



DEVELOPMENT OF THE CYCLONE®KEY:

HOW INTEROPERABILITY LEADS TO COMPACTNESS

V. Nuttens, M. Abs, J. Caulier, Q. Flandroy, W. Kleeven, E. Kral, J. Mandrillon, O. Michaux, N. Mine, E. Van der Kraaij



Life.
Science.

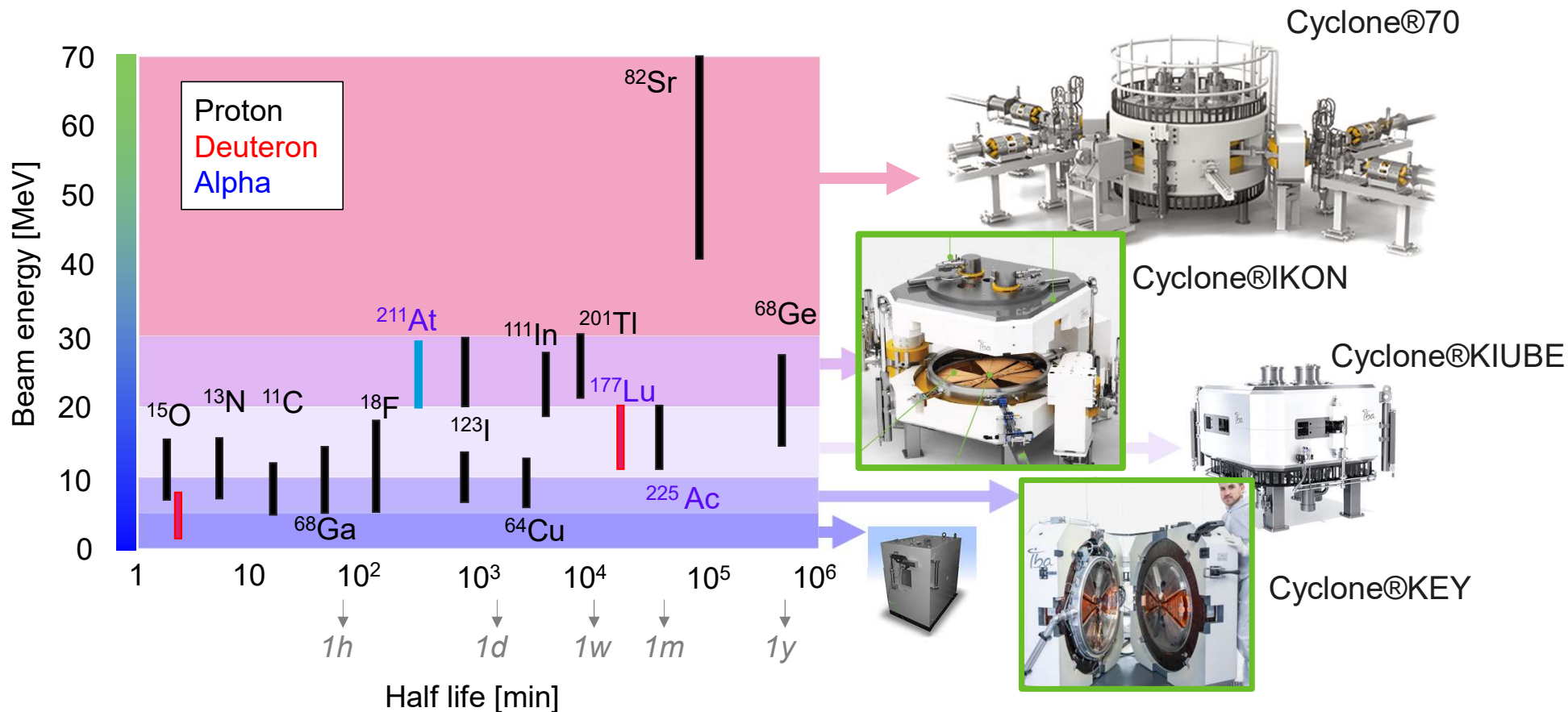
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CYC2022
23rd International Conference on
Cyclotrons and their Applications



Energy ranges & example of cyclotrons



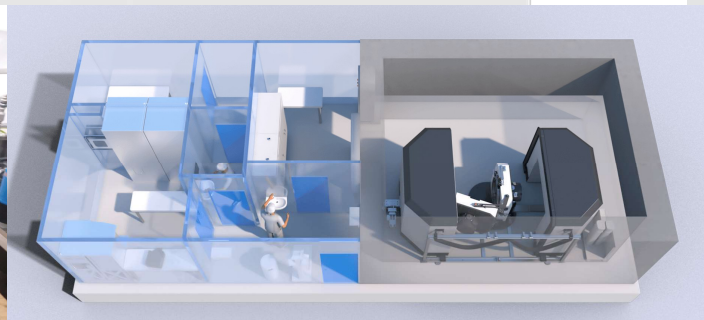
The Cyclone®Key

■ Design constraints:

- Simple to install and operate
- Compact (self-shielded & low activation concrete enabled)

Parameter	Value
Accelerated ions	H ⁻
Ion source	Internal PIG
Number of sectors	4
RF frequency	41MHz
RF mode	2
Dee angle	40deg
Dee voltage	32kV
Extraction	Stripper (1+5 spares)
Extracted energy	9.2MeV
Cyclotron footprint (L×W×H)	1.5m×1.4m×1.35 m

The Cyclone®KEY,
the little brother of
the Cyclone®KIUBE



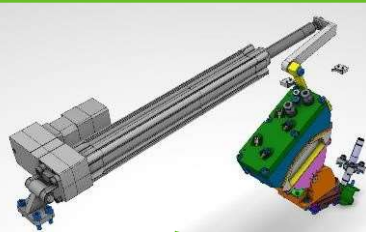
Cyclotron subsystems

iba

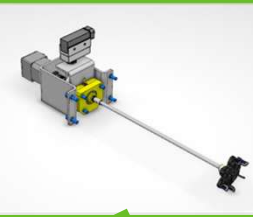
Pop-up



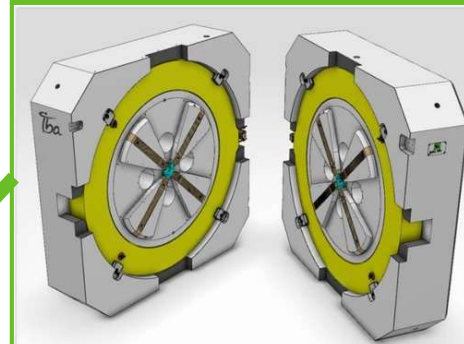
Target changer



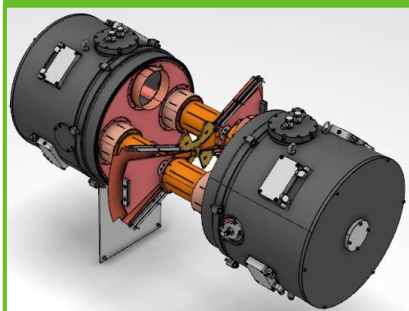
Strippers



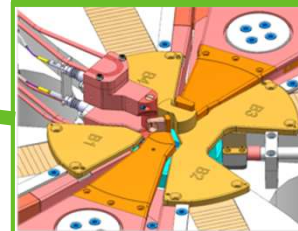
Magnet



RF



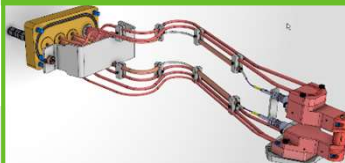
Central region



Vacuum



Ion source



RF coupling &

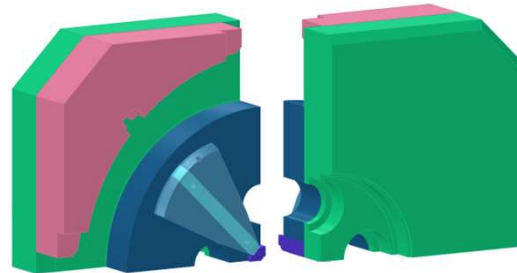


tuning

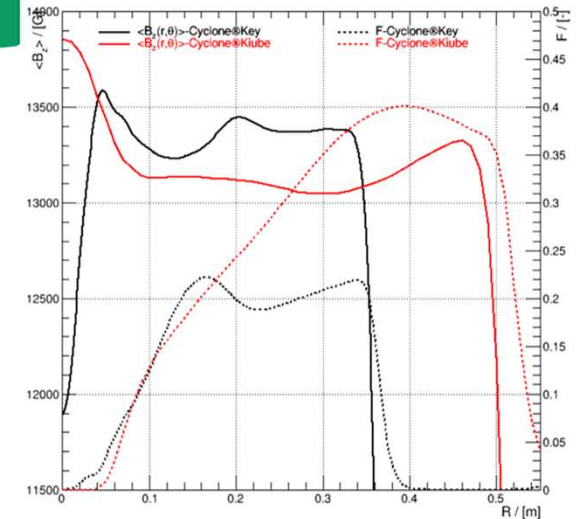
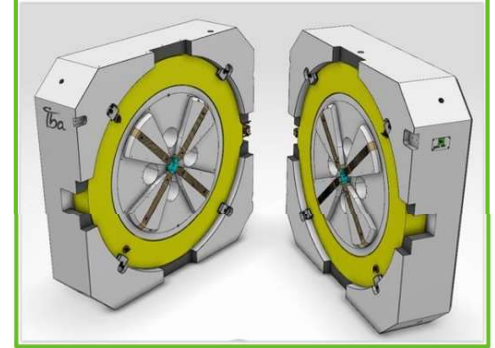


Magnet design with OPERA

- Vertical median plane : no yoke lifting system, door opening
- Cyclone®KIUBE inheritance
 - 24mm of pole gap to optimize coil power consumption
 - Square shape: iron only where it is needed
 - Symmetry of yoke penetration for
 - RF coupler (left)
 - Coil connections (right)
 - Ion source (bottom)
 - Target (top)
 - Pole insert for cyclotron isochronisation during mapping
 - Vacuum chamber sits on the sectors
- Each half of the magnet is milled from a single plate of iron
 - Precision machining -> very low level of harmonic imperfection
 - High impact on vacuum performance (no virtual leak, faster pumping)
- Hole in the return flux for vacuum and RF system



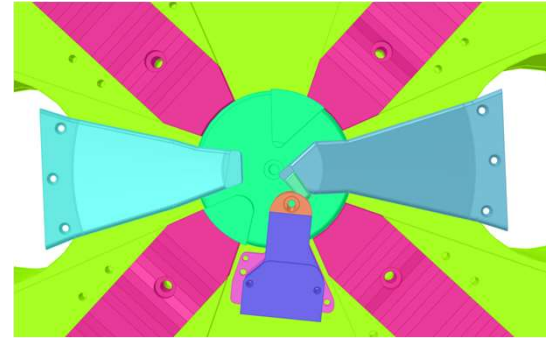
Magnet



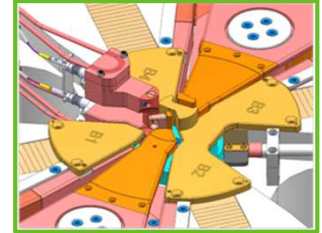
Ion source and central region with AOC

■ Design constraint: same ion source as the Cyclone®KIUBE

- PIG internal ion source for H⁻ production
- Consequence:
 - Central plug gap is fixed but too low field if flat
 - 2 magnetic extensions have been added to locally increase the magnetic field and keep isochronism
 - Not too close to the ion source to avoid plasma column deformation



Central region

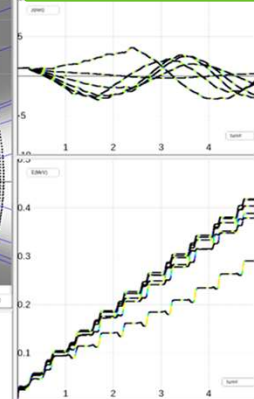
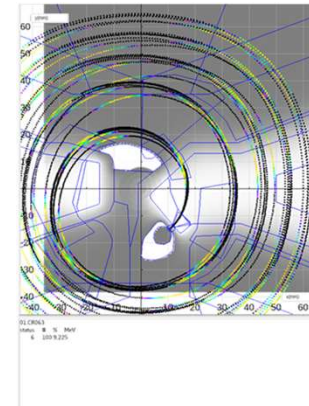
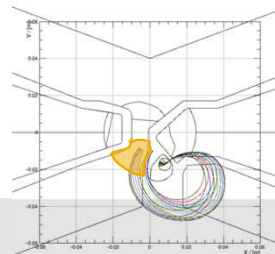


Ion source



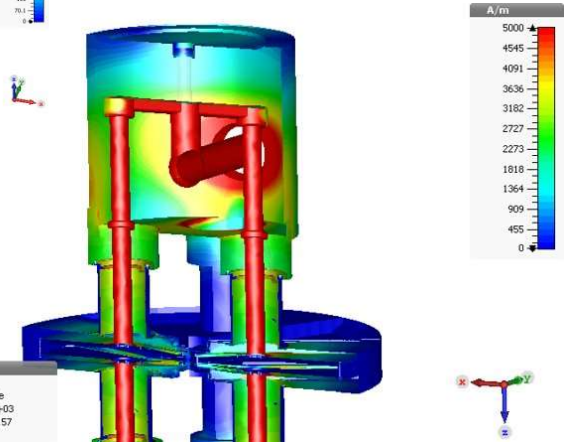
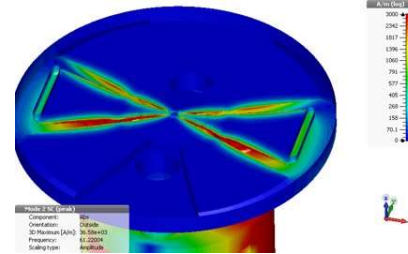
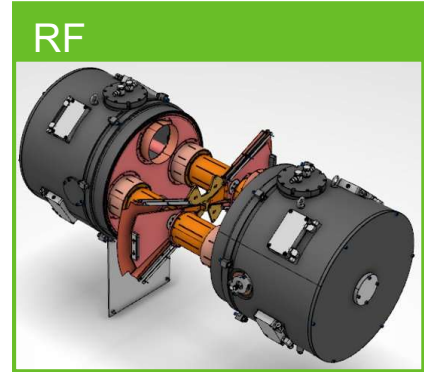
■ Central region design based on particle tracking with our tracking code AOC

- Dee tip geometry has been optimized to provide
 - Orbit centering
 - Good phase acceptance
 - Horizontal and vertical electric focusing
- Beam stop for protons



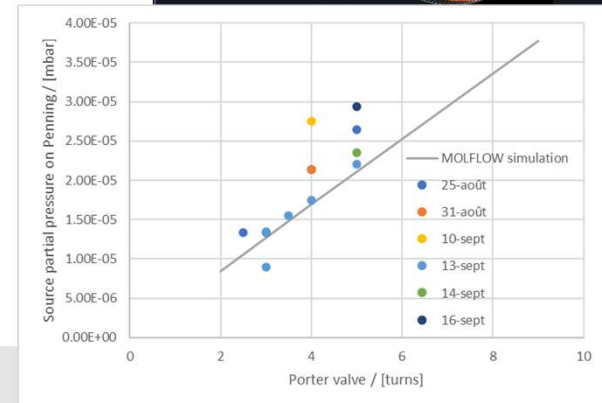
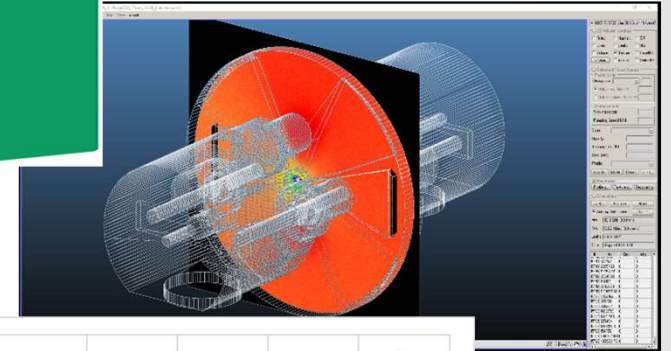
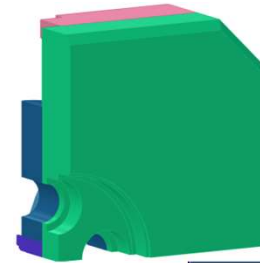
RF system design with CST

- Design constraint: combine the RF system with the vacuum box
 - H2 mode at 41MHz and 32kV
 - Compatible with Cyclone®KIUBE RF amplifier chain
 - Symmetric wrt cyclo median plane
 - Slightly higher power consumption (5,3kW)
- BUT
- No RF current in the poles (no heating of the poles) and vacuum chamber
 - No RF field on the stripper
 - No need for good RF contact between upper and lower parts in the CR
 - More stable and reliable during operation



Vacuum system with MolFlow+

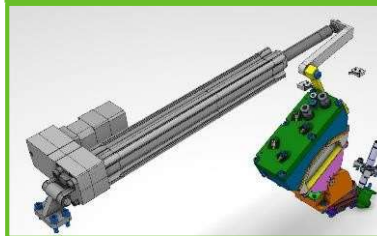
- Design constraint: combine the RF system with the vacuum box
- Turbo molecular pump (TMP) HiPace2300
 - Compact and low maintenance requirements
 - Lower power consumption wrt ODP
 - $S(N_2)=1900L/s$ - $S(H_2)=1850L/s$
 - Possibility to install one or two pumps
- 3D model of the vacuum system
 - H_2 gas from source only
 - After validation with the Cyclone®KIUBE design
 - Holes dimensions in the valleys optimized for vacuum conductance, RF power and magnetic field
 - Measurement: primary pump was limiting the TMP
 - (note: Penning pressure corrected for H_2)



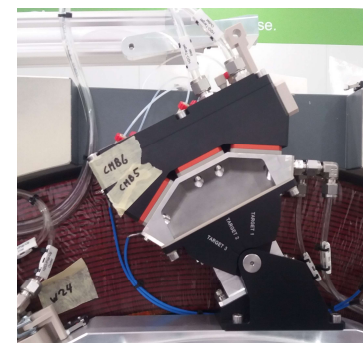
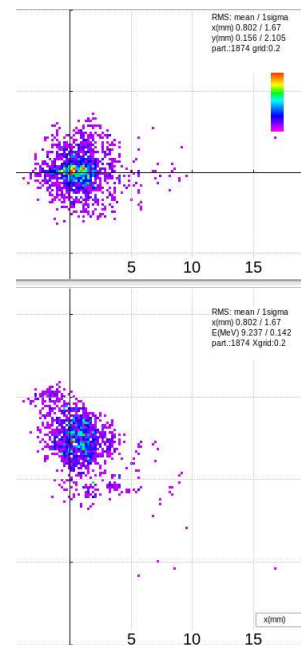
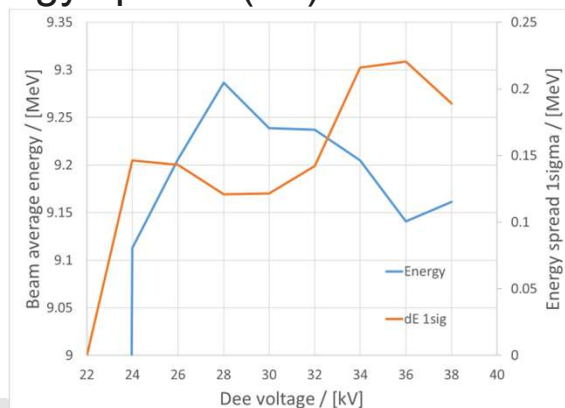
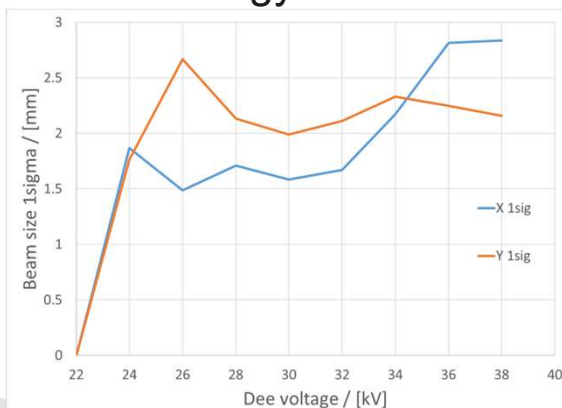
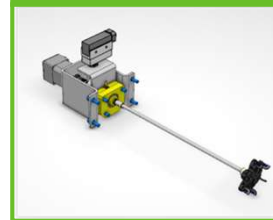
Extraction system and target changer

- Design constraints: 3 targets inside the yoke
- Stripping extraction:
 - 1 exit port with target changer
 - stripper carousel with up to 6 strippers
- Beam tracking from the ion source up to extraction was performed in AOC. At 32kV, in target:
 - Expected (1σ) beam sizes: X:2.1 and Y:1.7mm
 - Energy ≥ 9.2 MeV - Energy spread (1σ) 150keV

Target changer

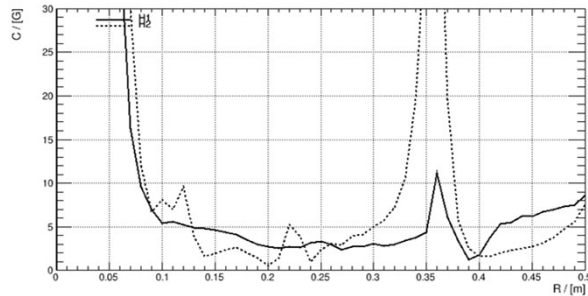


Strippers

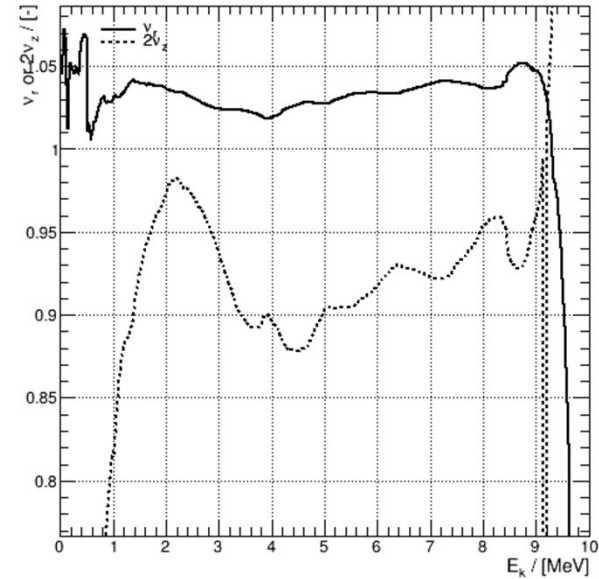
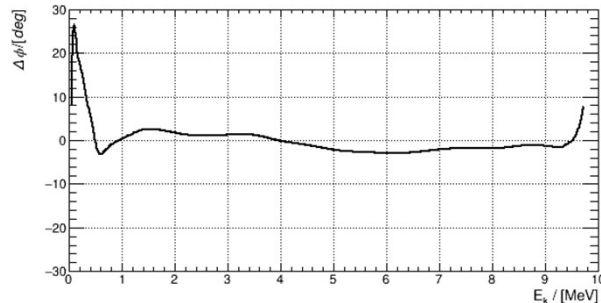


Tests results

- Successfully mapped
 - Very low imperfection harmonics



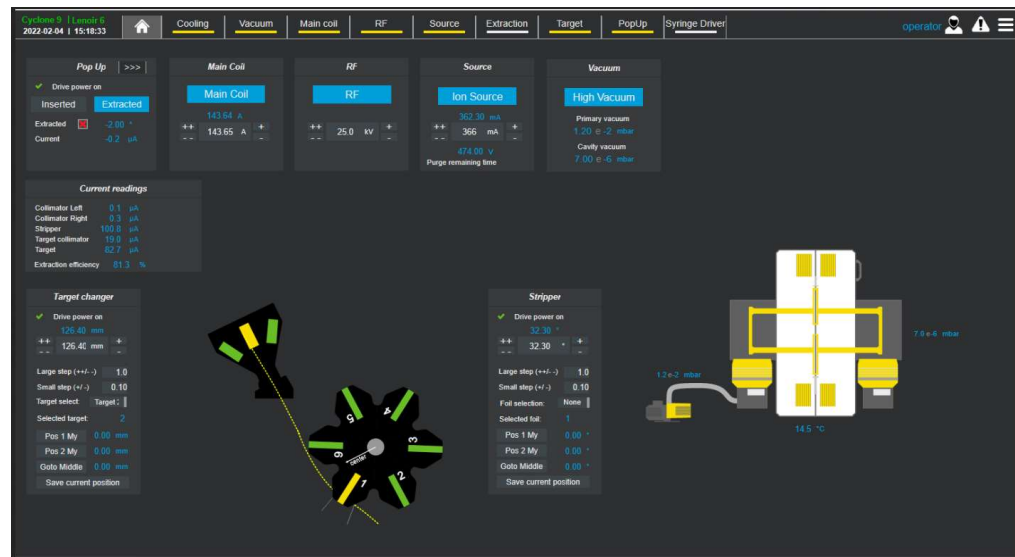
- Excellent isochronism
 - Confirmed by beam test with H^+



Tests results

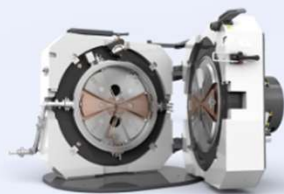
■ Beam tests (with 2 TMP)

- Base vacuum: $5,3\text{E-}7\text{mbar}$
- Source on vacuum: $<1,2\text{E-}5\text{mbar}$
- Stripper current: $100\mu\text{A}$ for 2h
- Transmission Pop-up/Stripper: 60-67% (depending on source gas quantity and source current)
- Extraction ratio: 81%



Conclusion

- In parallel of the Cyclone® IKON, IBA has successfully design, develop & test its new compact cyclotron for the low energy range



Cyclone® KEY
9,2 MeV

Small, low-energy cyclotron enabling a simple yet efficient multiple isotopes production.

30 FDG doses / 2-hour run

The most compact Cyclone®

SEE MORE +



Cyclone® KIUBE
18 MeV

Cyclone® KIUBE is established as the cyclotron of choice offering the highest production capacity ever reached with a PET cyclotron and a maximized profitability.

Maximized uptime with the Twin proton sources

Up to 300 FDG doses / 2-hour run

SEE MORE +



See MOBO01

Cyclone® IKON
13 to 30 MeV

Cyclone® IKON is a variable-energy cyclotron that accelerates protons from 13 to 30 MeV.

Compact design

Large scale production of SPECT & PET :⁶⁸Ge and ¹²³I

SEE MORE +



Cyclone® 30 XP
30 MeV

Cyclone® 30 XP is a variable-energy cyclotron that accelerates protons,deuteron and alpha from 15 to 30 MeV.

Multiparticle production

Combines the field of diagnosis and therapy as well as research works

SEE MORE +



Cyclone® 70
70 MeV

Cyclone® 70 is a variable energy cyclotron that accelerates protons from 30 to 70 MeV with 750µA current.

Proven Expertise

Optimized production of ⁸²Sr & ⁶⁸Ge for generators

SEE MORE +

Any question?

DEVELOPMENT OF THE CYCLONE®KEY:

HOW INTEROPERABILITY LEADS TO COMPACTNESS

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Certified

