Design of IBA Cyclone®11 cyclotron magnet

V. Nuttens, M. Abs, W. Kleeven, B. Nactergal, D. Neuveglise, T. Servais, and S. Zaremba
IBA, 3, Chemin du Cyclotron, B-1348 Louvain-la-Neuve, Belgium
(www.iba-worldwide.com)

Introduction

To extend customer choice in the low energy range, IBA is developing the Cyclone®11. It is a fixed energy 11 MeV H^- cyclotron for the production of PET isotopes. The cyclotron magnet is based on the well known Cyclone®10/5, with the same yoke dimensions, which is compatible with the IBA self-shielding design [3]. The higher proton energy compared to the 10 MeV machine is beneficial for higher PET isotope production yield.

Cyclotron model

The 3D model of the Cyclone®11 cyclotron is based on the Cyclone®10/5 geometry (figure 1). The movable inserts have been removed and the isochronous magnetic field is obtained by milling one pole edge on each pole.

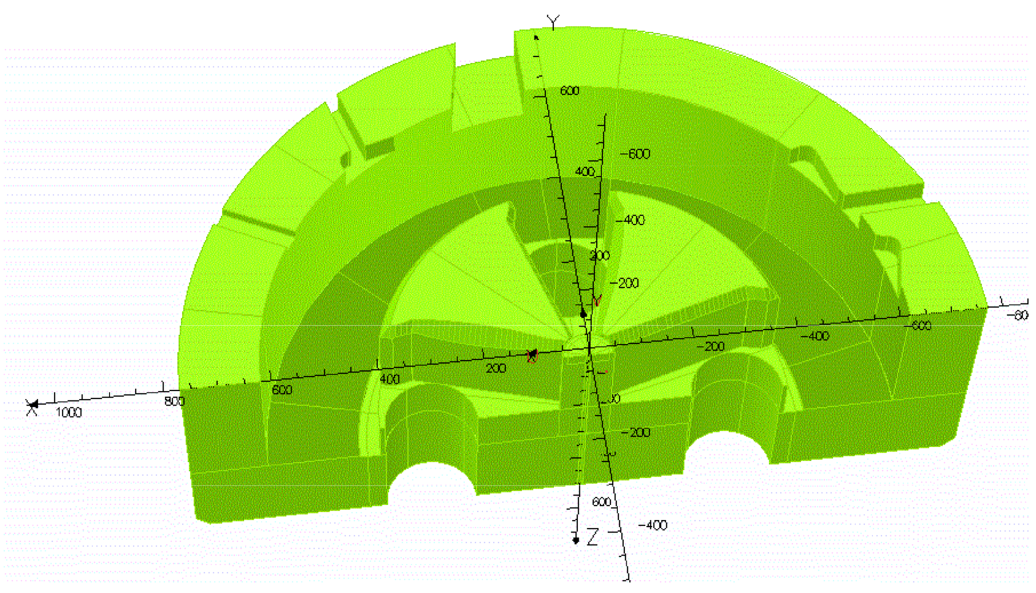

Figure 1: Opera-3D 180° symmetry model of the Cyclone®11 cyclotron.

Magnetic field

The magnetic rigidity is proportional to the particle momentum. Therefore, the energy that can be extracted at a given radius in a cyclotron is proportional to the square of the magnetic field. Hence, the relative increase of energy is:

$$\Delta E/E = 2\Delta p/p = 2\Delta B/B \quad (1)$$

According to the Cyclone®10/5 mapping results, the magnetic field should be increased by at least 520 Gauss to be able to extract H^- at 11.0 MeV instead of 10.2 MeV. The magnetic field increase can be provided by a higher main coil current and/or a reduced valley depth.

Effect of the main coil current

The 90° symmetry model has been simulated for different main coil currents (176 A, 186 A, 196 A). The average magnetic field gain at the level of the poles is about 160 Gauss per 10 A.

Effect of the valley depth

Reducing the valley depth increases the magnetic field in the valleys. The 90° symmetry model has been simulated for different valley depth with a main coil current of 186 A.
Compared to the Cyclone®10/5, the average magnetic field gain at the level of the poles is about 180 Gauss with 50 mm of additional iron in the valleys and 450 Gauss with 100 mm of iron. The effect on the flutter is less than 5% and do not affect the beam stability.

Adopted solution

The main coil current has been increased up to 185 A and the valleys filled with 10 cm of iron. It should provide a magnetic field gain of about 690 Gauss. The TOSCA magnetic field is compared to the isochronous experimental map of Cyclone®11 on figure 2. The agreement is very good.

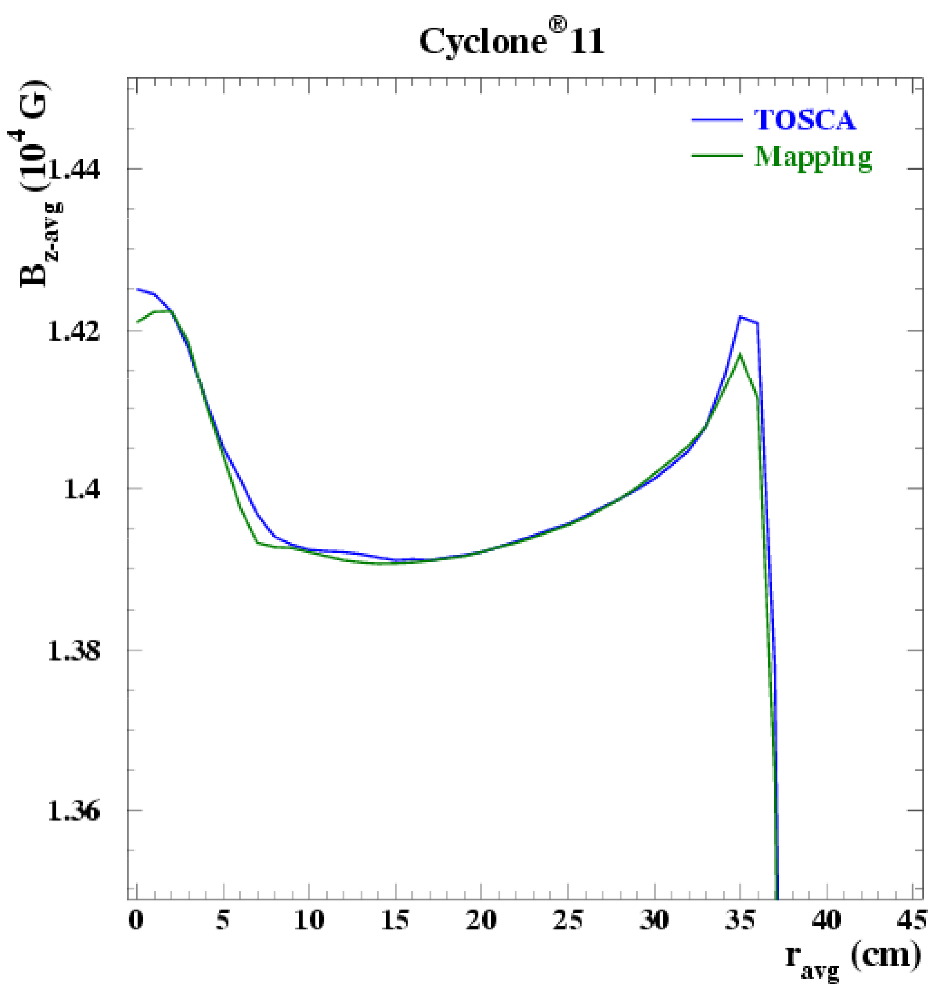

Figure 2: Comparison of the experimental magnetic field profile with the results of the TOSCA analysis.

Isochronism

Isochronism of the cyclotron is obtained by milling one edge per pole. The BH curve used for the TOSCA analysis is directly provided by the iron supplier. It can be seen on figure 3 that the magnetic fields are isochronous with the (second harmonic mode) RF frequency of 42.877 MHz.

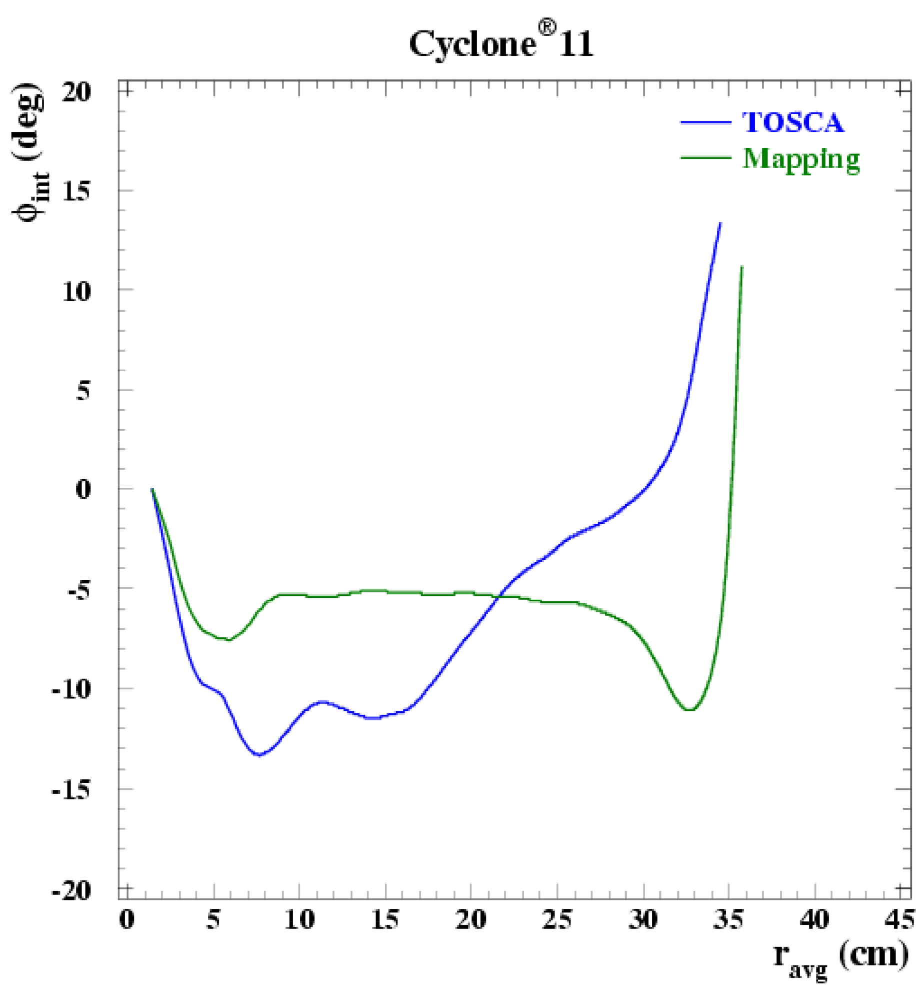

Figure 3: Experimental and simulated integrated phase shifts for the Cyclone®11.

Extraction

Proton extraction is performed by stripper foils mounted on a carrousel (figure 4) with the same design as the Cyclone®18/9 carrousel with a fork length of only 25 mm. The fork length is 5 mm shorter than the one of the Cyclone®10 which allows for extraction of higher energy orbits.
The extraction study has been performed on the two first ports. As the experimental magnetic field measurement can be performed only up to a radius of 45cm, we extend the experimental map with the TOSCA map for radii from 46 cm to 100 cm.

The particles are tracked in that map and it has been found that the extracted beam in the Cyclone®11 has an energy of 11.5MeV (figure 5).

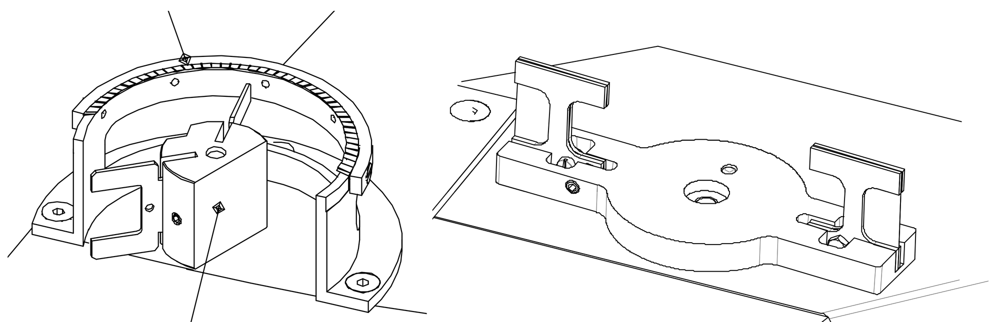

Figure 4: Carrousel for extraction: Cyclone®10/5 design (left); Cyclone®18/9 design used for Cyclone®11 (right).

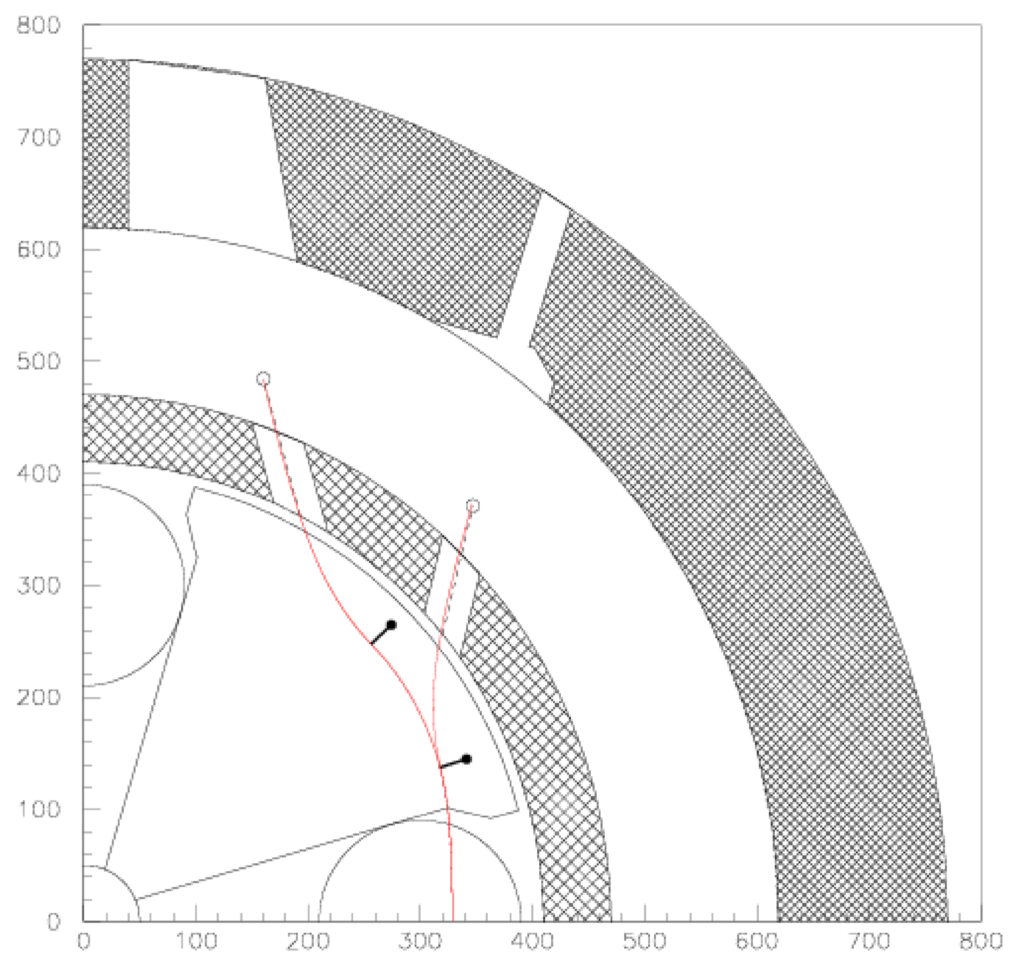

Figure 5: Particle tracks at the extraction in the experimental map of the Cyclone®11.

Note that compared to the Cyclone®10/5, the position and direction of the exit ports in the vacuum chamber have been adapted to the new extracted orbits.

Present status

The iterative procedure to obtain the isochronous magnetic field in Cyclone®11 was successfully finished in the mechanical workshop of IBA subcontractor. The installation of other subsystems of the cyclotron in the assembly hall of IBA is nearly completed and initial beam tests will follow.

Conclusions

Calculation results of the Cyclone®11 are in very good agreement with the experimental data. Compared to the Cyclone®10 (with movable inserts removed), increasing the main coil current up to 185 A and filling the valley with 10 cm of iron allows to increase the energy above 11 MeV. The experimental map of magnetic field shows that we manage to get the Cyclone®11 isochronous and the extracted energy can be expected to be close to 11.5 MeV.

References

[1] S. Zaremba et al. – Beam Dynamics in Newly Designed Cyclotrons at Ion Beam Applications; Proceedings EPAC 1990, p. 1774-1776.
[2] M. Abs et al. – RF Systems Developed for CYCLONE 3D and CYCLONE 10/5; Proceedings EPAC 1990, p. 967-969.
[3] F. Stichelbaut Design of the Cyclone®11 Self-Shielding; IBA internal report.