



High Intensity Cyclotrons for Production of Medical Radioisotopes

05 dec 2022 –

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E. van der Kraaij (speaker)



Life.
Science.

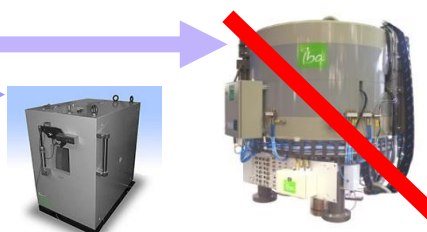
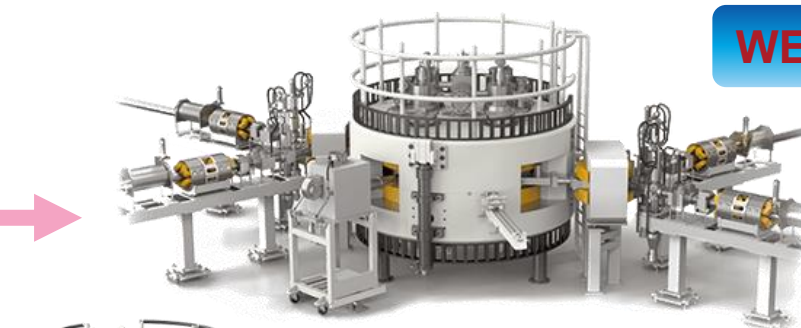
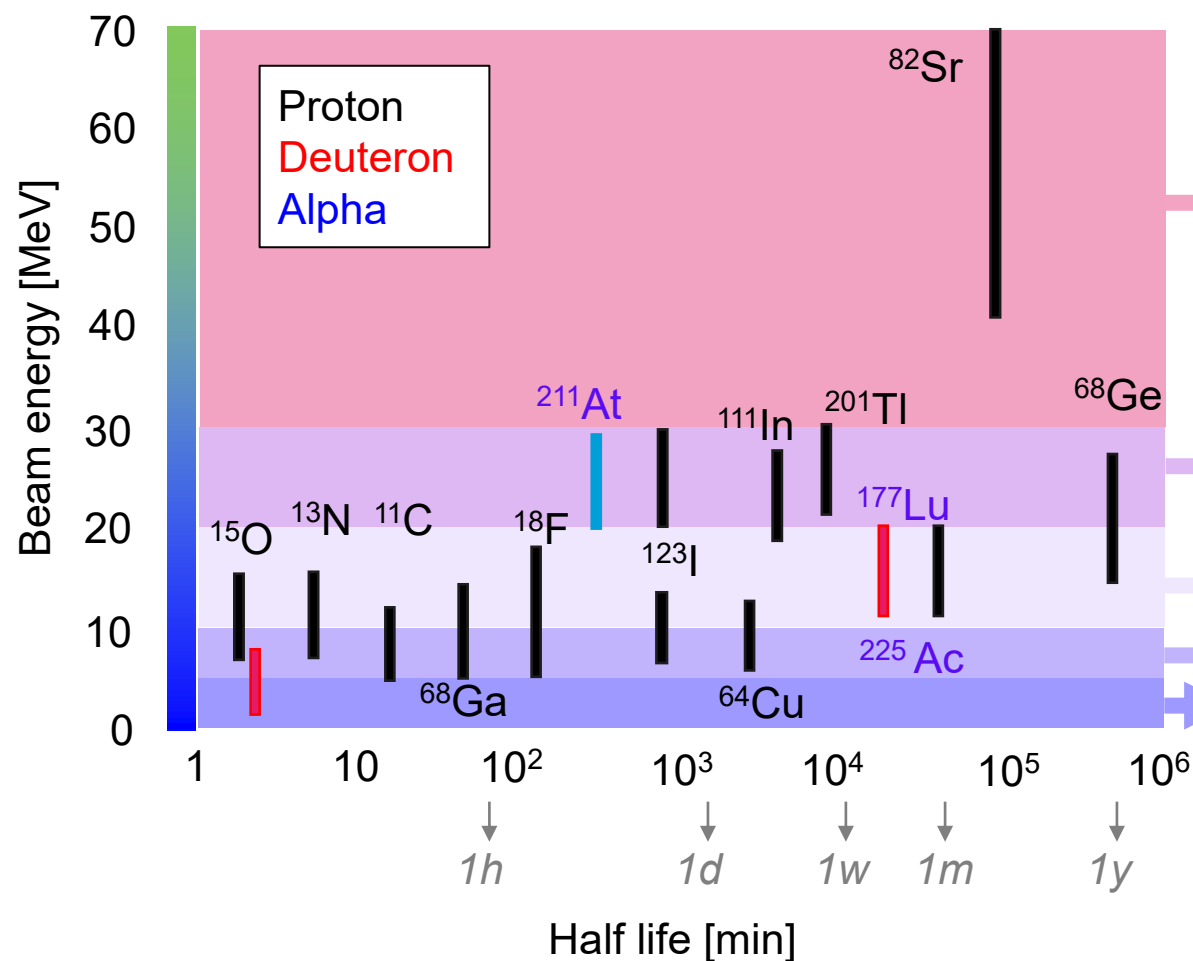
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MOBO01



Energy ranges & example of cyclotrons

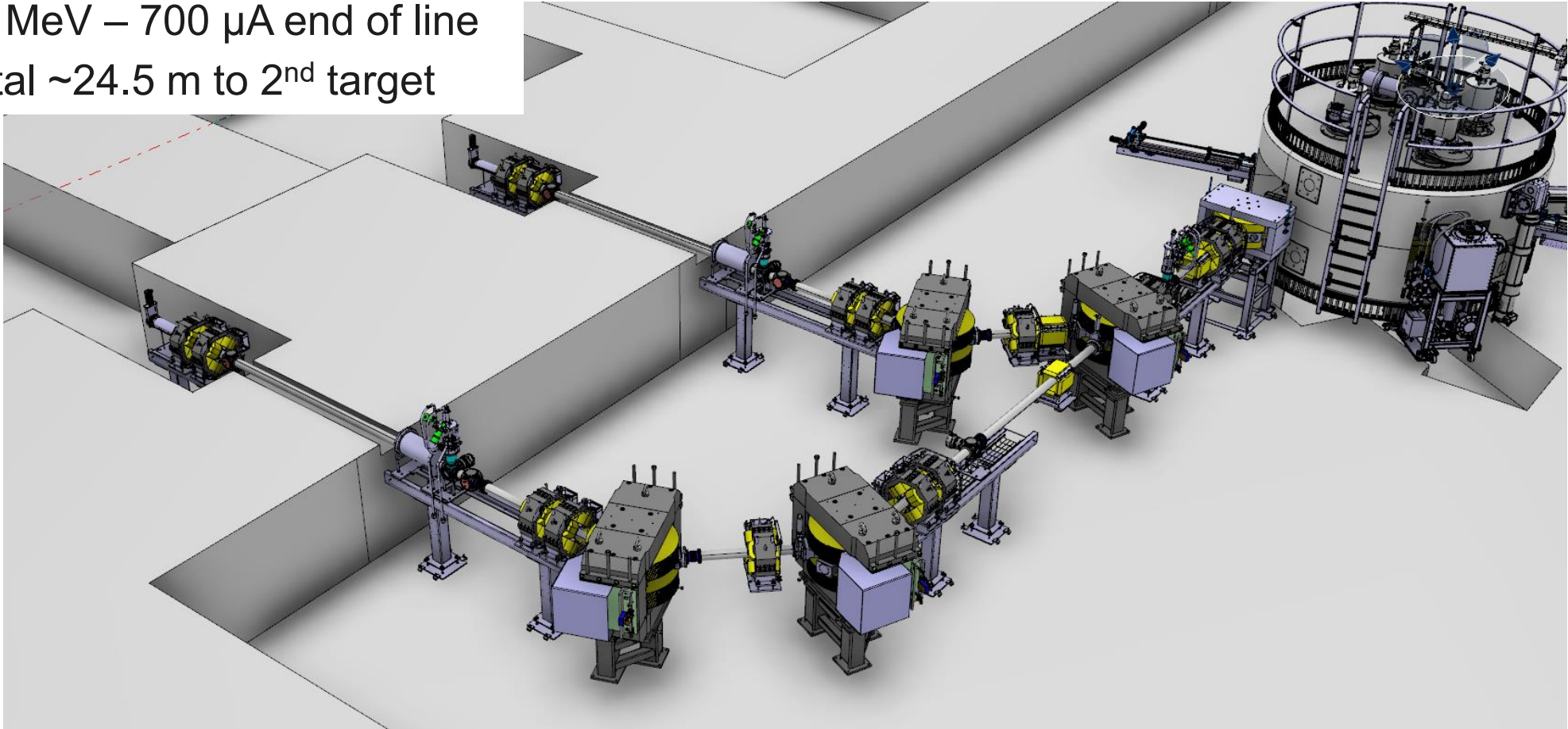
See iThemba :



Cyclone® 70P installed in IBS, Korea

Installed in existing bld complex:

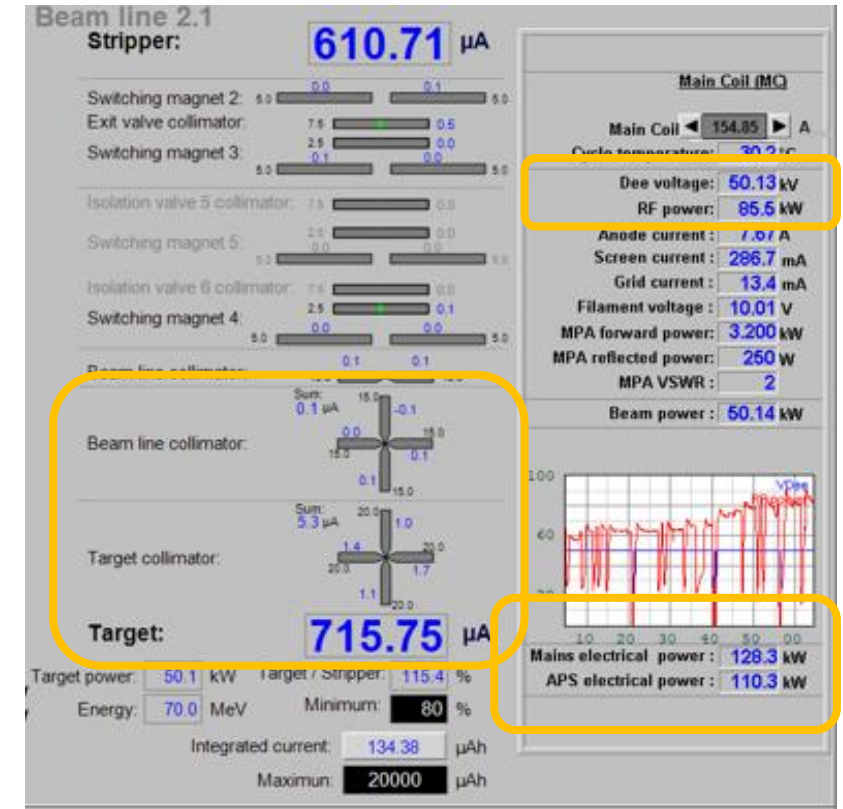
- 70 MeV – 700 μ A end of line
- Total ~24.5 m to 2nd target



Nov 2022: effective completion

- 12 month after the rigging, the Cyclone 70 is now ready for operation.
- Beam power 50 kW,
Elec load 238 kW

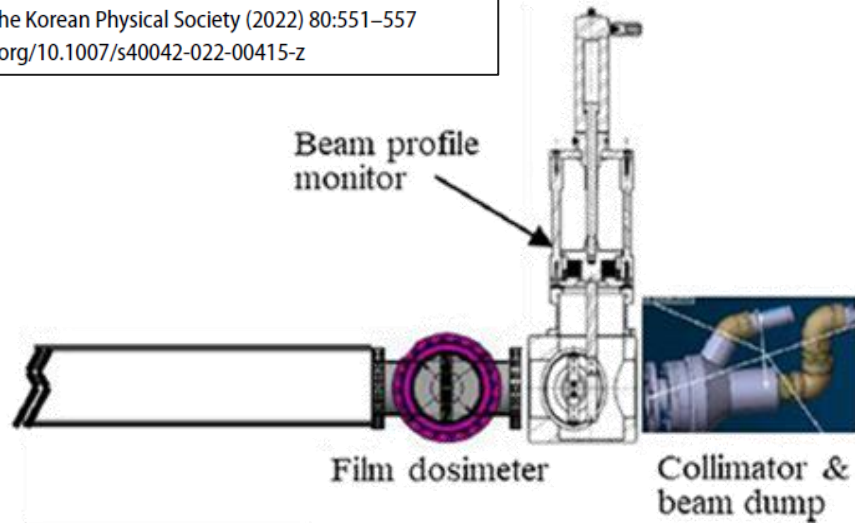
See IBS : **THBO5**



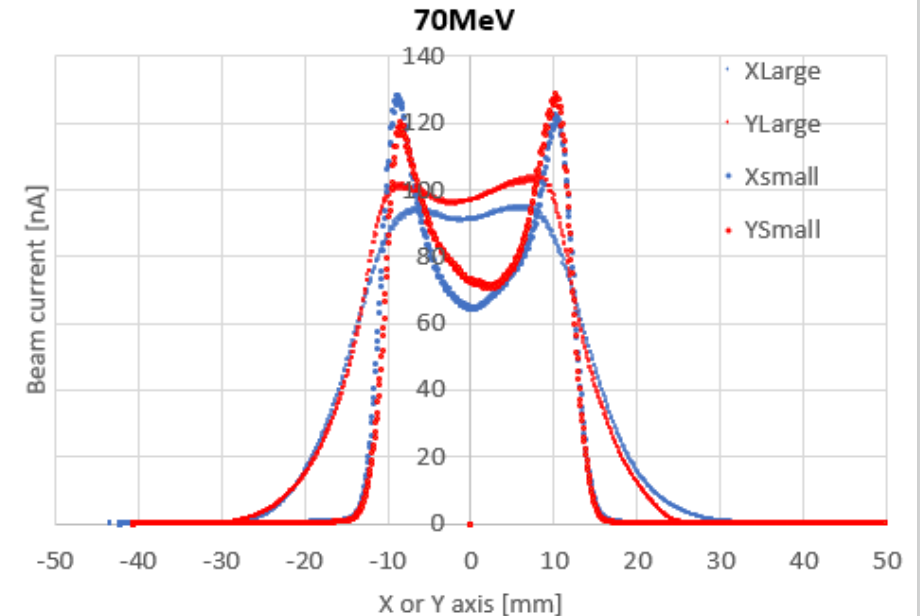
IBA in-house BPM 'wire scan'

- Beam shapes measured using a film dosimeter and a wire scanner for beam profile monitoring, upstream of the beam dump.
- ISOL target will be placed at position of beam dump

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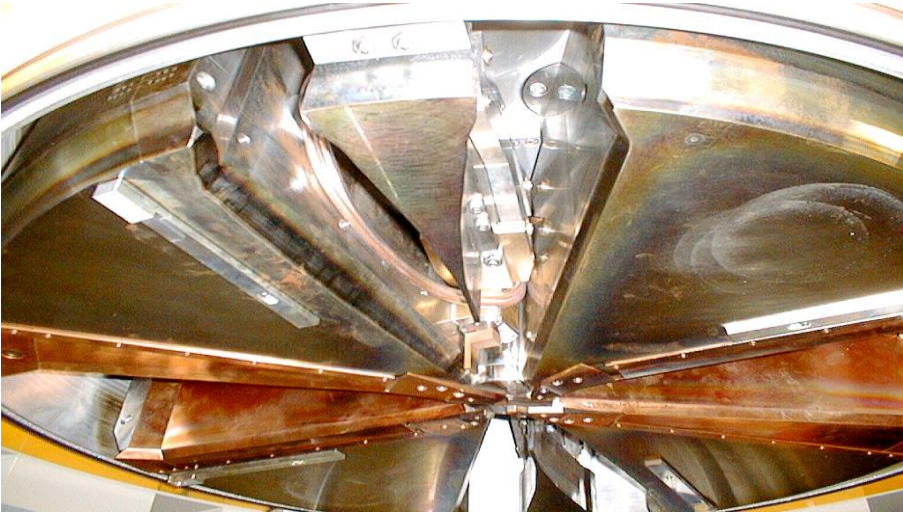
➤ Possible beam tuning:
(customer needs 'donut'-shape)



Multi particle cyclotron: Cyclone®30XP

Particle	E [MeV]	Curr Spec [μAe]	Extraction
P	15-30	300	Stripping
D	8-15	50	Stripping
α	30	50	ESD

- “Flaps” to isochronize magnetic field



EANM 2010, # 7, session P14, Sunday Oct 10,

Deflector current

Beam stop:

20.07

μA

Preseptum:

6.64

μA

Sum:

26.71

μA

Beam st./Sum:

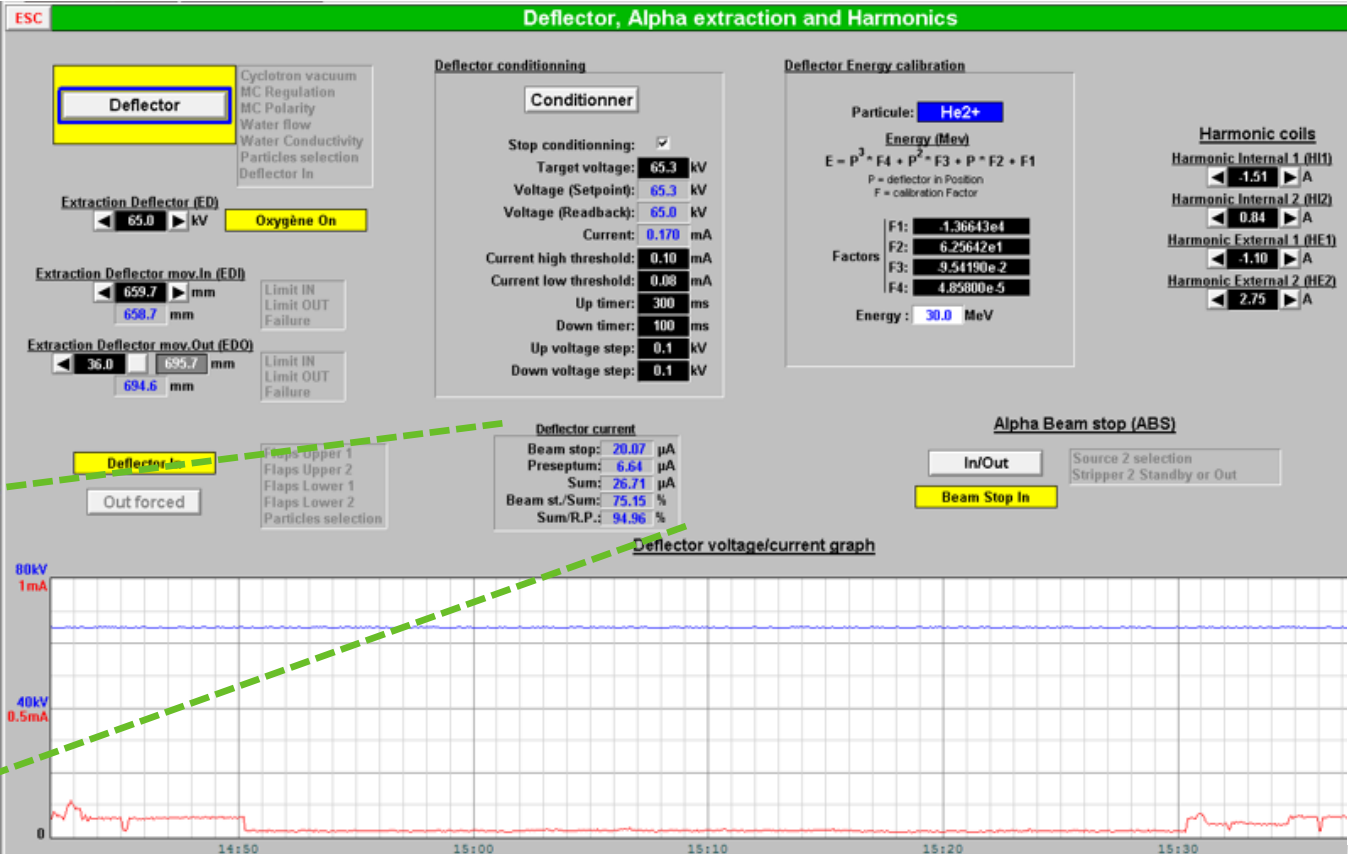
75.15

%

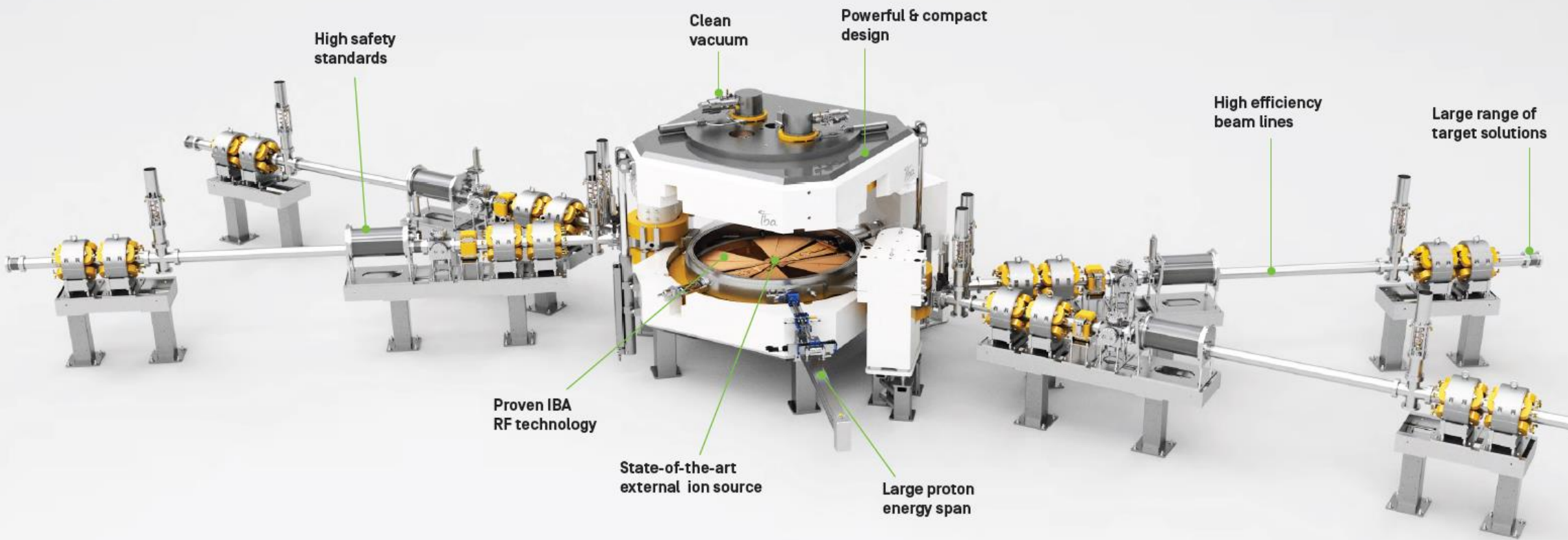
Sum/R.P.:

94.96

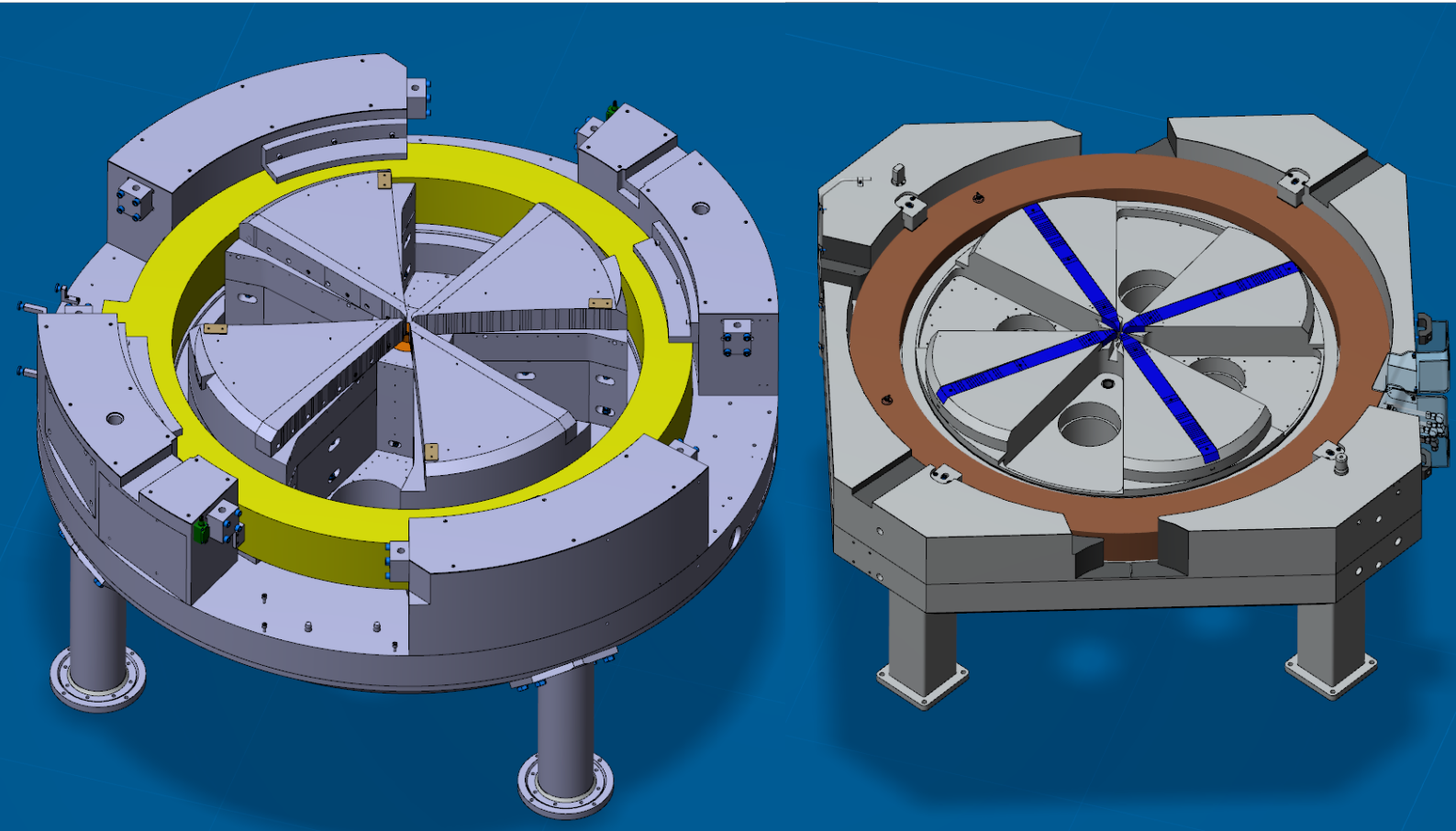
%



CYCLONE[®]IKON

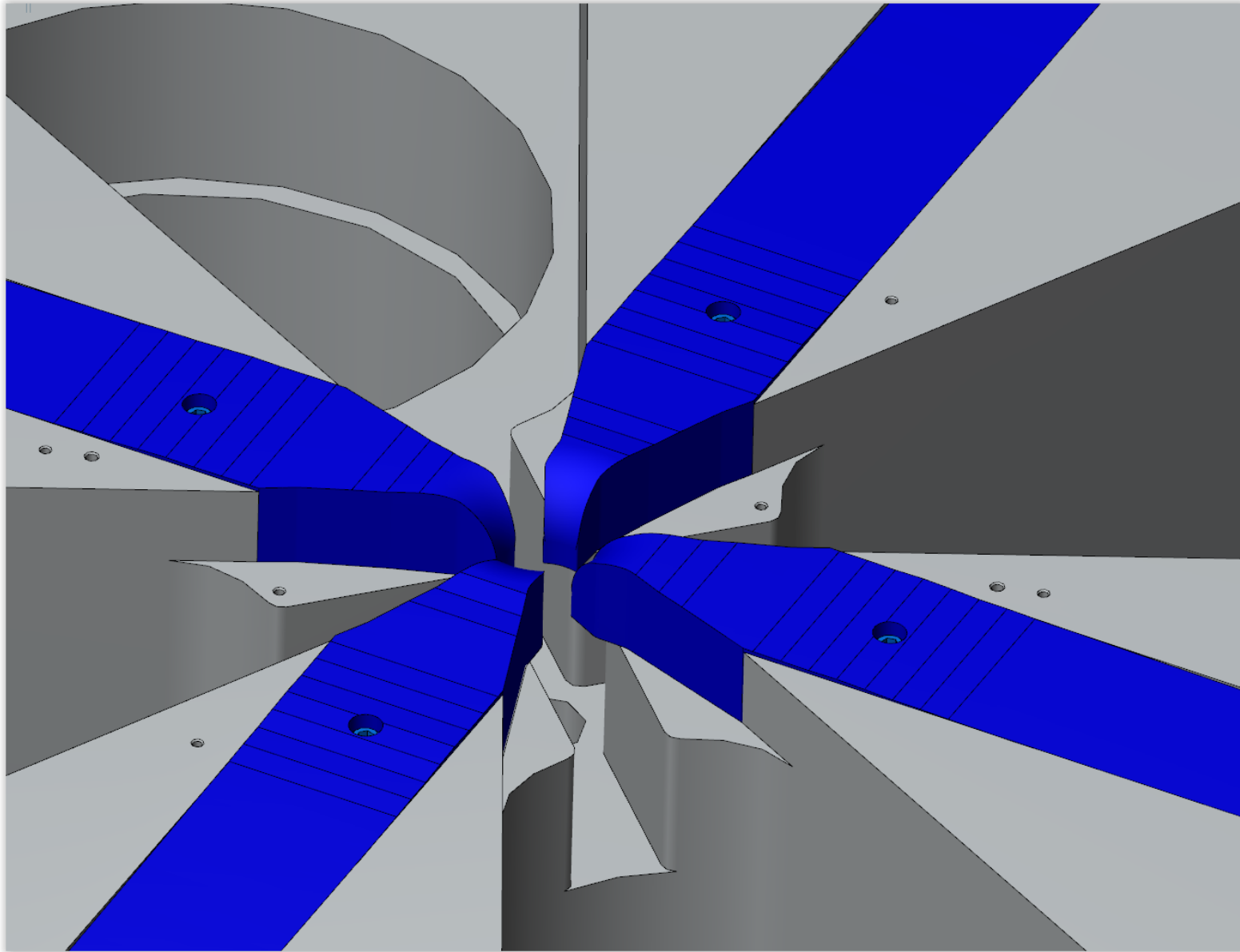


Cyclone® 30P vs IKON



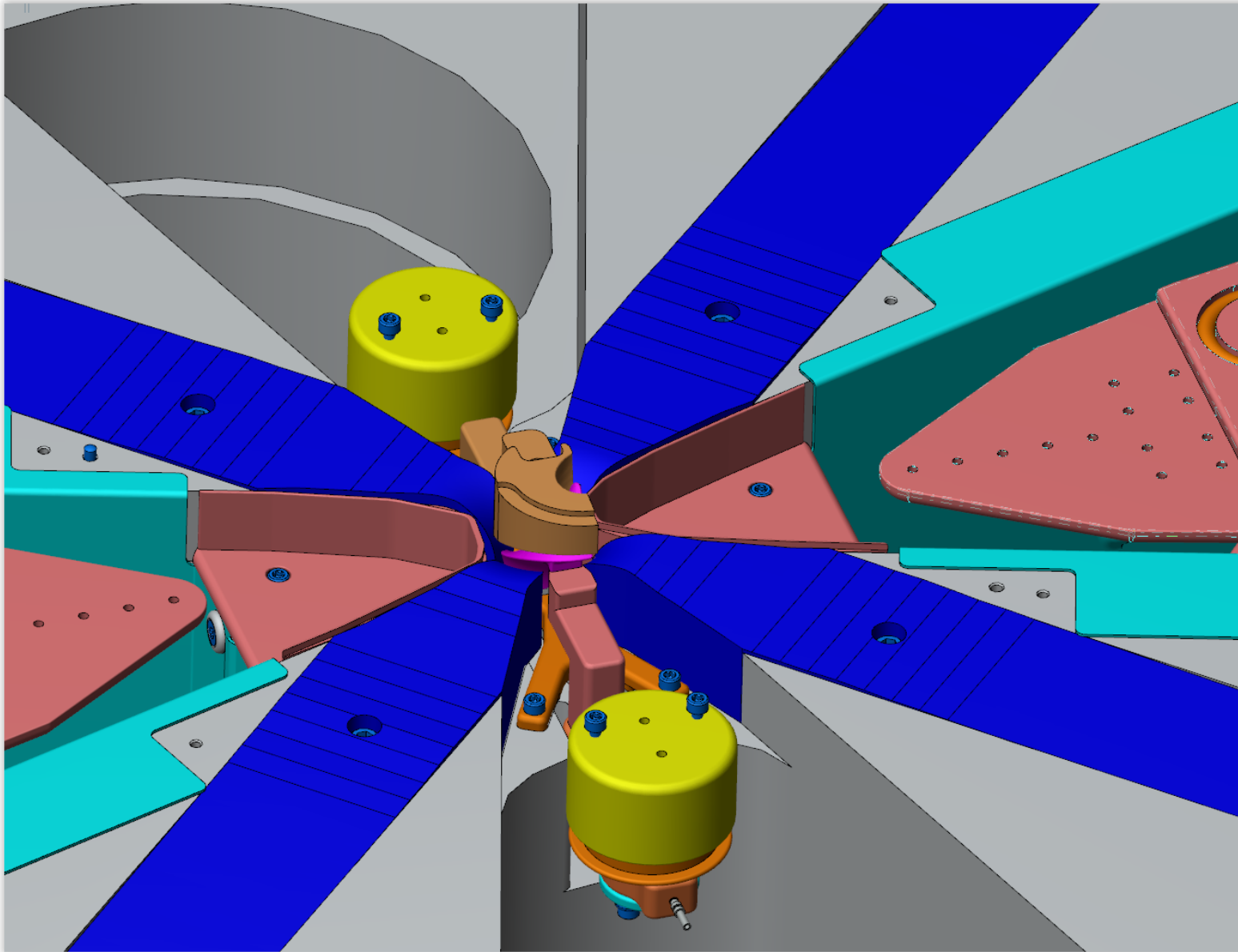
		30p	IKON
Pole gap (total)	[mm]	30	30
Valley depth to MP	[mm]	550	159
Cyclo height	[mm]	1550	920
square size / diameter	[mm]	2700	2145
Amp-turns	[.10 ³]	42.7	35.9
Iron Mass	[10 ³ kg]	43	23
Copper mass	[kg]	1440 *2	1125 *2
RF freq	[MHz]	62	75
Harmonic mode	[-]	4	4
Beam E	[MeV]	15 – 30	13 – 30
Beam intensity	[mA]	0.5 – 1.2	0.8 – 1.2

CR

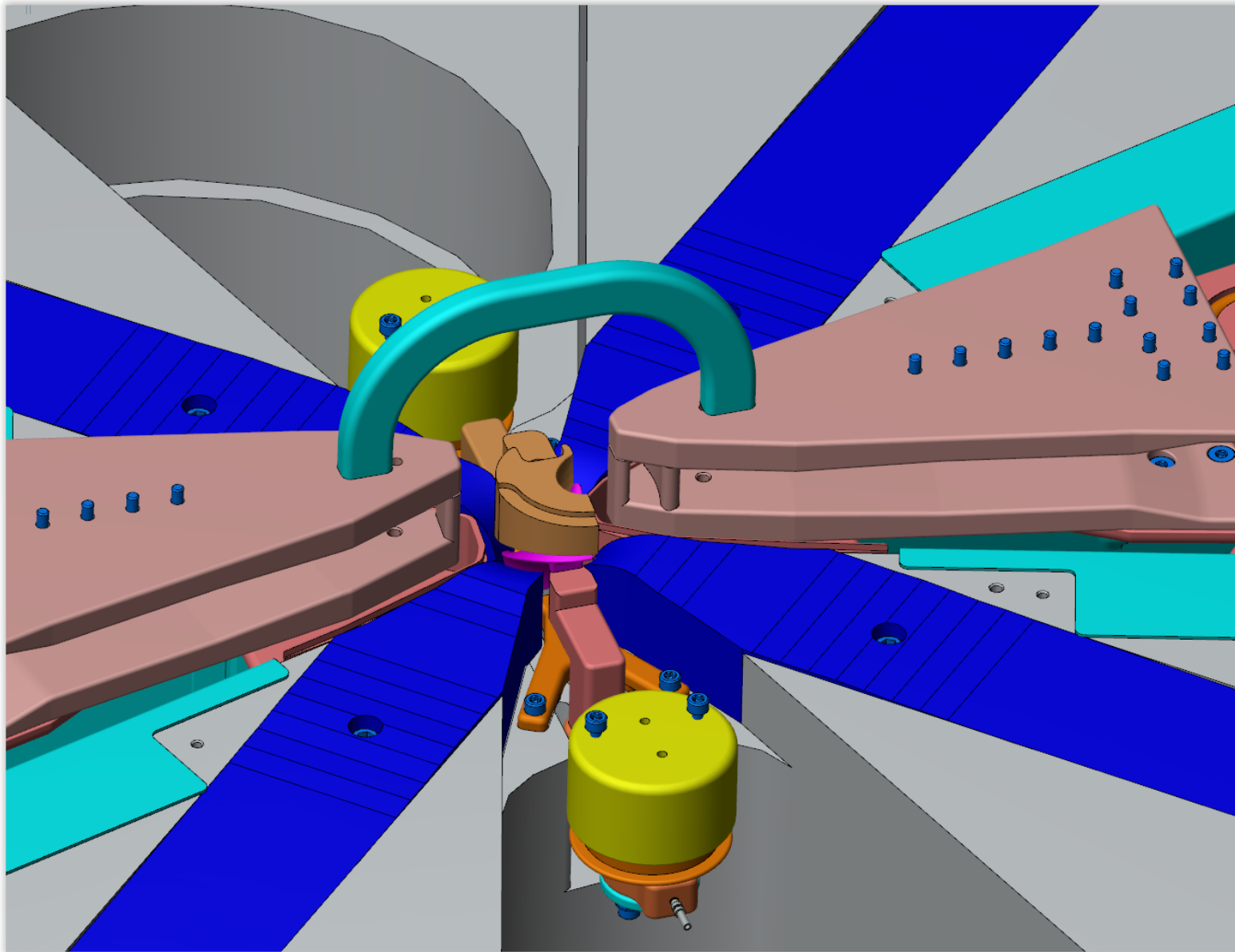


Public

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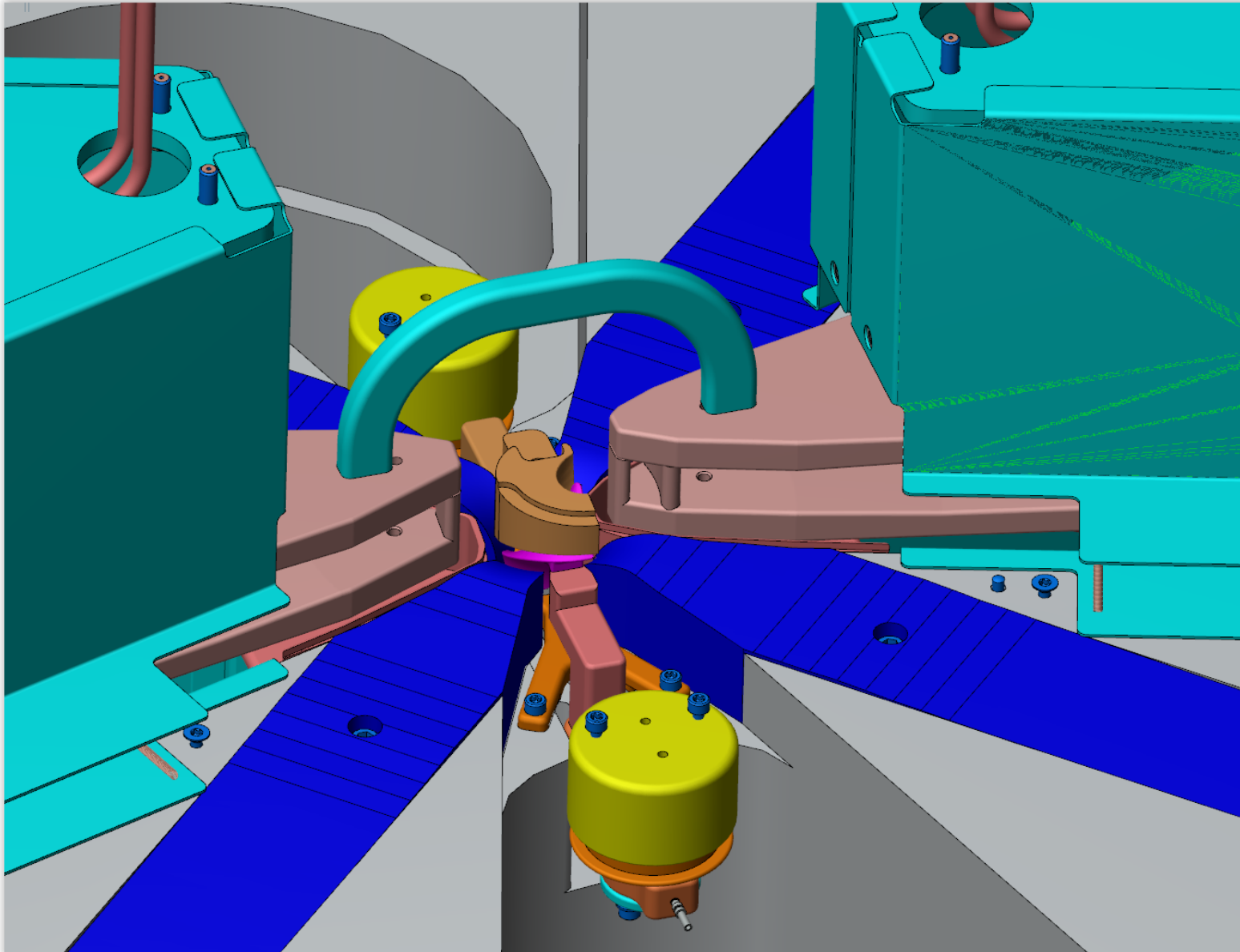


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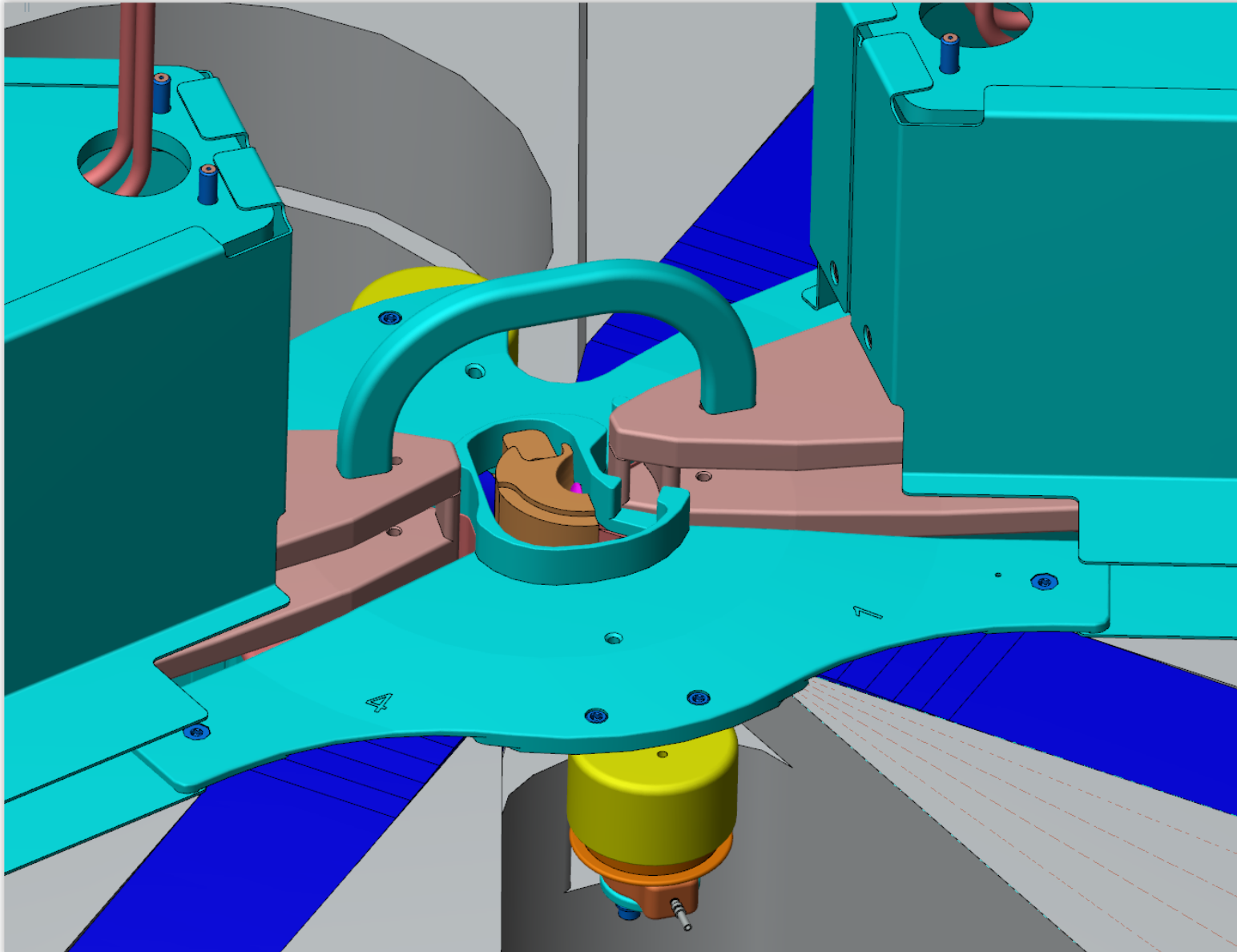


Public

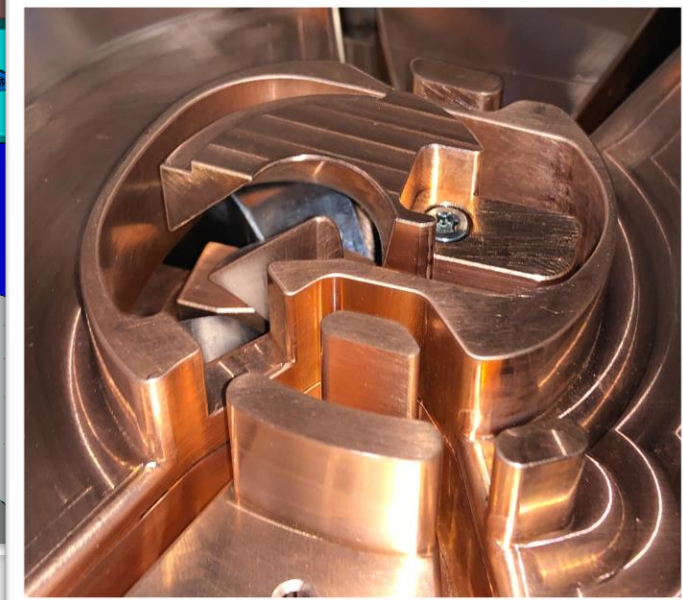
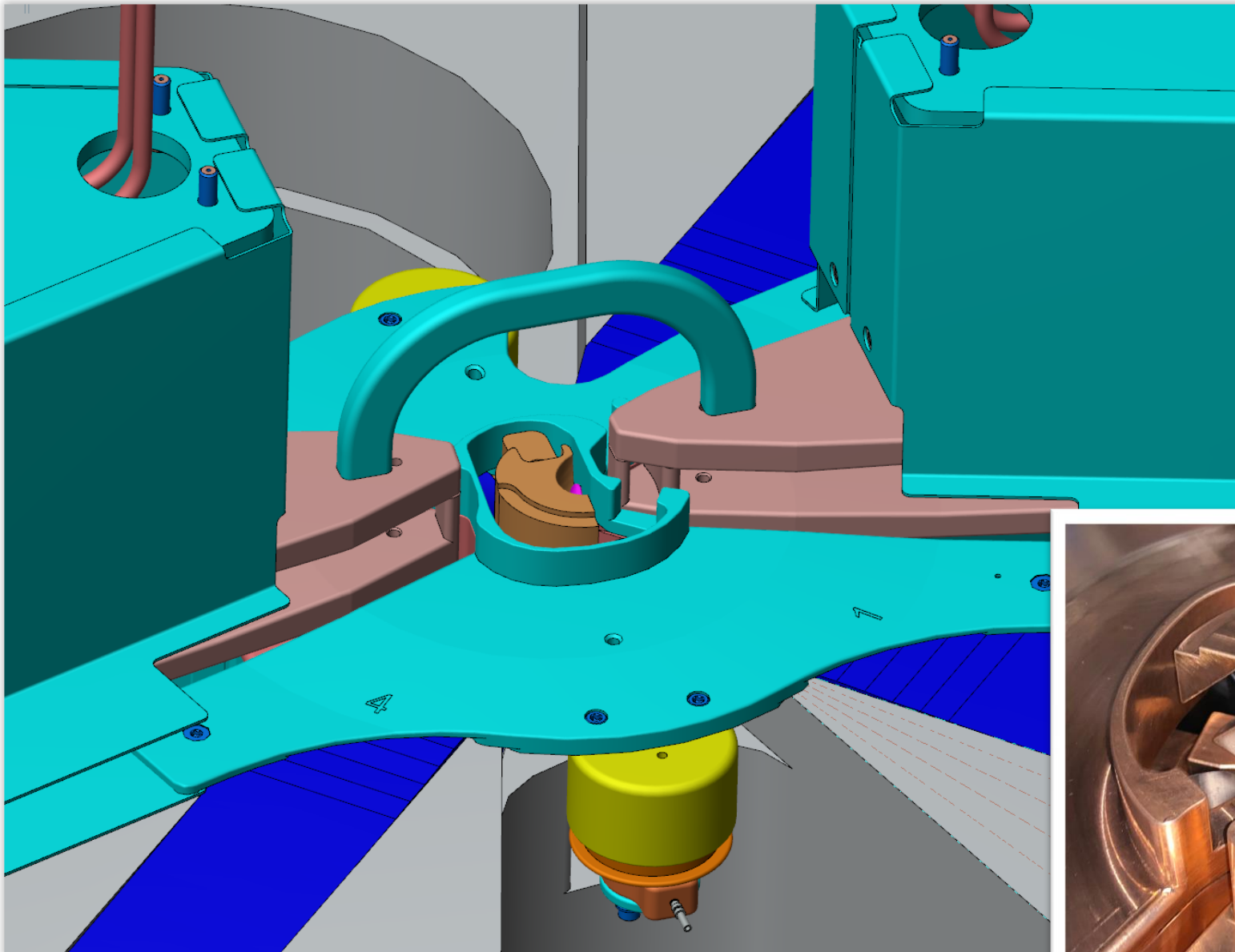
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CR

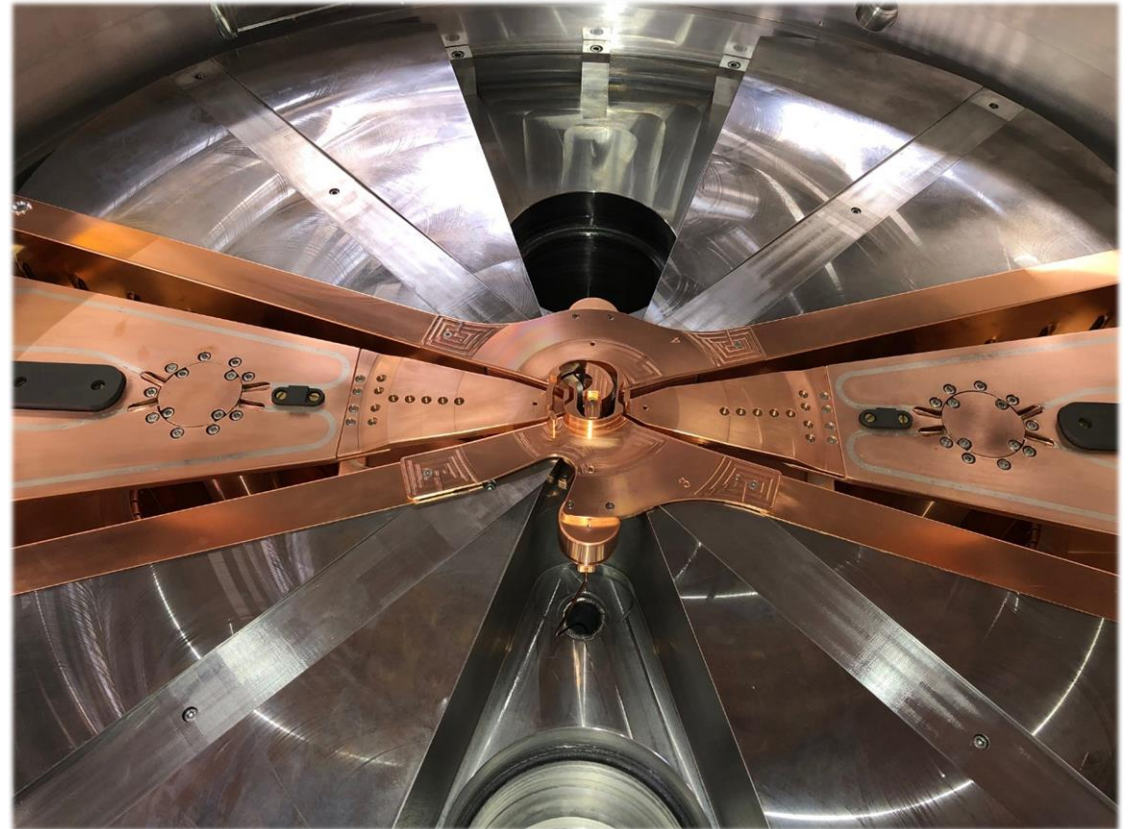
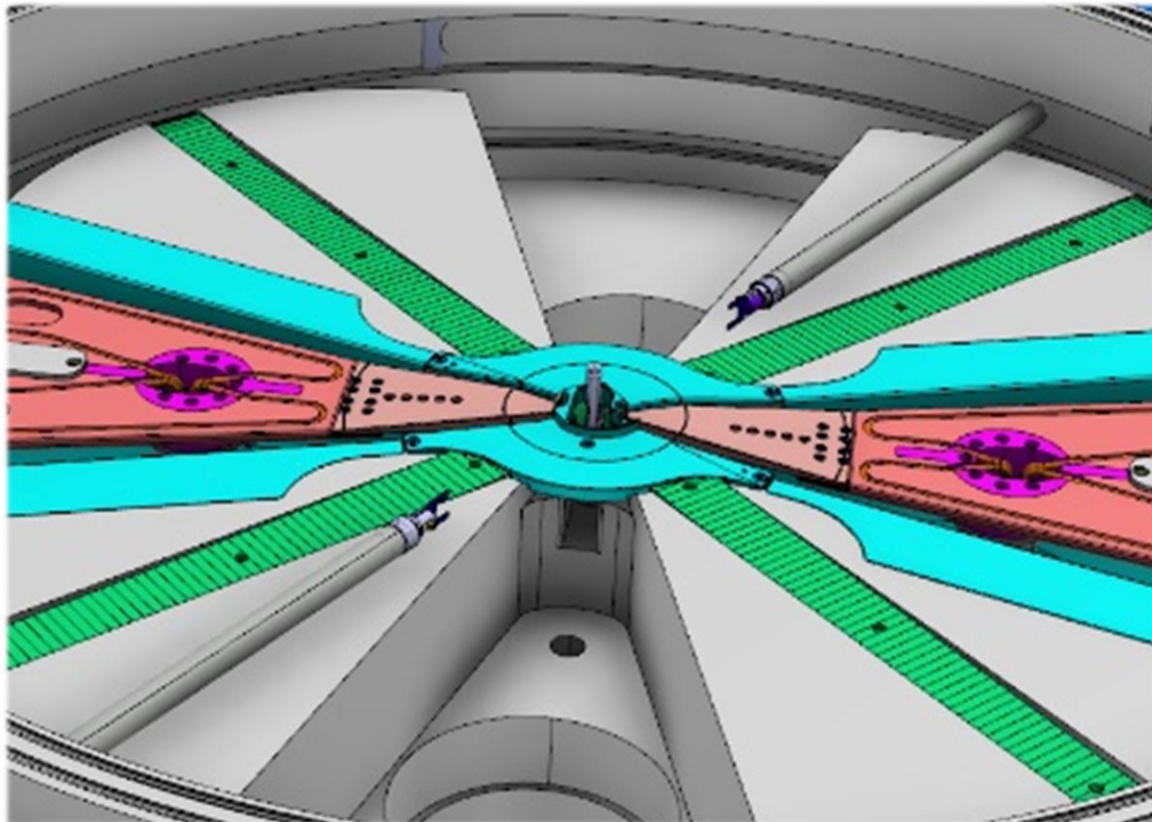


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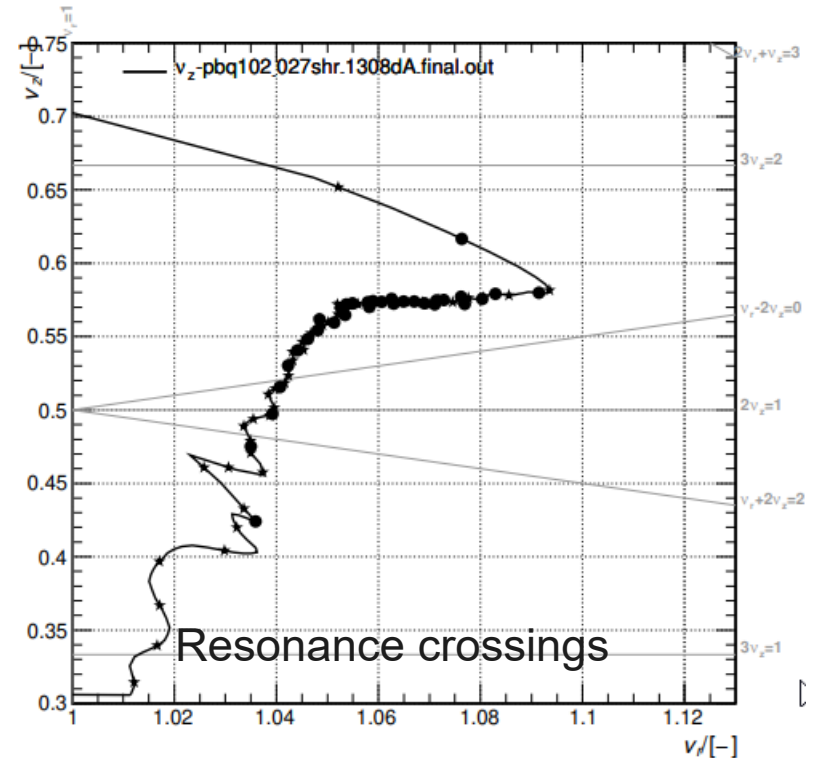
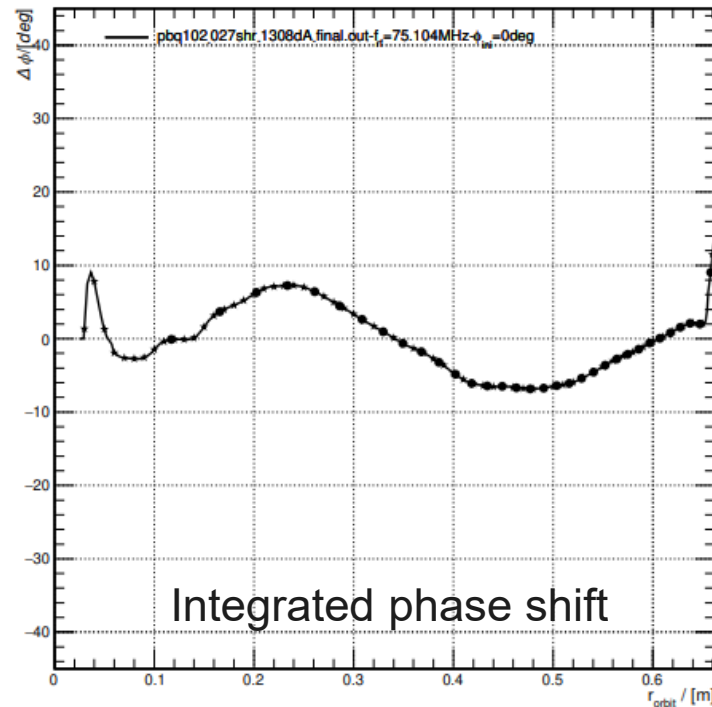
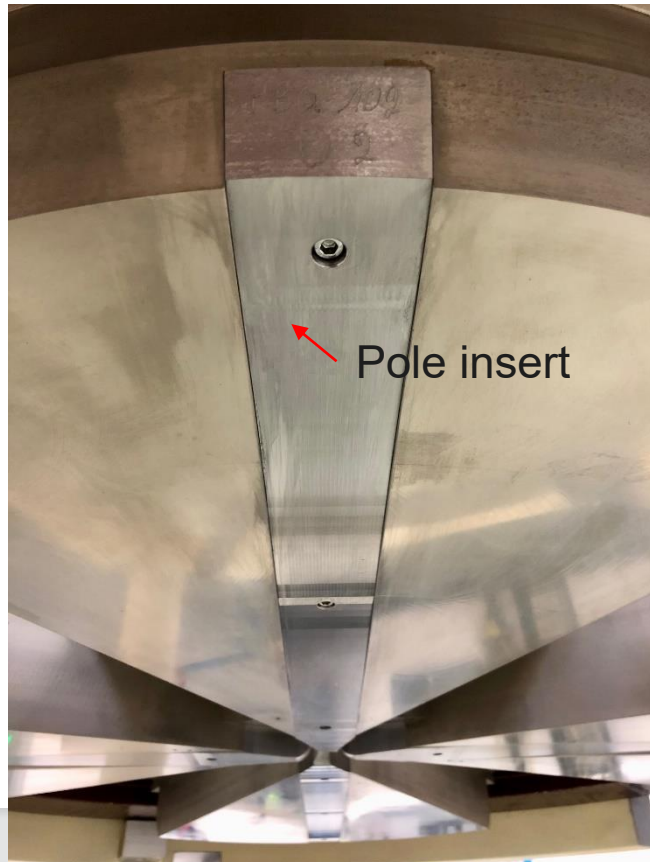
Construction and assembly has finished

- 3D modelization versus reality...



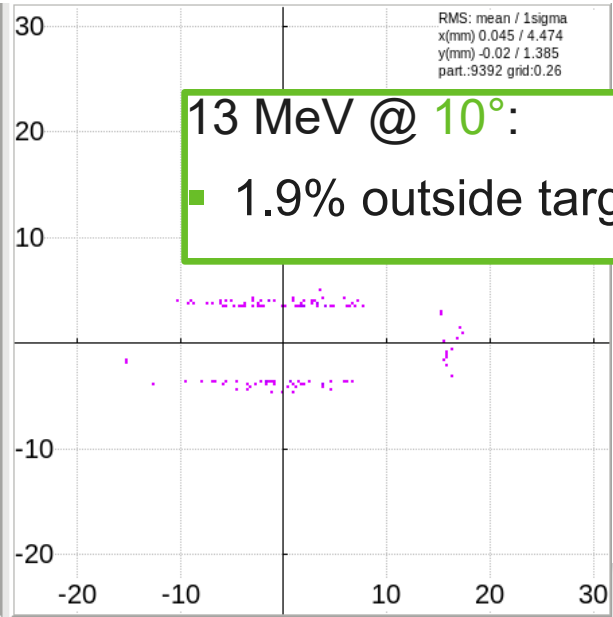
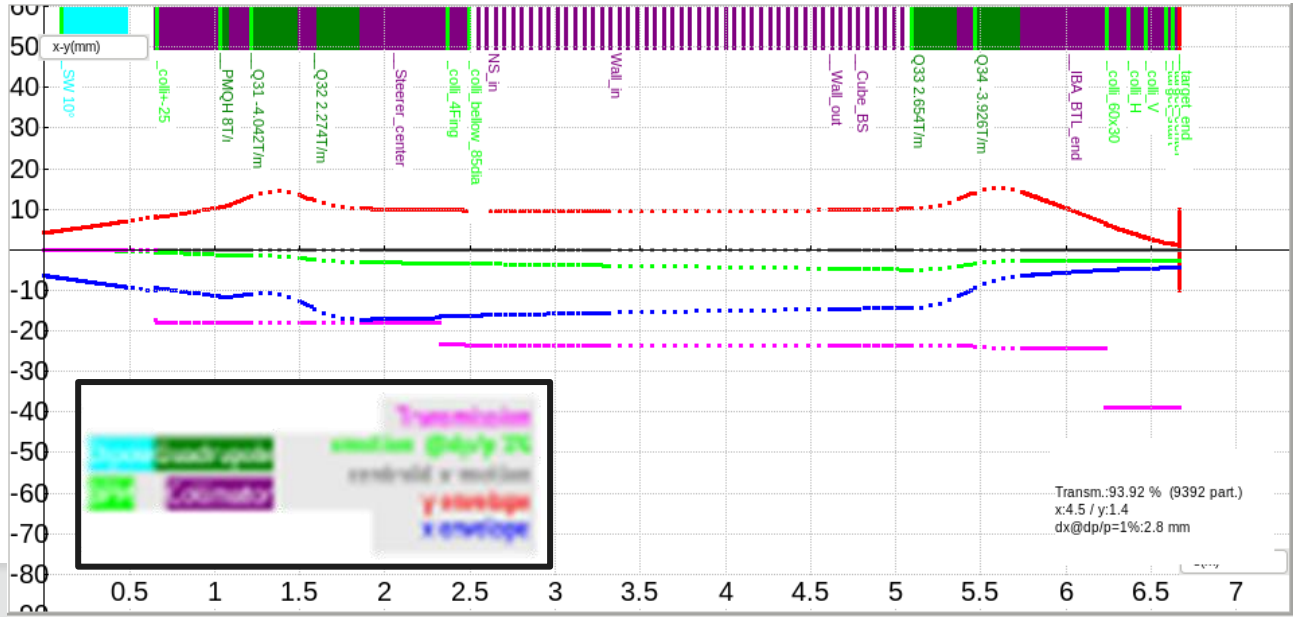
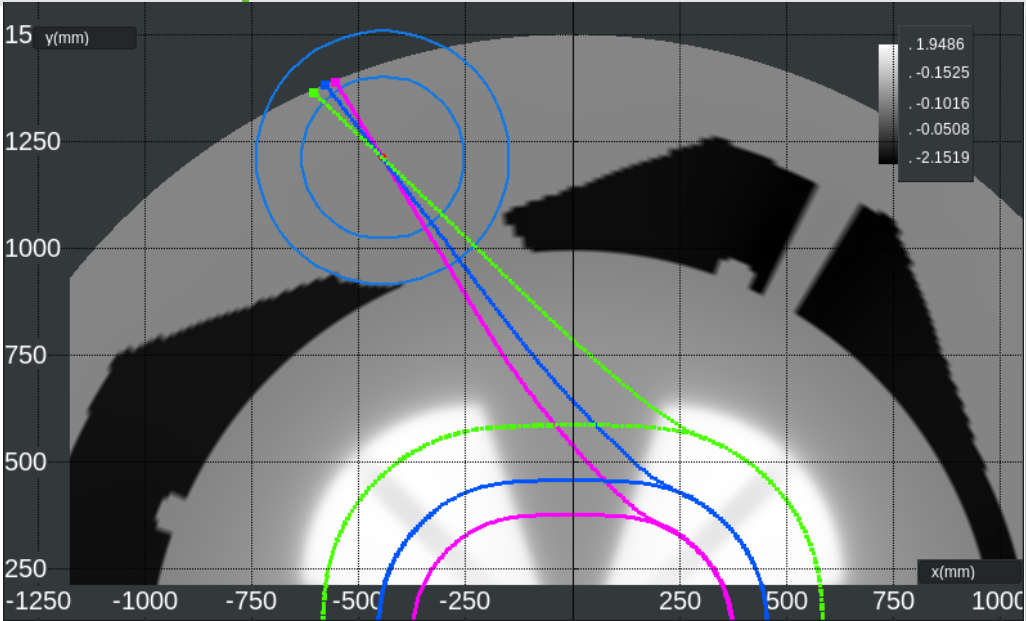
Cyclone® IKON – mapping and isochronisation

- Magnetic field shaped by machining patented pole inserts according to field map results:
 - External elements (hydraulic jacks, feet, switching magnets yoke)
 - Deformation of magnet yoke due to atmospheric pressure and magnetic force



Extraction & BTLs

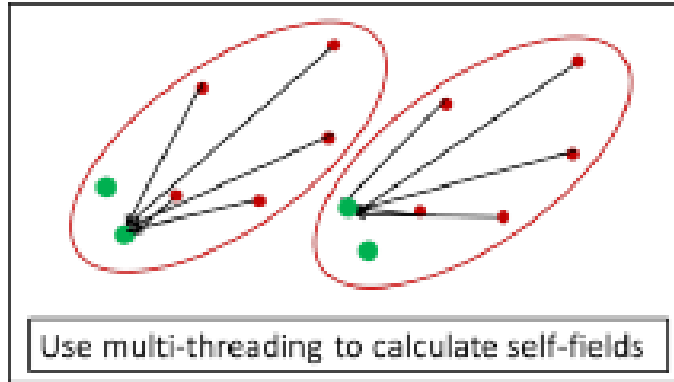
	vs BL1		vs BL2		vs BL3
	Orientation	Trans.	Orientation	Trans.	Orien.
13 MeV	25°	96%	-10°	94%	-35°
30 MeV	10°	99%	-25°	99%	N.A.



13 MeV @ 10°:
■ 1.9% outside target

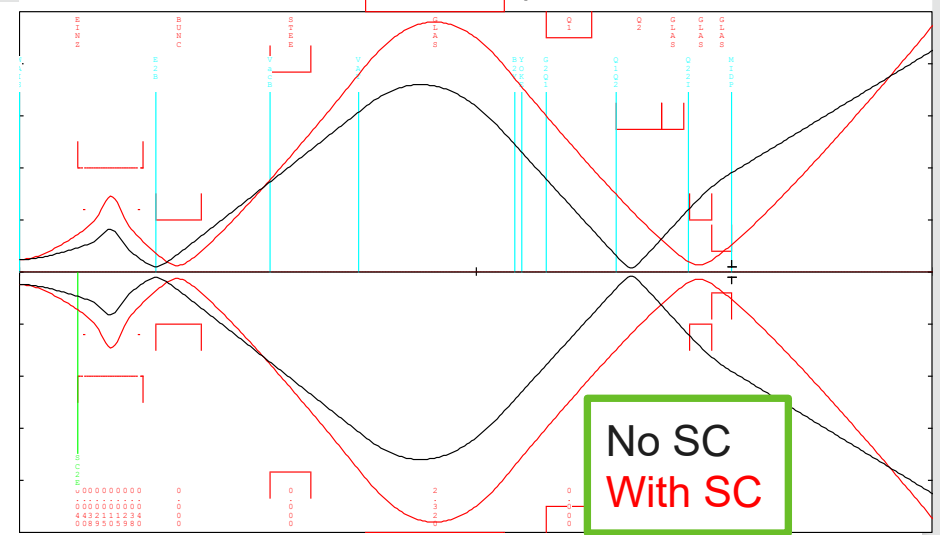
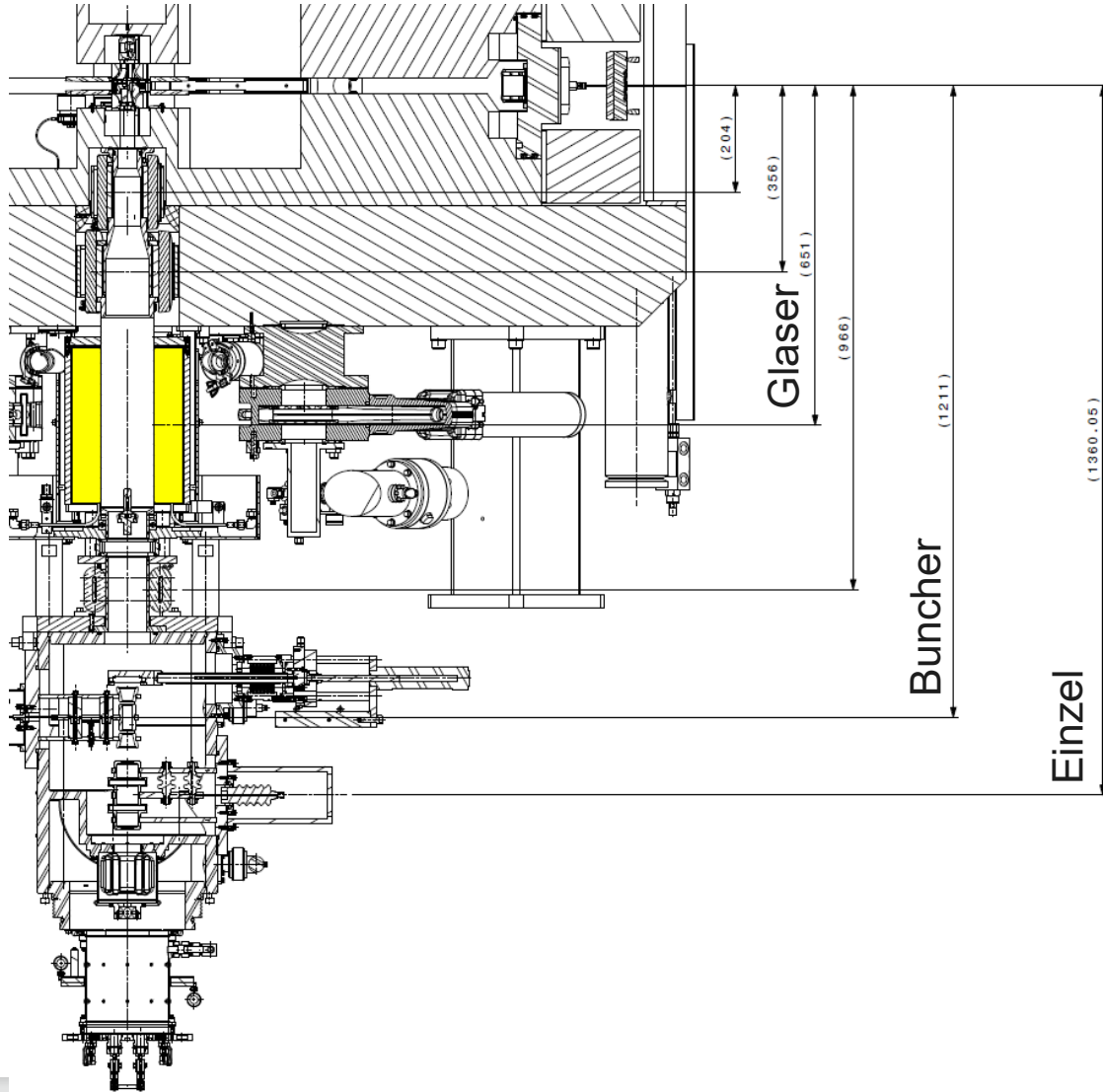
Space Charge effects in AOC

- Particle-to-particle method used for calculation of self-field of a bunch.
- Assume self-field acting on one particle is obtained as sum of contributions of all other particles in bunch.



- Advantage is that one can immediately include SC option together with existing 3D features of the E- and B-fields and with a complex 3D shape, such as for the spiral inflector.

Cyclone® IKON – Axial Injection



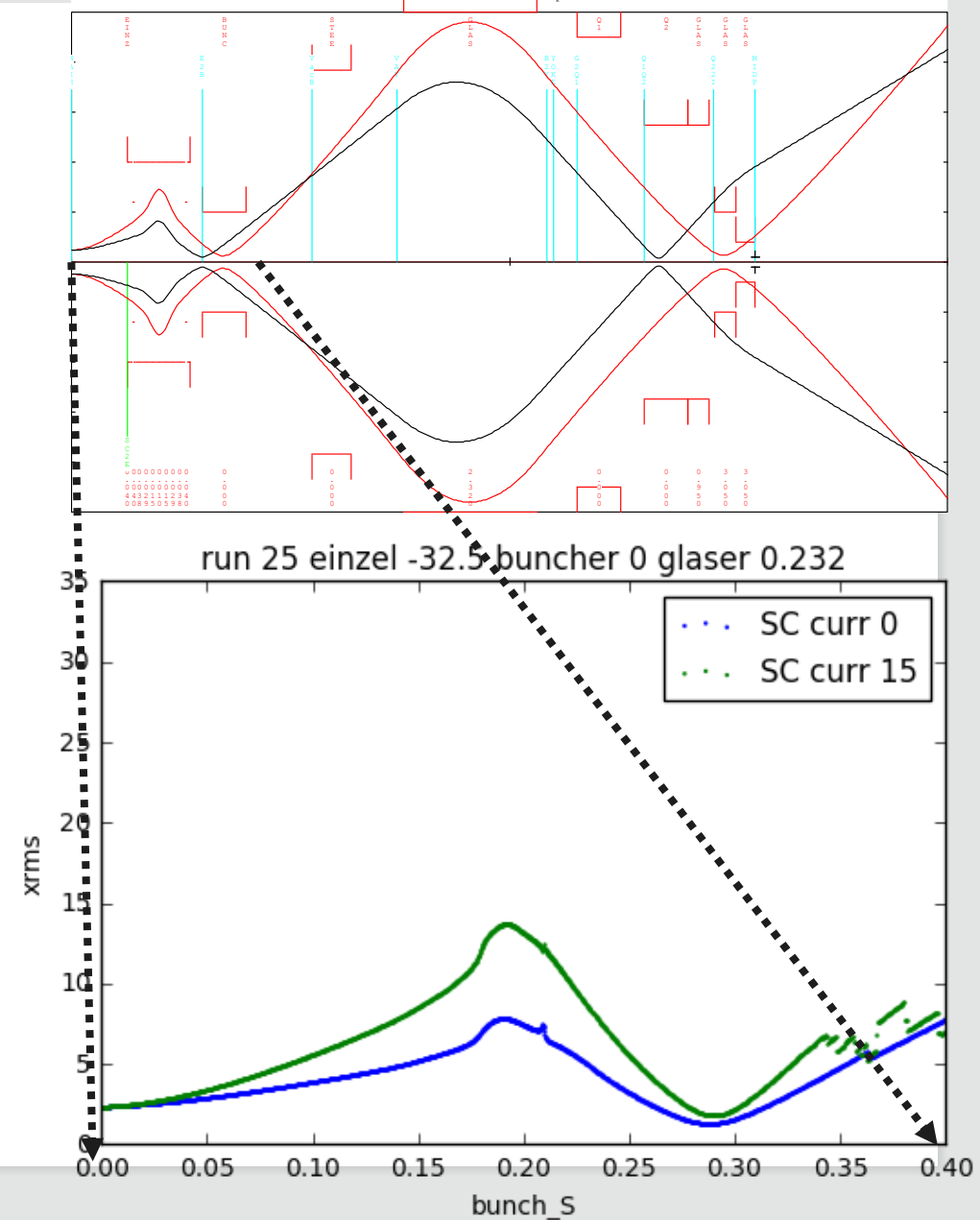
- Similar to injection line used in upgraded Cyclone® 30HC
- D-pace DC volume cusp source for 15 mA of H⁻ beam with 89 pi.mm.mrad at 30 keV for injection
- Machine tuned for 40 keV to reduce SC effects

Injection : AOC calculations VS transport

- Measured in mm from source, the focal point is at :

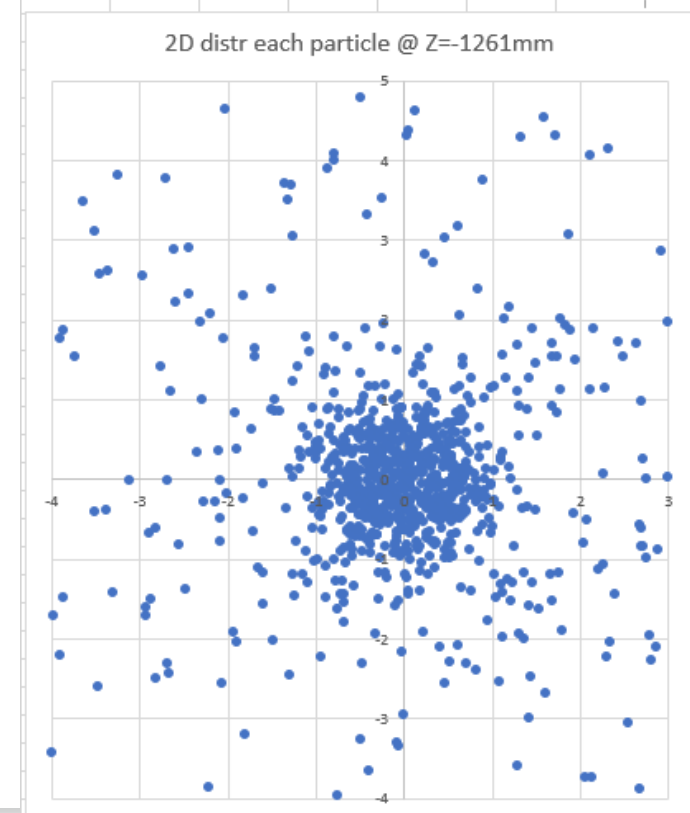
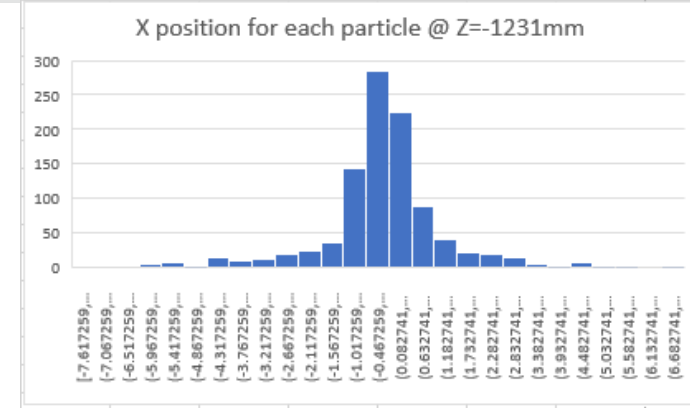
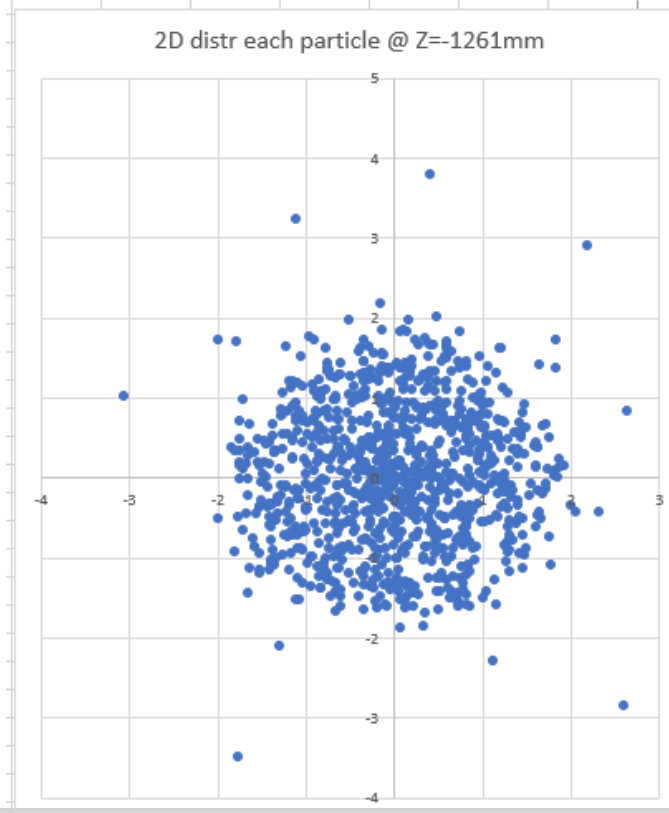
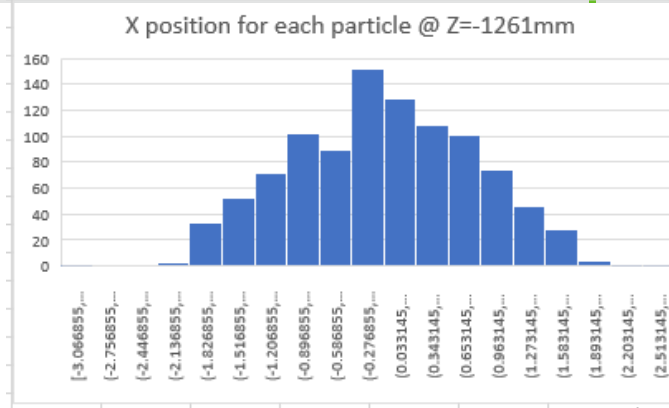
	SC 0 mA	SC 15 mA
Transport	300 mm	350 mm
AOC	285 mm	290 mm

- No matter the distribution used in AOC, the position of the focal point hardly changes, and never gets near the 350 mm of Transport.



SC effect on trans. distr.

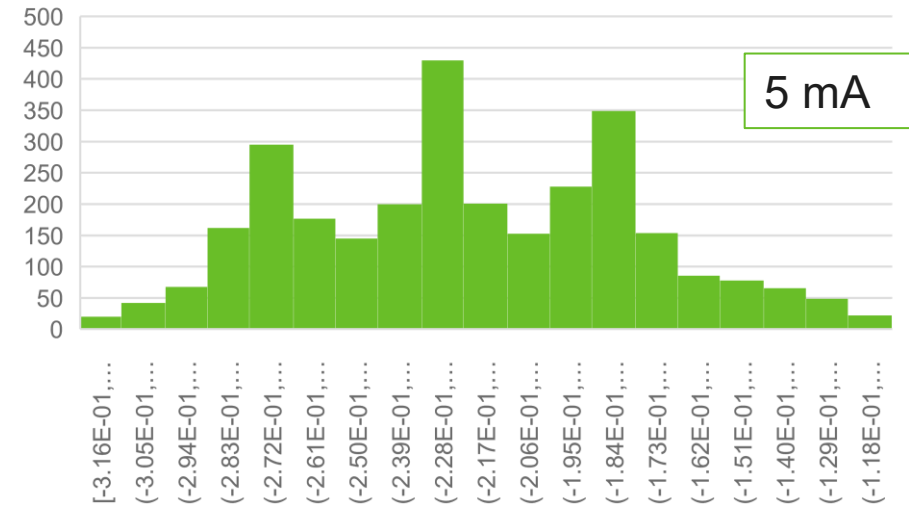
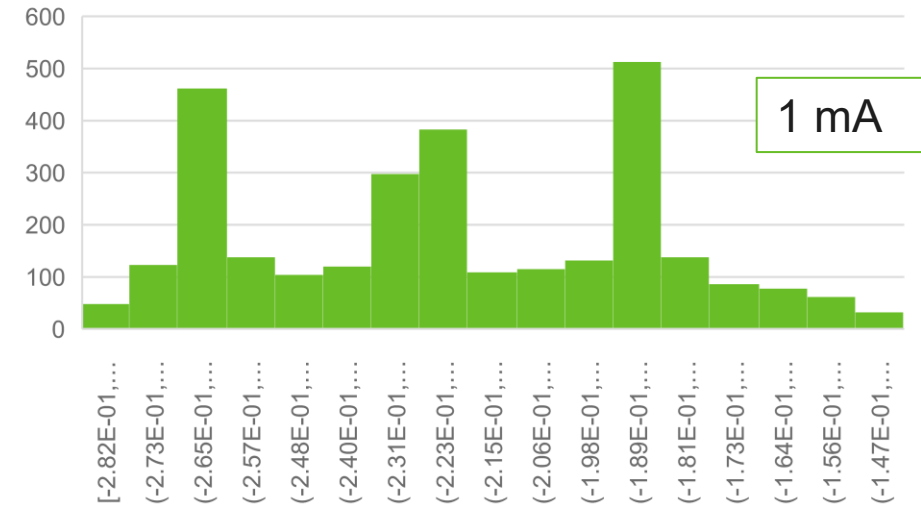
- Transport assumes a gaussian distribution everywhere. In AOC however, the distribution changes.
- In this example, beam starts out gaussian in 2D, and is still such just before the waist, see left distributions. Just after the waist, see right distributions, this has changed.
- Comparing the rms(X) values of transport with the rms of the patches in AOC is thus not equivalent.



Approximate DC by 3 bunches

Starting longitudinally with flat uniform distribution, 3 RF periods long, with buncher at 563 V:

- with 1 mA, at inflector :
 - Three sub bunches visible.
 - Distance between the two is ~ 36 mm,
 - As expected from $\beta\lambda$ (=37mm)
 - With 5 mA, at inflector:
 - Distance between the two bunches increase to 45 mm
- “injecting” 1-by-1 the particles in AOC creates an artificial longitudinal force, non-existent in real DC bunches



- High intensity cyclotrons for medical radioisotopes continue to develop
- At IBA, the new generation of cyclotrons, which started with the 18 MeV Cyclone® KIUBE, has expanded with the 30 MeV Cyclone® IKON and 9 MeV Key
- For the IKON, the construction phase has finished, and it is currently being installed
- Started study on the Space Charge effects in the high intensity beam along the injection line