Proposal to increase the extracted beam power from the LNS-INFN Superconducting Cyclotron

HIAT 2015

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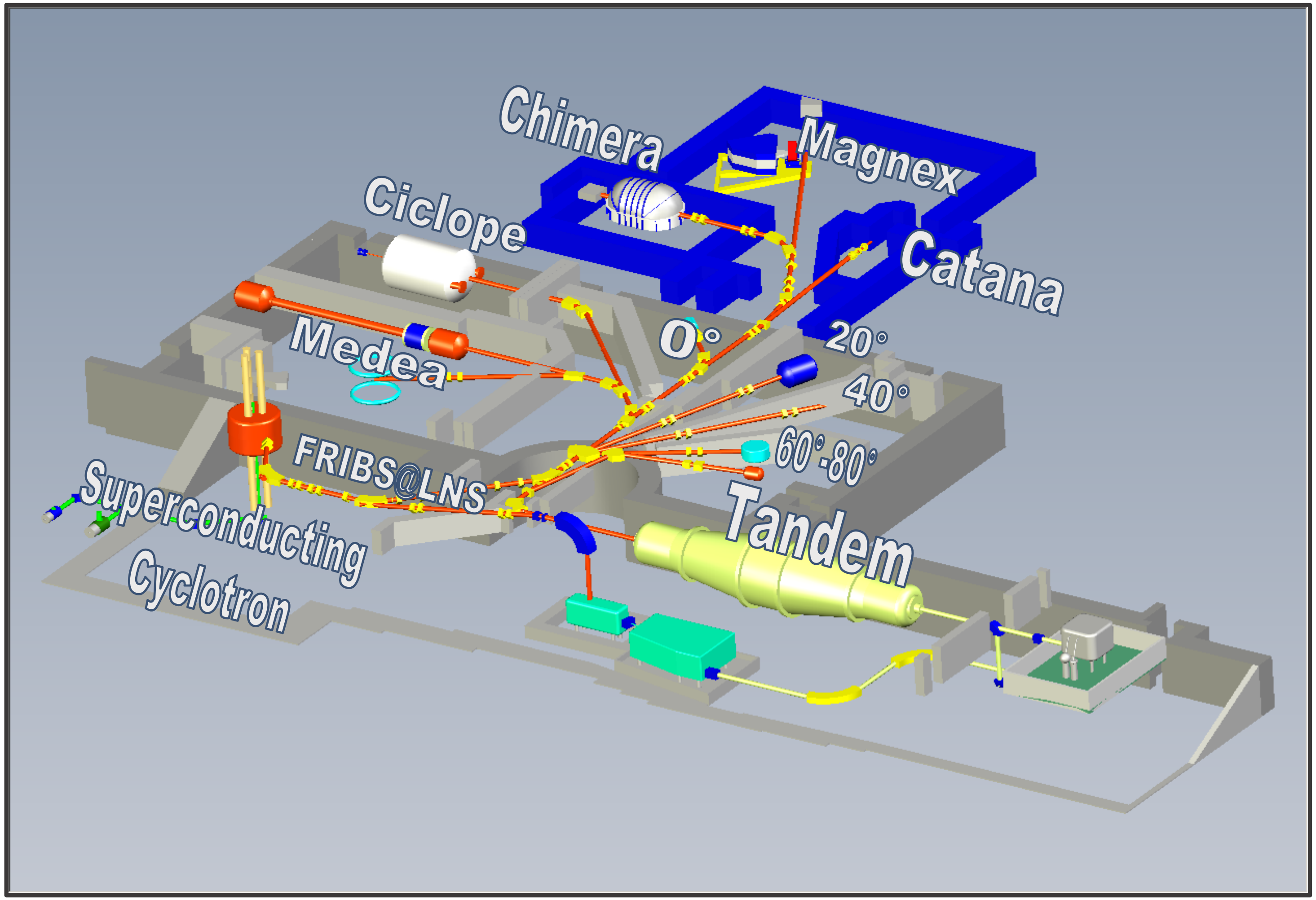
Overview

- Presentation of LNS-INFN accelerators: focus on the CS
- New requests for high power beams: NUMEN
- Possible upgrades to increase the extracted power
- Feasibility study for the extraction by stripping
- Beam dynamics results

INFN -LNS LABORATORIES



LNS-INFN ACCELERATORS

Injector 450 KV
2 sources
sputtering

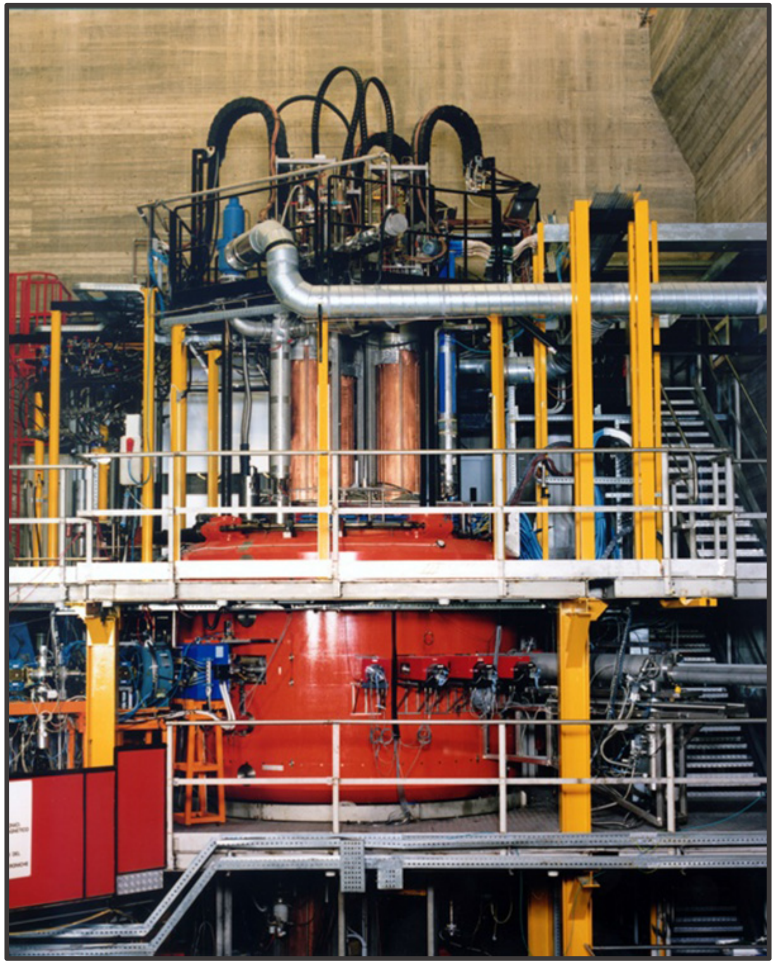
↑

Superconducting ECR source:SERSE

Normal conducting ECR source: CAESAR

↓

LNS-INFN SUPERCONDUCTING CYCLOTRON



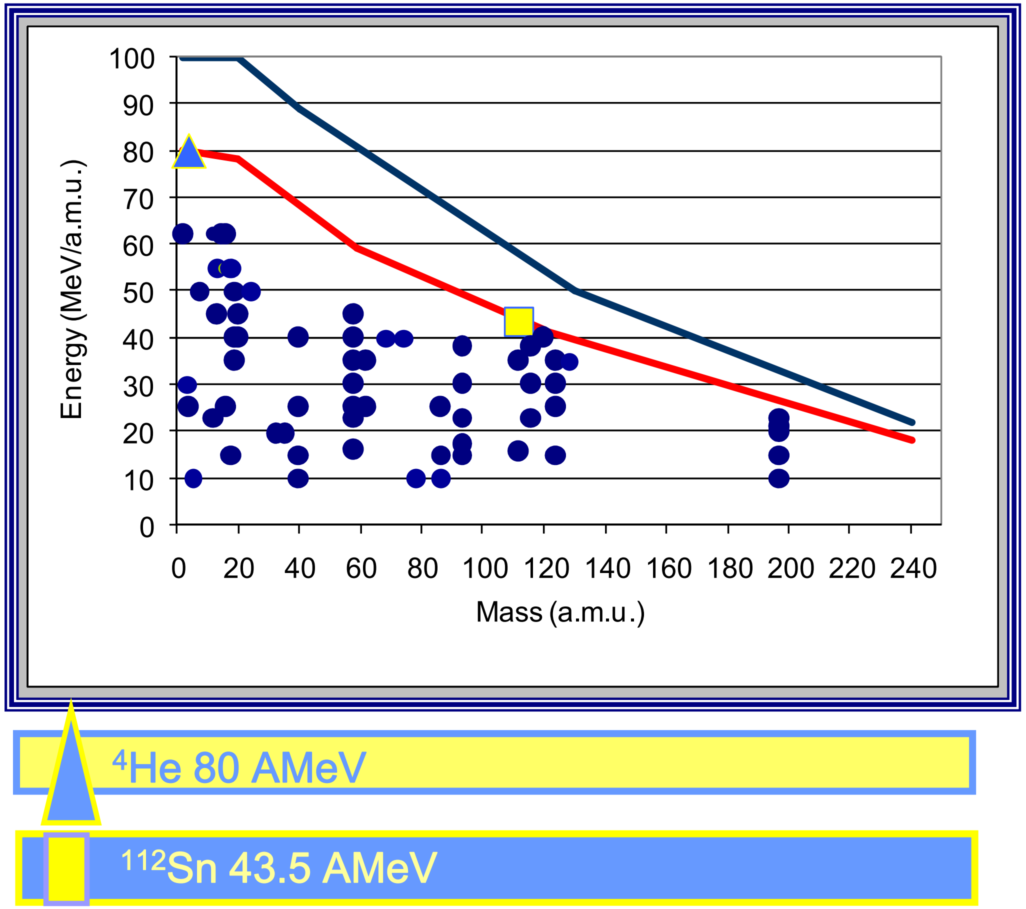
3 SPIRAL SECTORS

# of accelerating cavities	3
Harmonic #	2
RF frequencies	15-48 MHz
Magnetic field on the mp	2.2-4.8 T
Pole radius	90 cm
External radius	190.3 cm
Total height	286 cm
Weight	196 tons
K bending	800
K focusing	200

Energy = 10-80*A* MeV

Able to accelerate up to the Uranium

CS BEAMS



In red beam with intensities of 10^{12} pps

^{A}X	E (AMeV)
H_2^+	62,80
H_3^+	30,35,45
$^{2}D^+$	35,62,80
^{4}He	25,62,80
He-H	10, 21
^{9}Be	45
^{11}B	55
^{12}C	23,62,80
^{13}C	45,55
^{14}N	62,80
^{16}O	21,25,55,62,80
^{18}O	15,55
^{19}F	35,40,50
^{20}Ne	20,40,45,62
^{24}Mg	50
^{27}Al	40
^{36}Ar	16,38
^{40}Ar	15,20,40
^{40}Ca	10,25,40,45
^{42,48}Ca	10,45

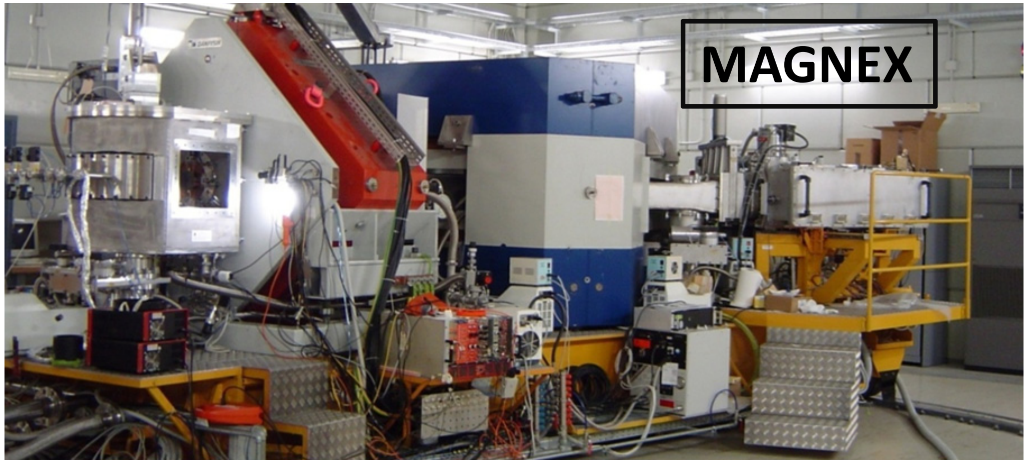
^{A}X	E (AMeV)
^{58}Ni	16,23,25,30,35,40,45
^{62,64}Ni	25,35
^{68,70}Zn	40
^{74}Ge	40
^{78,86}Kr	10
^{84}Kr	10,15,20,25
^{93}Nb	15,17,23,30,38
^{107}Ag	40
^{112}Sn	15.5,35,43.5
^{116}Sn	23,30,38
^{124}Sn	15,25,30,35
^{129}Xe	20,21,23,35
^{197}Au	10,15,20,21,23
^{208}Pb	10

New requests for high power beams: NUMEN

PHYSICS CASE: information on the nuclear matrix element $M_{0\nu}$ of 0νββ from the rate of reaction of Double Charge Exchange

$$[T_{1/2}]^{-1} = G_{0\nu} \ |M_{0\nu}|^2 \ |f(m_i, U_{ei})|^2$$

Hot beam 0νββ: ^{12}C ^{18}O ^{20}Ne
Energy $15 - 70$ AMeV
Power $5 - 10$ kWatt



- Wide angolar acceptance
- Possibility to measure at 0 deg
- Possibility to detect ^{16}O, ^{18}F, ^{18}Ne, ^{20}Ne
- High resolution spectrum
- Angular distribution up to 10 nb/sr

Pilot Experiment
$^{40}Ca(^{18}O, ^{18}Ne)^{40}Ar$

2 test-run done in October 2014 and February 2015 :^{18}O at 15 & 25*A* MeV Intensity 6 enA

→**too low statistics, need x10**

Next run: $^{116}Sn(^{18}O,^{18}Ne)^{116}Cd$
Energy 15- 30 AMeV
Intensity needed 60 eμA

–> P ≈ kWatt

CS UPGRADE

We need to increase the extracted beam power to
5- 10kWatt for ^{12}C ^{18}O ^{20}Ne
Energy $15 - 70$ AMeV
all the other beams now accelerated will be still available

New central region:
Percentage of particles after the 7th turn respect to the 3° turn: **99%**

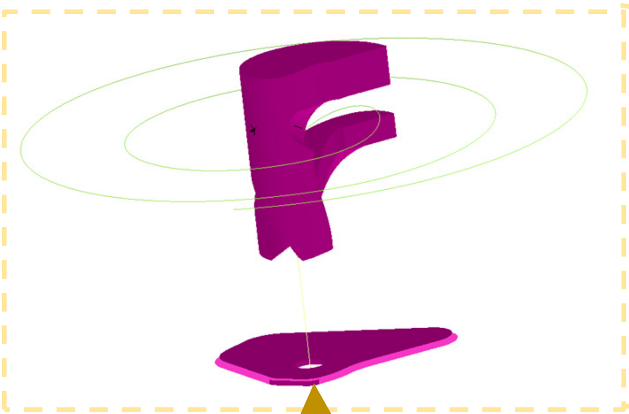
New extraction mode with a stripper foil:

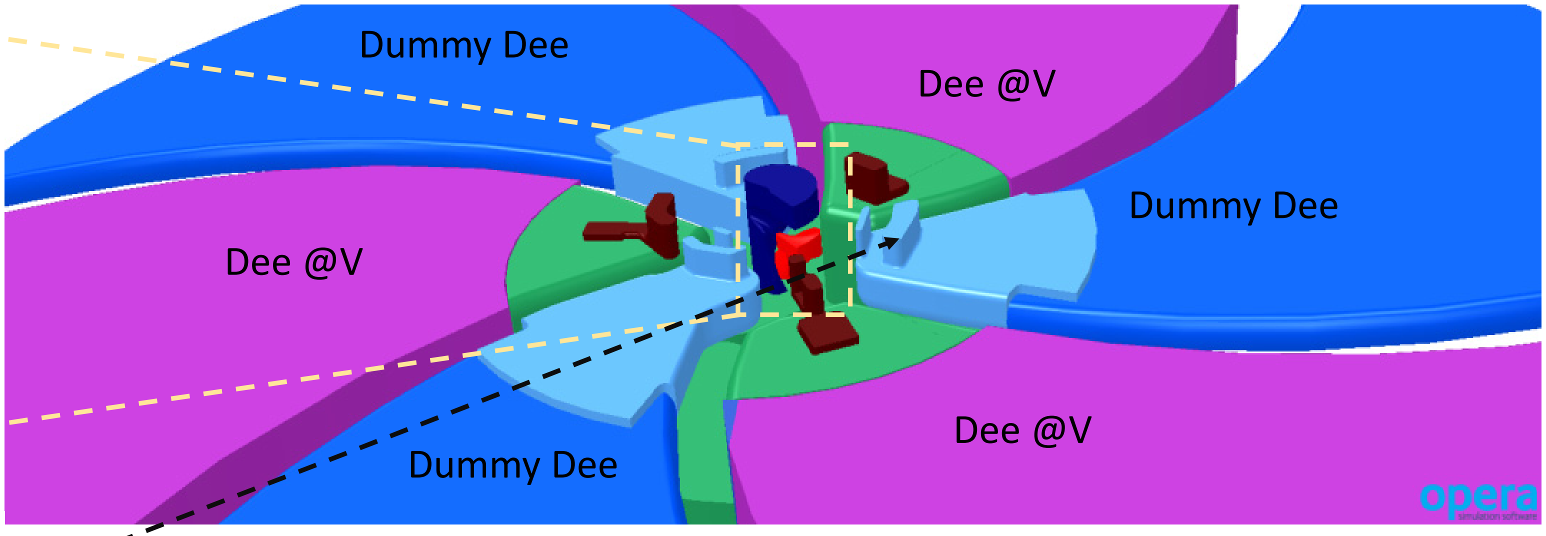
Today efficiency extraction through the electrostatic deflectors ε ≈ 50 %

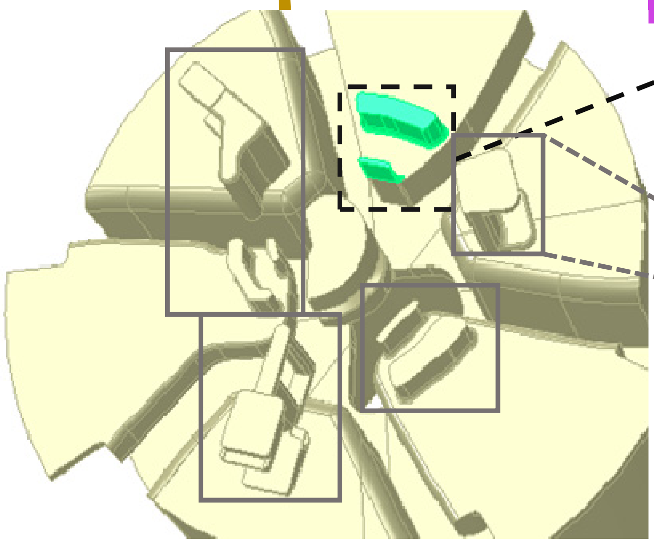
Only 100 Watt is the power that can be lost inside the cyclotron→ max extracted power 100 Watt

CS CENTRAL REGION

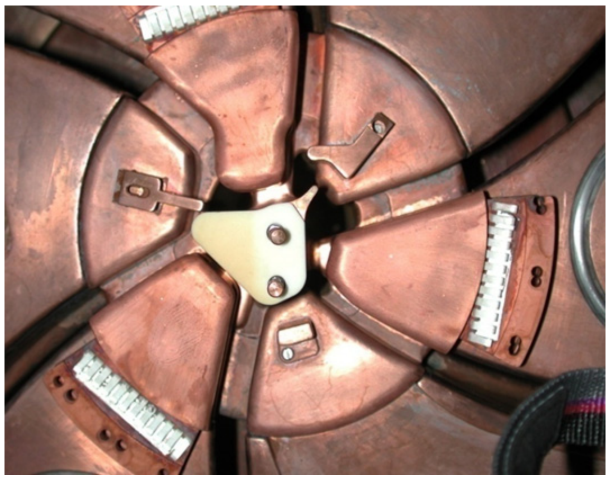
Spiral inflector







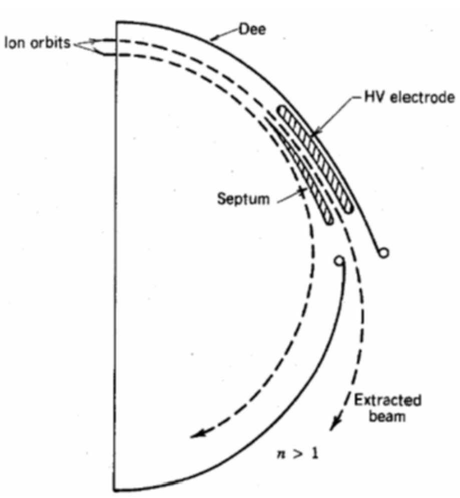
Post:
To clean halos and select phases

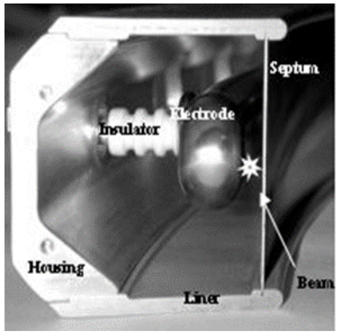


New spiral inflector and central region design planned. Anyway, the improvements are not enough (x2 bp) to satisfy NUMEN requirements: new extraction mode

With the courtesy of G. d'Agostino

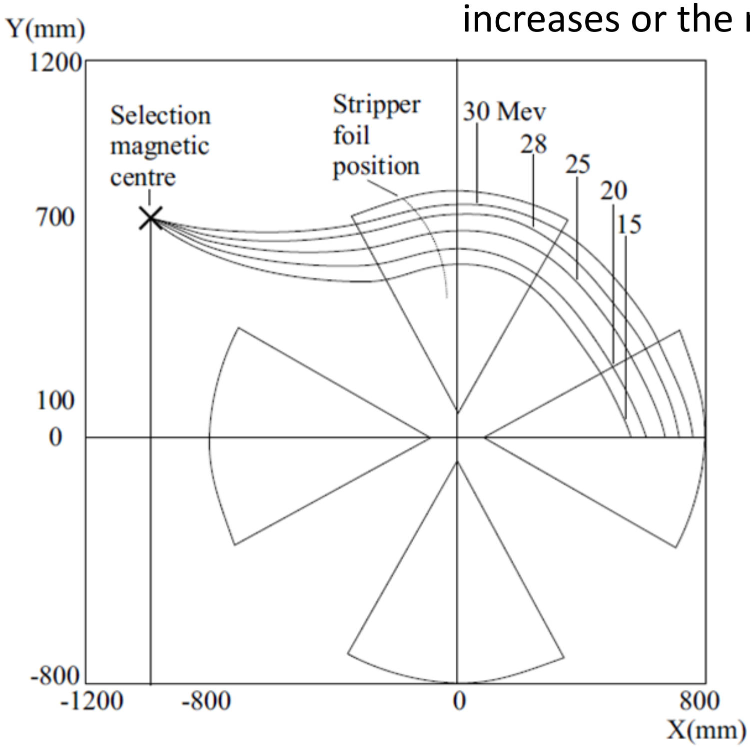
WHAT IS STRIPPING EXTRACTION?



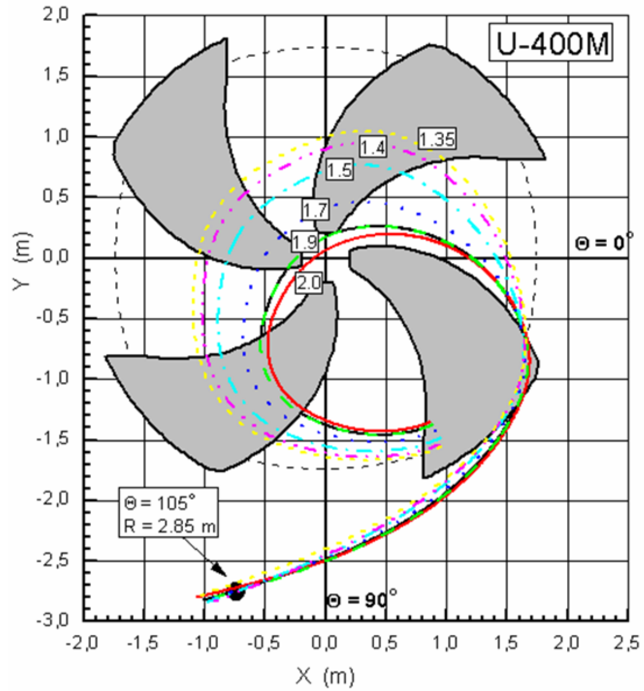


CS existing extraction

Stripping Extraction :
magnetic rigidity changes after the stripper foil (carbon) since the charge state increases or the masses decrease



$\boldsymbol{H^-}$ IBA Cyclone 30.



Dubna U-400M, positive ions before and after the stripper

WHY STRIPPING EXTRACTION?

Carbon	**E = 15 MeV/u**	**F(4) = 1.74e-7**	**F(5) = 8.35e-4**	**F(6) = 0.99917**
	E = 20MeV/u	**F(4) = 2.56e-8**	**F(5) = 3.20e-4**	**F(6) = 0.99968**
Oxigen	E=15 MeV/u	F(6) = 2.48e-6	F(7) = 3.14e-3	F(8) = 0.9969
	E= 20 MeV/u	F(6) = 4.18e-7	F(7) = 1.29e-3	F(8) = 0.9987
	E = 30 MeV/u	F(6) = 3.50e-8	F(7) = 3.74e-4	F(8) = 0.99963
Neon	E = 15 MeV/u	F(8) = 2.00e-5	F(9) = 8.90e-3	F(10) = 0.9911
	E =20MeV/u	F(8) = 2.66e-6	F(9) = 3.26e-3	F(10) = 0.9967
	E = 30 MeV/u	F(8) = 2.26e-7	F(9) = 9.51e-4	F(10) = 0.9991

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

For light ions at these energies the percentage of **q=Z after the stripper >99%**

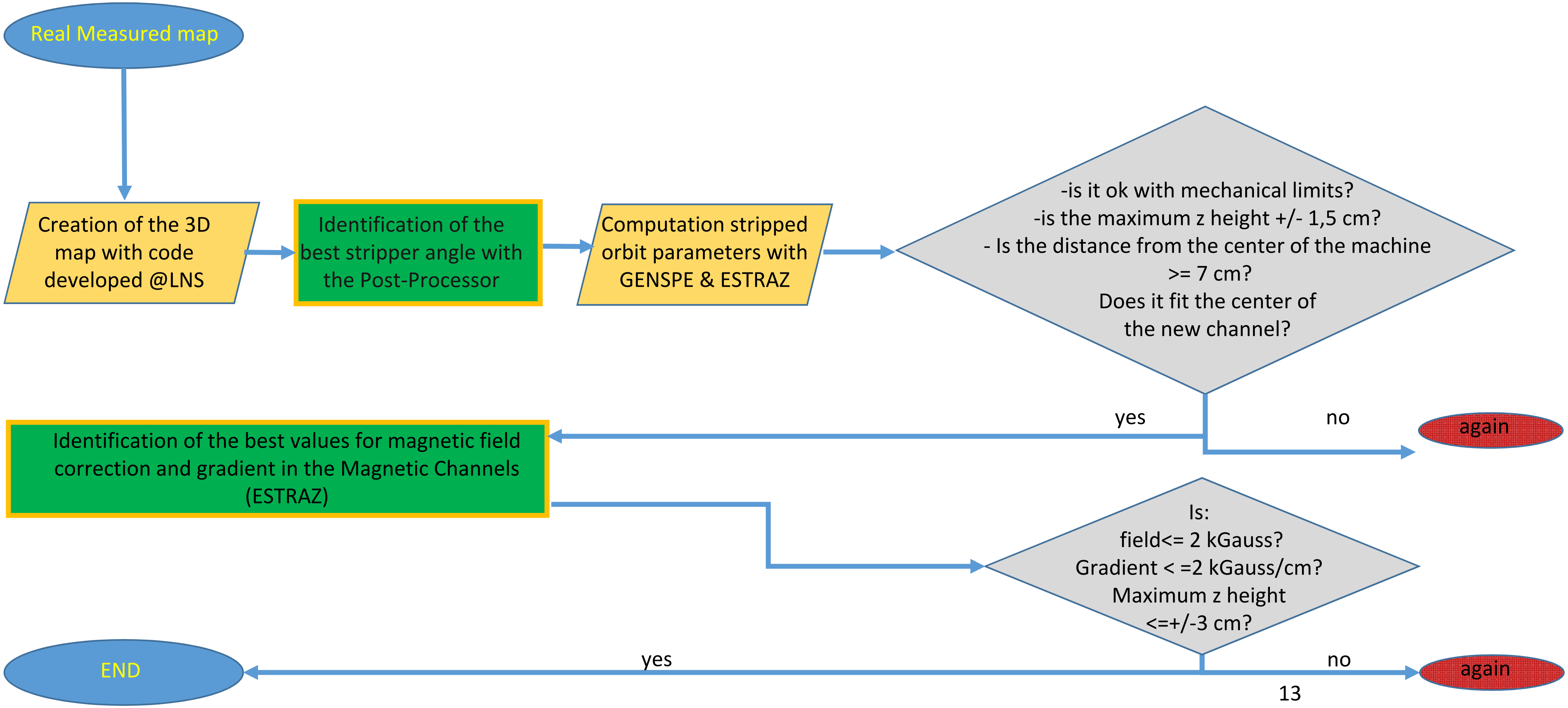
Expected extraction efficiency 99%

EXPECTED BEAMS

Ion	Energy	Isource	Iacc	Iextr	Iextr	Pextr
	MeV/u	eμA	eμA	eμA	pps	watt
^{12}C q=4+	18	400	60 (4+)	90 (6+)	$9.4 \cdot 10^{13}$	3240
^{12}C q=5+	30	200	30 (4+)	45 (6+)	$4.7 \cdot 10^{13}$	2700
^{12}C q=4+	45	400	60 (4+)	90 (6+)	$9.4 \cdot 10^{13}$	8100
^{12}C q=4+	60	400	60 (4+)	90 (6+)	$9.4 \cdot 10^{13}$	10800
^{18}O q=6+	20	400	60 (6+)	80 (8+)	$6.2 \cdot 10^{13}$	3600
^{18}O q=6+	29	400	60 (6+)	80 (8+)	$6.2 \cdot 10^{13}$	5220
^{18}O q=6+	45	400	60 (6+)	80 (8+)	$6.2 \cdot 10^{13}$	8100
^{18}O q=6+	60	400	60 (6+)	80 (8+)	$6.2 \cdot 10^{13}$	10800
^{18}O q=7+	70	200	30 (7+)	34.3 (8+)	$2.7 \cdot 10^{13}$	5400
^{20}Ne q=4+	15	600	90 (4+)	223 (10+)	$1.4 \cdot 10^{14}$	6690
^{20}Ne q=7+	28	400	60 (7+)	85.7 (10+)	$5.3 \cdot 10^{13}$	4800
^{20}Ne q=7+	60	400	60 (7+)	85.7 (10+)	$5.3 \cdot 10^{13}$	10280

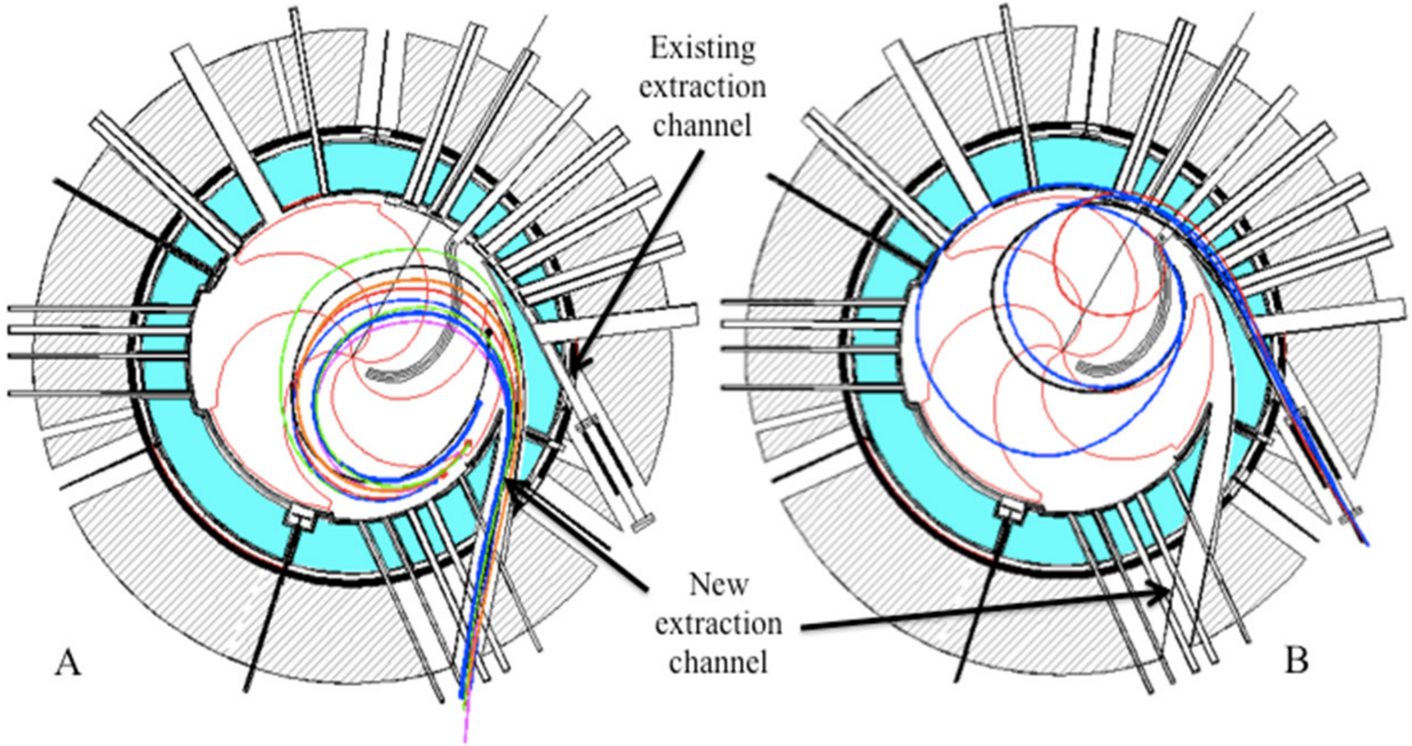
New Power up to 10 kWatt!

FAESABILITY STUDY PROCEDURE



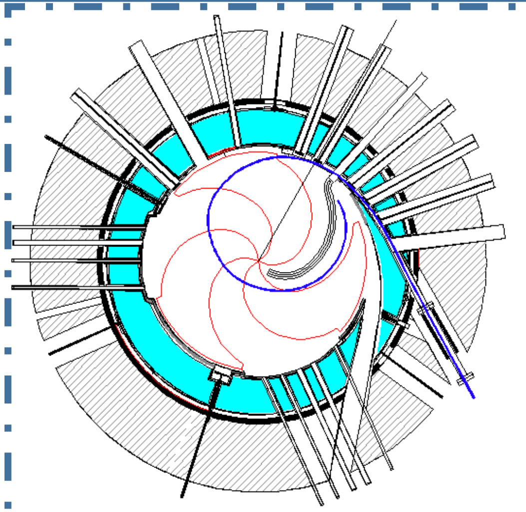
2 EXTRACTION CHANNELS

Overview of all extraction orbits: a new extraction channel, 30 deg away simplify the extraction system for a lot of ions. That means smaller radial and axial enveloppes and less and weaker magnetic corrections needed

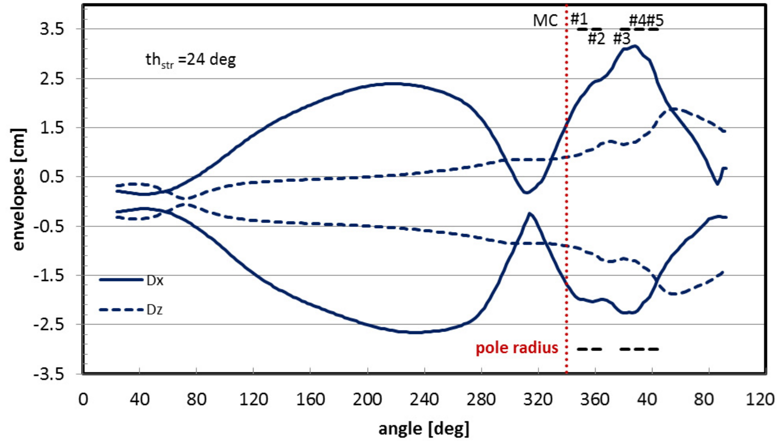


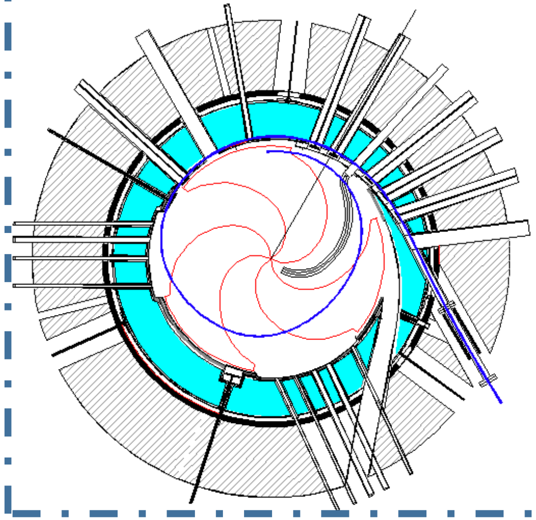
RADIAL AND AXIAL ENVELOPPES INCLUDING ENERGY SPREAD

*2 examples of extraction through the **OLD EXTRACTION CHANNEL**: Up to 8 Magnetic channels after the pole radius needed.*

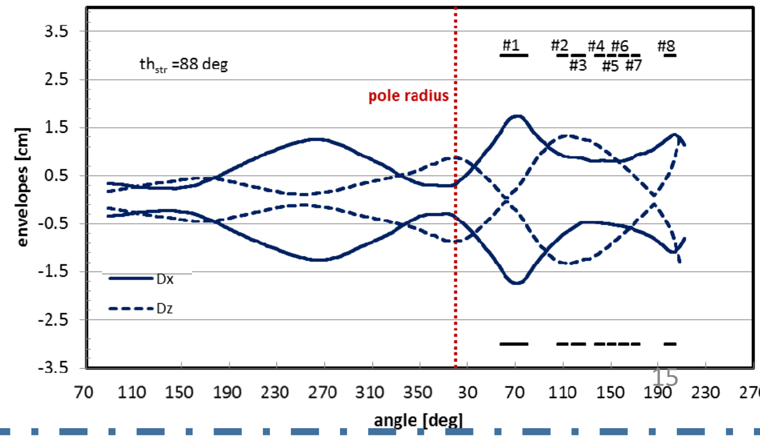


12 Carbon 18 A MeV q=+4 -> q=+6
energy spread 3‰

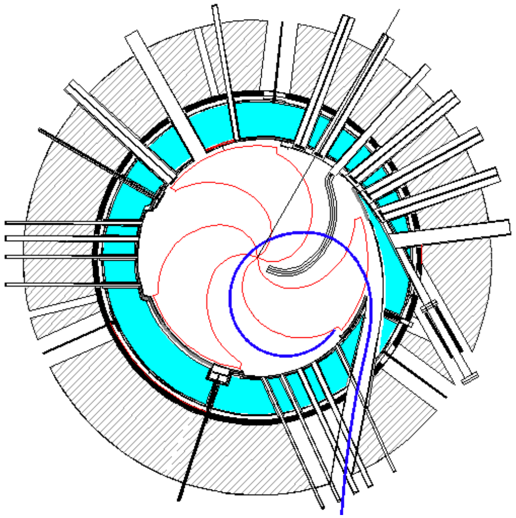




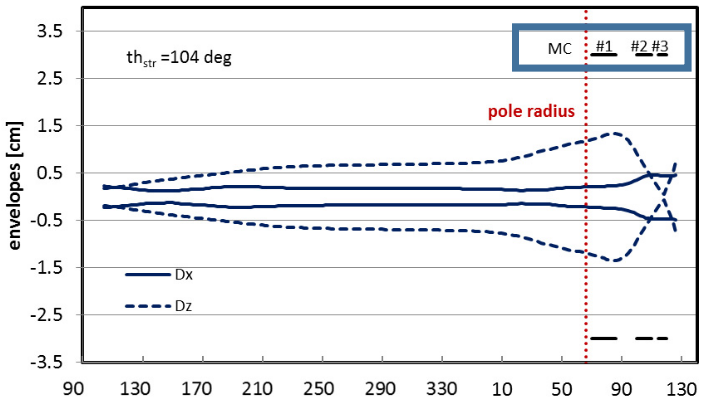
18 Oxygen 70 A MeV q=+6 -> q=+8
energy spread 5‰

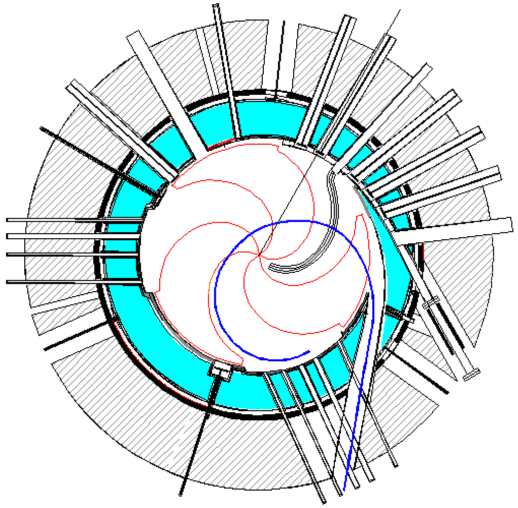


RADIAL AND AXIAL ENVELOPPES INCLUDING ENERGY SPREAD

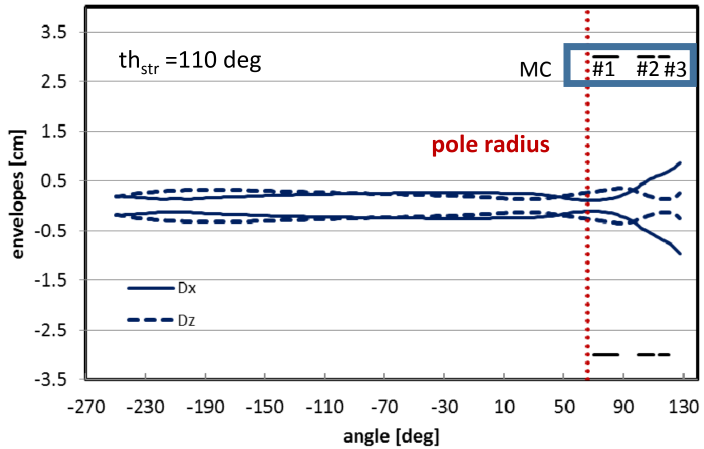


12Carbon 45 A MeV q=+4 -> q=+6
energy spread 3‰

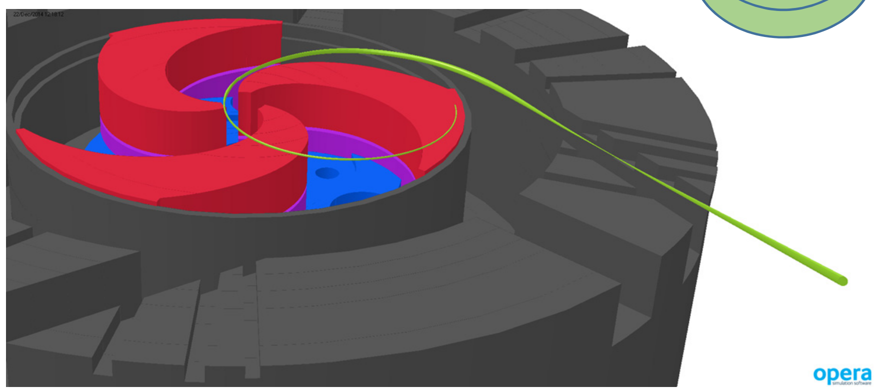




20 Neon 60 A MeV q=+7-> q=+10
energy spread 2‰



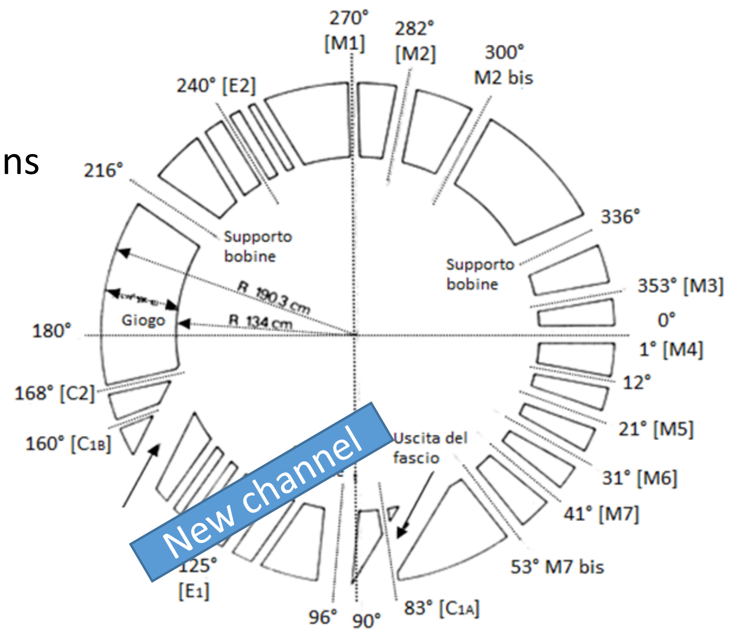
2 examples of extraction through the ***NEW EXTRACTION CHANNEL****: 3 Magnetic channels after the pole radius are enough*

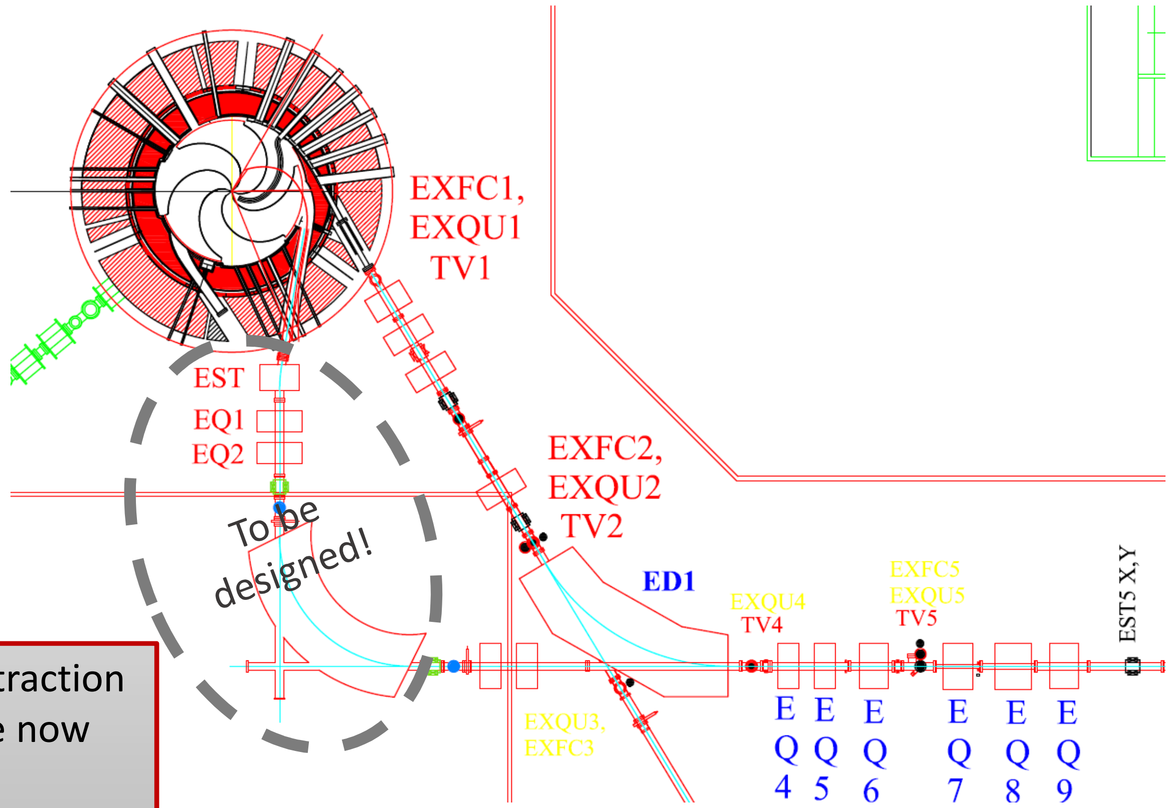


FURHER CONSIDERATIONS

More studies are on going and both solutions are under investigation.
The new channel is definitely more appealing from a beam envelope point of view, but the mechanical constraints and modifications to the yoke and to all systems just outside the yoke are important and need to be carefully evaluated

All actual yoke penetrations

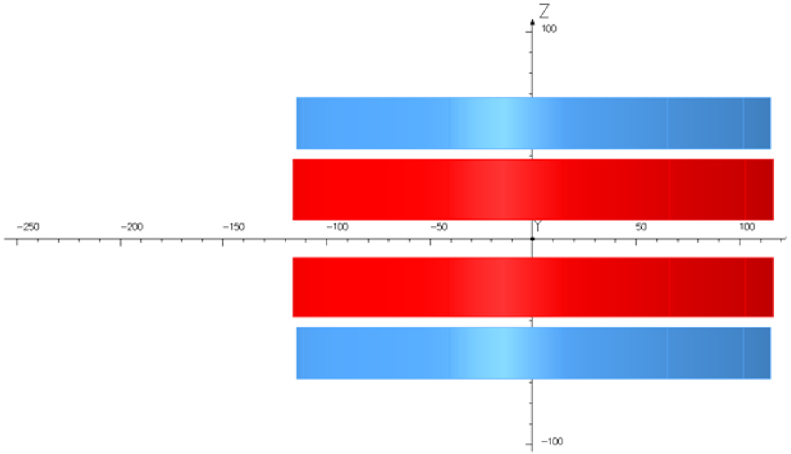


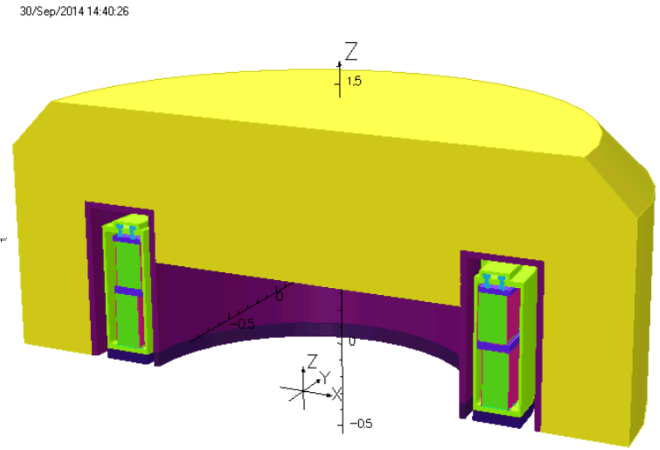


With the new beam powers, the cross-section of the 2 extraction channels has to be broadened respect to the one we have now and a cooling system has to be designed.

A NEW CRYOSTAT IS MANDATORY IN ANYCASE

FIRST CONCEPTUAL DESIGN OF THE NEW CRYOSTAT

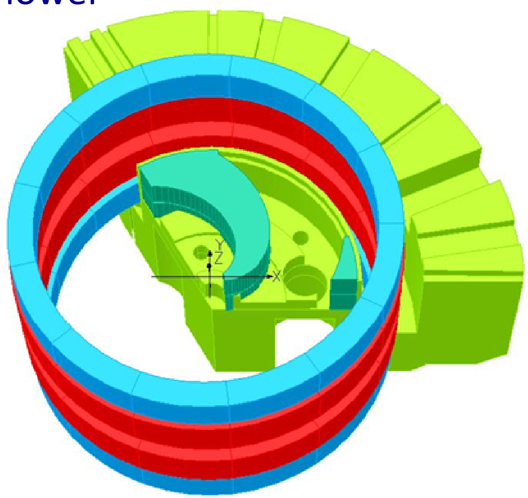




Specifications

- Form factor equal to the actual in 0,1%
- Broaden the cross-section of the extraction channel
- Nitrogen and helium consumption lower than the actual ones
- Magnetic, thermic and structural computation
- Cost estimation

MIT CONCLUSION: Feasible



CONCLUSIONS

- Feasibility study of beam extraction → **OK (LNS)**
- Preliminary study of the new cryostat → **OK (MIT)**
- Detailed forecast of costs and time schedule for the full upgrade → **on going (AS-G + LNS)**
- 3D design of the actual central region and the CS magnetic circuit → **OK (LNS)**
- New design of the spiral inflector, central region and new extraction line→ **on going (LNS)**

To reach few kWatt of beam extracted power from the CS is feasible