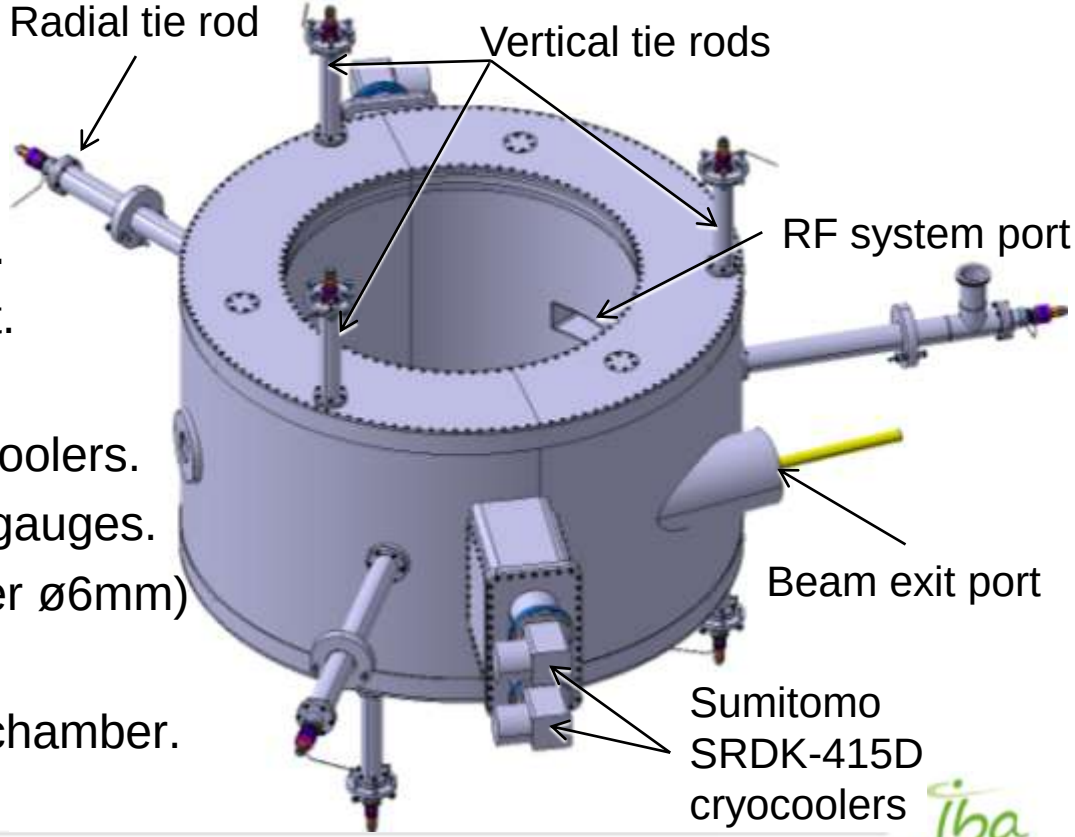
Superconducting coil

- NbTi wire in channel coil.
- Suspended cold mass: 3tons.
- Overall weight: 4tons.
- Nominal current: 650A (56A/mm²).
- Nominal ampere-turns: $4.3x10^{+6}$At.
- Stored energy: 10MJ.
- Conduction cooled by 4 SHI cryocoolers.
- 9 Inconel tension rods with strain gauges.
  (radial ø14mm; upper ø8mm; lower ø6mm)

- Cryostat is the cyclotron vacuum chamber.



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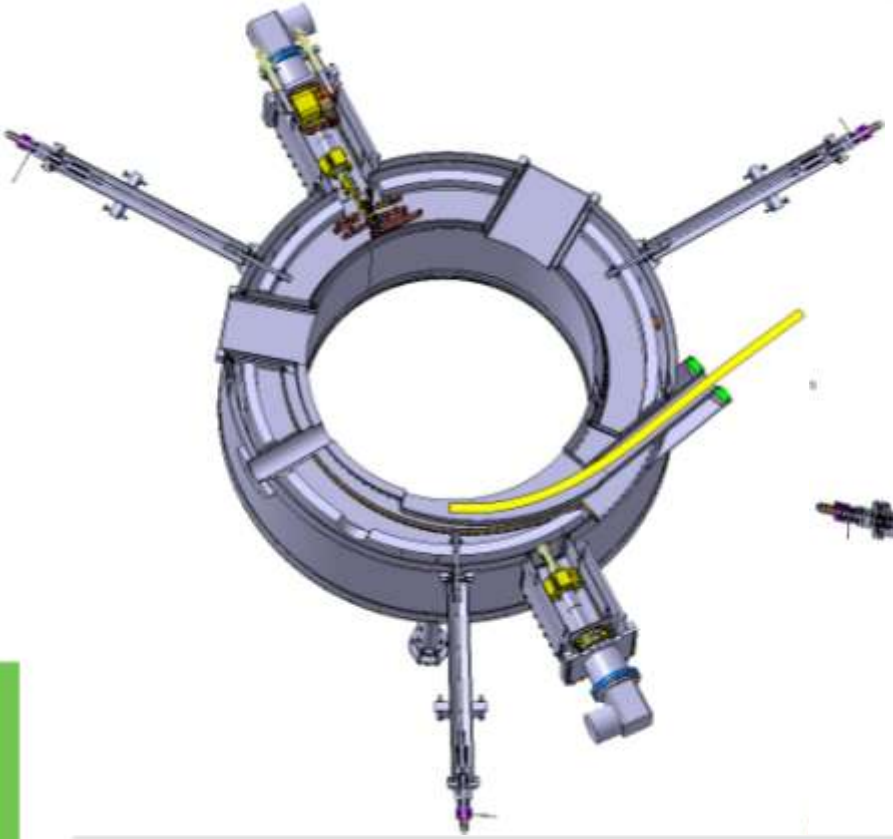
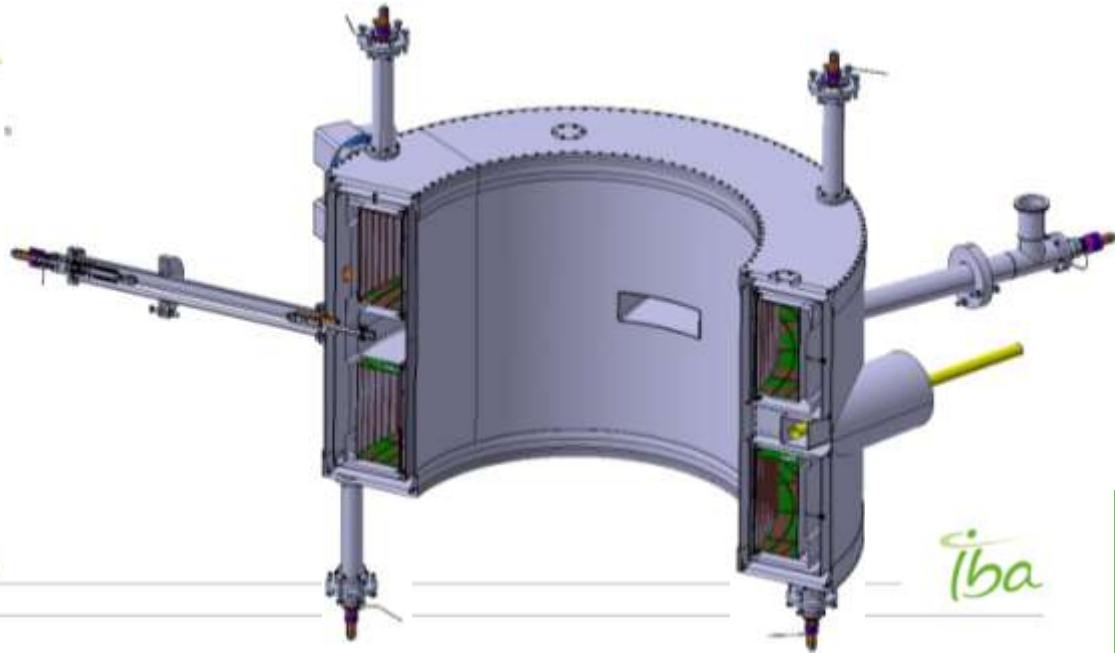
Superconducting coil





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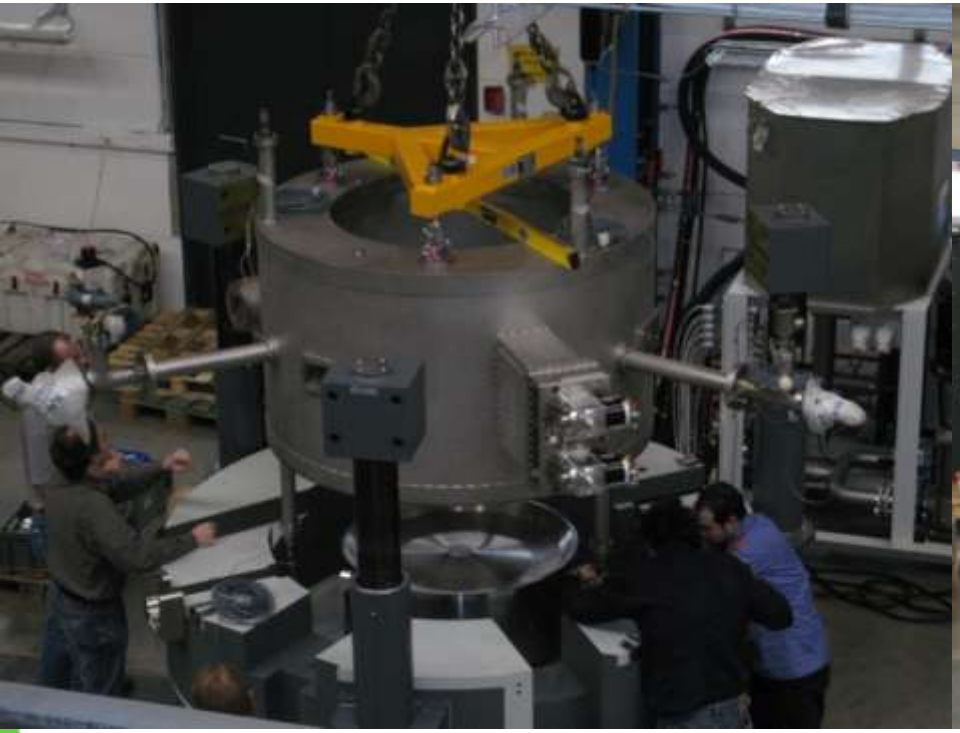
Superconducting coil



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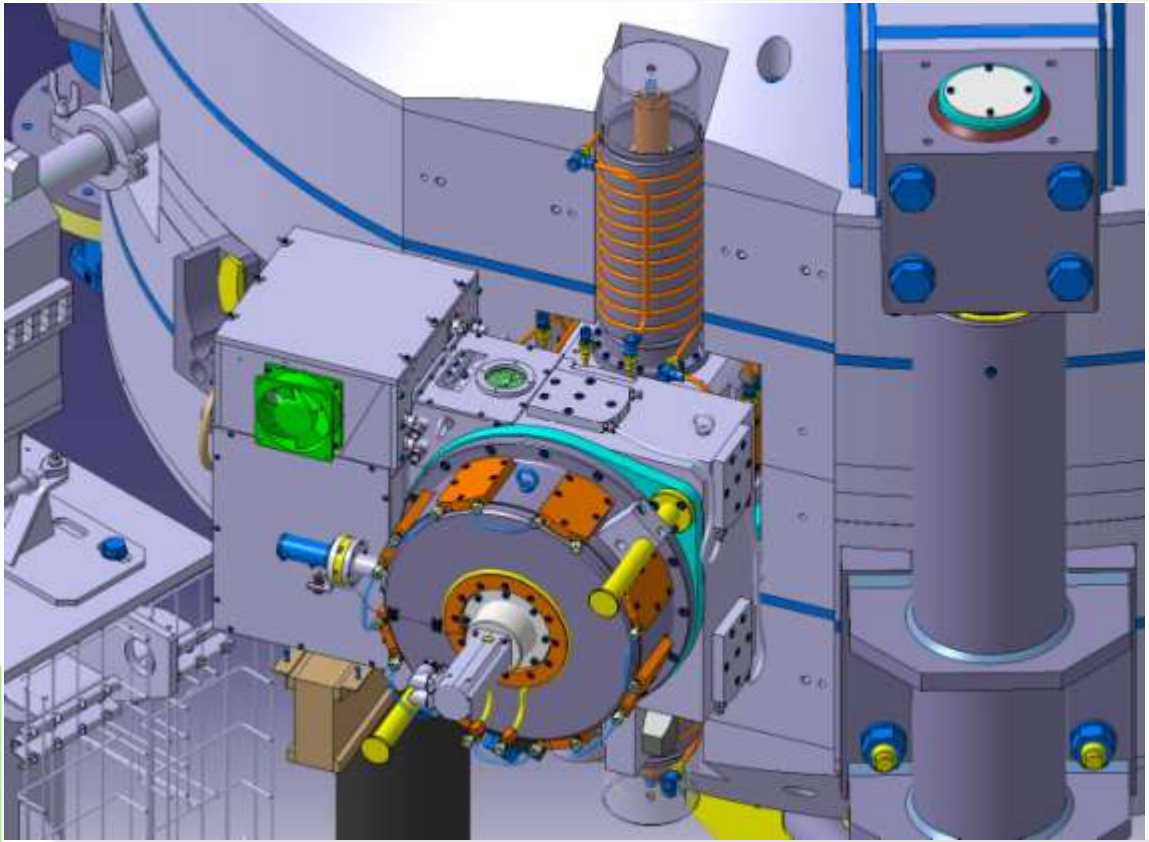
RF system



- Self oscillating system: Harley oscillator driving and driven by structure own resonant frequency, modulated by a rotating condenser.
- RF Frequency: 60~90MHz
- Modulation frequency: 1kHz
- Dee voltage: 3~12kV
- Peak power: 15kW

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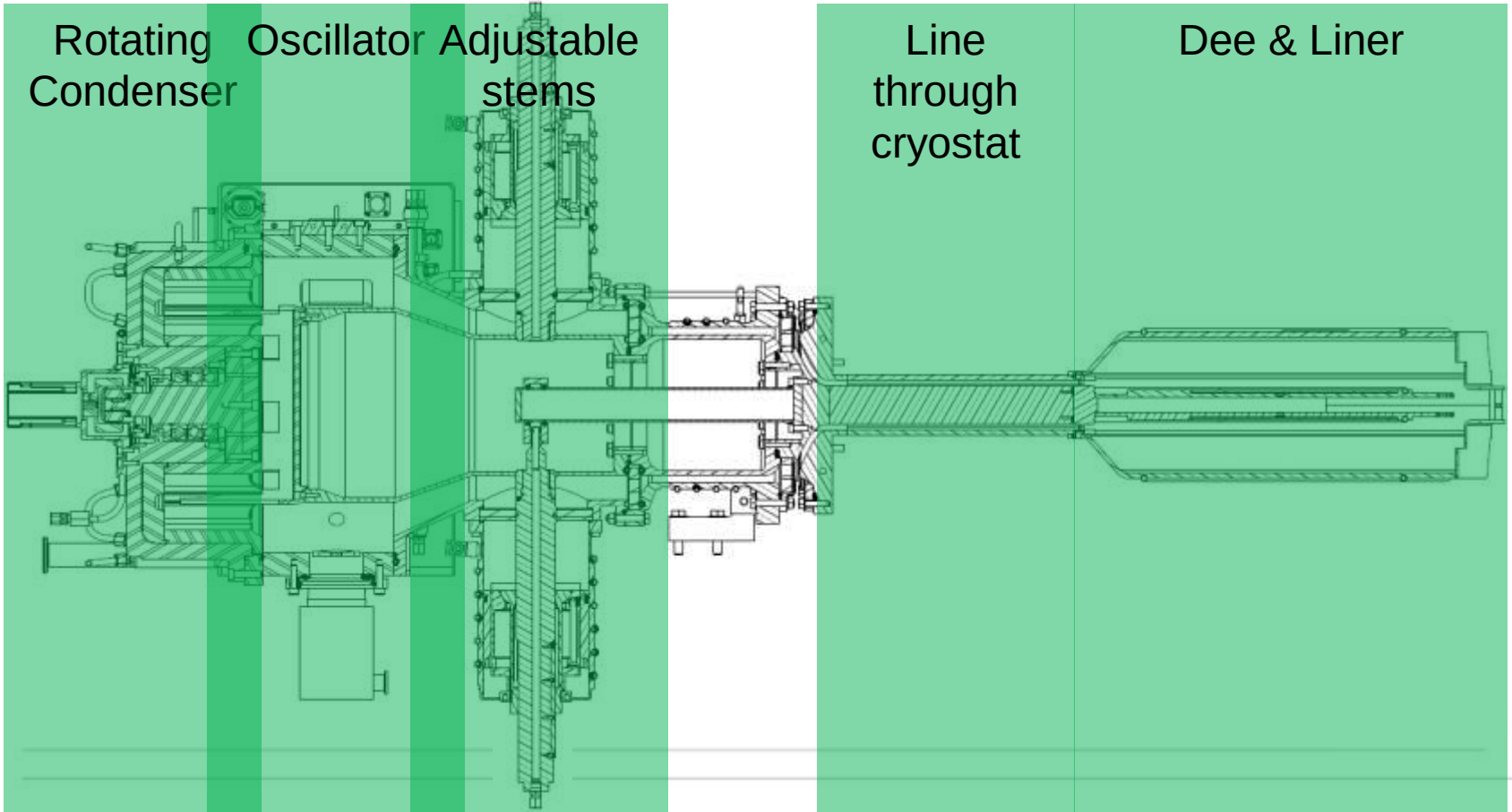
RF system



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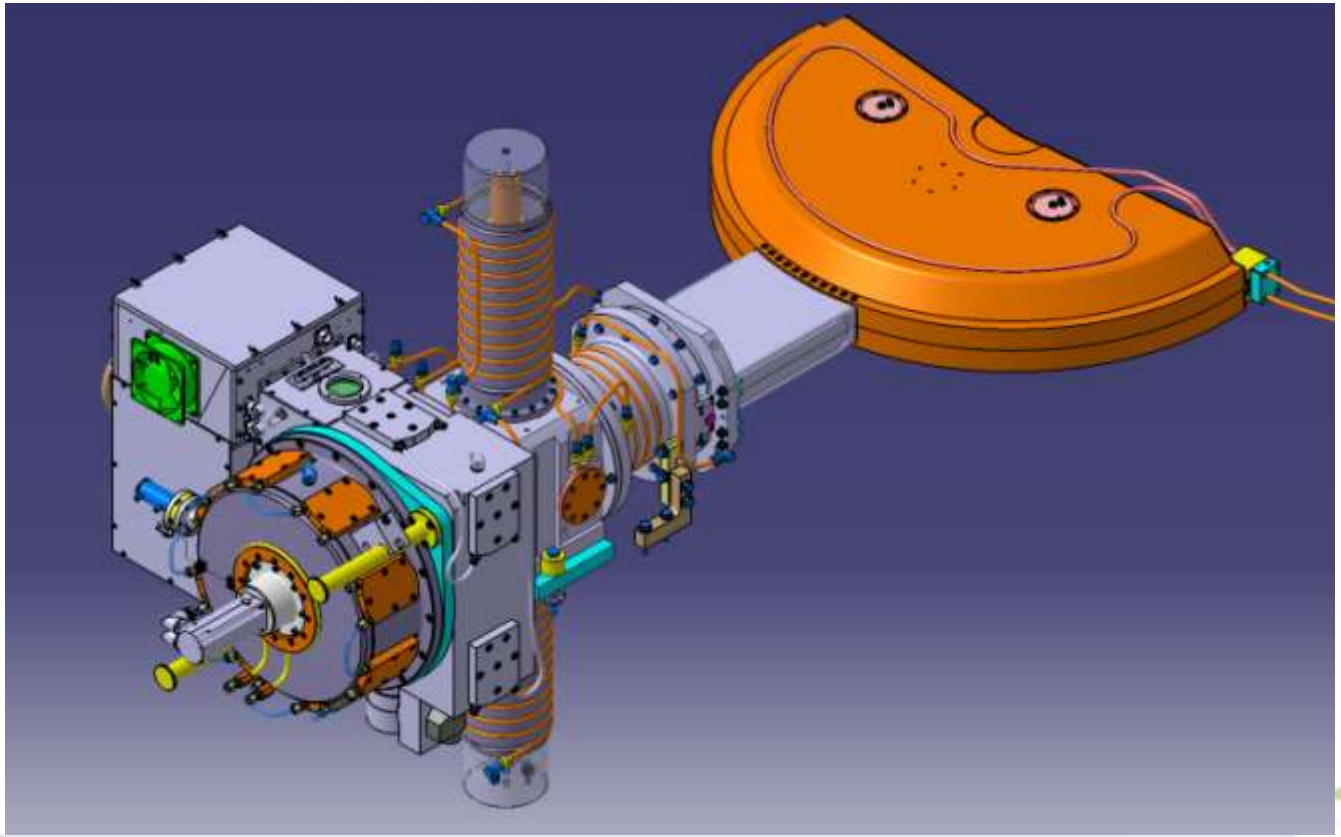

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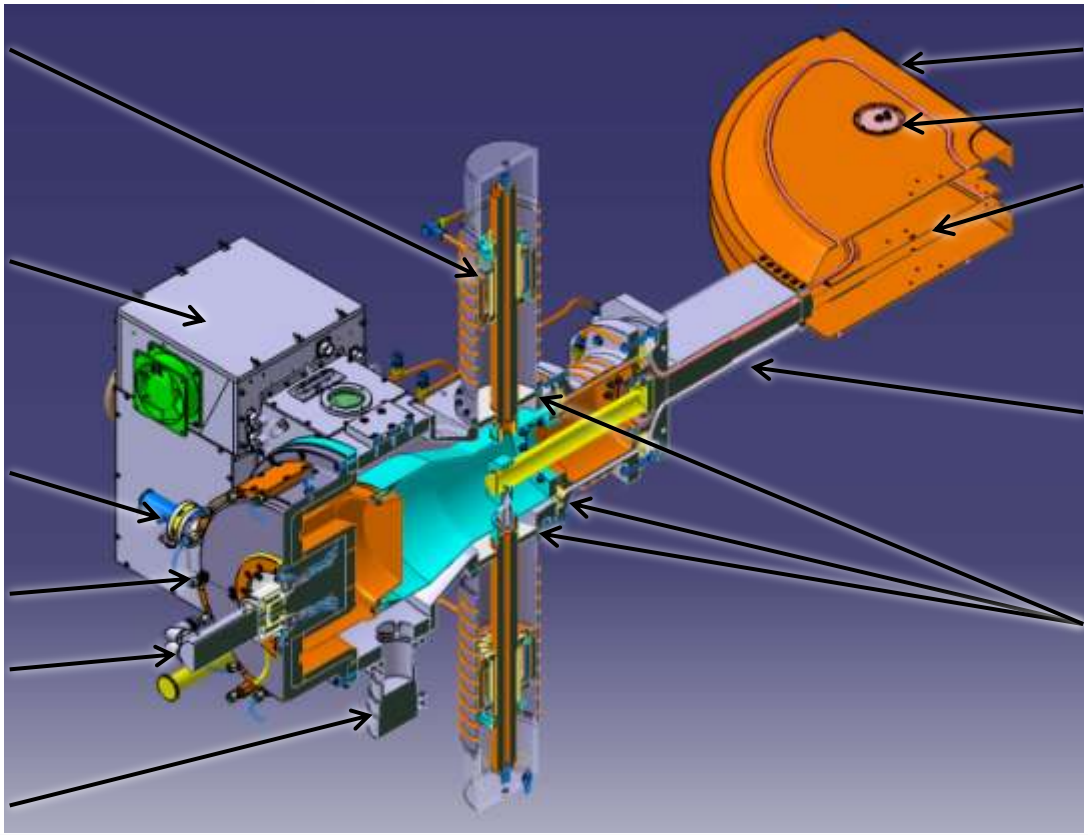
RF system



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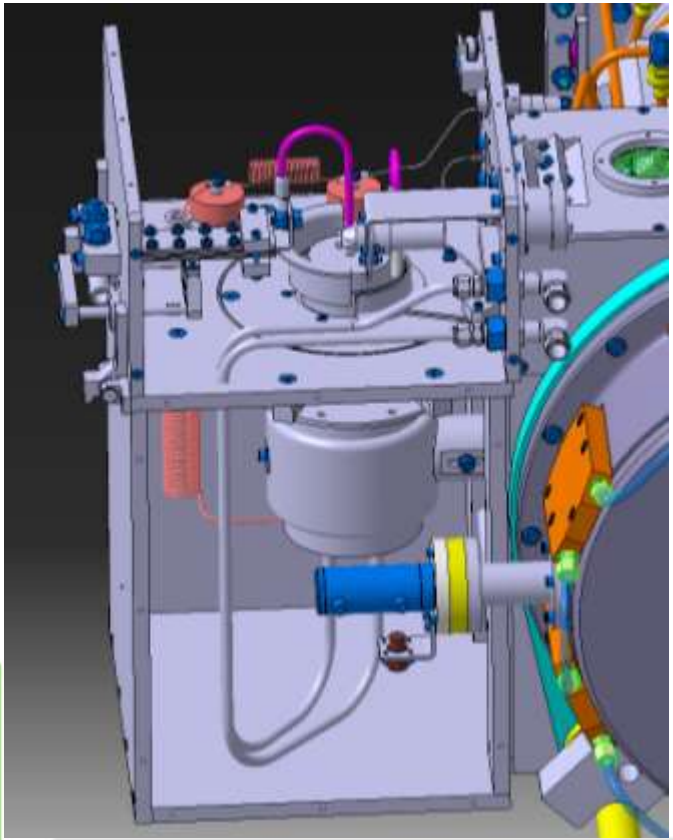
RF system



Hartley type oscillator driving the RF structure at its own resonant frequency. Build around a Thales ITK12 triode, connected in grounded grid mode and a cathode reinjection in phase supplied by an adjustable voltage pick-up loop in the main resonator. It starts oscillating as soon as the anode voltage is applied.

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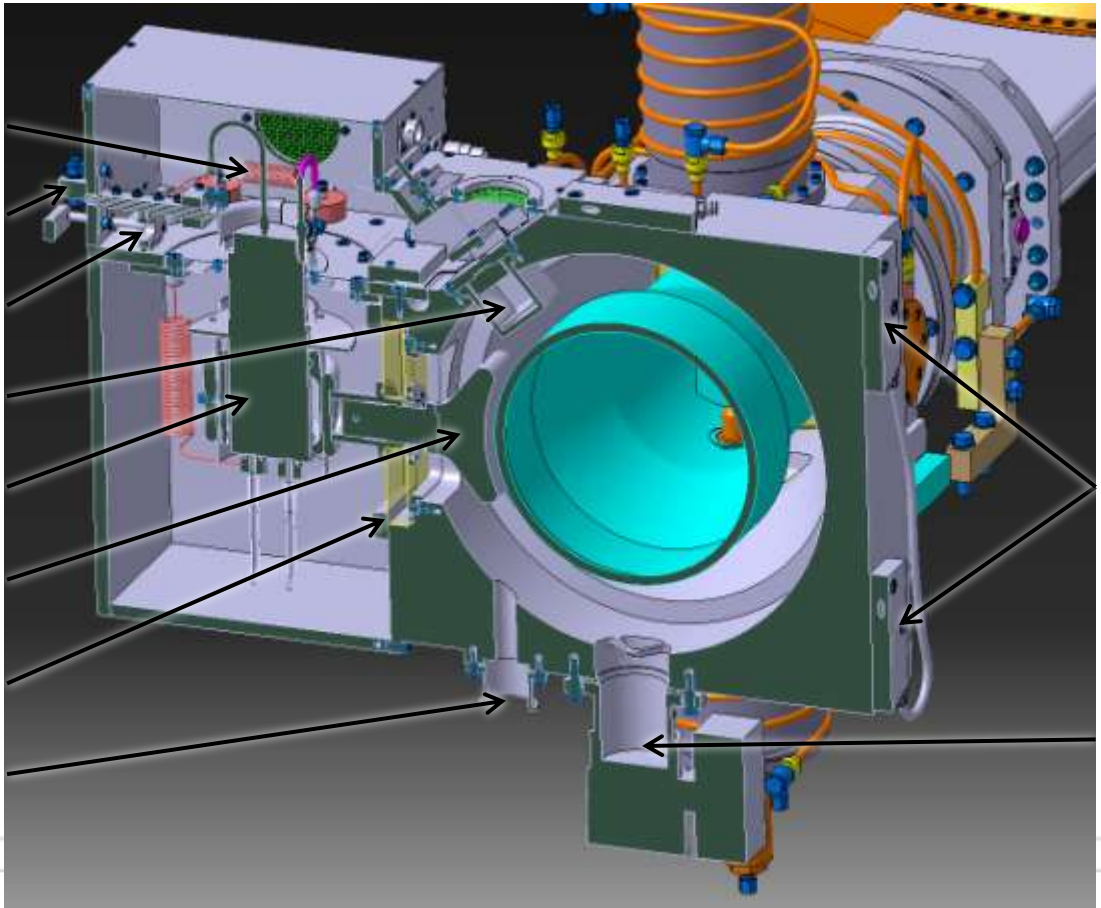
RF system



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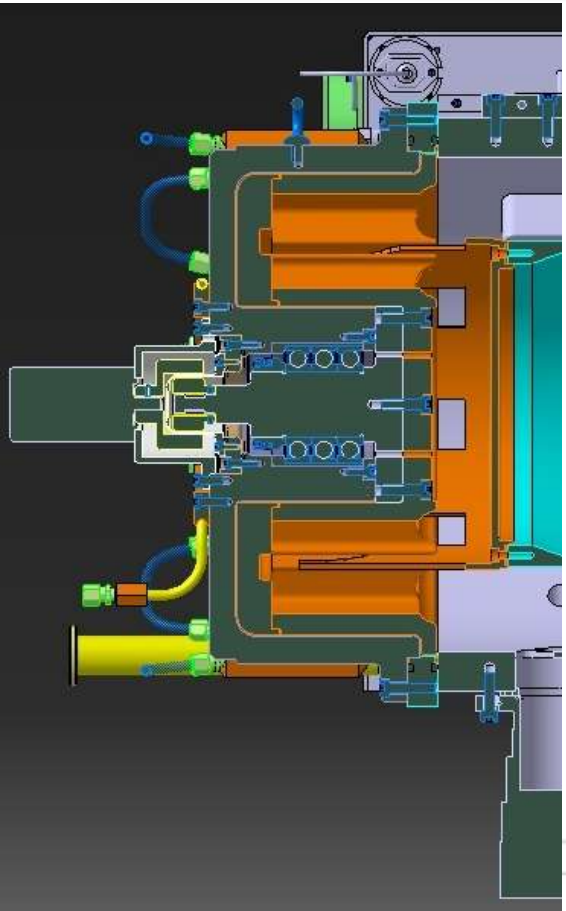
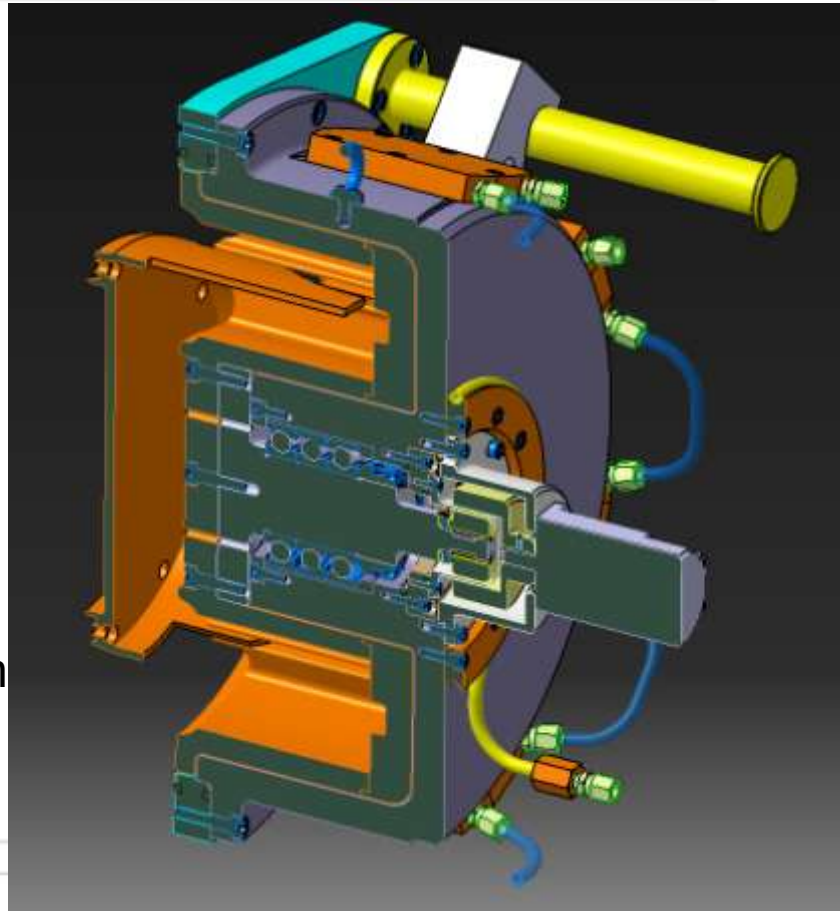


RotCo

Stator: 8 blades with a carefully designed profile to have the desired df/dt curve.

Rotor: large wheel with 2x8 electrodes spinning at 7500rpm on hybrid bearings, driven through a magnetic coupling by a synchro servo motor.



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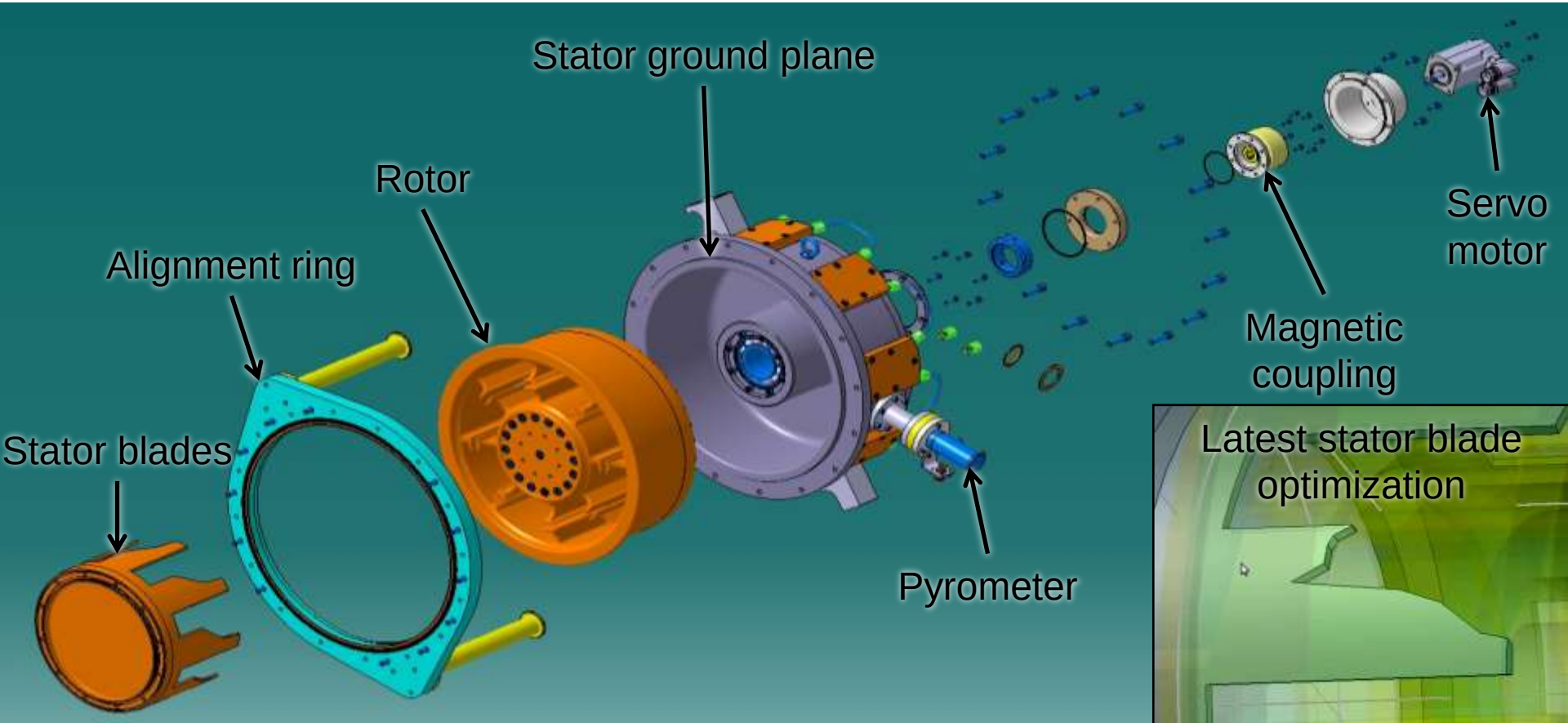
RF system



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RF system

RF structure middle section on assembly support frame.

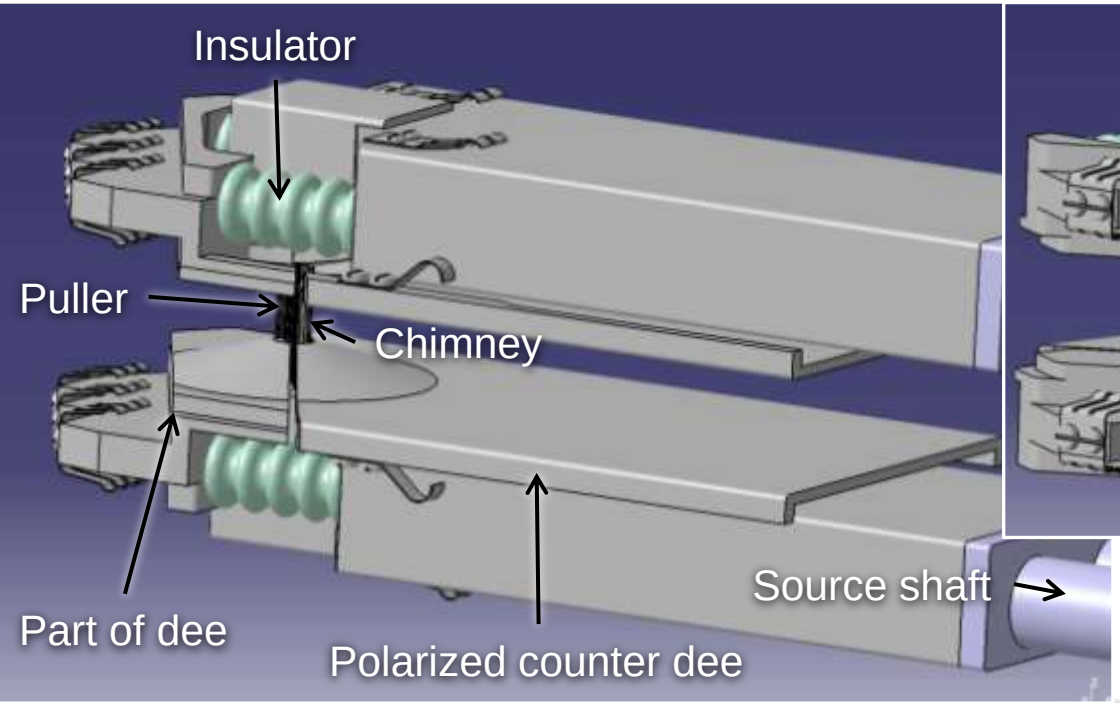
Dee just before e-beam welding.

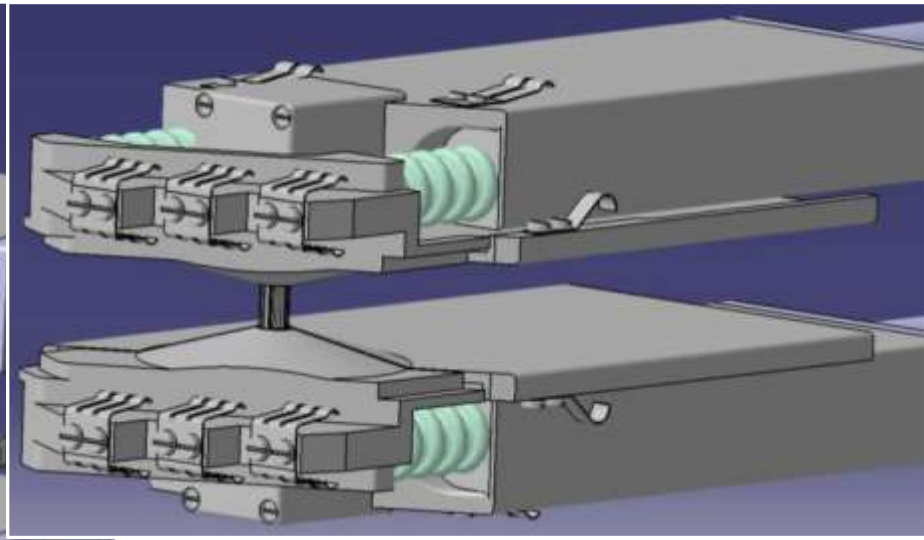
RF liner just before cooling tubes brazing.

S2C2 guided tour

Ion source

- The Ion Source assembly, including the central region, can be extracted for maintenance without having to open the magnet yoke.





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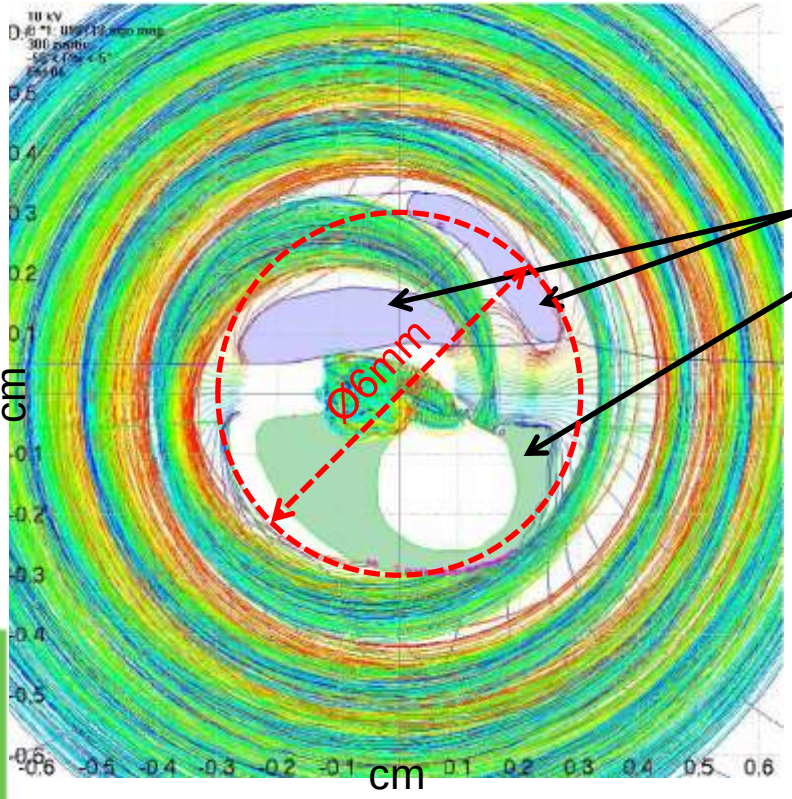
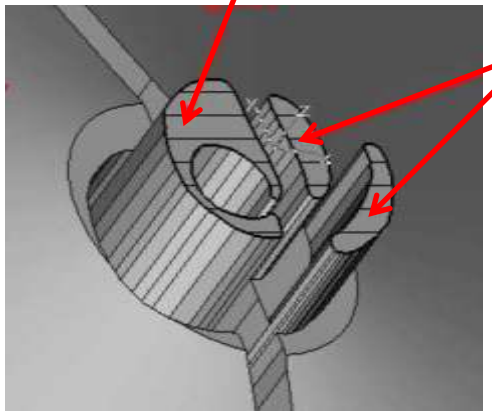
Ion source



Because of the high magnetic field (5.65T) and the low dee voltage (11kV), the source has to be extremely small.

Puller

Chimney



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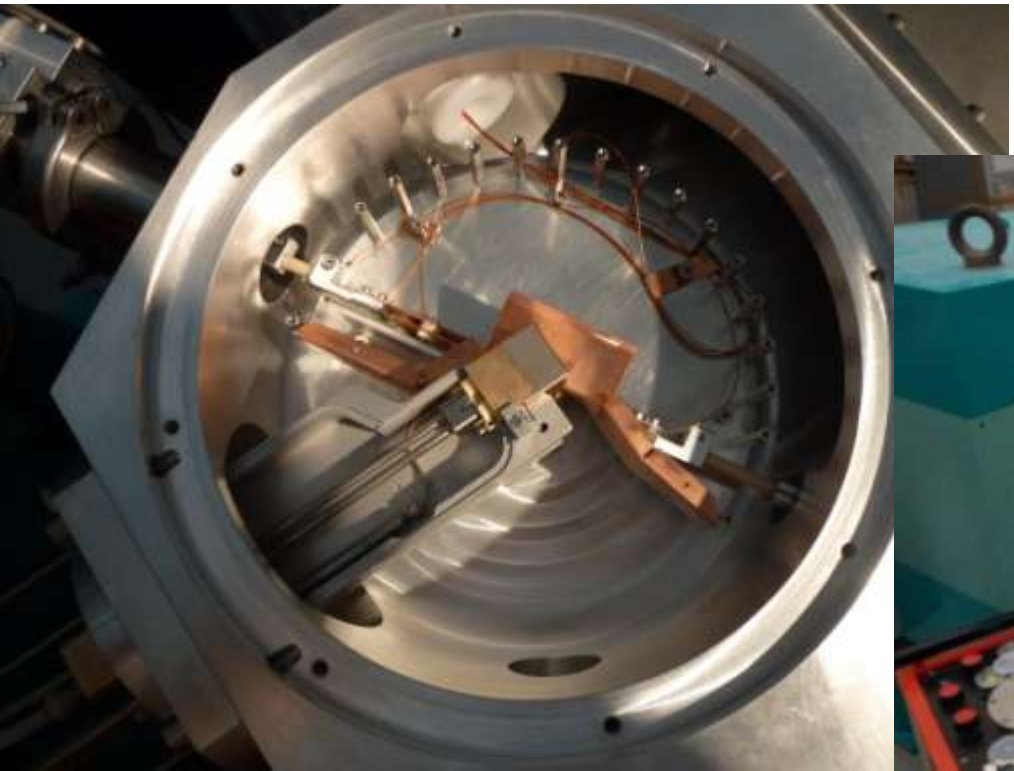
Ion source

- The ion source and its power supply have been fully tested in Nice at AIMA. This allowed us to fully optimize the design.



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Extraction system

Harmonic coils

Correction bars

Regenerator

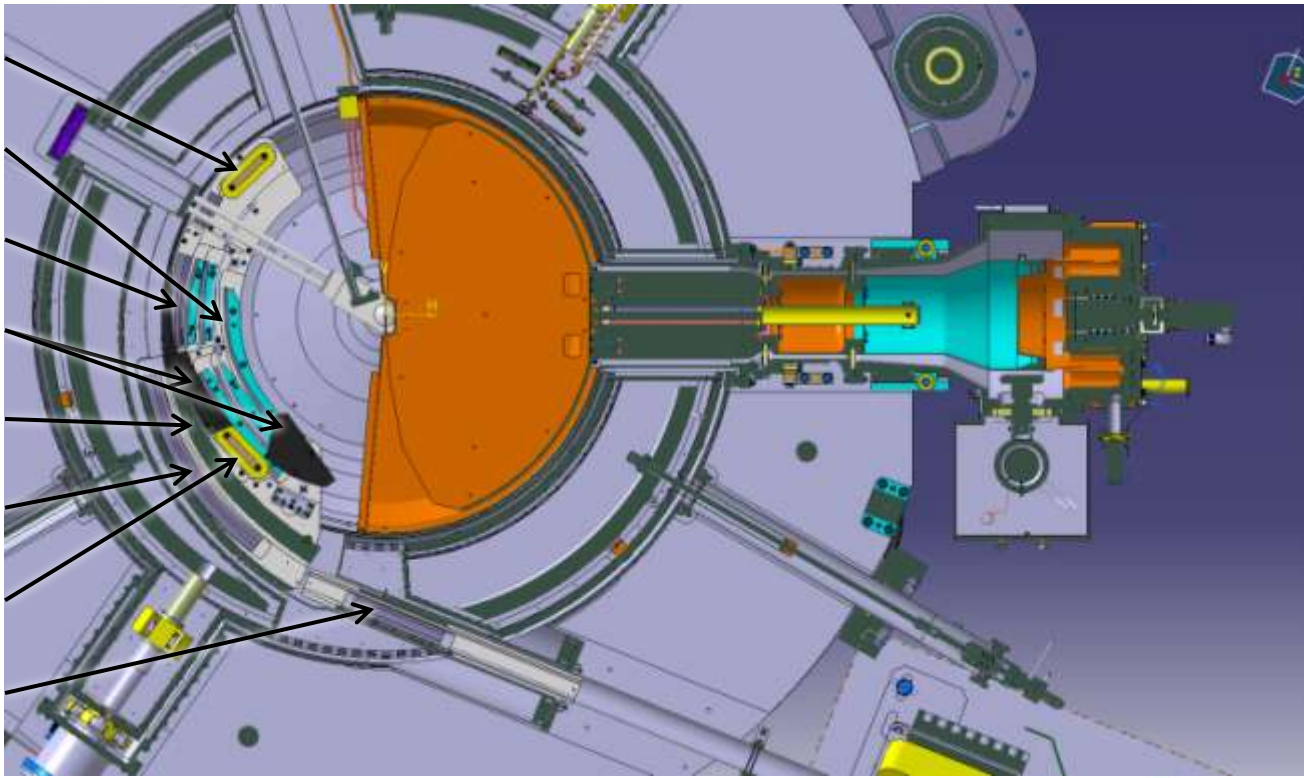
Graphite beam stops

Magnetic septum

Anti-septum

Harmonic coils

3 bar gradient corrector



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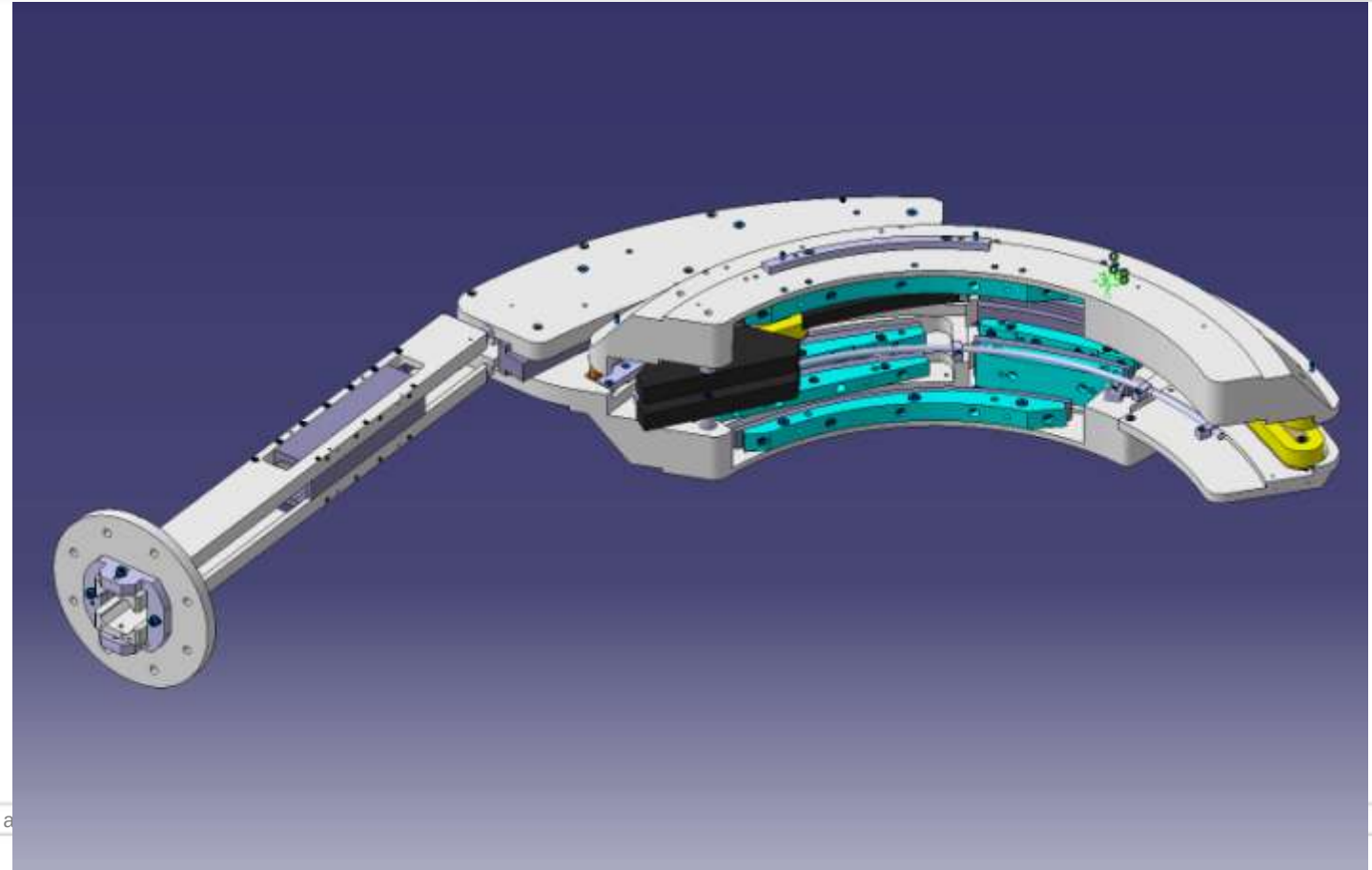
Extraction system



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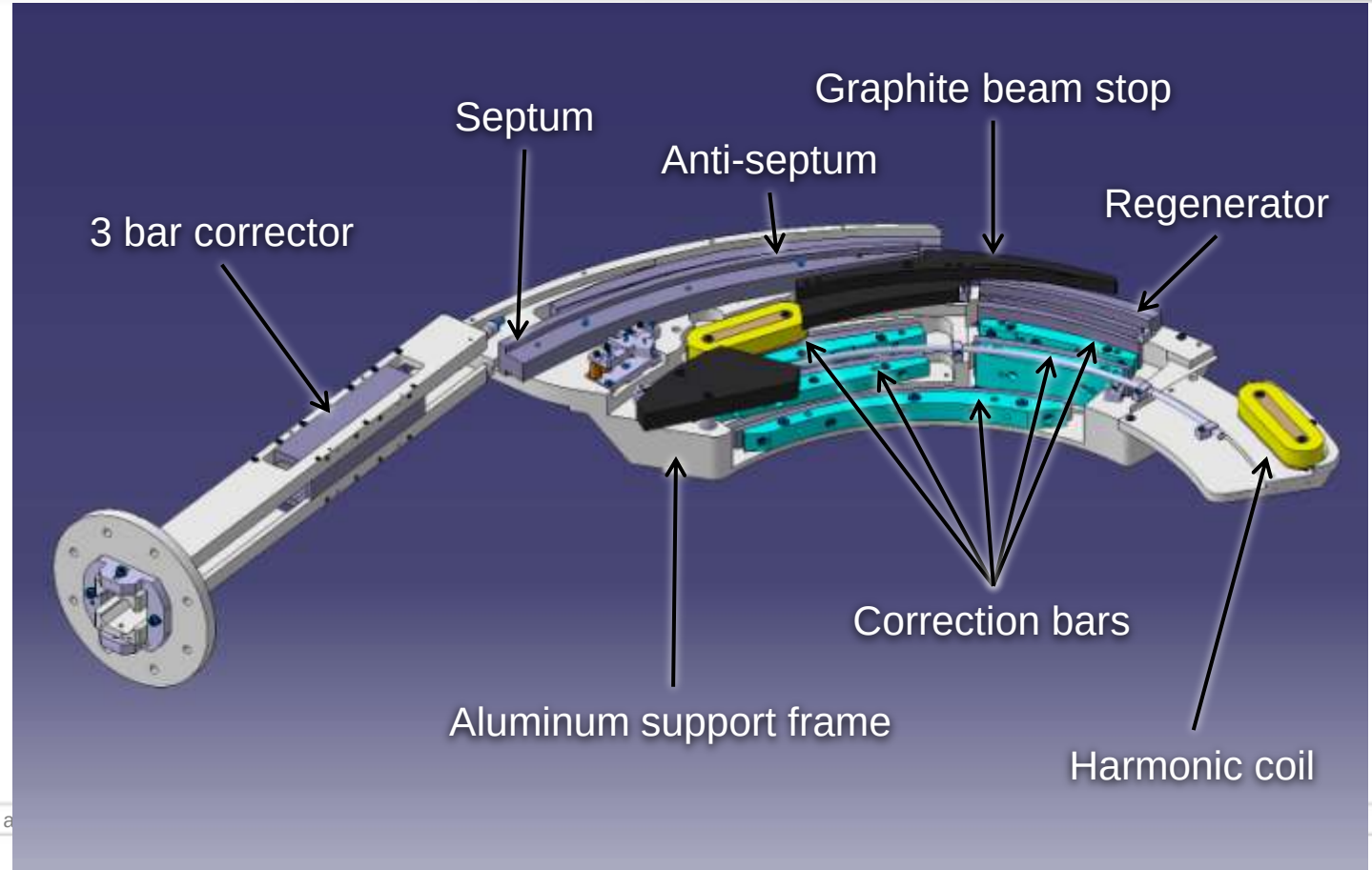
Extraction system



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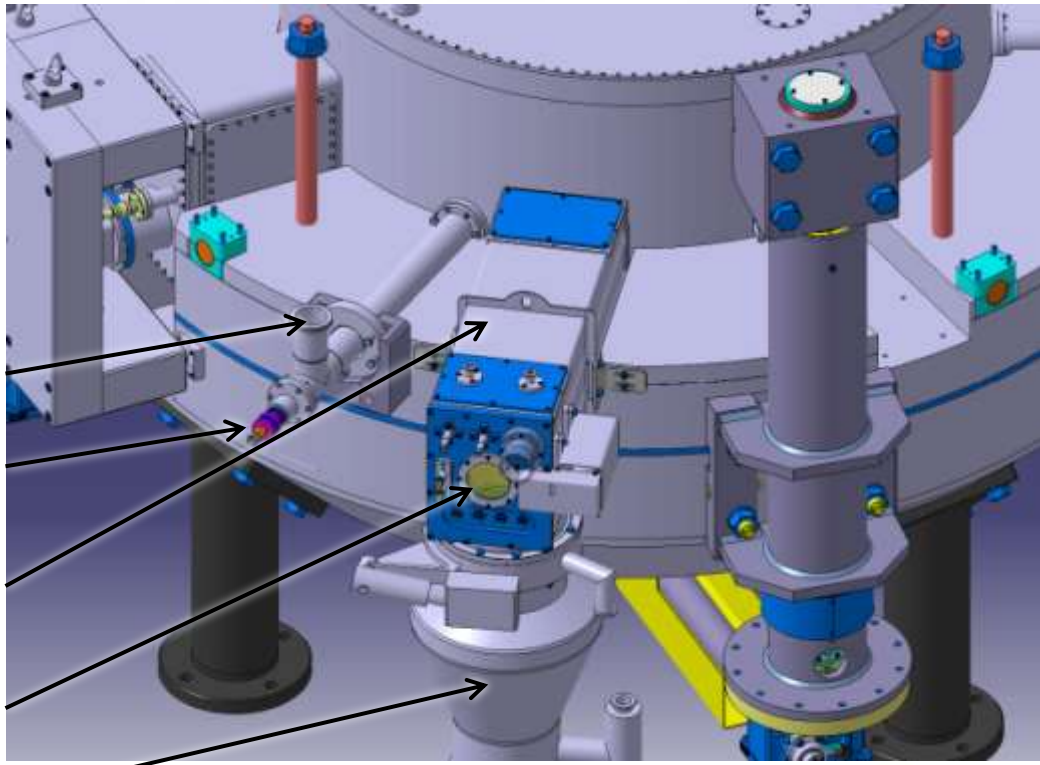
Vacuum system

Simple, reliable and easily accessible vacuum system, based on an Edwards ODP and Leybold RV pump.



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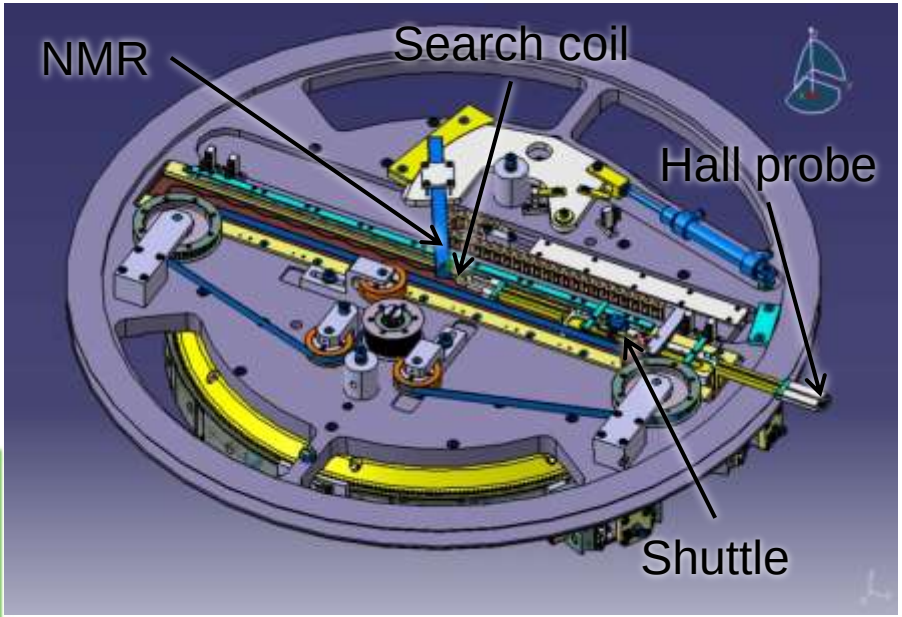
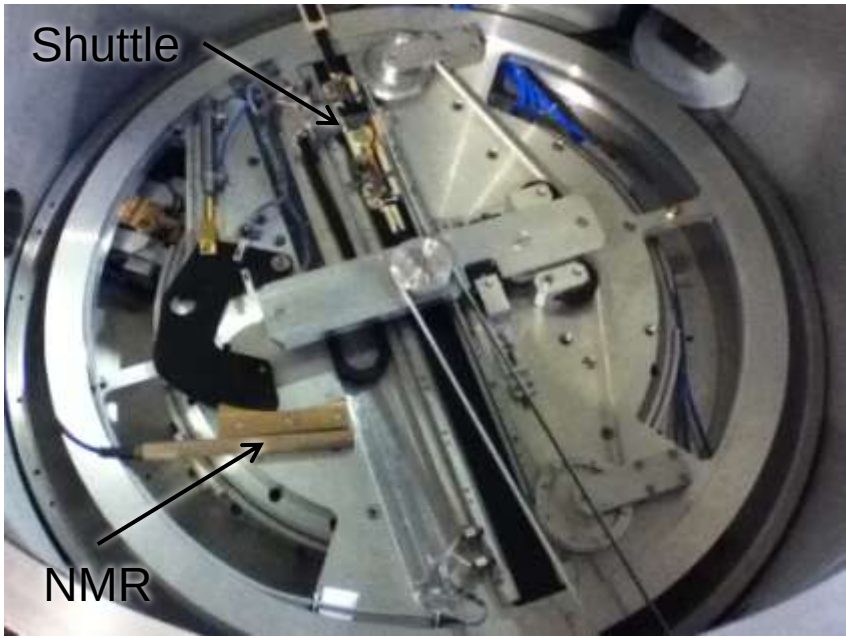
Magnetic field mapping system

- Twin system :
  - Search coil on one side of shuttle with NMR probe at center
  - Hall probe on the other side of shuttle





S2C2 guided tour

Water conditioner

- Cooling capacity: 550kW.
- Nominal flow: 600 l/m.
- Regulated pressure 6~10bars.
- Capacity: 1m³.
- Automatic switchover of pumps.
- Automatic switchover of deionizing bottles.
- Flow and temperature transducers on each heat exchanger leg.

S2C2 guided tour

Power distribution

S2C2 factory tests

…until now

- Supervision software validated on simulator based on initial requirements.
  - The software has evolved as more functions were added once the hardware was installed and functional.
- Yoke lifting system: variable speed, position and torque control.
- Cyclotron vacuum: reached 10^{-6}mbar.
- Oscillator vacuum: reached 10^{-7}mbar.
- Superconducting coil: Cryostat leak checked, pulled vacuum, cooled down to 3.8K, energized and reached 650A in a few iterations.
  - It required to carefully trim the iron distribution either side of the median plane and reposition the coil to minimize the forces acting of the cold mass.
  - QPS was prone to noise induced false positive triggering.

Thank you

Any questions ?

Patrick Verbruggen