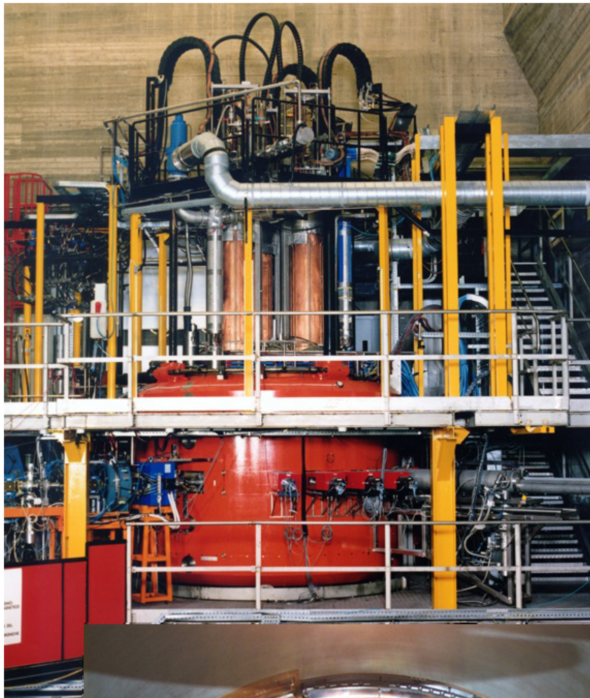
Extraction by stripping in the INFN-LNS Superconducting Cyclotron:

Study of the extraction trajectories

Grazia D'Agostino, PhD student in Physics

L. Calabretta, A. Calanna, D. Rifuggiato

INFN-LNS Superconducting Cyclotron (CS)



N° of accelerating cavities	3
Harmonic	2
RF cavity frequency	15-48 MHz
Magnetic field	2.2-4.8 T
Pole radius	90 cm
Yoke external radius	190.3 cm
Total height	286 cm
Weight	196 t
K bending	800
K focusing	200

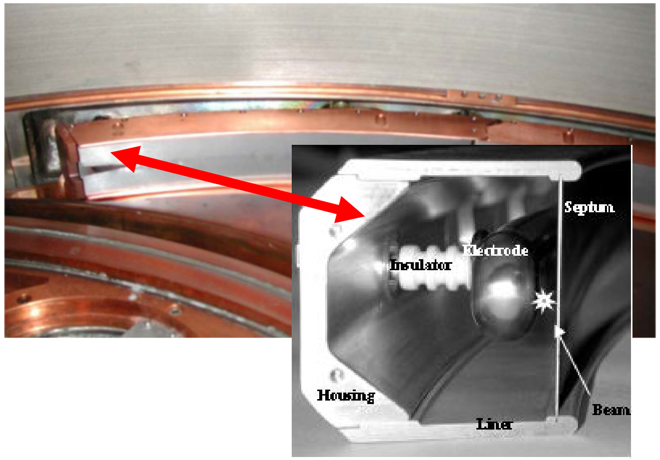
Able to accelerate from ^{2}H up to ^{208}Pb
Energy range 10÷80 AMeV
Maximum beam power about 100 W

CS upgrade

Details illustrated by L. Calabretta on Monday

Necessity to increase the extracted beam power to 2÷10 kW for ^{12}C, ^{18}O, ^{20}Ne with energy 30÷70 AMeV

NUMEN & FRIBS experiments at INFN-LNS



The existing extraction system will be maintained to meet the needs of the INFN-LNS community

Stripping extraction

Expected efficiency 99%

Atomic Data and Nuclear Data Tables, Vol. 51, No. 2, July 1992, Table 2 pag.187

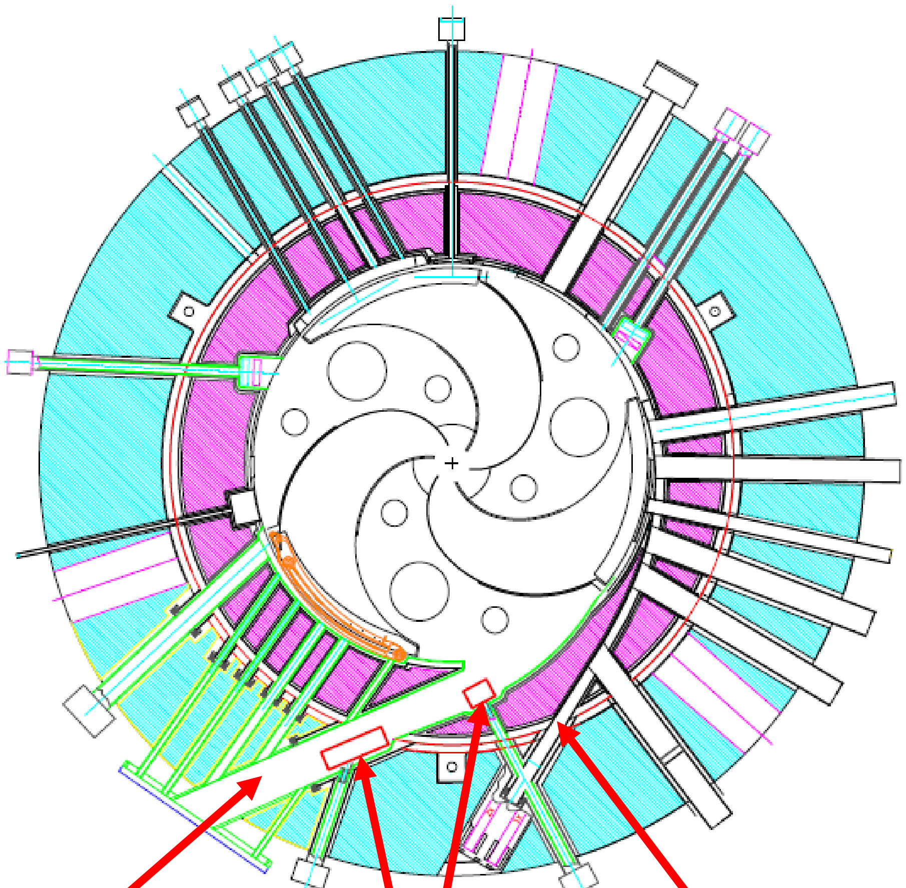
CS UPGRADE

- New extraction channel with a larger vertical gap vs existing channel
- New cryostat and new superconducting coils
- New magnetic channels and compensation bars

Other aspects of the project:

Increase source efficiency
Improve source-CS matching
Improve transport line efficiency

Studies of the stripping extraction



Results of the preliminary study (2014):

A **new extraction channel**, rotated of about 30° respect to the existing one, **simplifies the extraction of the ions of interest**

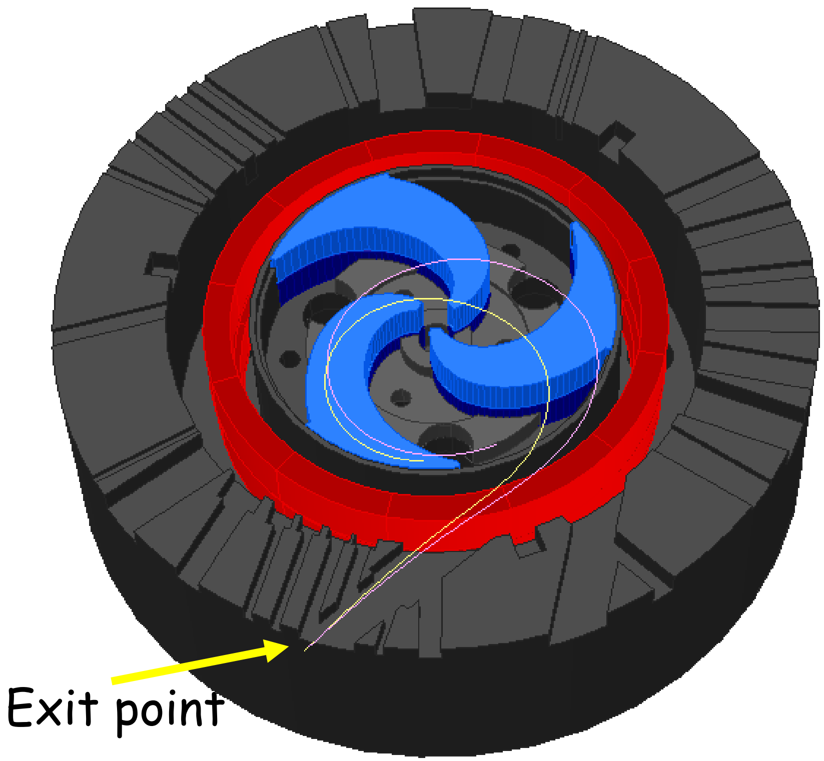
Stripping extraction not feasible through existing channel

Results of the latest study:

Only two magnetic channels are sufficient to permit the extraction of all ion beams of interest with different charge states and energies

How we designed the new extraction line

The ion beams to be extracted by stripping are $^{+12}C^{4+}$, $^{18}O^{6+}$, $^{20}Ne^{7+}$ accelerated at energies in the range 30÷70 AMeV.
They are fully stripped by their electrons after crossing the stripper foil

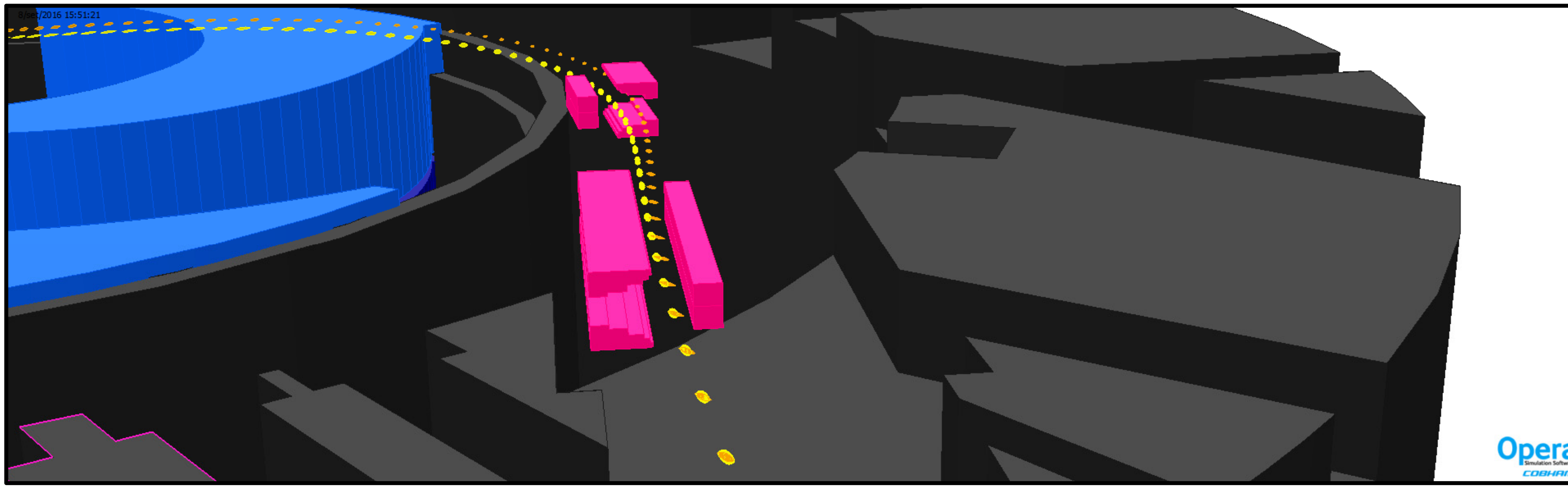


We determined the position of the stripper for each case in order to:

- convoy **all beams envelopes in a region as small as possible along the path of the extraction**
- to have **extraction trajectories as close as possible to the exit point from the CS**, appropriately fixed to facilitate the connection with new beam transport line

Transversal size and direction of the new E.C. fixed

For each case, we also found out the dipole and quadrupole component of the magnetic channels necessary to focus and steer the beam along the extraction path



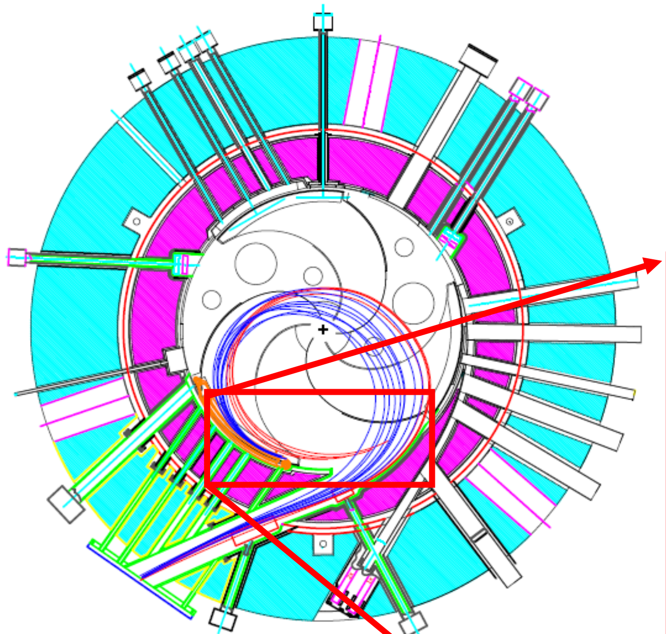
Only two magnetic channels MC1S & MC2S

Magnetic gradient: 1.8 kG/cm
(equal for each ion and energy)

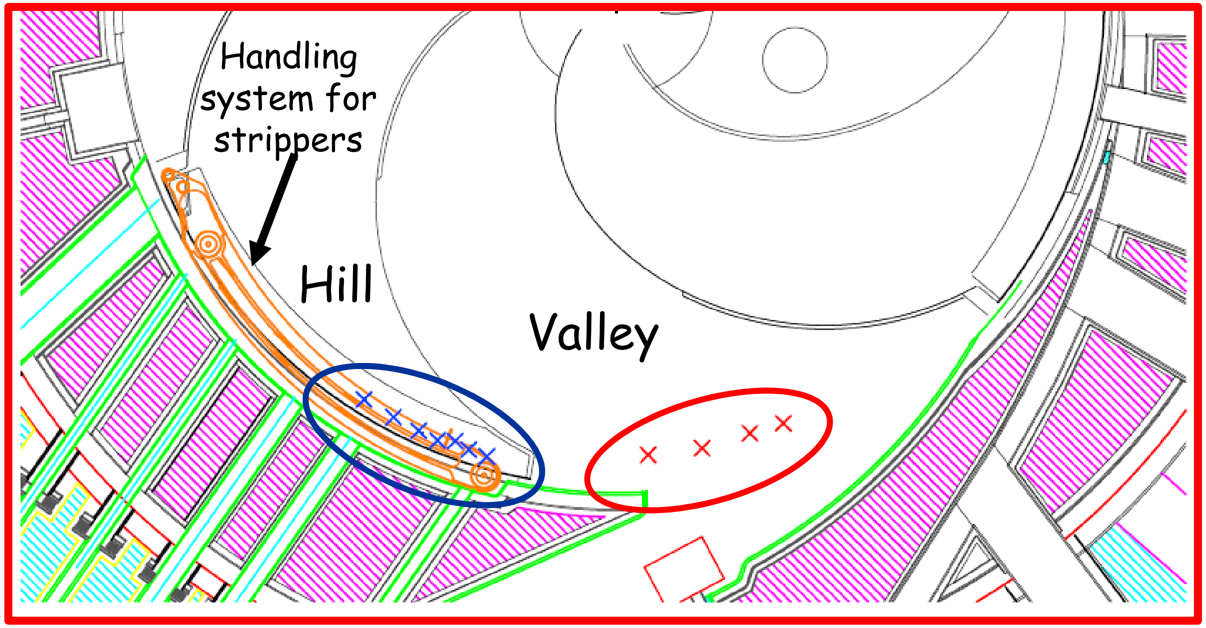
No opening the machine frequently

Stripper foil positions

Two main areas for the stripper foil:
- **on the hill** where the first electrostatic deflector (ED1) is placed
- **one on the valley**, just before ED1



For the stripping extraction, the electrostatic deflector ED1 on the hill will be removed to insert the handling system for the stripper foils
(For more details see Poster THP09 , G. Gallo et al.)



Blue: Stripper foil on hill
Red: Stripper foil on valley

How we evaluated the beam envelope along the extraction path

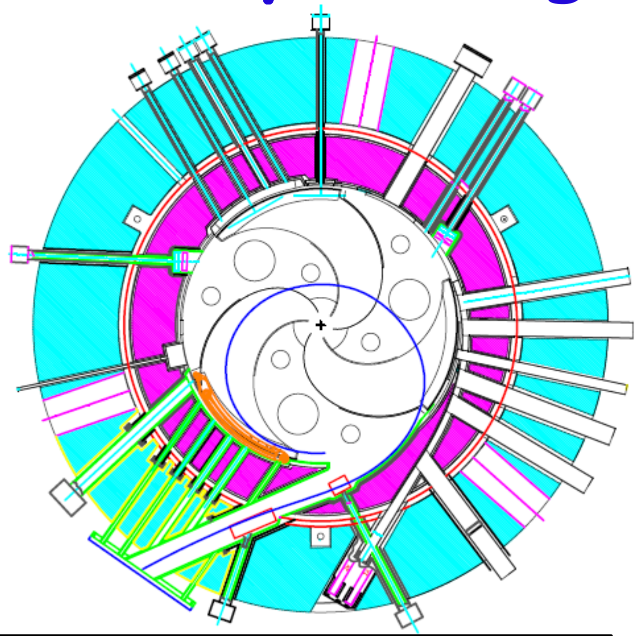
-By using the magnetic field maps, for each case we simulated the beam envelope around the Static Equilibrium Orbit at the last energy.

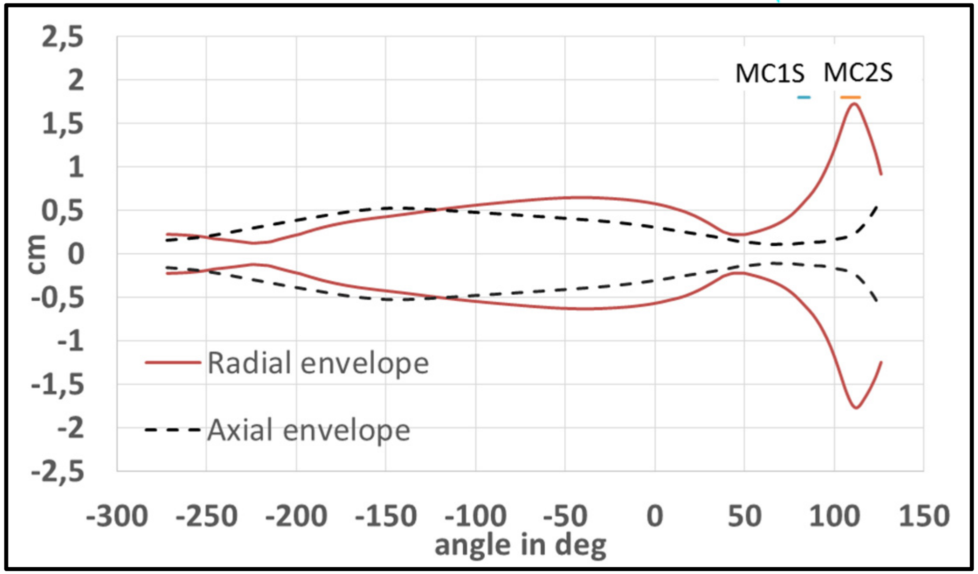
-The charge state of the ion was changed to simulate the stripping process.

-The trajectories of eigth particles, that describe the eigenellipse of the beam (X,X') and (Y,Y'), have been integrated to achieve the beam envelope along the extraction trajectory.

Codes: GENSPE & ESTRAZ
Norm. Emittance 1 π mm.mrad

$^{18}O_8^{4+}$
$\theta_{stripper}$=88°
$E_{stripper}$=65AMeV

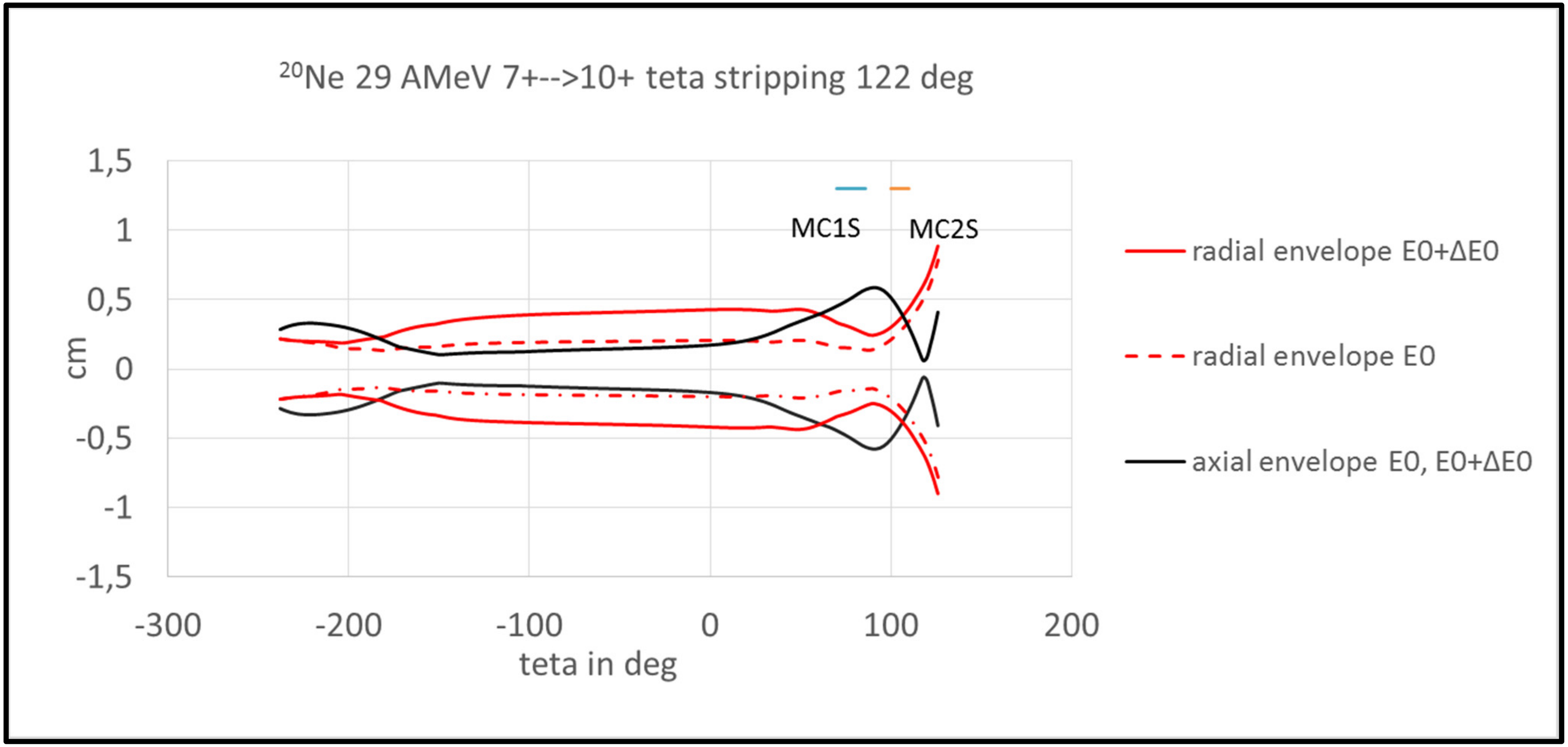




Energy spread

Energy spread of ±0.3 % for all ions at different energies → Radial beam envelope increased

Axial beam envelope unchanged

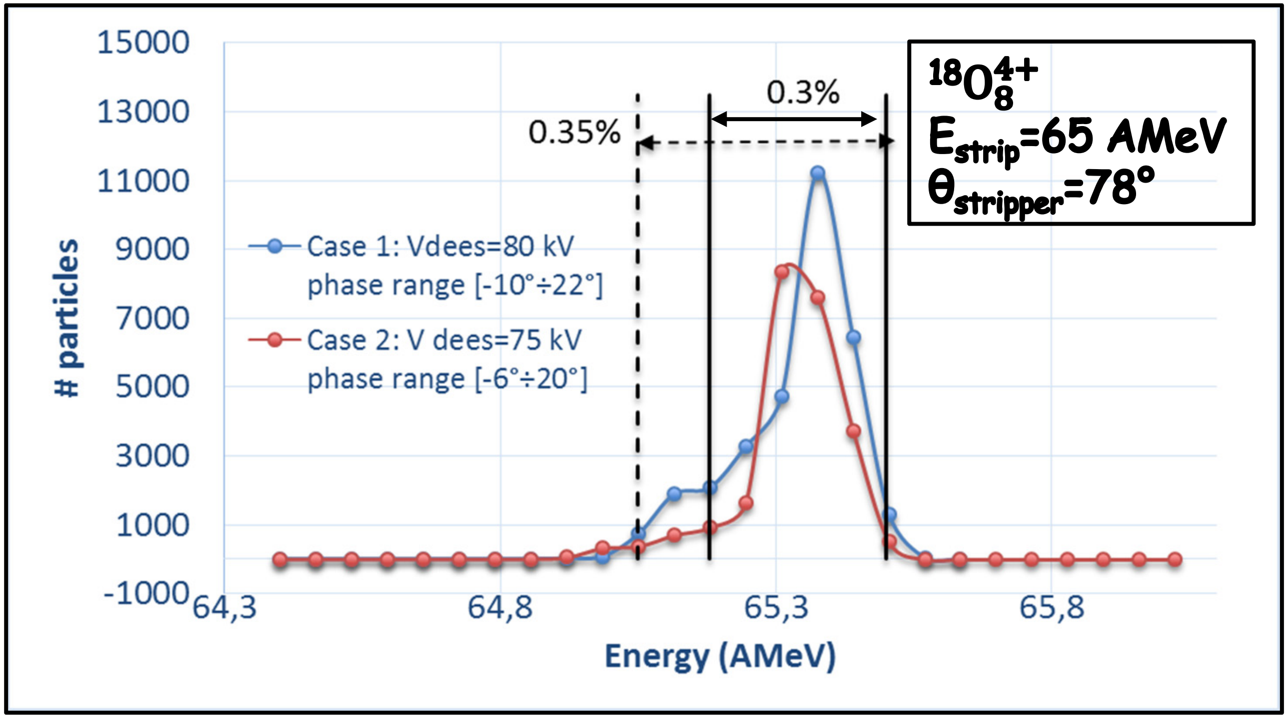


Energy distribution of the beam particles at the stripper foil

Energy distribution of a beam accelerated from 1 AMeV up to the stripper position. Two cases:

- 1° case: V_{dees}= 80 kV Phase range [-10°÷22°]
- 2° case: V_{dees}= 75 kV Phase range [-6°÷20°]

2000 particles for each phase
Uniform distribution in (X,X') and (Y,Y')
Norm. Emittance 1 π mm.mrad



1° case:
N particles ≈91.5%
Energy spread ±0.3%

N particles ≈97%
Energy spread ±0.35%

2° case
N particles ≈94%
Energy spread ±0.3%

N particles ≈97%
Energy spread ±0.35%

Energy spread ±0.35 % acceptable even for intense beams (10 kW → loss power 300 W)

Design study of the magnetic channels

Features of new magnetic channels:

- **Large trasversal size** to accomodate intense ion beams
- **Gradient costant in a region of about 4 cm**
- **Position** in a region **where the cyclotron magnetic field is enough to magnetize the iron**

Existing magnetic channels → Three bars technique
Current sheet approximation (B>0.5 T)

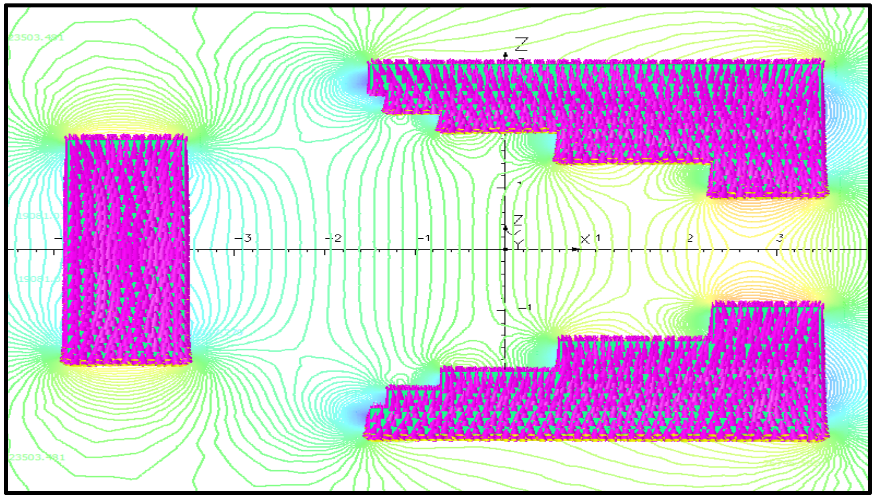
New magnetic channels → ~~Three bars technique~~
~~Current sheet approximation~~

Design study of the magnetic channels

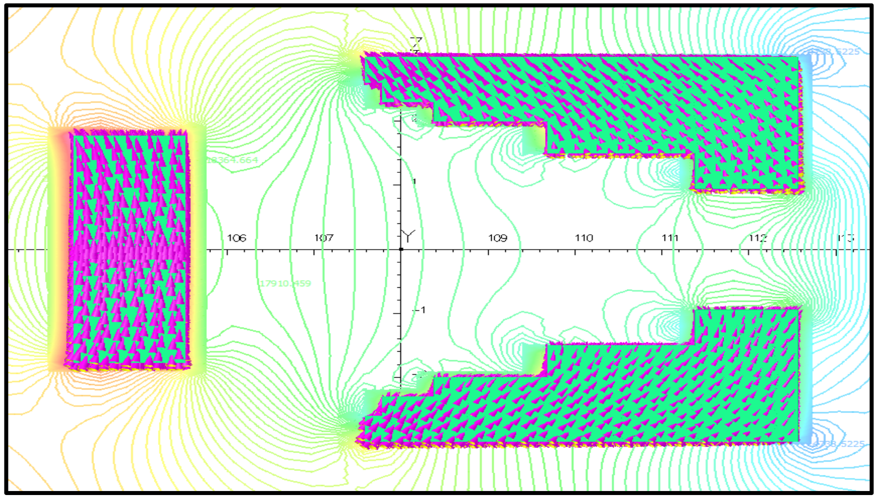
Three bars technique → ~~Gradient constant in the scale of mm~~ 

Current sheet approximation → Magnetic field higher 0.5 T 

~~Main magnetic field perfectly perpendicular~~ to the median plane 



Iron volumes in a uniform magnetic field



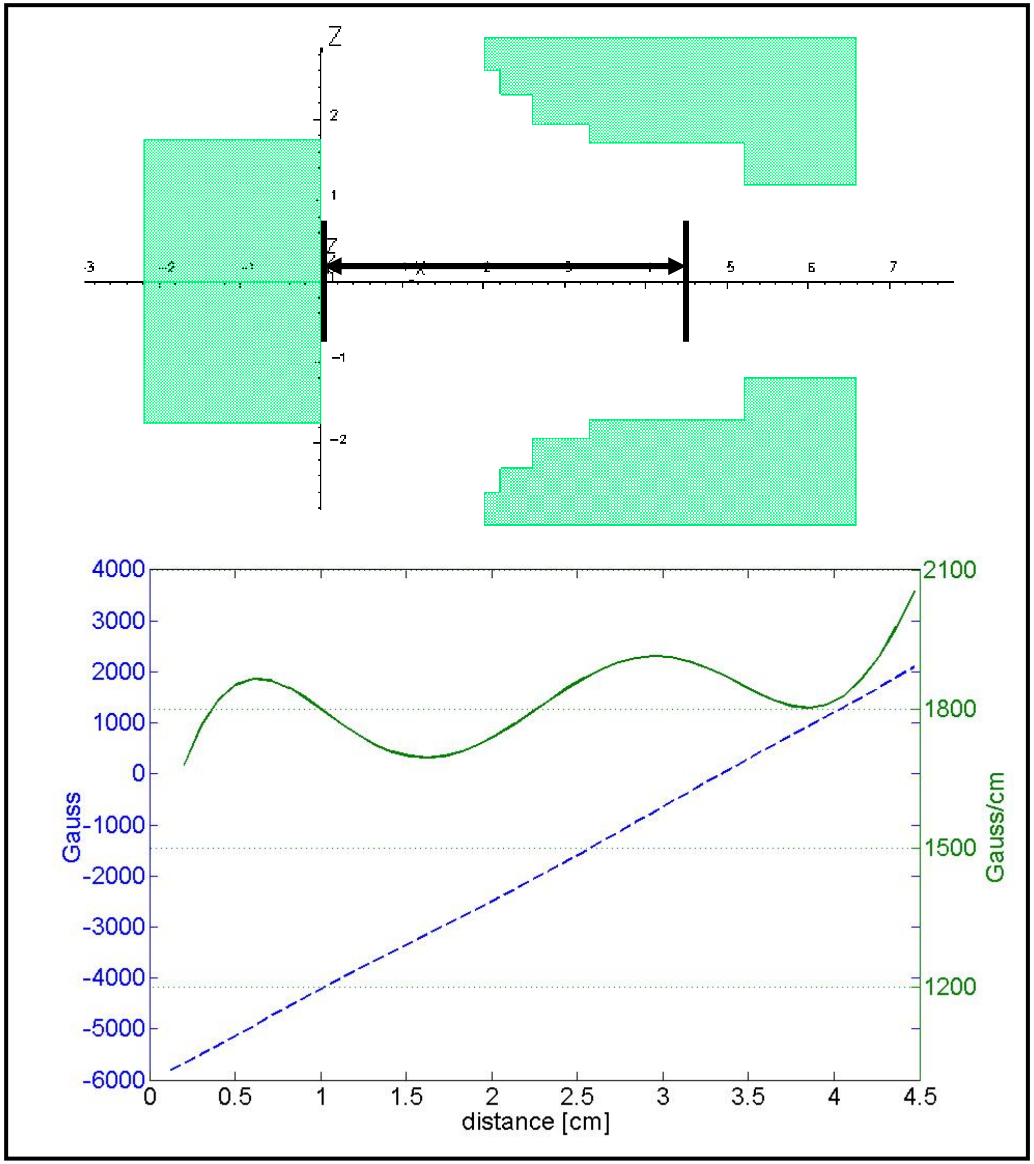
Iron volumes where the main magnetic field is non perfectly perpendicular to the median plane

How we designed the magnetic channels

As a starting point to define the profiles of the magnetic channels, we simulated the channels using the current sheet approximation.

We evaluated the field differences with the case of the magnetic channels made by iron volumes and placed where they really will be.

We compensated the field differences changing sligtly the iron profiles.



Magnetic channel MC1S

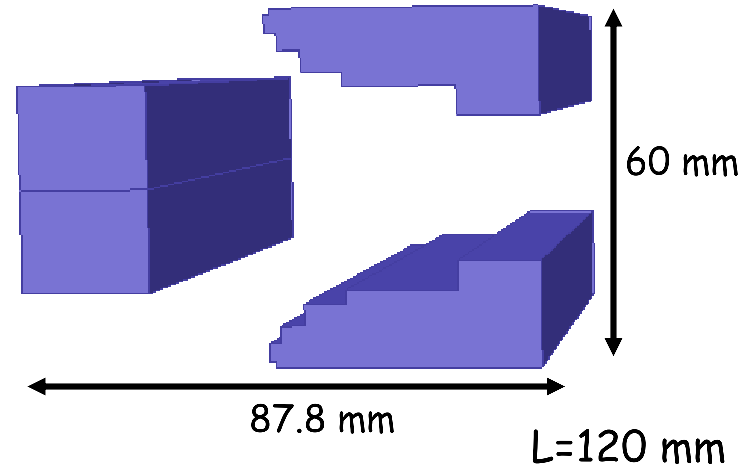
The steering action of each magnetic channel must be different for each ion and energy.
To assure that each reference trajectory undergoes the correct magnetic field, it is necessary to move the channels opportunely.

We fixed a reference position of the MCs ($^{18}O^{6+}$ E=65 AMeV and $\theta_{stripper}$ = 88°)

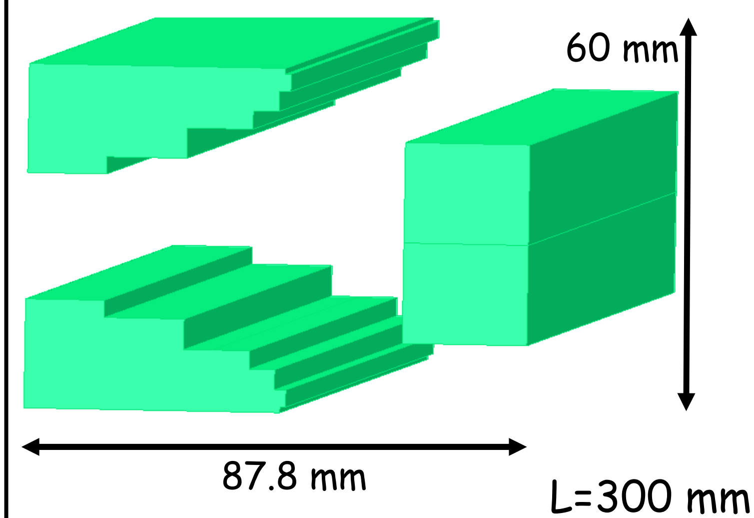
For some cases the displacement of the MCS necessary is few mm, for other cases few cm.

Maximum displacement that includes all cases is 60 mm for both MCs

Magnetic channel MC1S



Magnetic channel MC2S



First harmonic and compensation bars

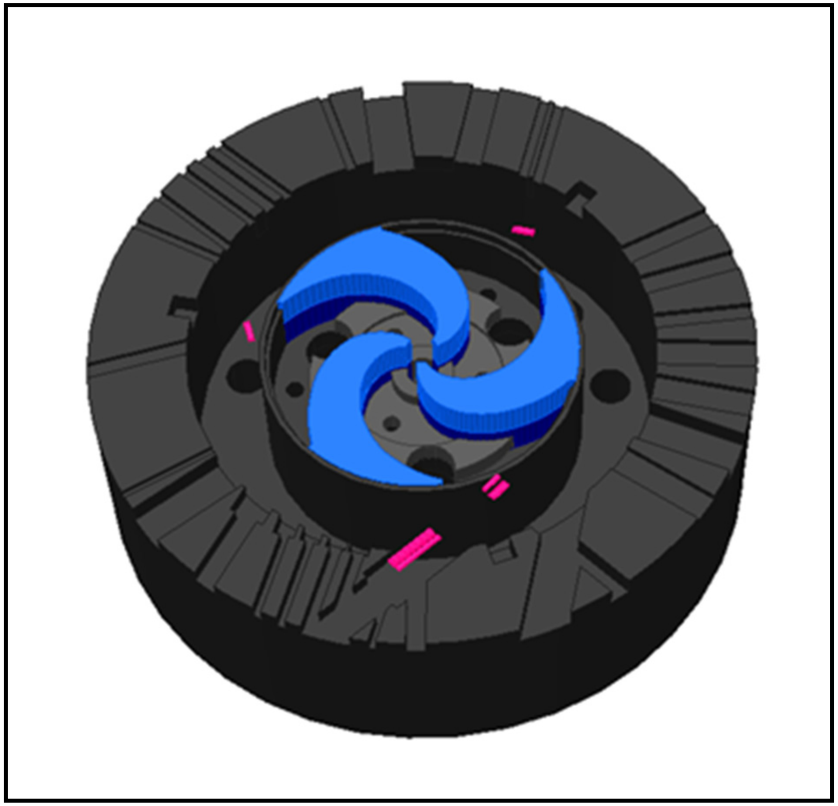
Introduction of the new magnetic channels, mainly the first block of MC 1

↓

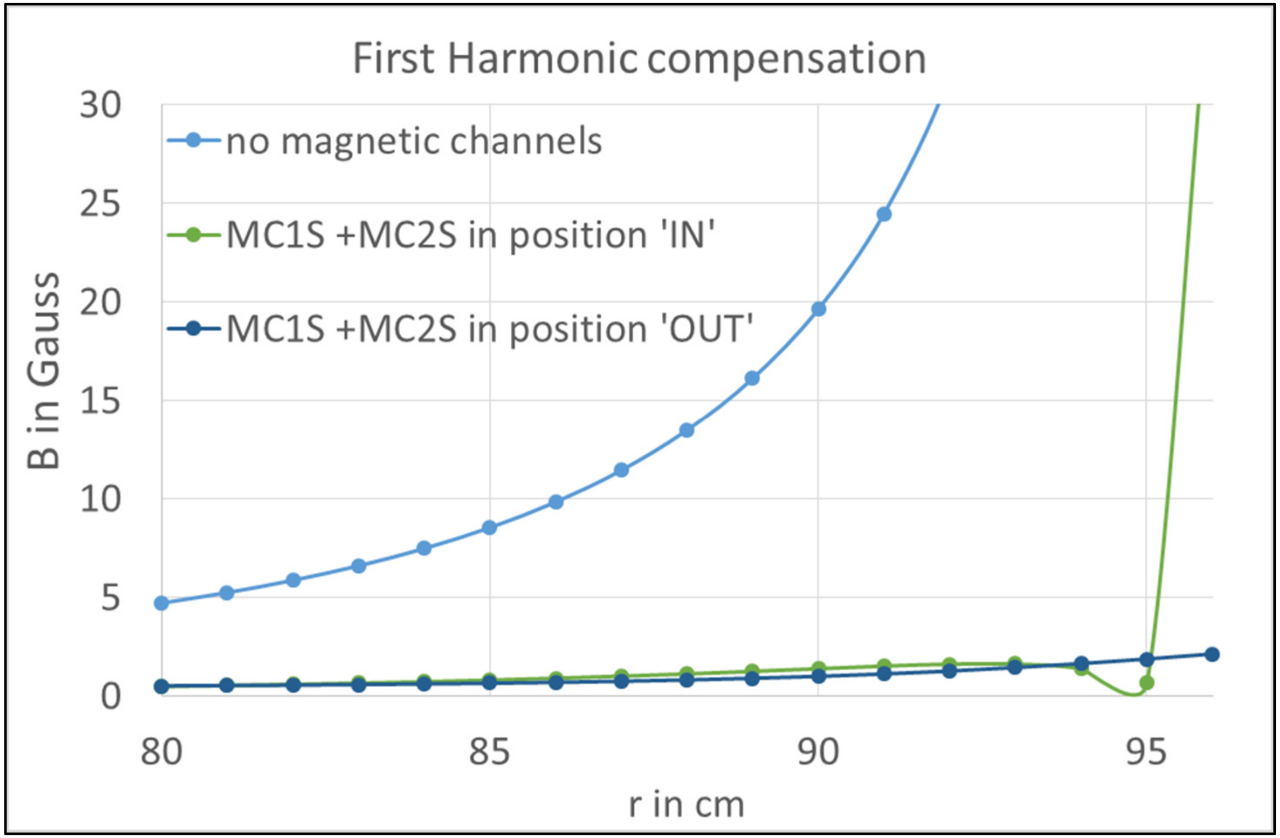
First harmonic component of the main magnetic field

↓

Two compensation bars to restore the three-fold symmetry of the main field



- Size 120x30x35 mm
- Installed at ±120° respect to the position of the first block of MC1S at R= 950÷990 mm.
- Movable as the magnetic channels (maximum displacement 60 mm)



The first harmonic component of the main magnetic field after the introduction of the bars decreases from about 15 Gauss to about 2 Gauss.

Achieved goals of the study

- Definition of the transversal size and direction of the new extraction channel in the CS
- Use of only two magnetic channels for all ions at different energies
- Evaluation of the stripping trajectories and energy spread
- Optimation of the stripper positions
- Design of the new magnetic channels and compensation bars

Thanks for Your Attention