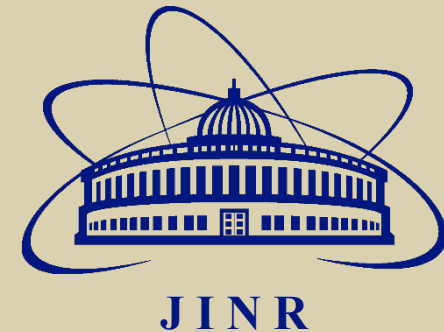


CONTINUOUS BEAM DYNAMICS SIMULATION IN COMSOL MULTIPHYSICS

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INTRODUCTION

Abstract:

The classic way of beam dynamics simulation in a cyclotron is to separate it into many different stages from the ion source to the extraction (or even further), this was absolutely necessary to fit the calculations into any reasonable time in a cost of influence of some operation devices from one stage, on beam dynamics of another (next or previous mostly) stage. We've managed to perform beam dynamics from ion source through a solenoid to the center region in a single model in COMSOL, using several fields simultaneously: external magnetic (the magnet), calculated magnetic (the solenoid) and alternating and stationary electric fields in the center region.

Some stages of cyclotron elements' simulation:

- Ion Source
- Bending Magnet
- Focusing Solenoids
- Spiral Electrostatic Inflector
- Magnetic Field Simulation in Center Region
- Accelerating Gaps in Center Region
- Main Magnet Simulation
- RF-system
- Magnetic Channels
- Deflectors
- and numerous elements of the delivery system...

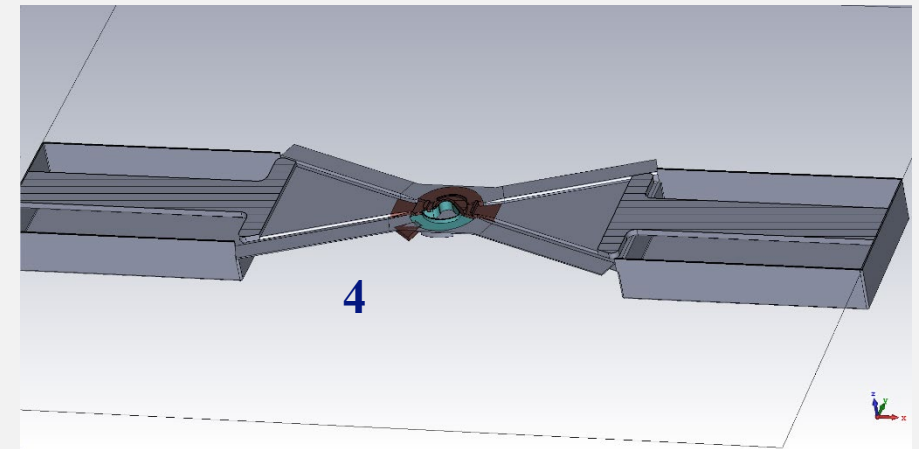
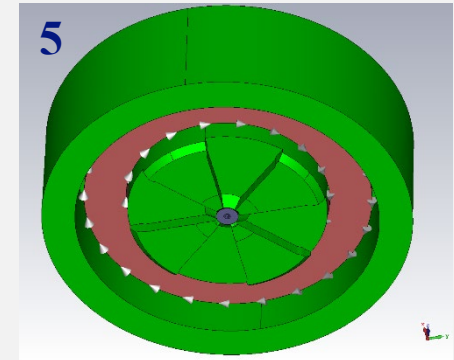
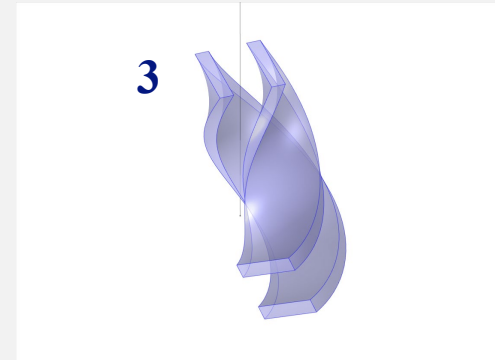
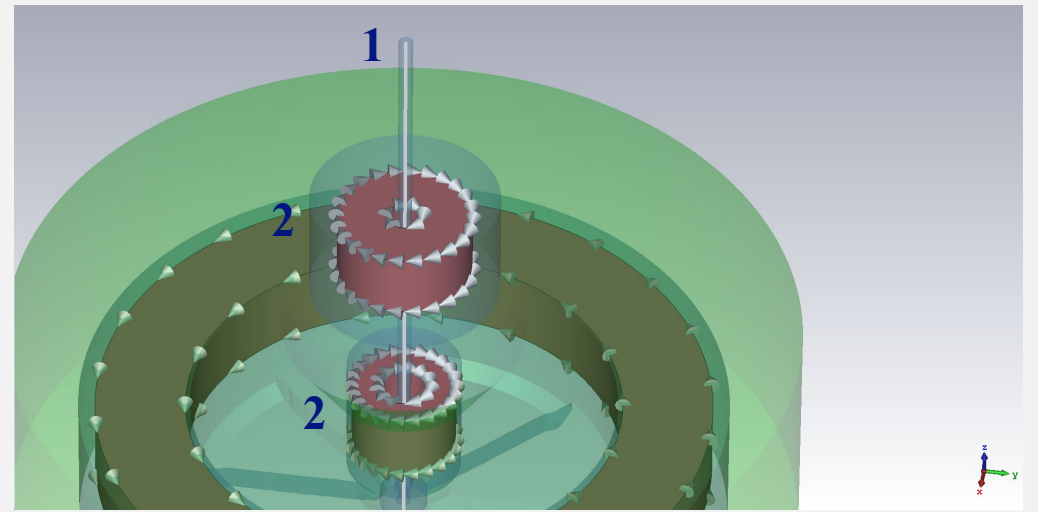
Almost every 1-2 stages are followed with a step of beam dynamics simulation.

ELEMENTS' DESCRIPTION

In our case the goal was to create a working COMSOL model with 5 elements of some cyclotron.

The elements:

1. **Ion Source:** H_2^+ ions with initial energy of 25 keV.
2. **Focusing Solenoids:** produce fields up to 0.19 T and 0.4 T along beam direction.
3. **Spiral Electrostatic Inflector:** voltage of 5.6 kV.
4. **RF-system:** alternating voltage of 50 kV.
5. **Main Magnet:** magnetic field in the center – 1.22 T.



COMSOL MODEL

The model consists of two components: one is purely for calculation of the magnetic field of the main magnet (Fig. 3), the other (Fig. 1) calculates the rest of the fields, imports the field from the first component, through General Extrusion operator, and performs particle tracing.

In the second component: the magnetic field calculation is restricted to the solenoid area (Fig. 2), whereas the electric field calculation proceeds in the rest of the model.

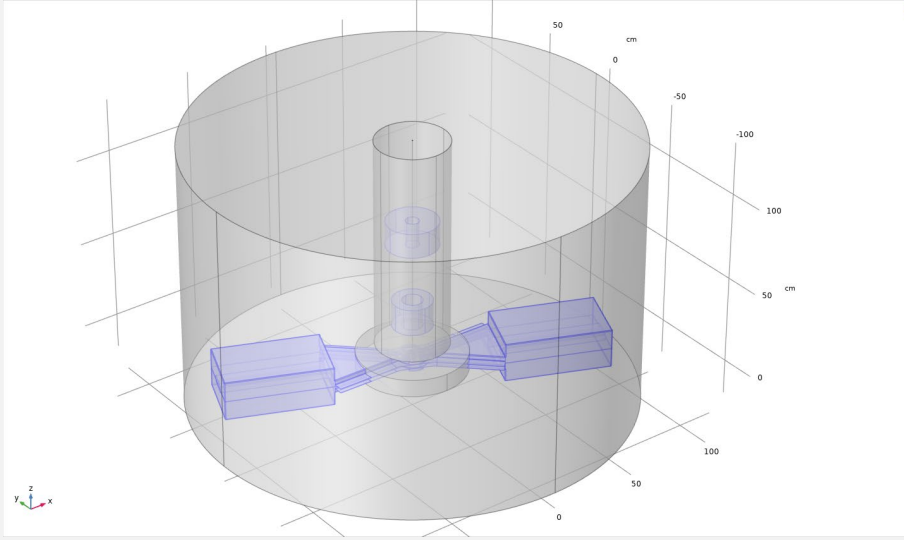


Fig. 1

Fig. 2

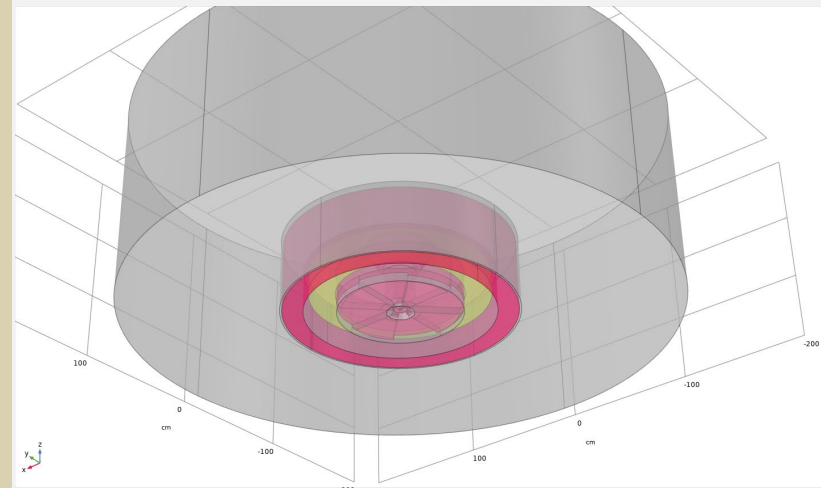
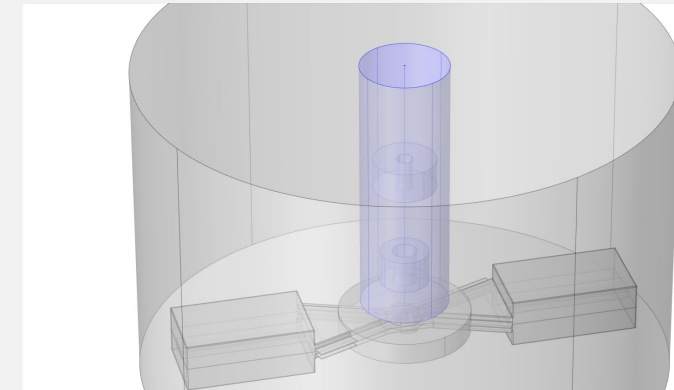


Fig. 3

OBTAINED RESULTS

The beam was focused by the solenoids (Fig. 2), caught by the inflector and then accelerated around by RF-system considering the magnetic field (Fig. 1).

I want to highlight here that the results on this slide depict only the correct working of the COMSOL model, not the correct beam acceleration in the cyclotron.

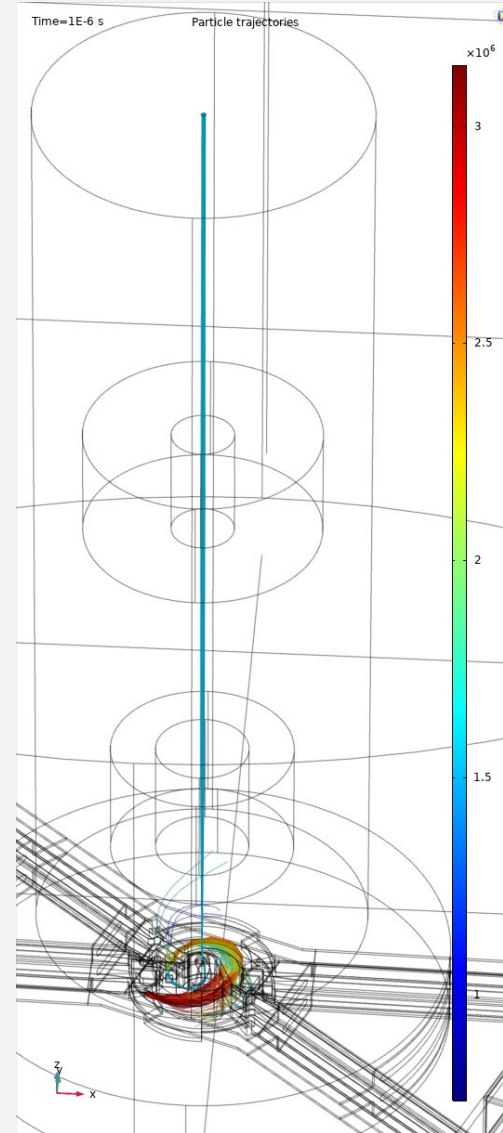


Fig. 1

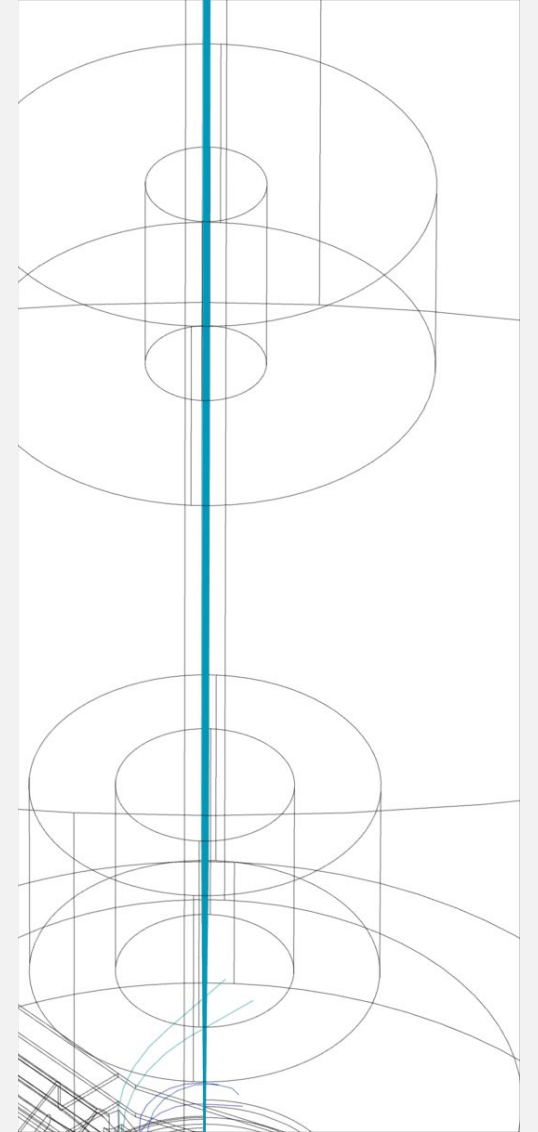


Fig. 2

EXTERNAL FIELD

Since the magnetic field in COMSOL is often hard to calculate, we developed an option to import external 3D magnetic field into the second component through the Interpolation operator.

As an example the magnetic field, calculated in CST Studio Suite (Fig. 3), was imported. The particle tracing was performed (Fig. 1). The spiral inflector was adjusted to improve beam dynamics (Fig. 2).

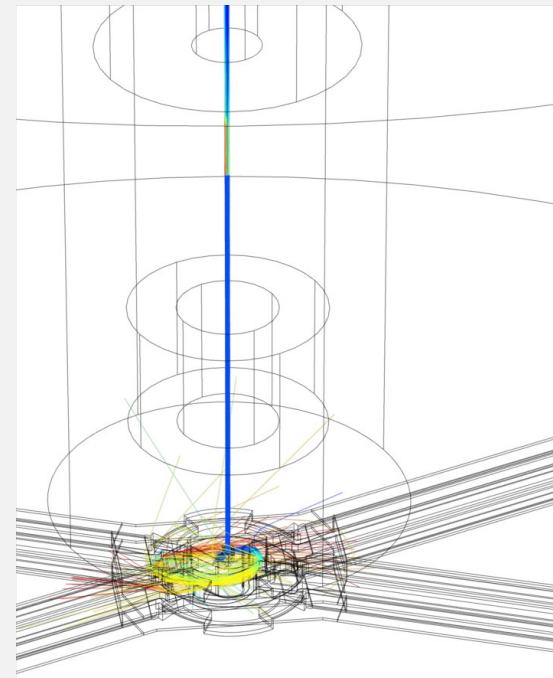


Fig. 1

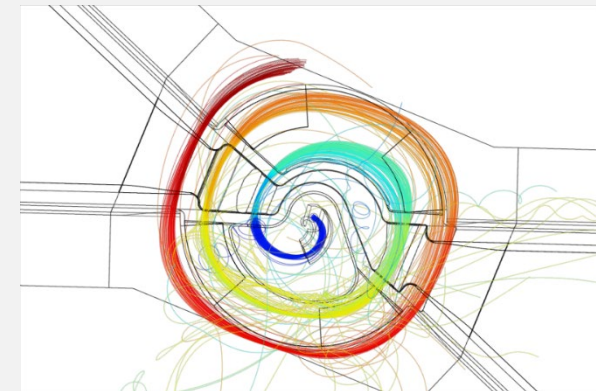


Fig. 2

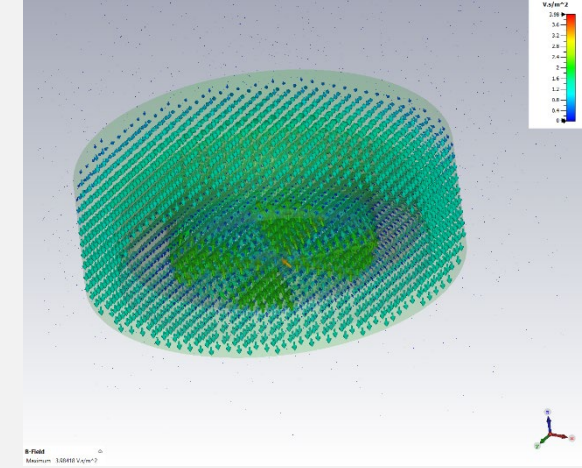


Fig. 3

BEAM LOSSES AND DOUBLE AXIAL INJECTION

COMSOL's one component simulation provides another useful opportunity – to assess beam losses on structure elements.

To increase beam current even more, the double axial injection was considered (Fig. 1-2). The simulation with beam losses was performed (Fig. 3).

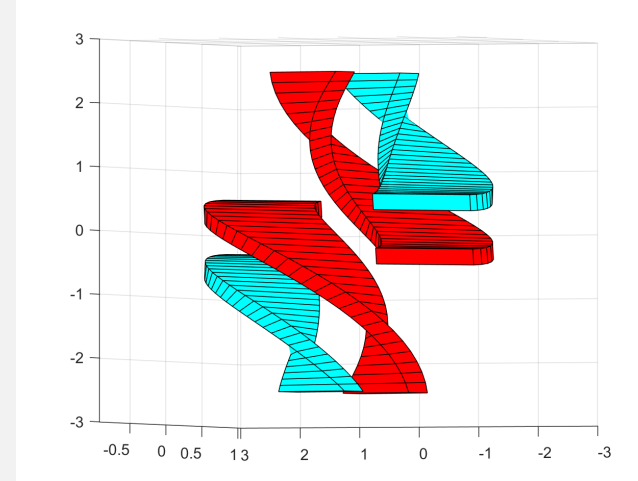


Fig. 1

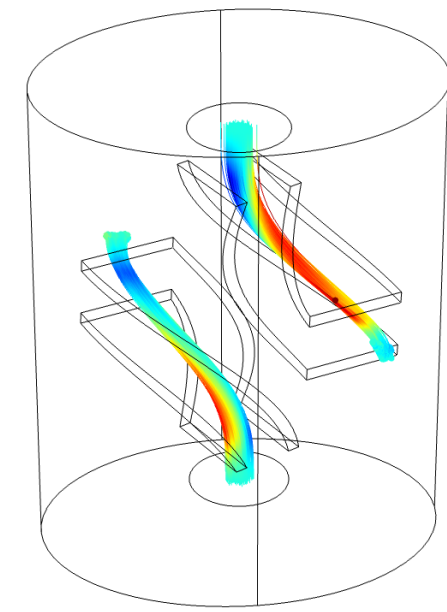


Fig. 2

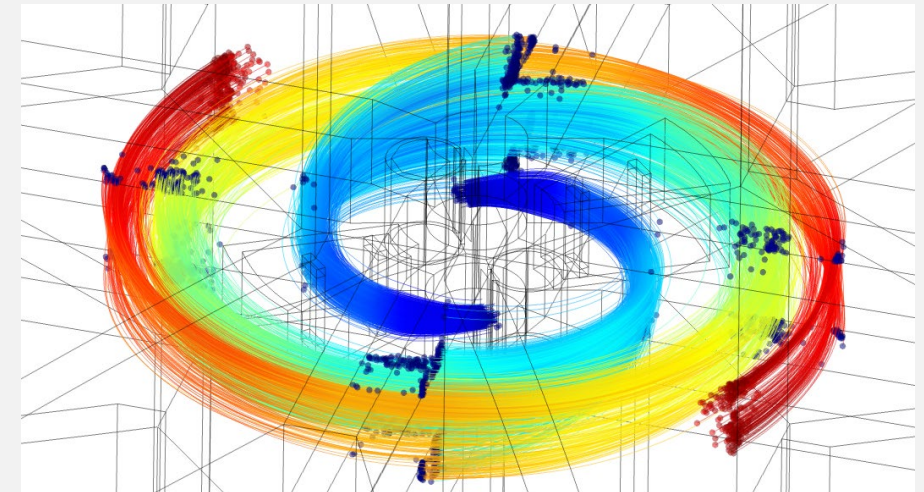


Fig. 3

CONCLUSION

Final words:

The main conclusion is that the COMSOL is very adjustable tool when it comes to cyclotron design. It could contain whole machine in one model, which could be neatly customized for every direction you prioritize: whether it would be mesh, physics, solver, particle tracing or even collisions with the structure, and many more...

This approach will be used in our future projects (SC230 cyclotron). The result it provides, along with its advantages and peculiarities, will be reported in our next work.

COMSOL's one model simulation brings several significant improvements and provides variety of opportunities to field simulation and tracing procedure:

- Makes it possible to estimate the impact of all elements in your model not only on particle tracing, but on each other.
- Allows you to partition your model not only in terms of your components, but in terms of physics inside every component.
- And the customization goes even more, by allowing you to import any external 3D-field if you dislike its COMSOL calculation.