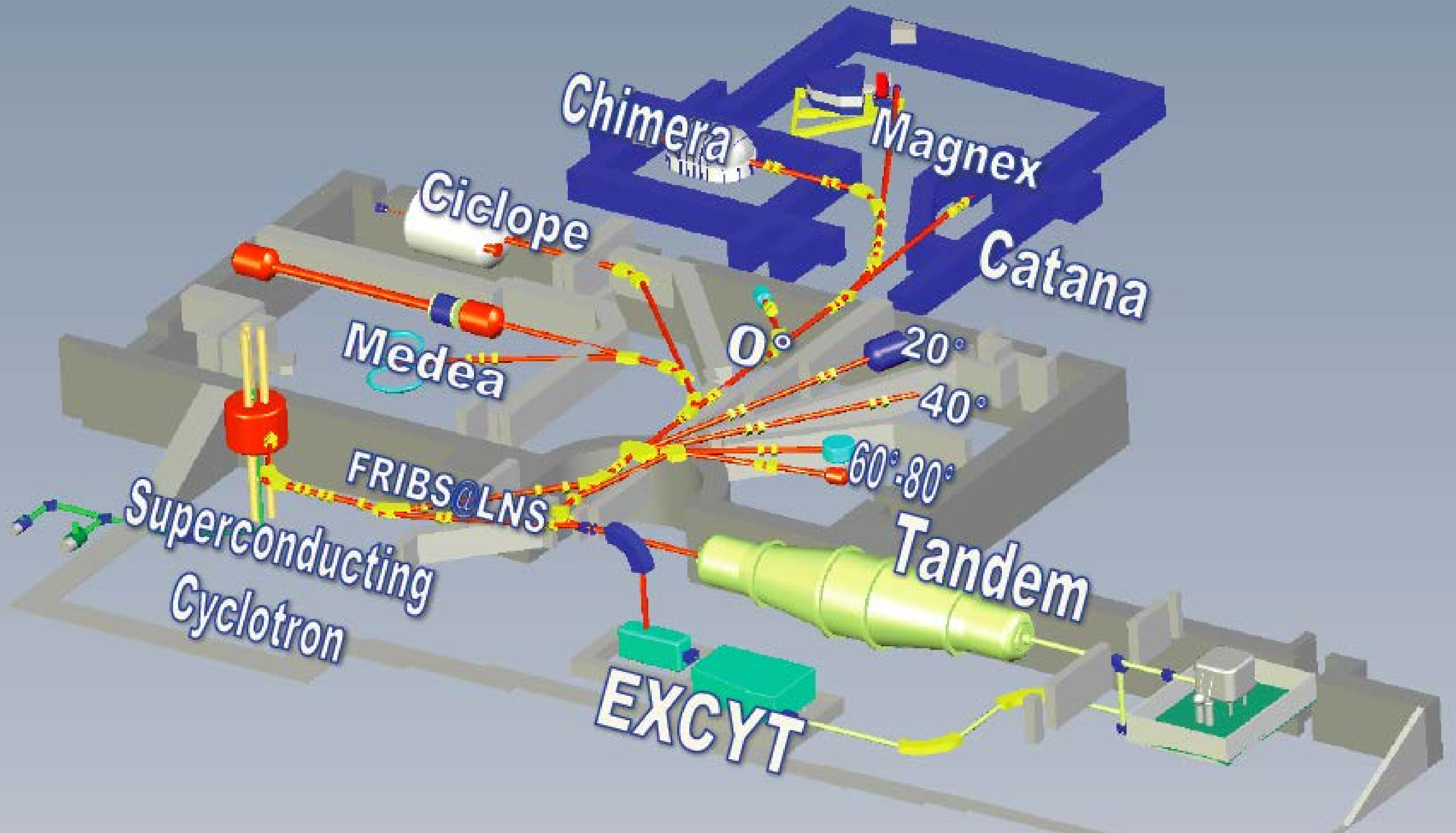
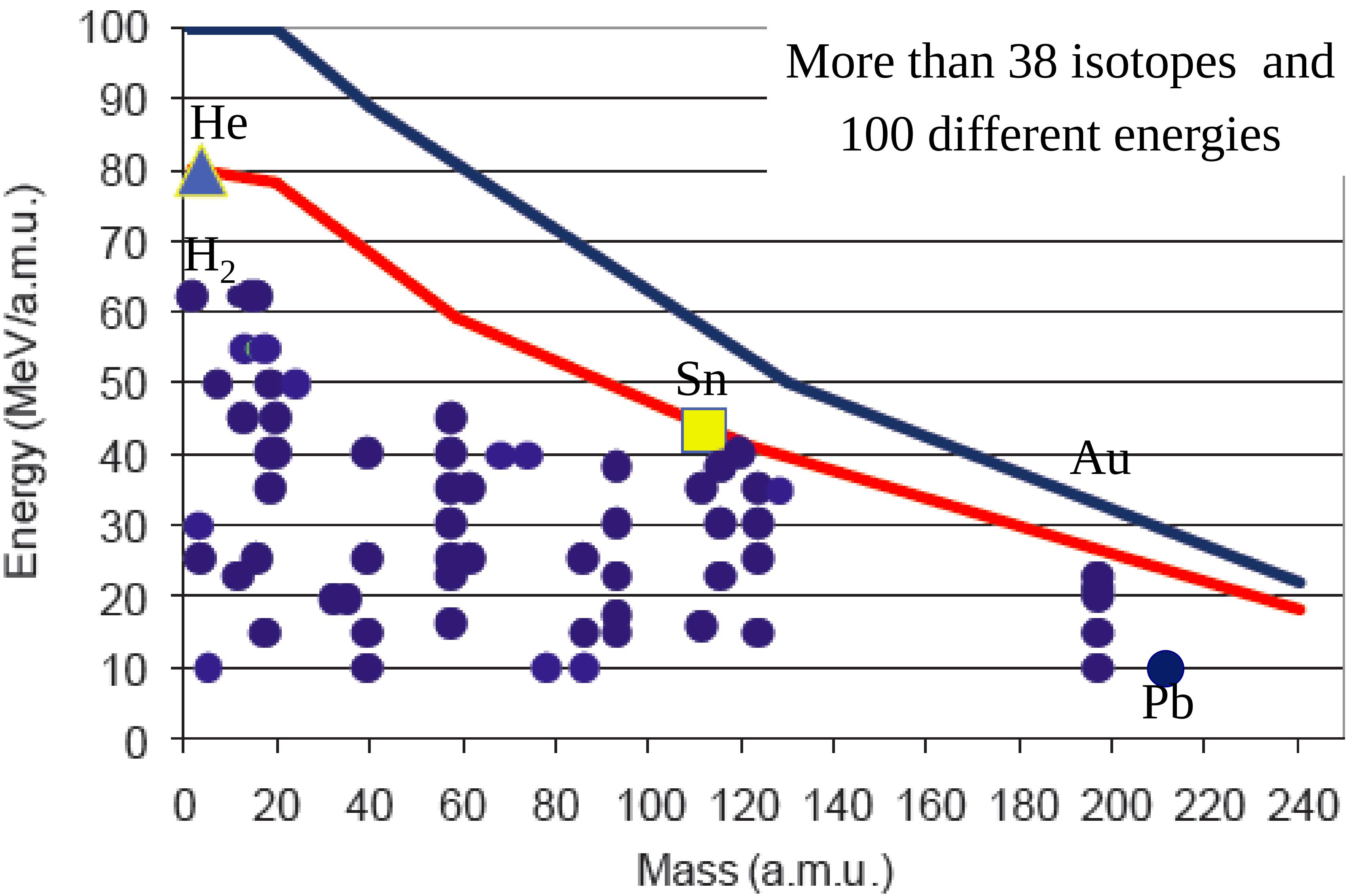
Refurbishing and Upgrading of LNS Superconducting Cyclotron or Production of Intense Light Ion Beams for NUMEN Experiment

Luciano Calabretta
On behalf of LNS

Accelerators room and Experimenthal area of LNS - Catania



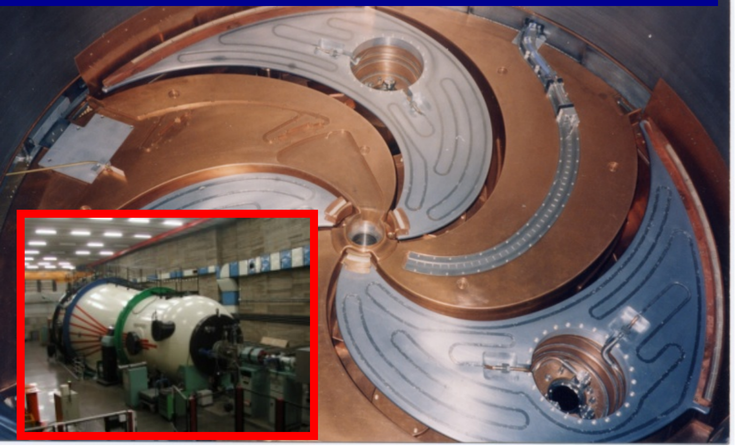
Beams delivered by Cyclotron

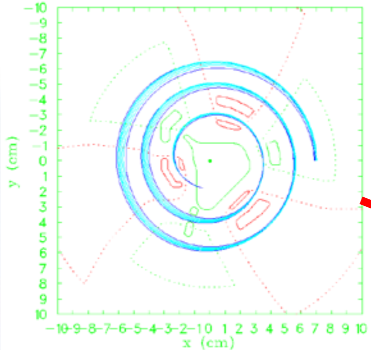


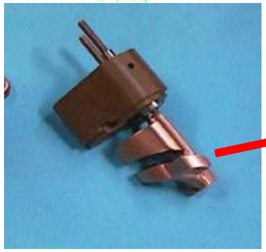
Cyclotron improvement and increased intensity

Axial injection allowed to simplify the operation and increase also the intensity

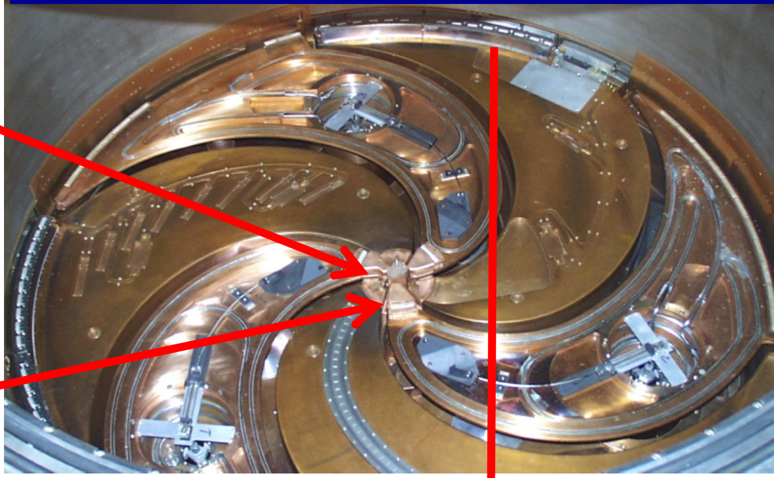
1994 – CS as Tandem booster



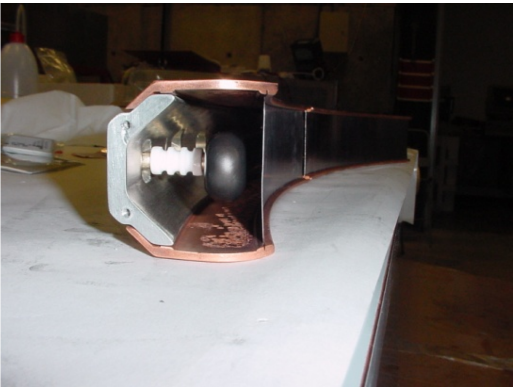




2000 – Stand alone



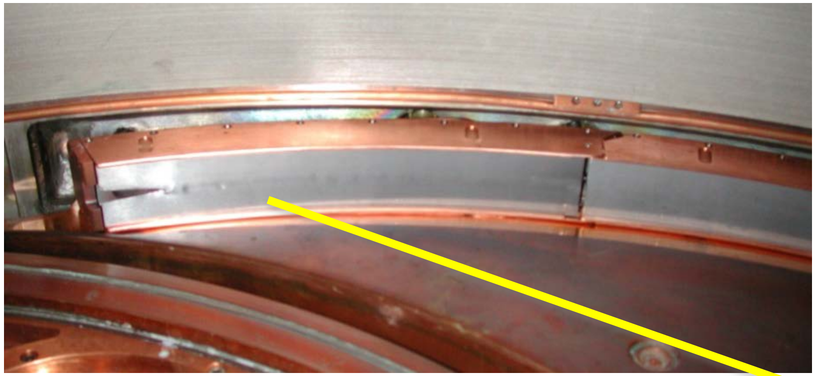
A consequence of cyclotron compactness is the low efficiency of extraction process: ε ≈50%



Separation among the turns at extraction

$$\Delta R = R \cdot (\Delta E/E) \cdot (1/\nu_r^2) \cdot \gamma/(\gamma+1)$$

Cyclotron improvement and increased intensity



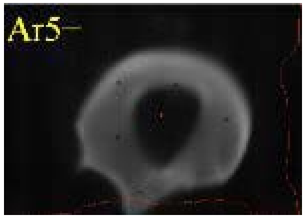
Septum: direct cooling

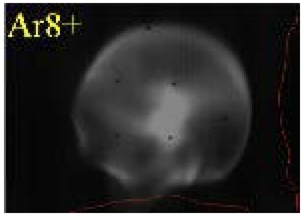
Septum new material: W vs. Ta

Double thickness: 0.3 vs. 0.15 mm

⇨Extraction efficiency 63% vs. 50%

$^{13}C^{4+}$ @ 45 AMeV
Pextr = 150 watt I=1020 enA=
$1.5x10^{12}$ pps



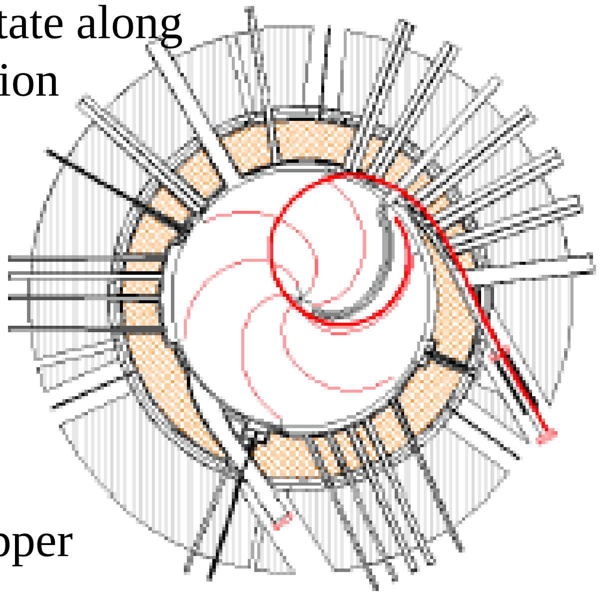


We need to increase the efficiency of sources and also of the source-cyclotron matching.

Beam injection line optic is studied according to the method used at MSU, JYFL, and KVI and will be updated

Stripping extraction allow to achieve high efficiency > 99%

Charge state along acceleration
q=Z-2



after stripper
q=Z

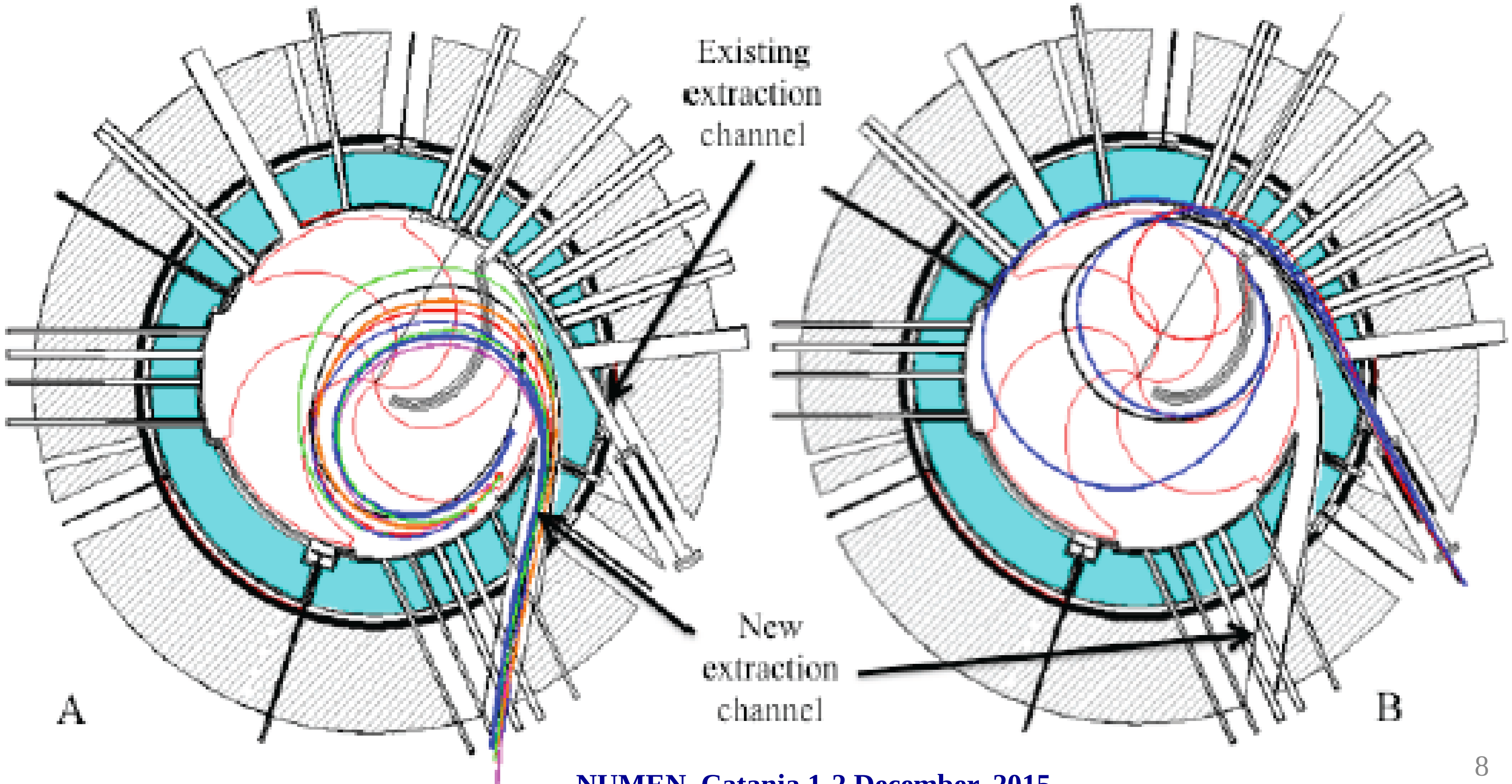
Stripping extraction consists to increase the charge states of the accelerated beam of 1, 2 or more units crossing through a thin stripper foil. Then the beam magnetic rigidity is suddenly reduced and the beam trajectory escape the cyclotron pole region!

Expected beam intensity for the simulated light ions

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

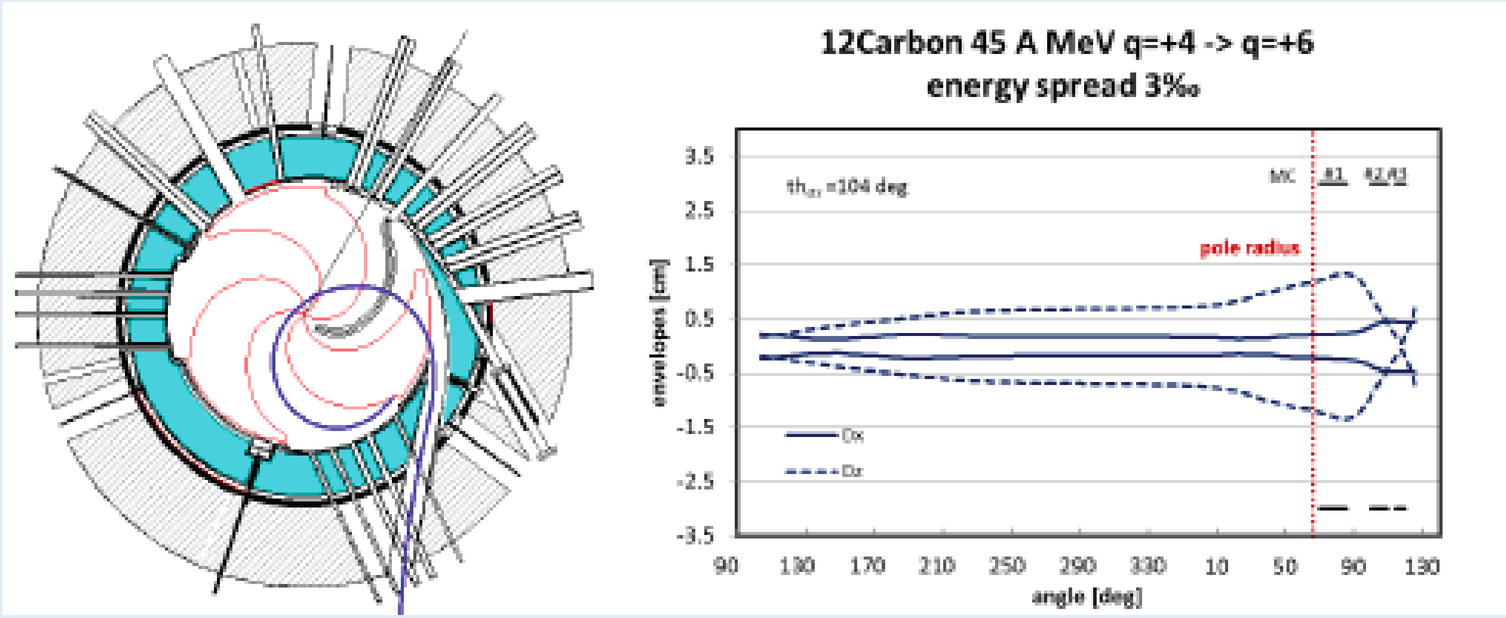
Feasibility of stripping extraction

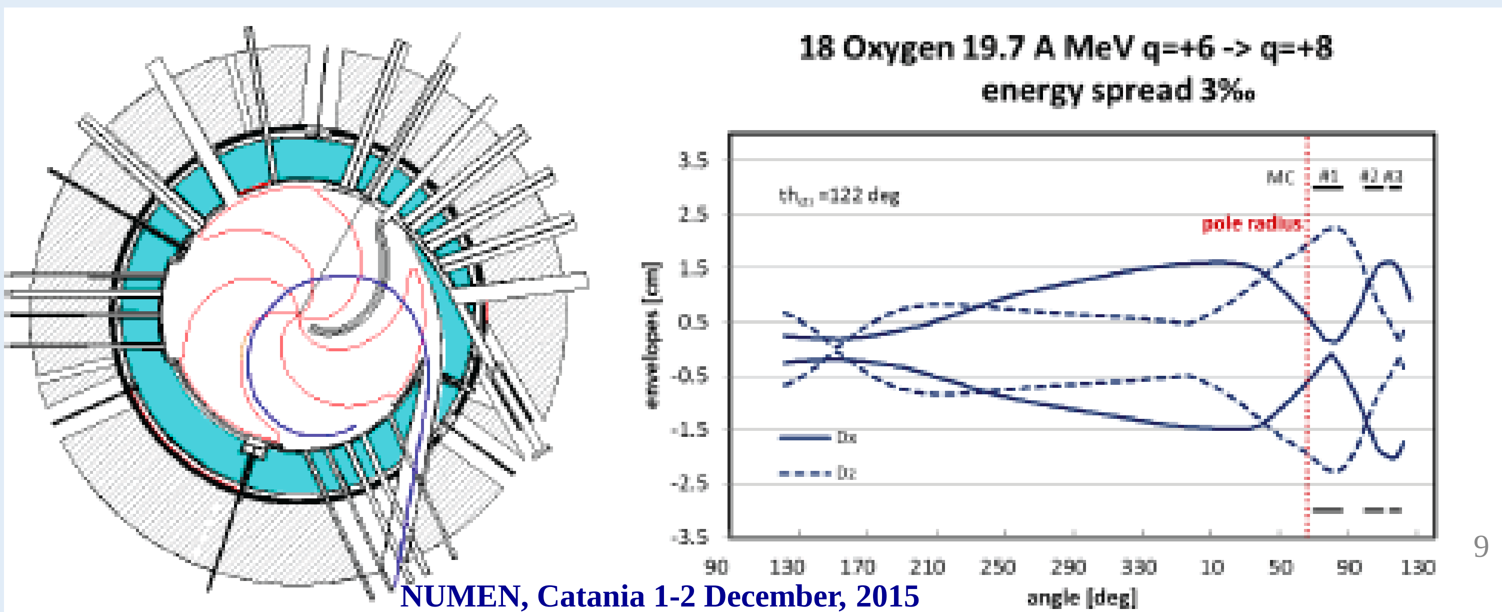
Unfortunately the beam dynamic simulations shown that only for few cases is possible to match the extraction trajectories produced by stripper with the existing extraction channel, but in these case the beams sizes are a bit too large!
Better solution is possible if stripped trajectories come out through a new one extraction channel!



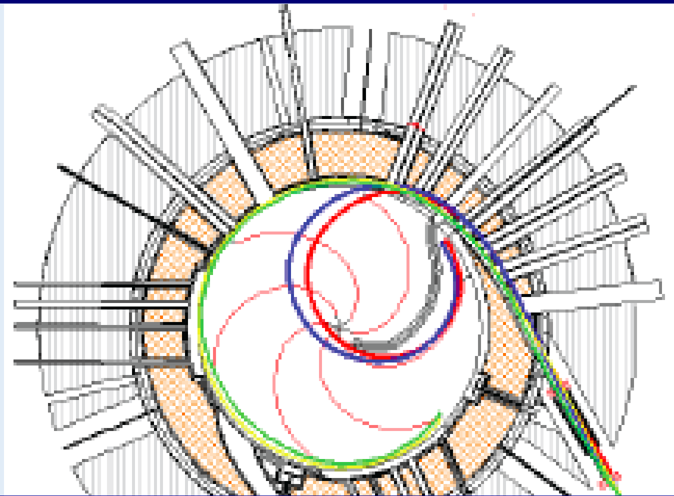
Radial and axial beam envelope along the extraction trajectories

New Chanel





Change to the cryostat and magnet of LNS cyclotron



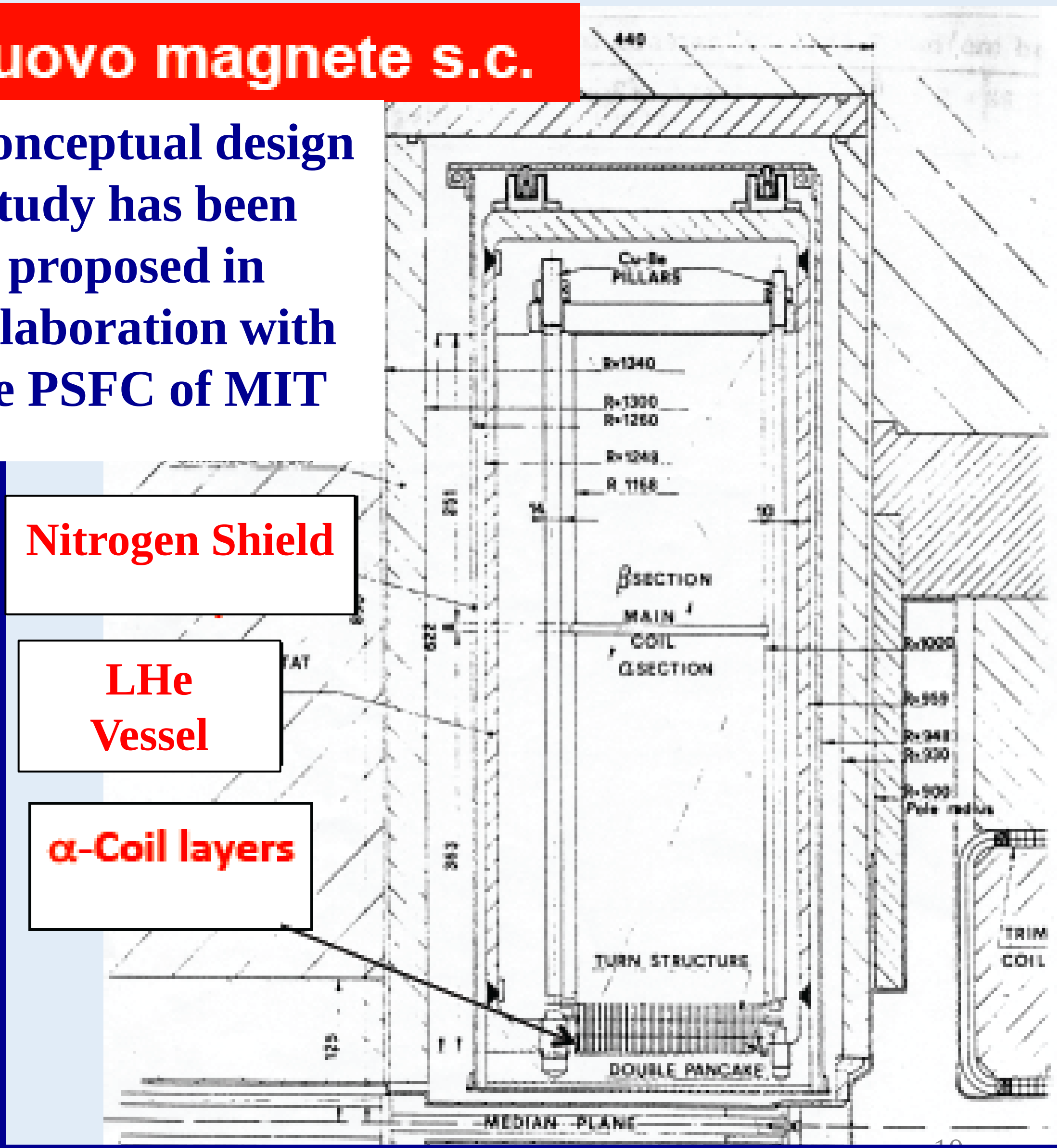
Nuovo magnete s.c.

A conceptual design study has been proposed in collaboration with the PSFC of MIT

To extract the beam we need:
Increase the vertical gap of the acceleration chamber and mainly of the extraction channel 24 →30 mm!

Remove the vertical tie rods to increase the room between the LHe vessel and the room temperature wall of the cryostat!

Drill a new channel

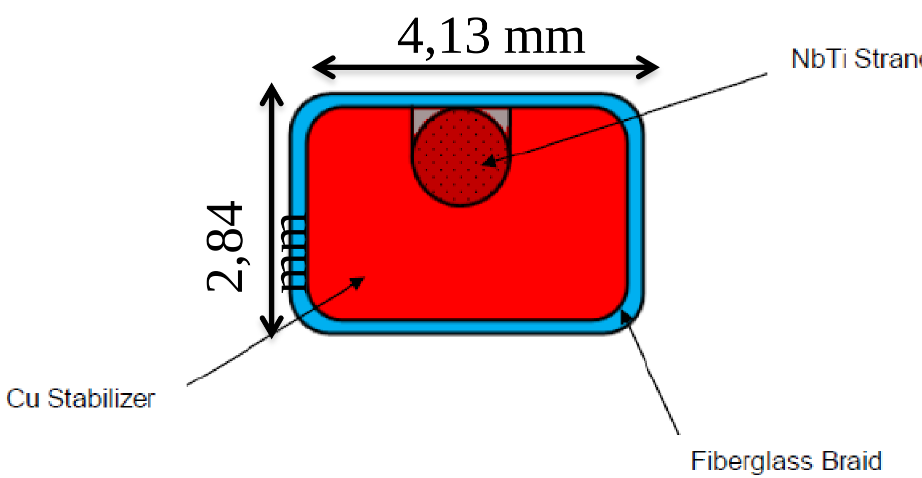


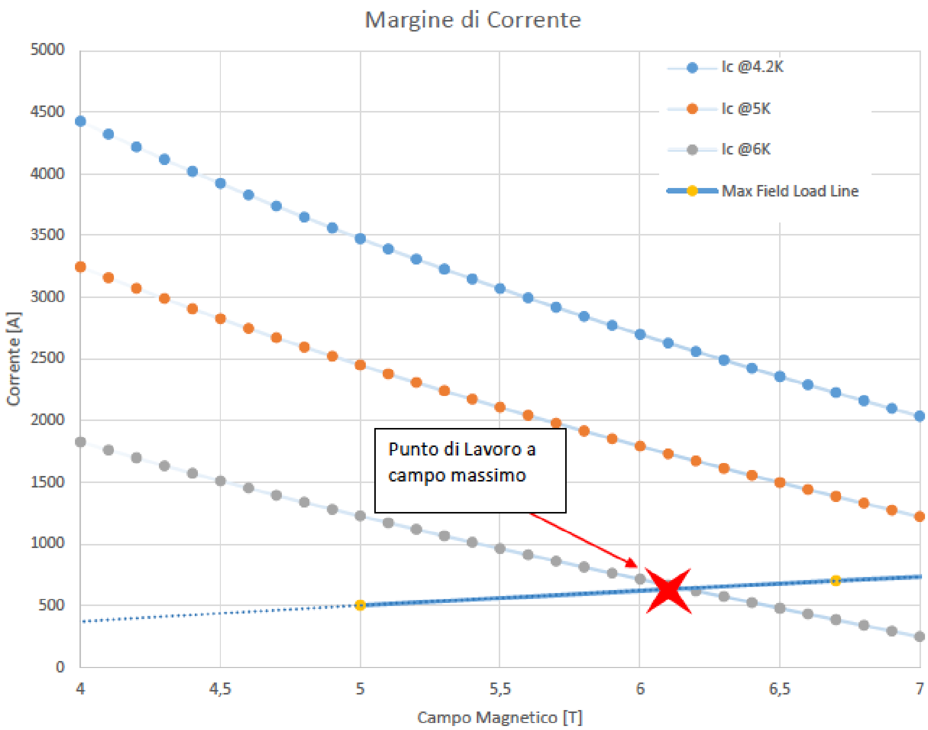
A preliminary engineering design for the new magnet and cryostat has been done by ASG. The main difference respect to the previous study of PSFC (MIT) is the size of the superconducting cable!

Layout	Wire-in-channel a singolo conduttore
Spessore cavo isolato [mm]	4.13
Altezza cavo isolato [mm]	2.84
Spessore cavo nudo [mm]	3.88
Altezza cavo nudo [mm]	2.59
Rapporto Cu/Sc	5.2
Diametro filamento [micron]	<= 156
RRR rame	80 – 100
Spessore treccia fiberglass [mm]	0.125

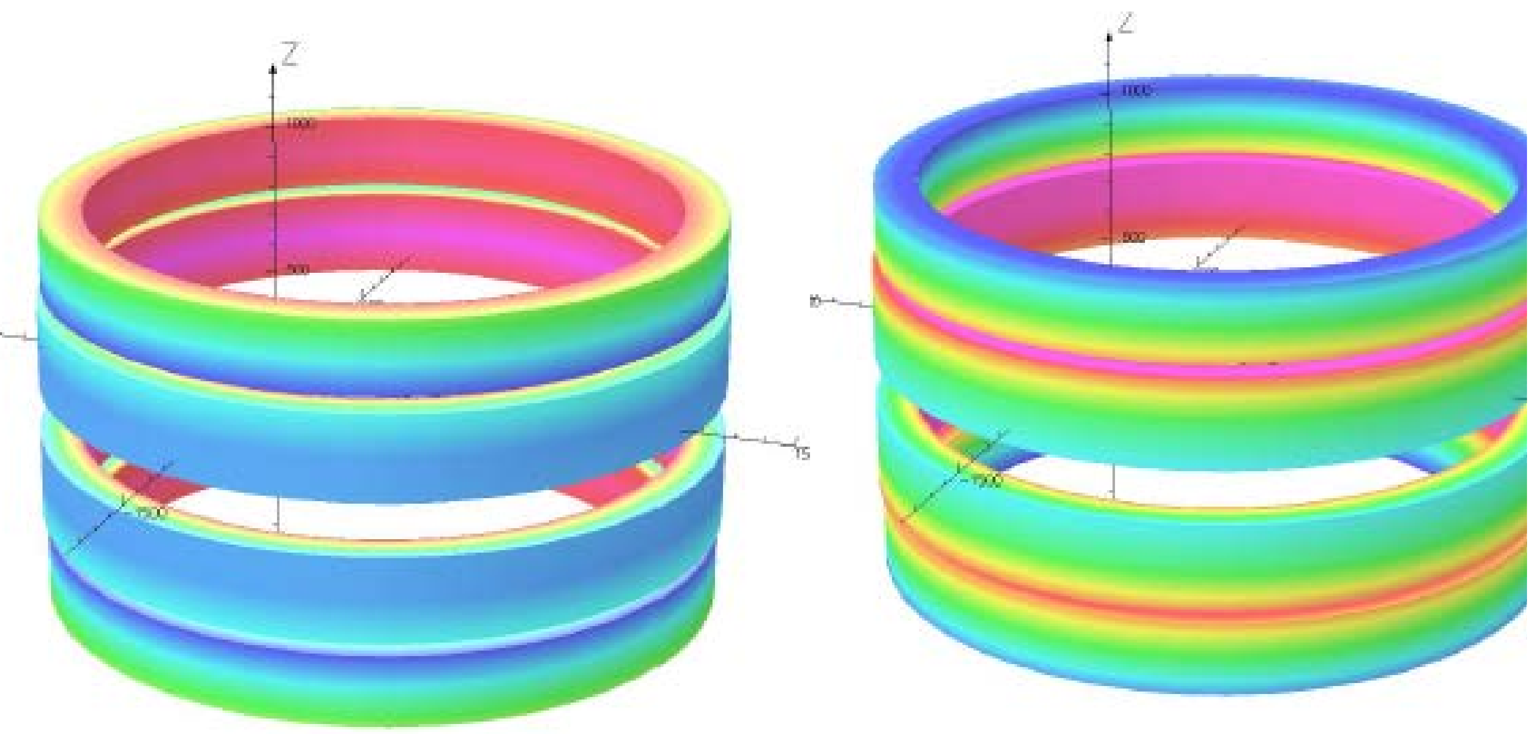
Tabella 3-1: Caratteristiche del conduttore.

Small cable, maximum current 670 A!

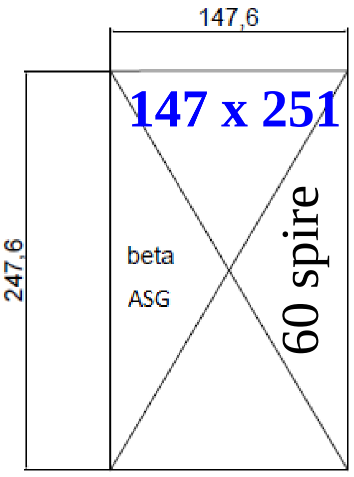


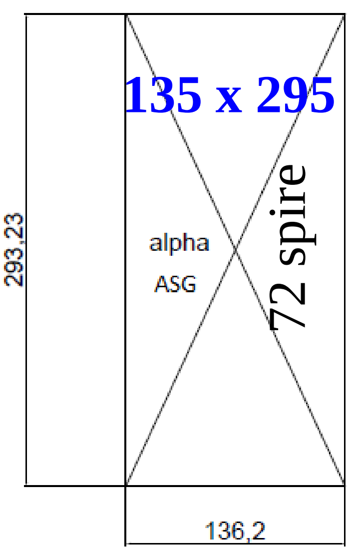


The Geometrical sizes of the new superconducting coil proposed by ASG is little different by the size of the coils proposed by the PSFC (MIT) but anyway the produced magnetic field have form factors very near to the originals, the differences stay below 0.1%!

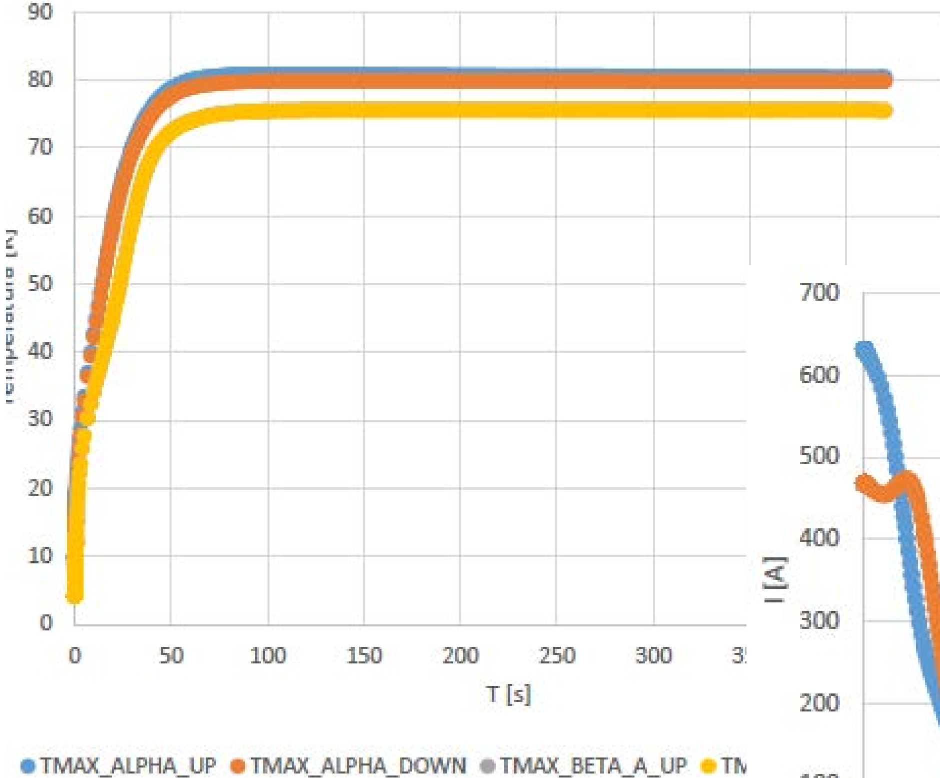


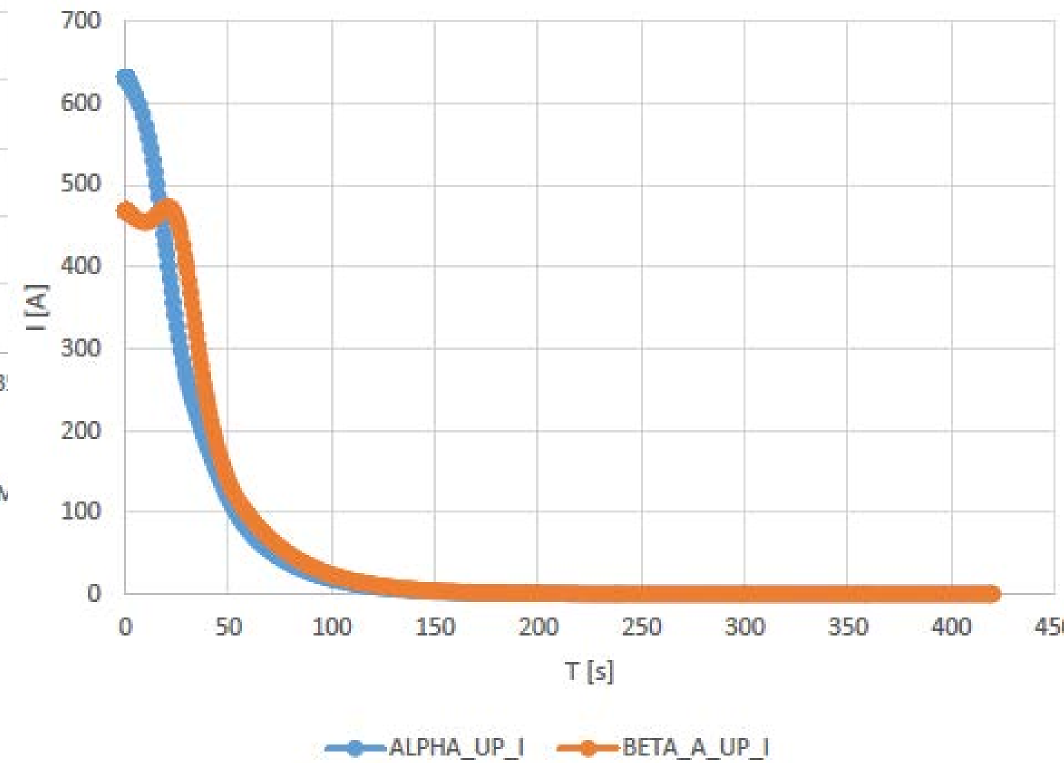
ura 4.4-6: Vista della distribuzione di campo sulle bobine rispettivamente nella modalità di funzion B, nella configurazione a "polo pieno".



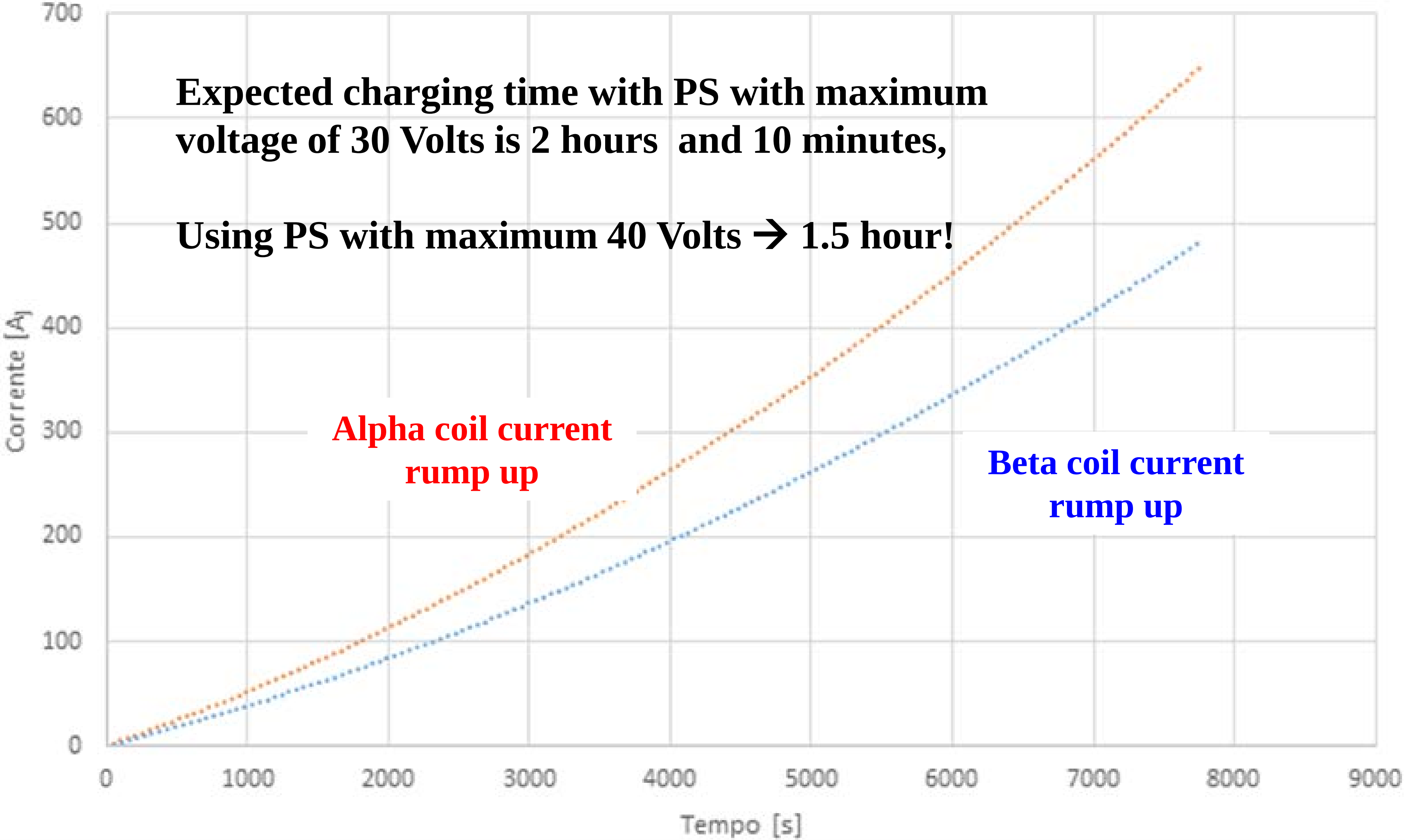


Coils are impregnated with epoxy, and maximum temperature of the coils in case of quench stay below 85 K!





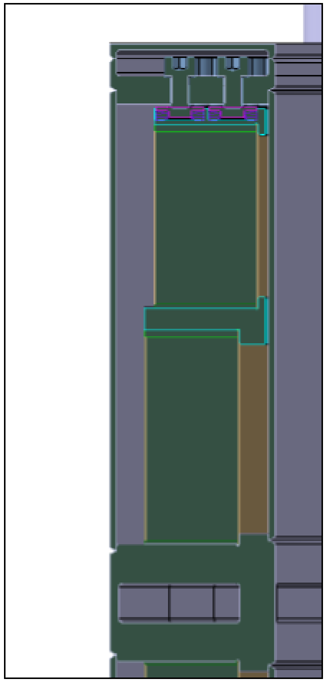
The use of a small cable with maximum current of 670 A, need to use a much longer cable.
The inductance is higher and this increase the rump-up time!

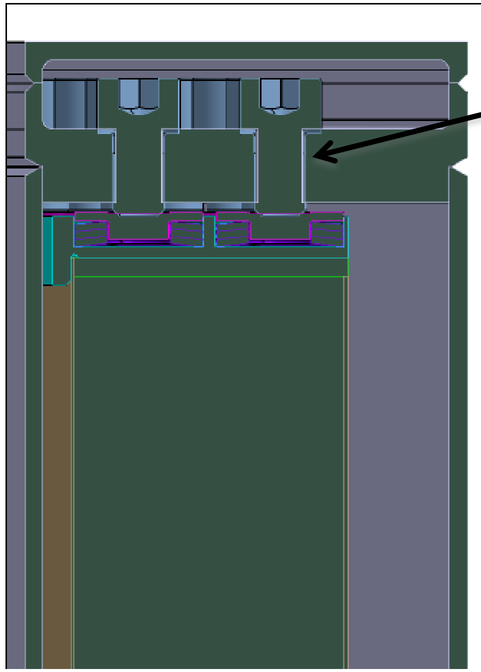


Expected charging time with PS with maximum voltage of 30 Volts is 2 hours and 10 minutes,

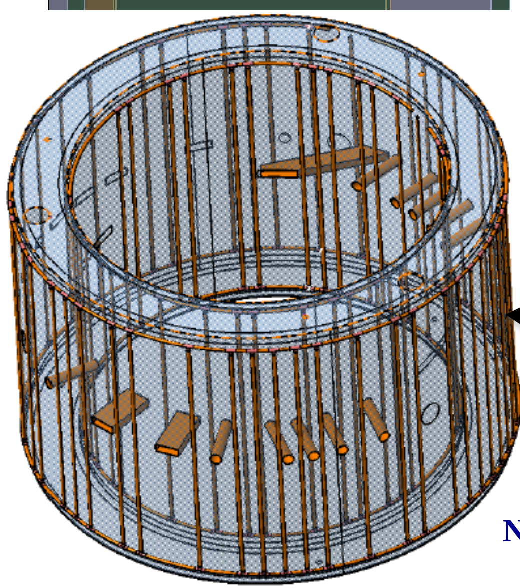
Using PS with maximum 40 Volts → 1.5 hour!

Technical details of the new cryostat





Preloading screw, that will replace the BeCu tie rods



The much more robust Liquid Nitrogen shield and the radial penetrations.

Stress analysis on the Lhe Vessel. Particular of the compression top flange.

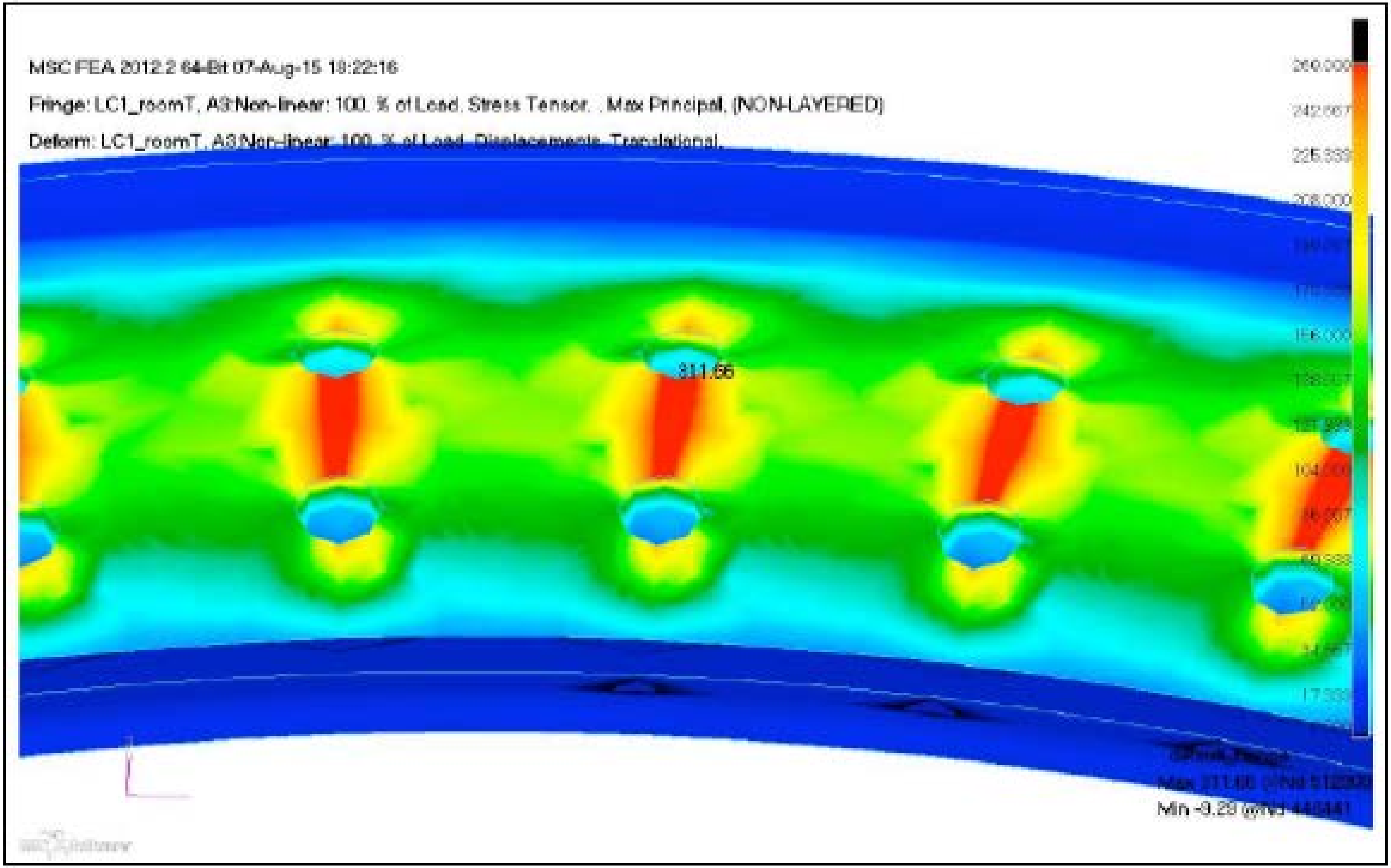
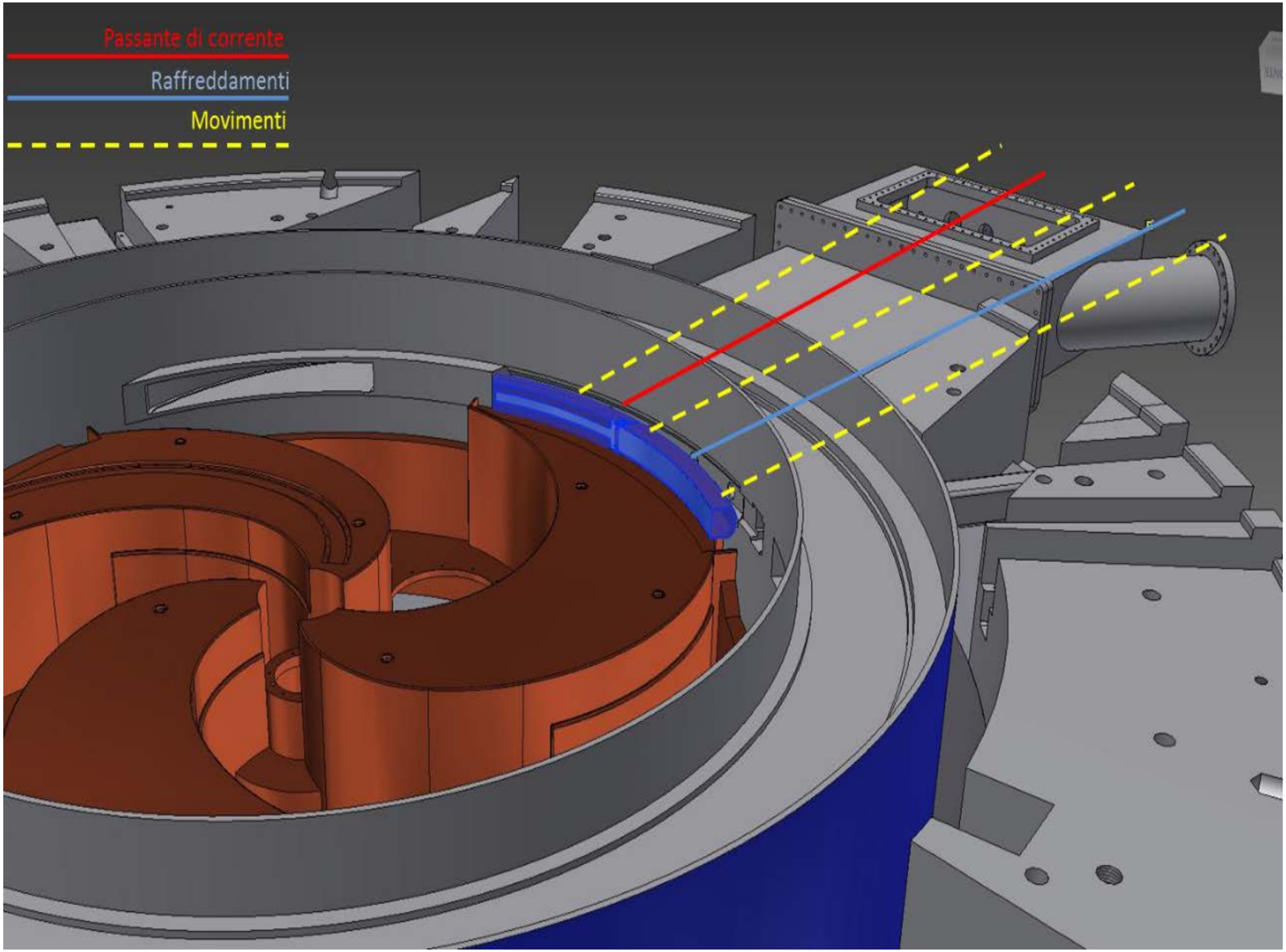
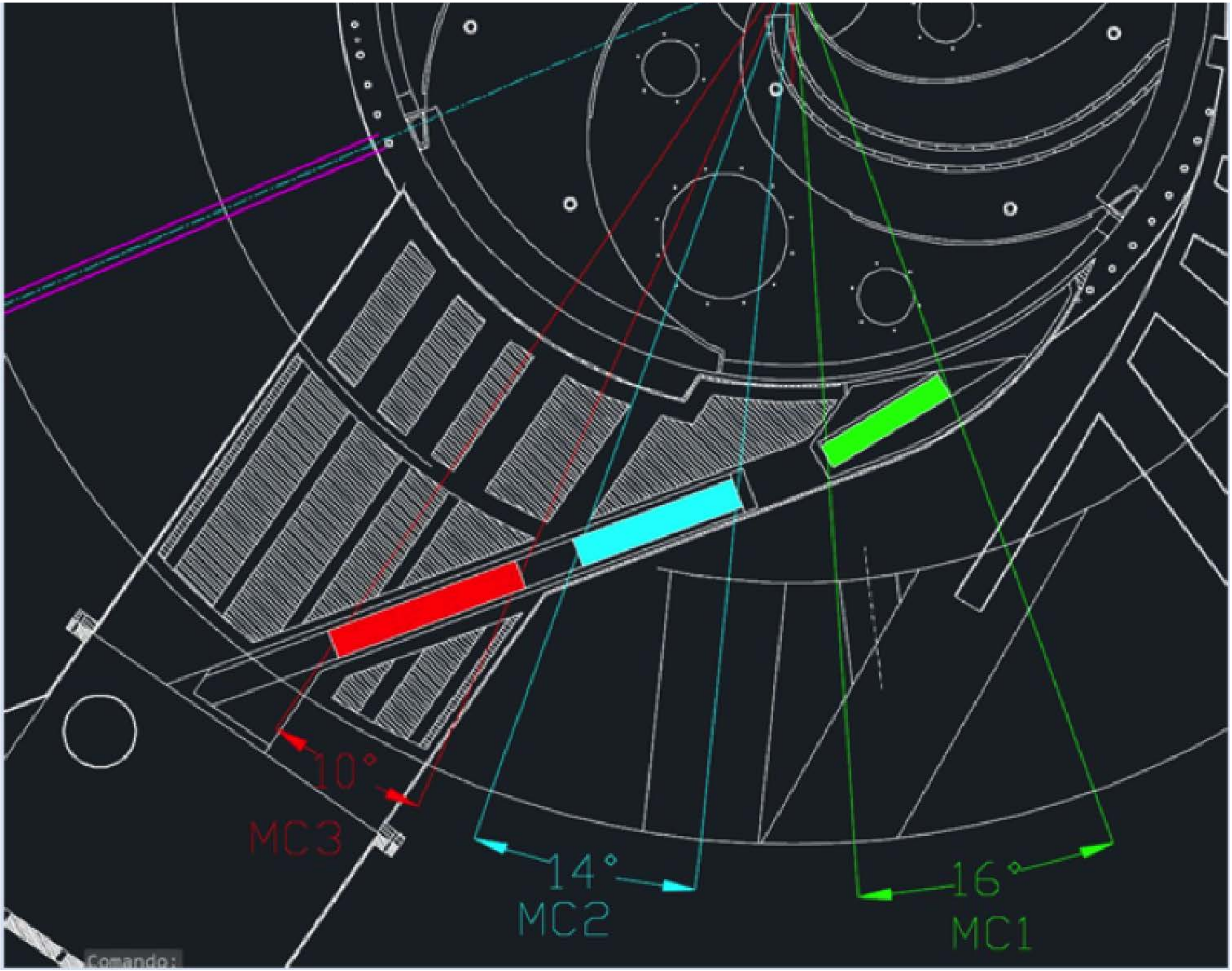


Figura 6.1-19: Flangia porta viti – sollecitazioni principali in LC1 [MPa].

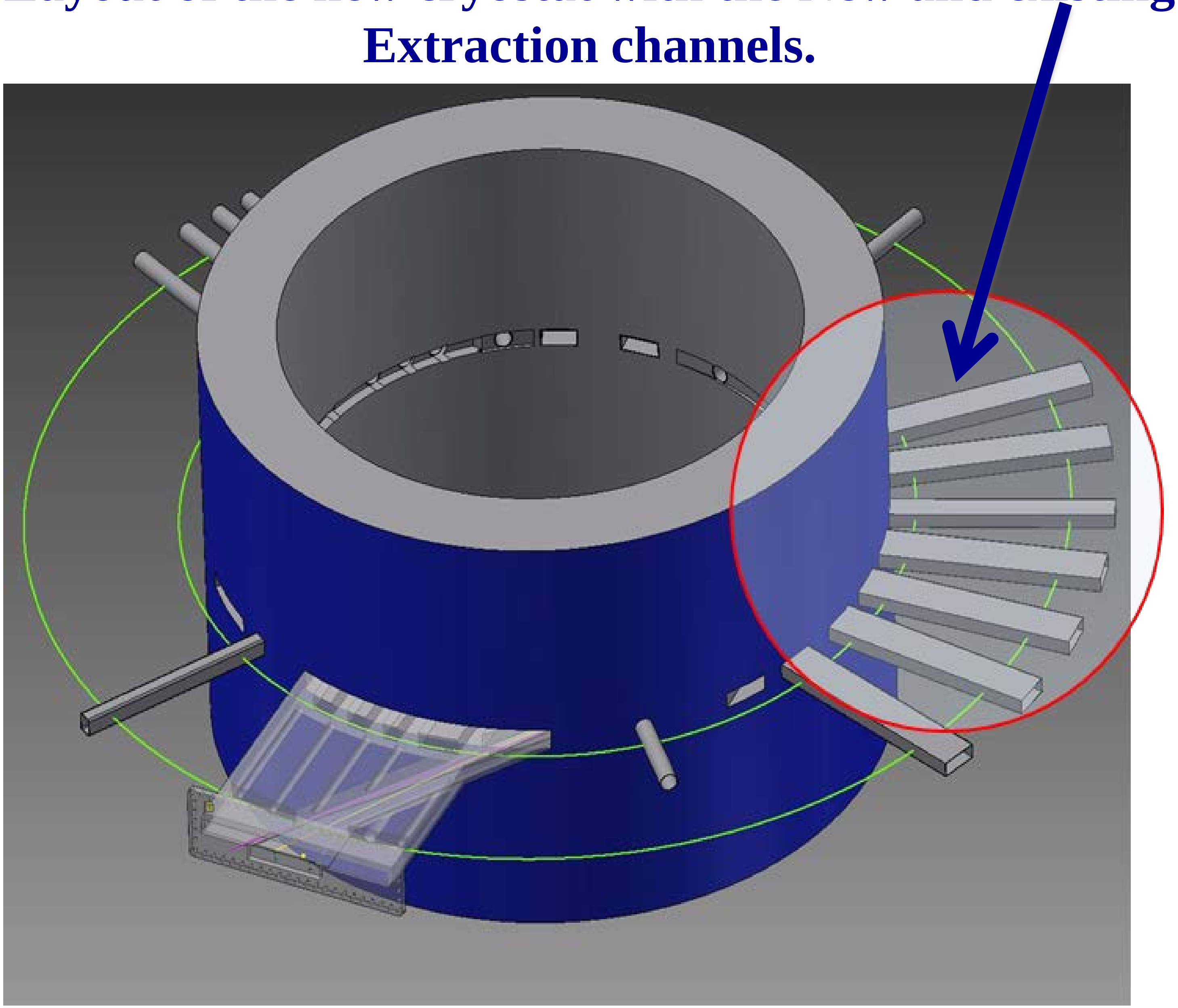
Mechanical interference of New Extraction channel with the magnetic structure and the Electrostatic deflector E1.



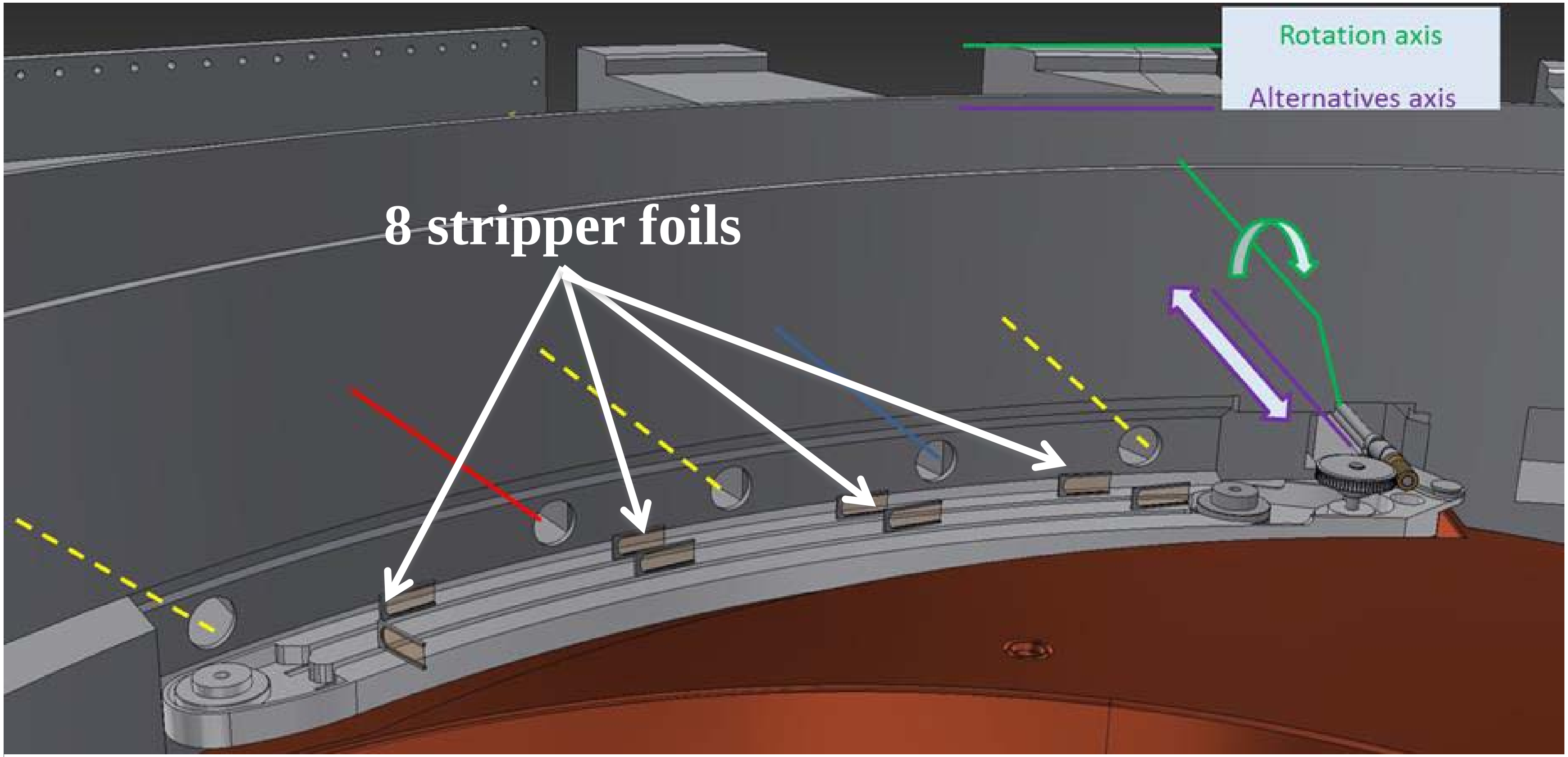
Preliminary layout of the New Extraction channel and of the three Magnetic channels



Layout of the new cryostat with the New and existing Extraction channels.

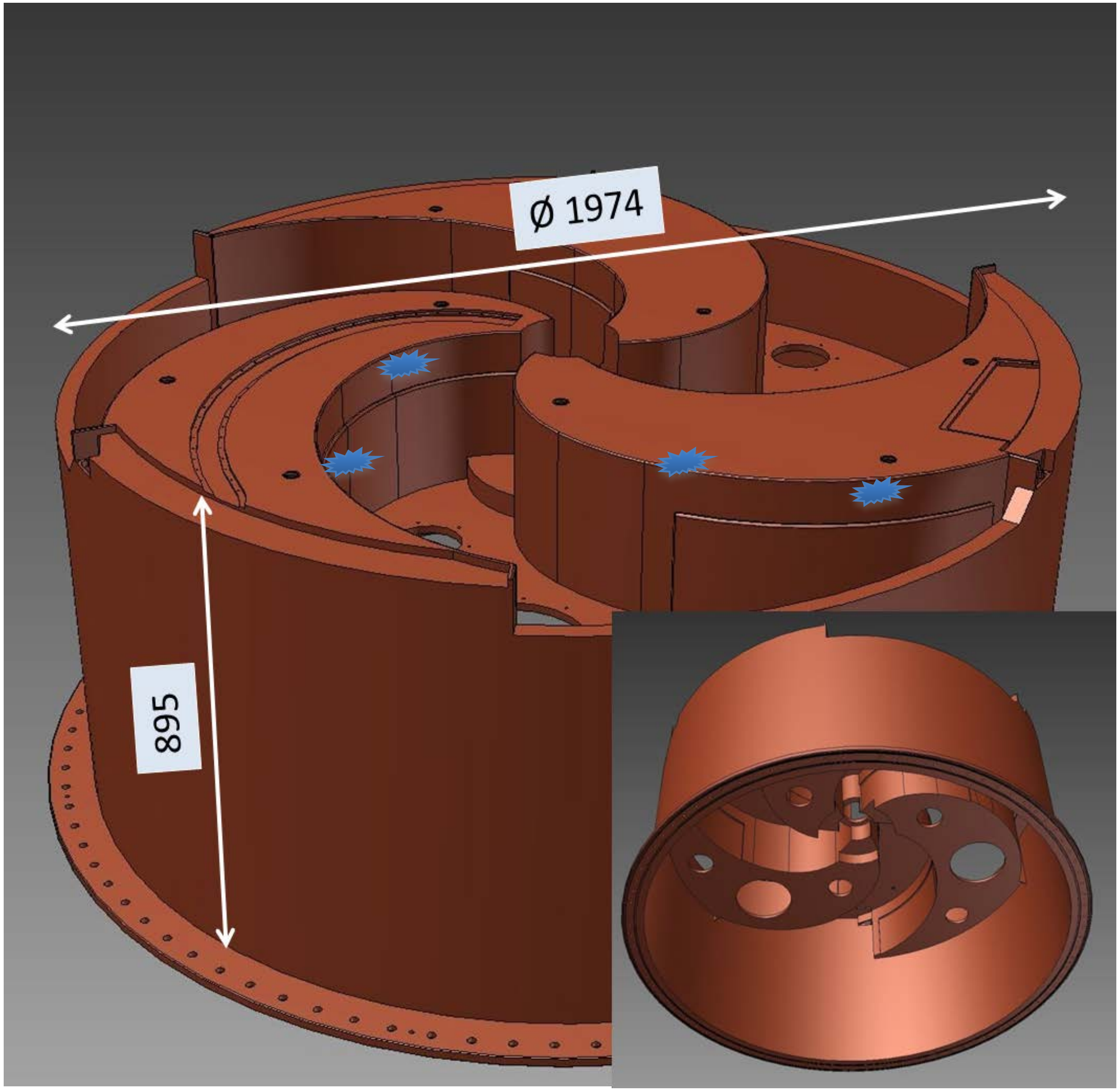


Preliminary layout of the moving and positioning system of stripper foils



The mean life of stripper foils used in commercial cyclotron with H^- @30 MeV is 20 mAh. For a Oxigen beam of 60 μA, and at 60 MeV/n (10 kW), the expected mean life is 333 (1000?) hours, equivalent to 14 (42?) days!

We plan to build a cuople of new "LINERS"



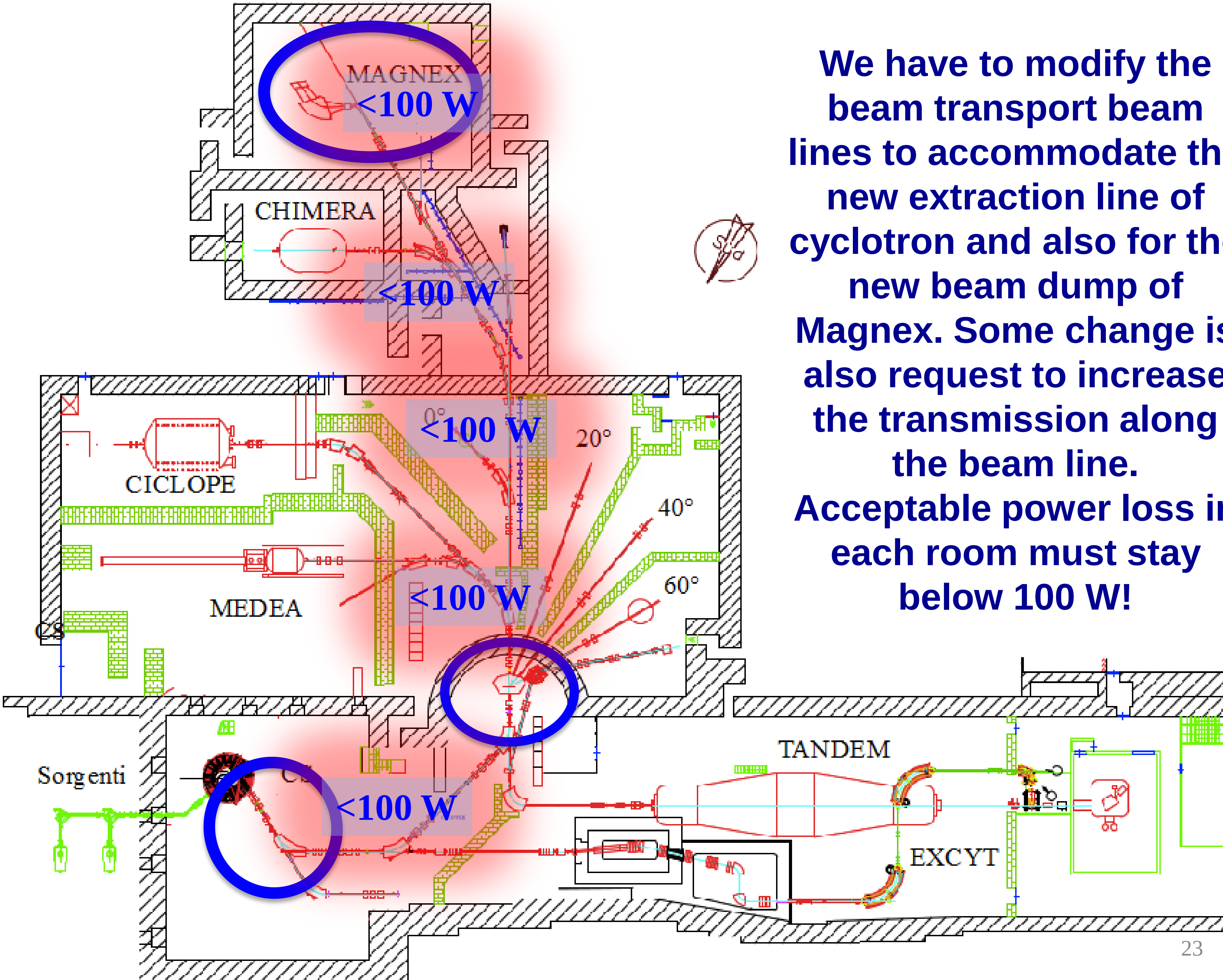
We will use the existing technical drawings, but the wall thickness will be increased of 1-2 mm to reduce/avoid the existing vacuum leaks. We hope to use a better welding procedure.

We have contact with specialised company www.teknobtm.it, Brescia.

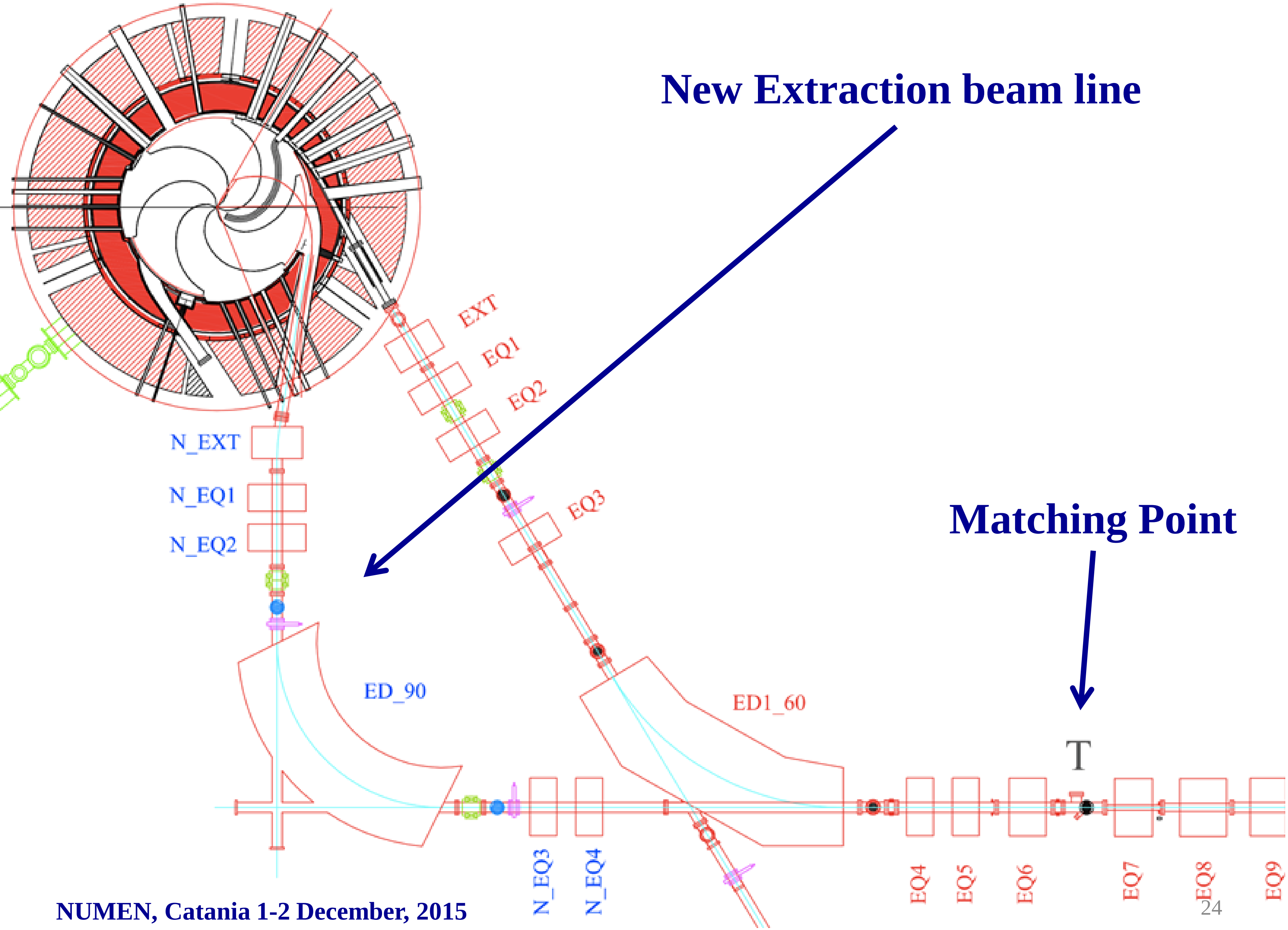
We plan to build also a set of 120 new trim coils!

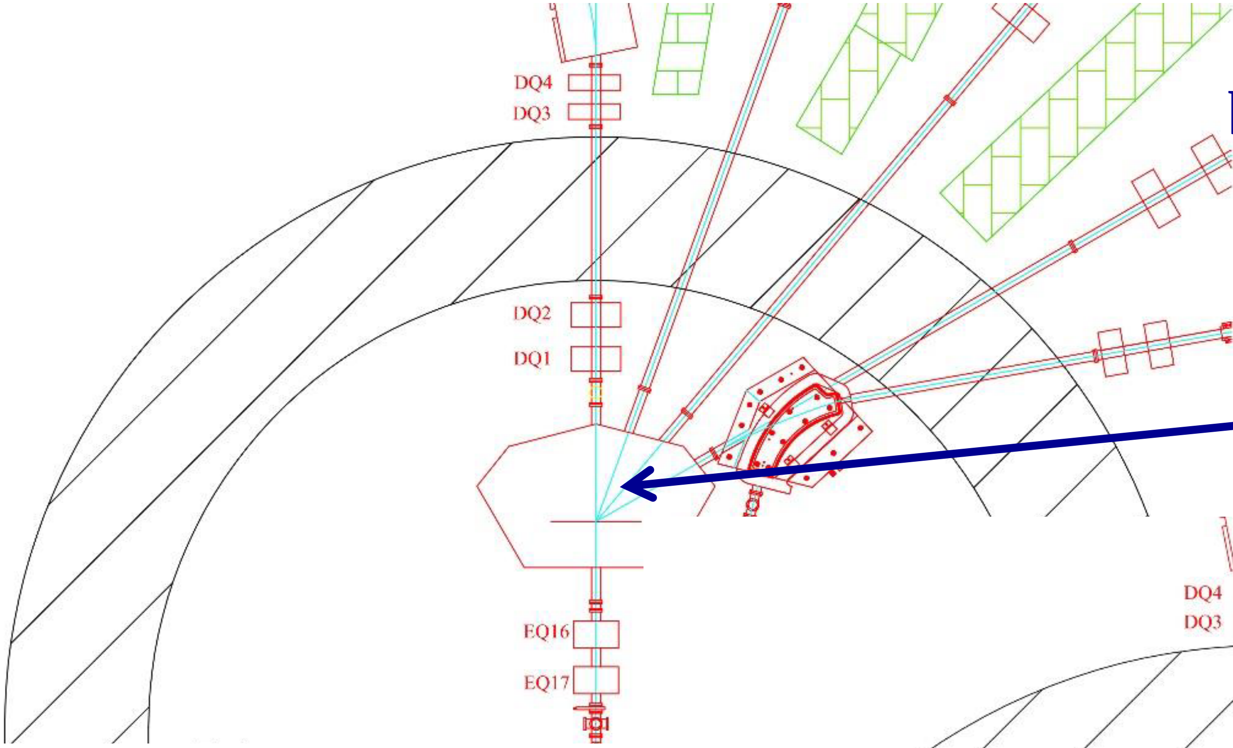
We plan to use the same procedure already used for the existing trim coils but using a cable with a smaller cross section to have more room for the “Liner wall thickness”.

Existing cable 6,35 x 6,35 mm,
new cable
6,35 x 5 mm

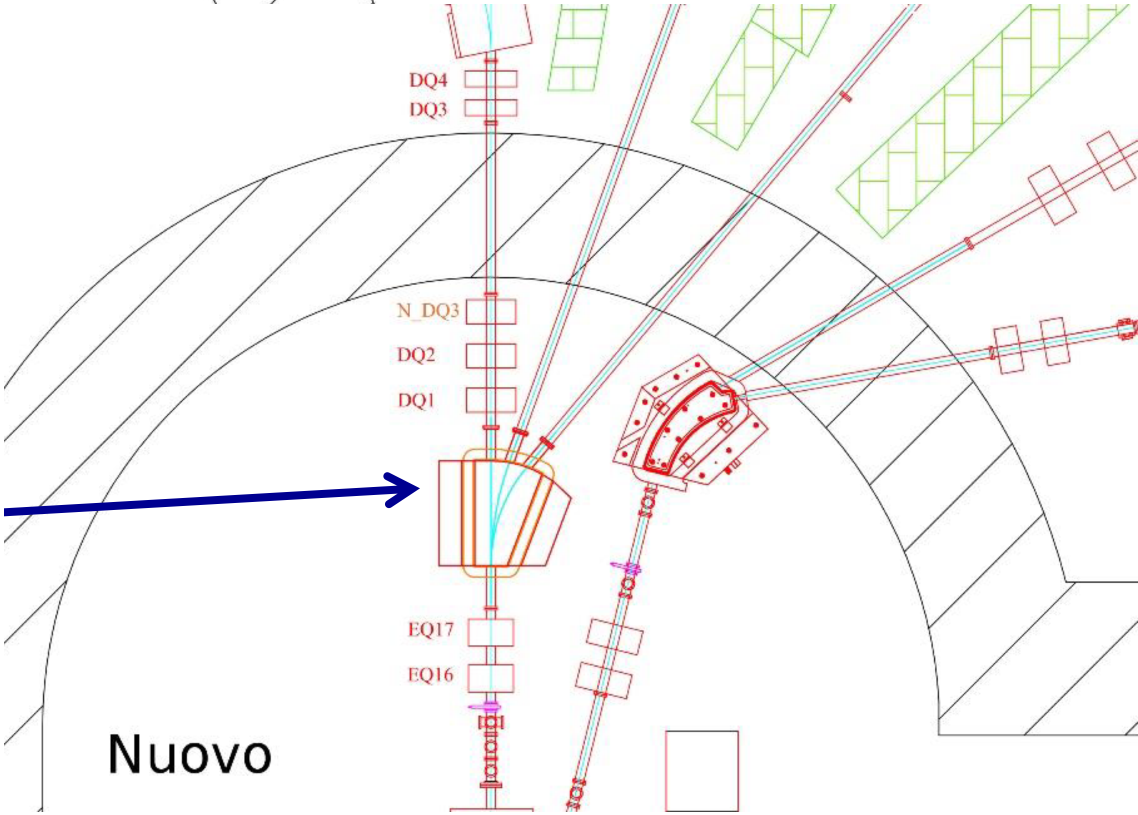


We have to modify the beam transport beam lines to accommodate the new extraction line of cyclotron and also for the new beam dump of Magnex. Some change is also request to increase the transmission along the beam line. Acceptable power loss in each room must stay below 100 W!


New Extraction beam line
Matching Point
EXT
EQ1
EQ2
EQ3
N_EXT
N_EQ1
N_EQ2
ED_90
ED1_60
T
N_EQ3
N_EQ4
EQ4
EQ5
EQ6
EQ7
EQ8
EQ9

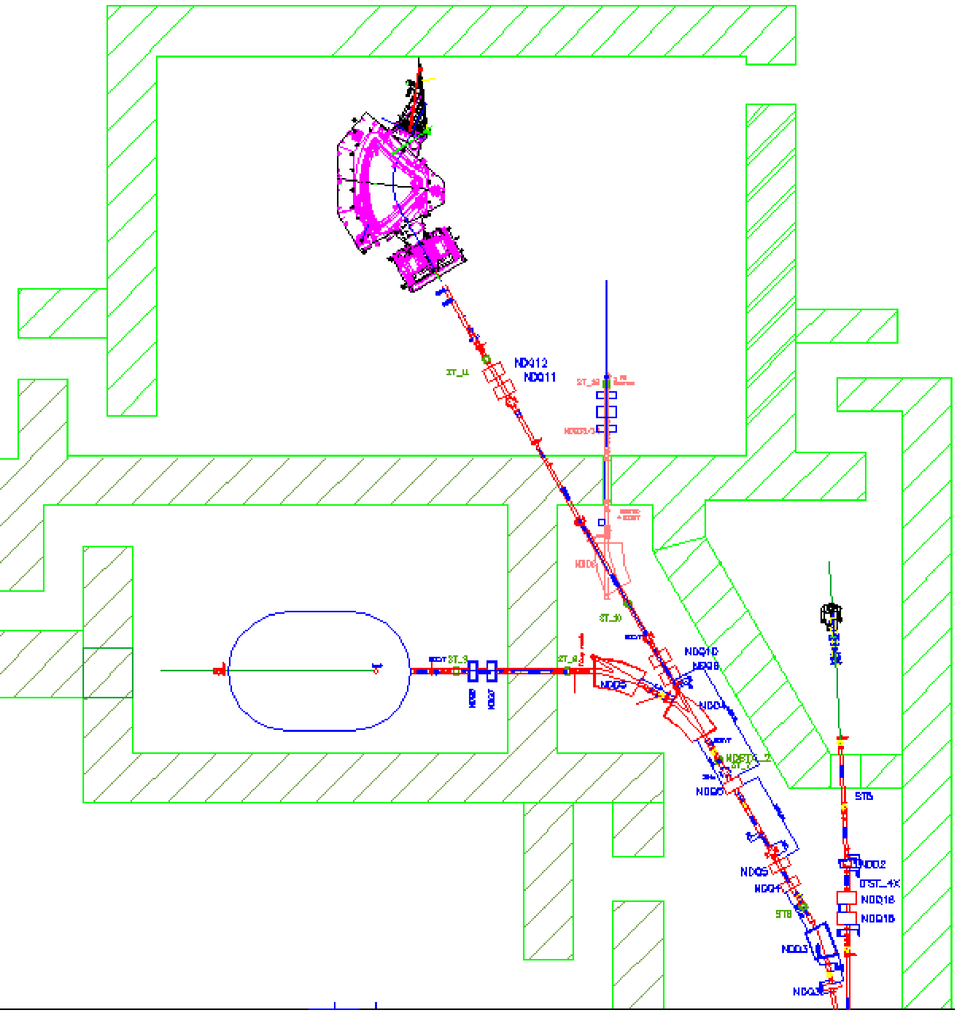


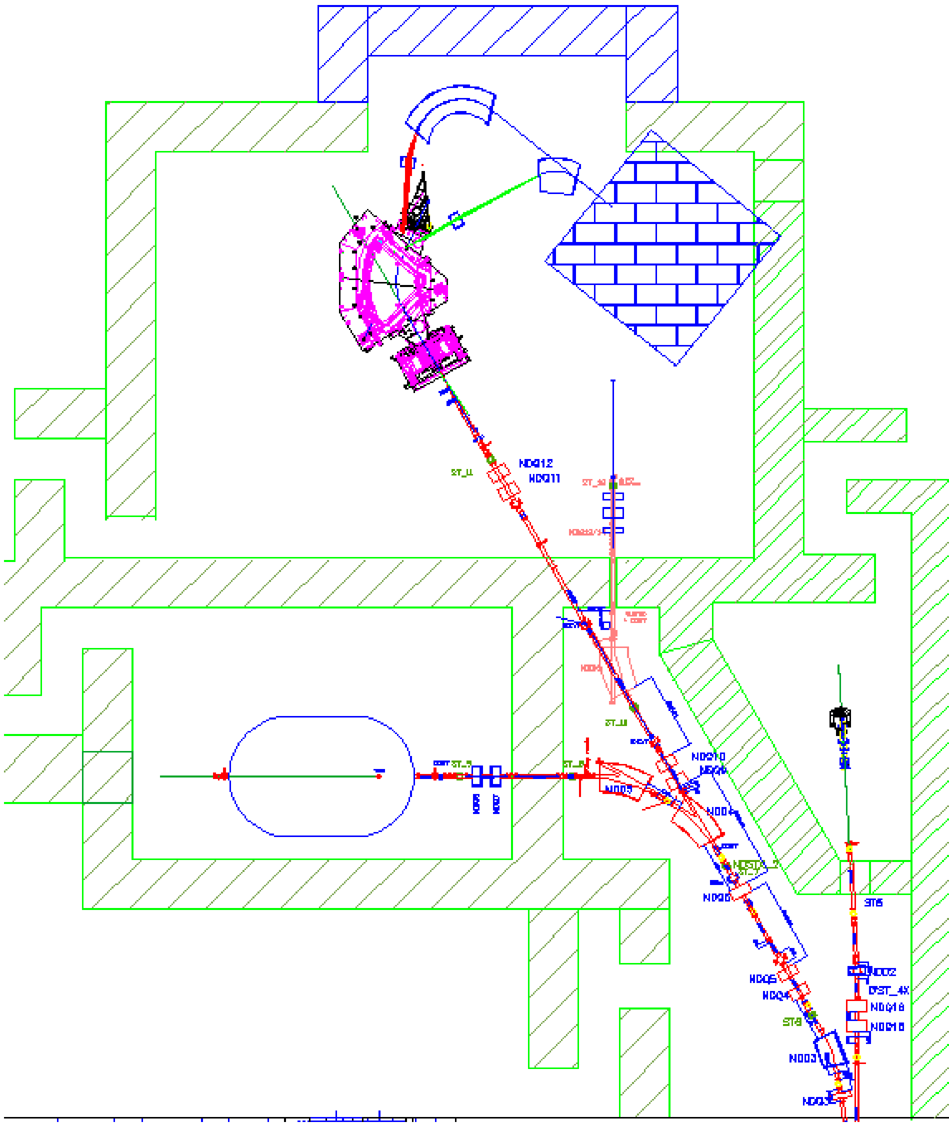
This area is critical for beam losses. This is due to the small gap (25 mm) of the switching magnet and of its sizes.



We plan to replace with a new switching magnet with 70 mm gap (just 60 mm for the beam). The new magnet has minor sizes and allows the insertion of an extra quad.

A new beam dump for MAGNEX spectrometer





The whole upgrade

Looking for intensity

- New s.c. magnet: cryostat with coils
- Stripper system
- Magnetic channels
- New liner
- Source-Cyclotron matching
- Cyclotron-Magnex beam line

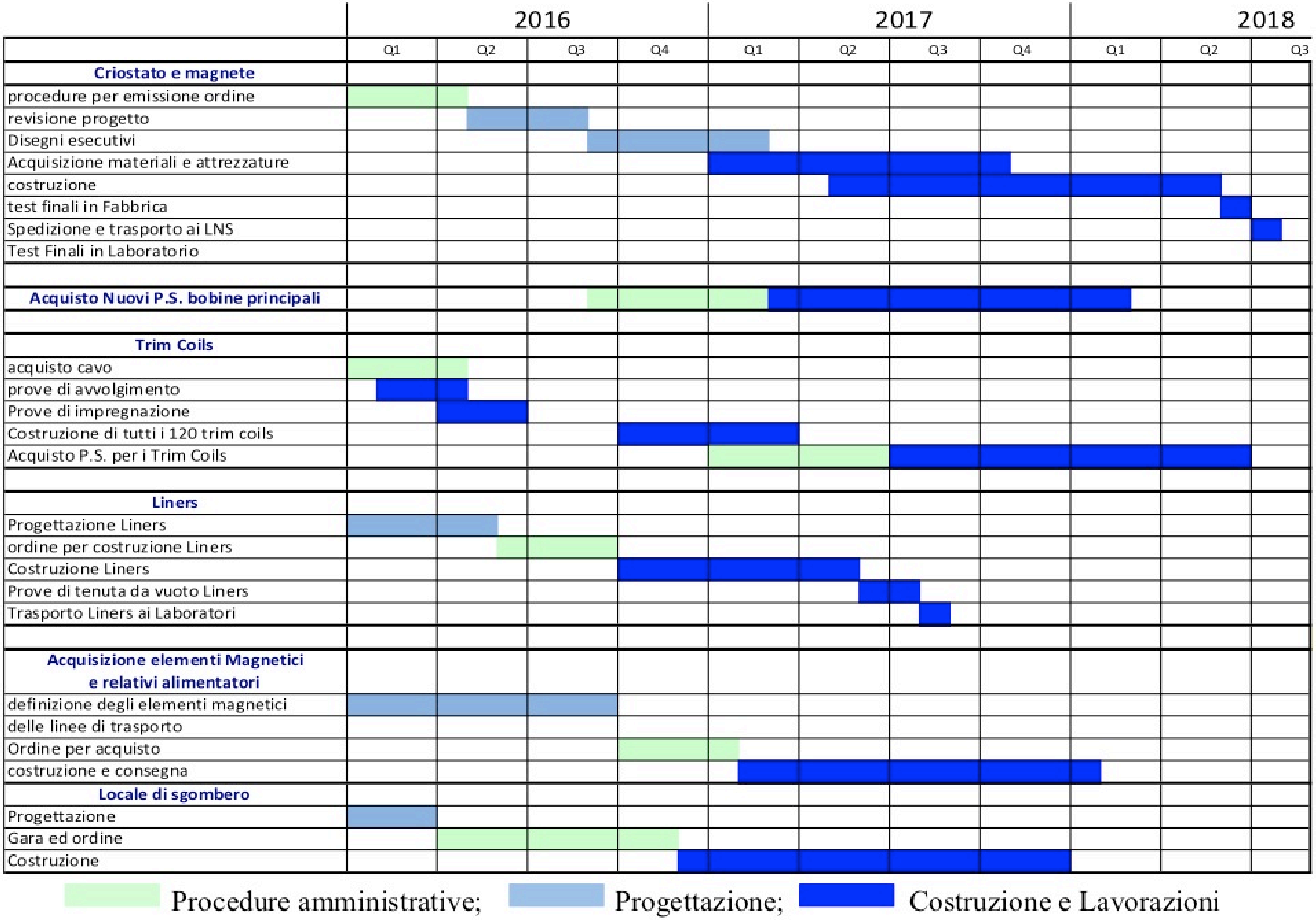
Looking for reliability

- New trim coils
- RF cavities insulators
- New power supplies
- New Helium liquefier

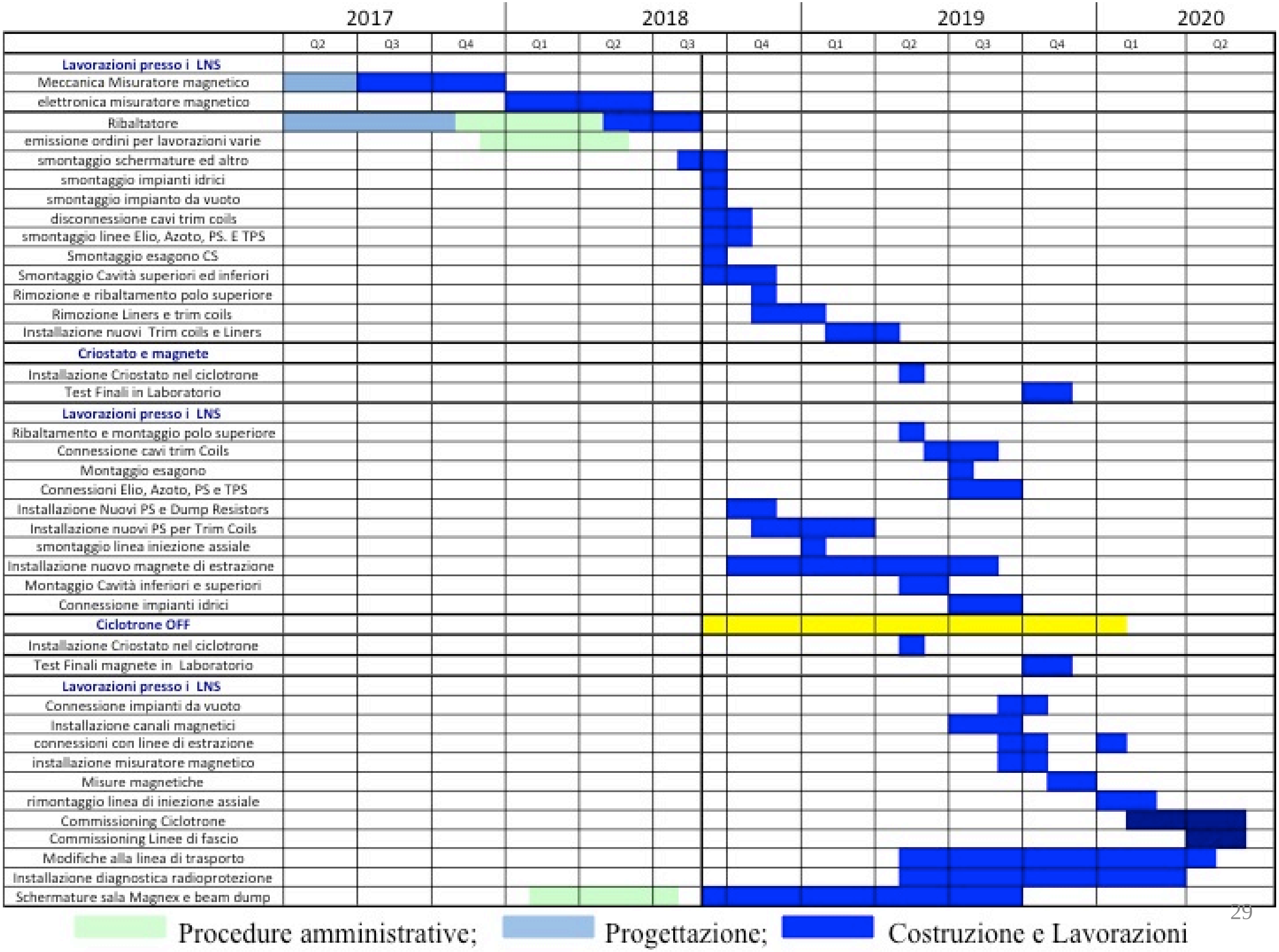
Roughly estimated cost

Cryostat, magnet and cyclotron refurbishing	7 M€
“Intensity” equipment and radioprotection	1.4 M€
“Reliability” equipment and beam line	2. M€

Time schedule: part 1.



Time schedule: part 2.



Thank you for attention

Construction Costs (tax not included)

capitolo	dettaglio	keuro	parziali keuro
Allegato 3	Magnete+Criostato	4078	**5094**
	torretta Criogenica	1006	
	QDS	10	
1.1	camera estrazione per stripping	40	**39.6**
	movimentazione stripper	30	
	controlli e diagnostica	16.8	
1.2	modifiche meccaniche al deflettore	10	**39.6**
	controlli e diagnostica per il nuovo deflettore	29.6	
1.3	canali magnetici nuovo canale	20	**110**
	canali magnetici canale esistente	30	
	controlli e diagnostica canali magnetici	60	
2	manifattura nuovo liner	350	**390**
	lucidatura e pulizia in bagno con utlrasuoni	25	
	verifica dimensionale	4	
	prova da vuoto	2.5	
	trasporto assemblaggio	8.5	
3	vuoto cs	90	**224**
	vuoto nuova linea di estrazione	134	
4	modifiche ai dee	10	**40**
	raffreddamento sistema RF	30	
5	trim coil avvolgimenti	360	**881**
	TC convertitori	450	
	quadro elettrico e linee	40	
	concentratore allarmi e pc	31	
6	N° 1 Dipolo 90°	229	**1265**
	N° 1 Switching magnet	188	
	N° 2 Dipoli 45°	298	
	N° 2 Dipoli 10°	120	
	N° 8 Quadrupoli	176	
	N° 2 Quadrupoli	54	
	vuoto	200	
7	TPS	13.1	**55.6**
	Beam losse monitor	42.5	

Construction Costs (tax not included)

	raffreddamento sistema RF	30	
5	trim coil avvolgimenti	360	**881**
	TC convertitori	450	
	quadro elettrico e linee	40	
	concentratore allarmi e pc	31	
6	N° 1 Dipolo 90°	229	**1265**
	N° 1 Switching magnet	188	
	N° 2 Dipoli 45°	298	
	N° 2 Dipoli 10°	120	
	N° 8 Quadrupoli	176	
	N° 2 Quadrupoli	54	
	vuoto	200	
7	TPS	13.1	**55.6**
	Beam losso monitor	42.5	
8	Alimentatori bobine principali	100	**420**
	Alimentatori della linea di fascio	320	
9	monitoraggio per neutroni e gamma in sala CS	60	**967**
	sistema di sicurezza sala CS e locali attigui	100	
	schermatura ECR	10	
	impianti idrici per il raffreddamento acqua CS	156	
	monitoraggio per neutroni e gamma in sala Magnex	90	
	Modifiche al sistema di sicurezza	50	
	schermature	421	
	impianti idrici per il raffreddamento beam dump o altro in sala Magnex	80	
10	ribaltatore	250	**836.15**
	nuova impalcatura per il nuovo magnete di estrazione	25	
	meccanica protezione vitoni	15	
	interfaccia camera pulita	15	
	movimentazione schermature	12.3	
	manpower esterno per smontaggio/rimontaggio	150	
	locale di sgombero	368.85	
		TOTALE	**10361.95**