Status of the accelerators

Danilo Rifuggiato

LNS User meeting
December 2, 2014

Accelerator equipment for ion beam production

450 KV injector
2 sputtering sources

Normal conducting ECR source CAESAR

↓

↑

Superconducting ECR source SERSE

Improvements on ECR sources: cryogenics of Serse and new injection system of Caesar

Limited availability of SERSE due to cryogenic problems

Autonomous system based on Helium recondensation

- **Dimensioned and designed - cost defined to be around 300 k€ : project LNS Nuclear Astrophysics**
- **Realization : a) purchase of cryocoolers done 128 k€ b) assembling of cryocoolers and high T_C current leads → middle of 2015**

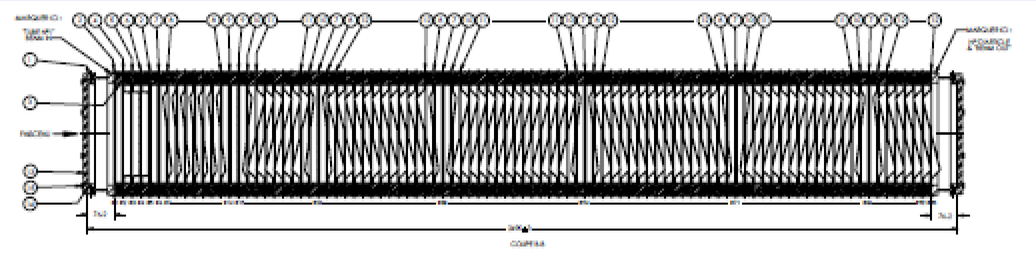
New beams with CAESAR new injection system

- **metallic species through the installation of an oven**
- **new control system implemented**

Tandem upgrade : a new Accelerator Tube n. 1

Tube n. 1 damaged : high residual pressure in the Low Energy section due to vacuum losses

Order to VIVIRAD, France, dated December 20th 2013: 237.000,00 € for 2 accelerator tubes - Delivered in May 2014



Replacement from the L.E. side

Dedicated system manufactured to remove the old tube and assemble the new one

July 9 2014 – The new tube positioned inside the Tandem

Tests are being carried out

Tandem upgrade: Belt –> Pelletron conversion

Charging system

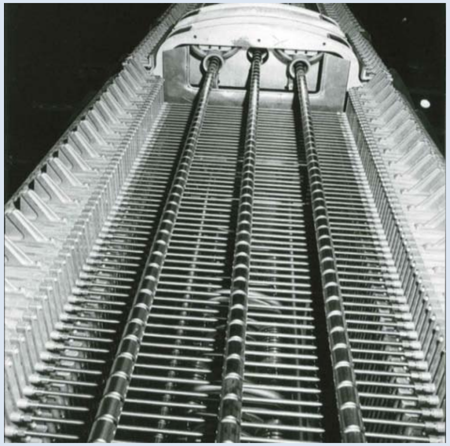
HVEC does not produce belts any longer. The insulating material of belts different from the original ones does not resist to temperature and discharges. Belts must have good mechanical and electrical characteristics - No company is available to improve them

Alternative to the belt : Pelletron by NEC

Order to National Electrostatic Corporation (NEC, USA) issued in July 2013: 598.845 US$ - Shipment on January 6, 2015 - Installation on January 19, 2015 (if the present tests end positively by Dec 5) Time needed : 2-3 weeks

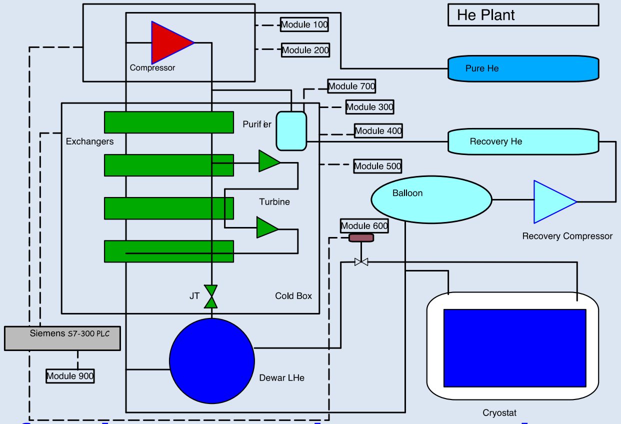
From the belt

to the Pelletron



Superconducting Cyclotron: Helium liquefier revamping

- **January 1st 2013 Breakdown of the helium liquefier: turbine found broken due to impurities (Air Liquide diagnosis) – restart on January 15 - Cyclotron operating on January 25**
- **May 2nd 2013 a new failure! Air Liquide inspection: again problems at the turbine - extraordinary maintenance and upgrade (revamping) needed to restore the reliability grade of the past 20 years**



- **July 8th 2013 Economical offer for the revamping operation produced by Air Liquide after a heavy interaction**
  Estimated time: 6 months from the order
- **July 20th 2013 Contract approved by the INFN Executive Board – performance bond and declarations requested to Air Liquide**
- **October 8th 2013 Air Liquide documents ready**
- **October 15th 2013 order issued**

Helium liquefier revamping

3 Planning documents received from Air Liquide since the order issue (October 15)

1) : end of revamping in March 2014
turbines not repaired, software not ready

2) : end of revamping in May 2014
software malfunctioning

3) : end of revamping in July 2014
problems of vacuum tightness in the turbine

LNS was kept open in August
The Cyclotron cryostat was full of LHe on September 23

Proton beam extracted on October 2

Beam delivery

Superconducting Cyclotron

The experimental activity re-started in October 2014 after the liquefier revamping. The program October-December 2014 is being carried out. The program January-April 2015 is close to be published

In June 2013 beam time was assigned for 1 year. Therefore there are approved experiments until the end of 2015 at least (390 BTU)

Few months before the end of 2015, a new call for proposals will be sent

Beam delivery

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Tandem

After the replacement of Tube n.1, tests are in progress in view of the Pelletron conversion, that will be accomplished in January 2015, as scheduled.

After the Pelletron installation, the approved experiments left (85 BTU) will be performed and a call for proposals will be sent

The LNS Superconducting Cyclotron

$(T/A)_{max} = K_{bending}\,(Q/A)^2$ ~ 25 AMeV Au36+

$(T/A)_{max} = K_{focusing}\,(Q/A)$ 100 AMeV fully stripped

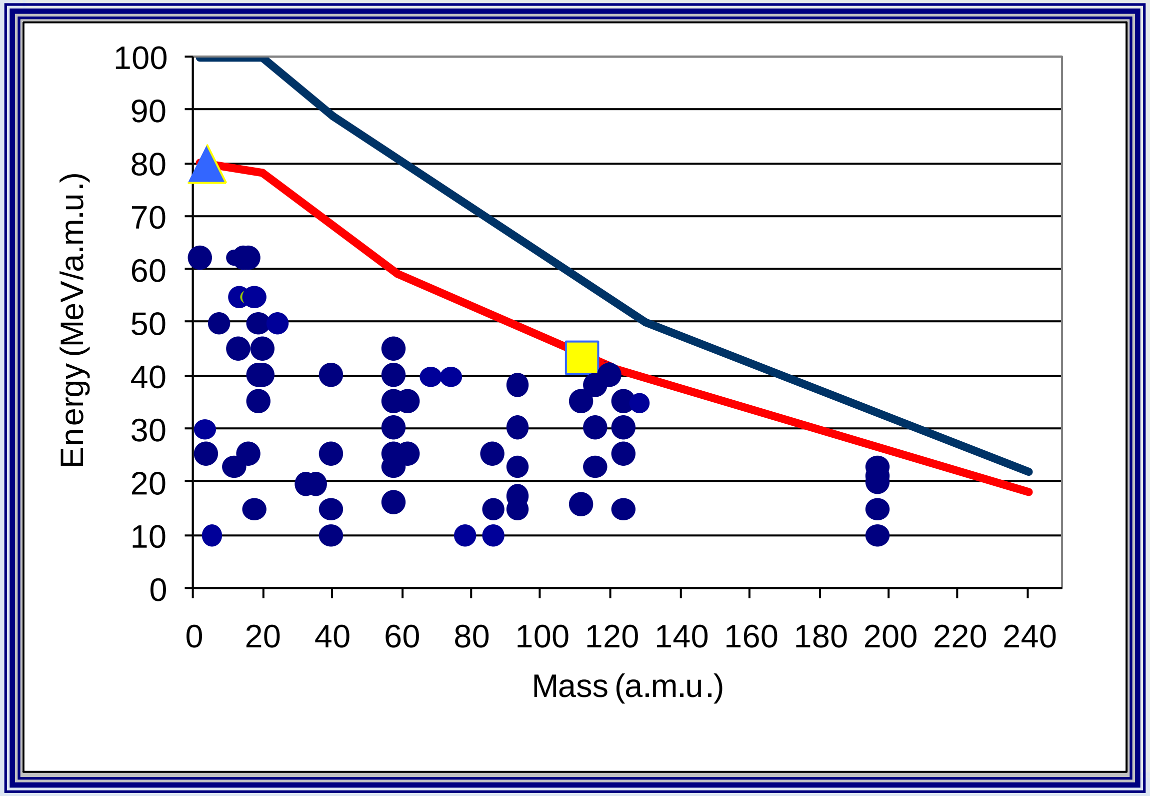
Bending limit	**K=800**
Focusing limit	**Kfoc=200**
Pole radius	**90 cm**
Yoke outer radius	**190.3 cm**
Yoke full height	**286 cm**
Min-Max field	**2.2-4.8 T**
Sectors	**3**
RF range	**15-48 MHz**

Versatility (performance)

Reliability (protontherapy)

High intensity (radioactive beams)

Superconducting Cyclotron developed beams



^{4}He 80 AMeV

^{112}Sn 43.5 AMeV

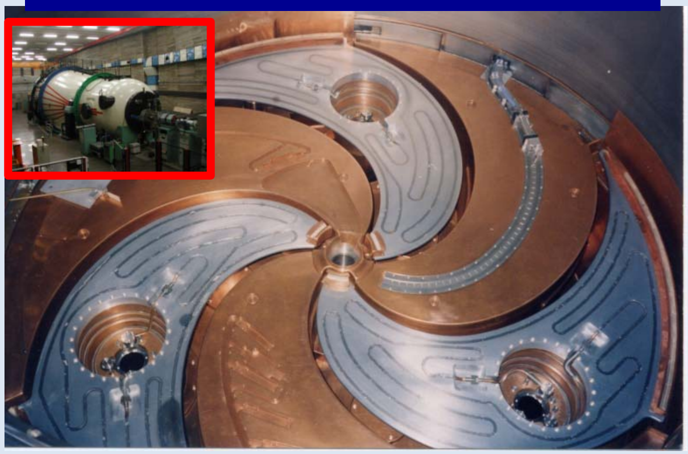
In red beams with intensity 10^{12} pps

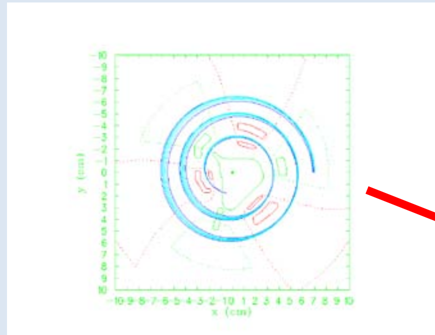
^{A}X	E (AMeV)
H_2^+	62,80
H_3^+	30,35,45
$^{2}D^{+}$	35,62,80
^{4}He	25,62,80
He-H	10, 21
^{9}Be	45
^{11}B	55
^{12}C	23,62,80
^{13}C	45,55
^{14}N	62,80
^{16}O	21,25,55,62,80
^{18}O	15,55
^{19}F	35,40,50
^{20}Ne	20,40,45,62
^{24}Mg	50
^{27}Al	40
^{36}Ar	16,38
^{40}Ar	15,20,40
^{40}Ca	10,25,40,45
^{42,48}Ca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

Upgrade of the Cyclotron: beam intensity

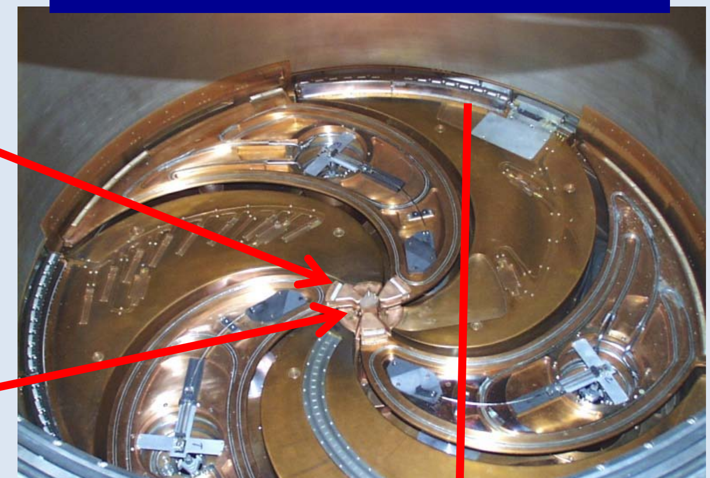
Axial injection allows for intensity enhancement

1994 – Booster of Tandem

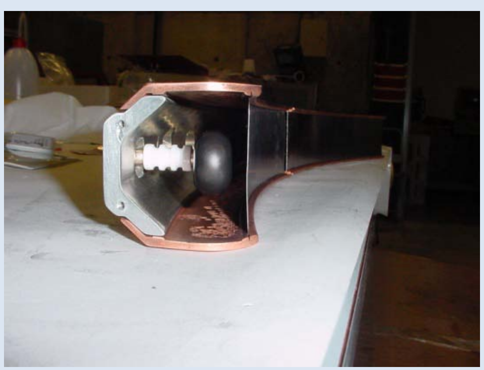




2000 – Stand alone



Compactness makes extraction a critical process : $\varepsilon \approx 50\%$



Inter-turn separation

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

Increasing the Cyclotron beam intensity

Septum: directly cooled

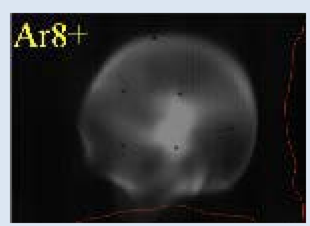
New septum material: W vs. Ta

Bigger thickness: 0.3 vs. 0.15 mm

⇨extraction efficiency 63% vs. 50%

$^{13}C^{4+}$ @ 45 AMeV (EXCYT primary beam)

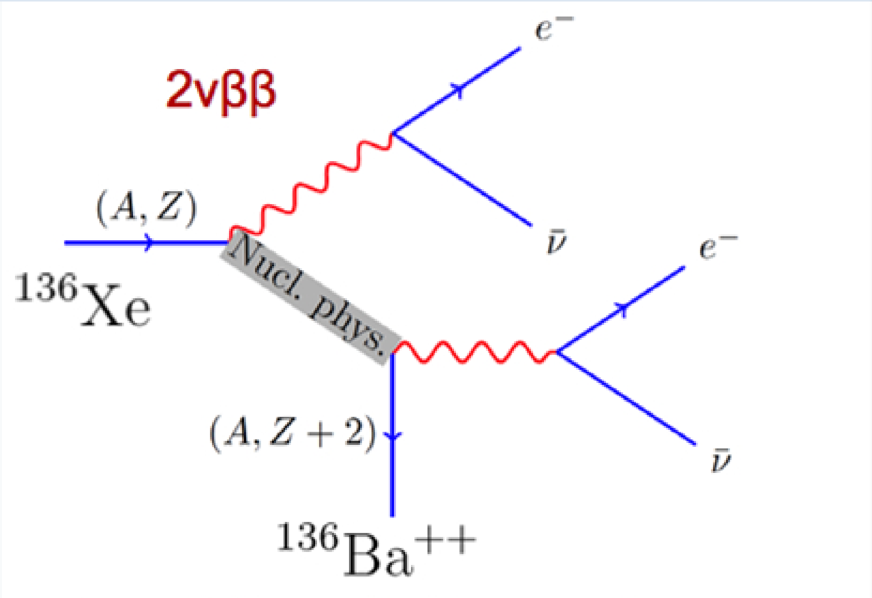
Pextr = 150 watt I=1020 enA= 1.5×10^{12} pps

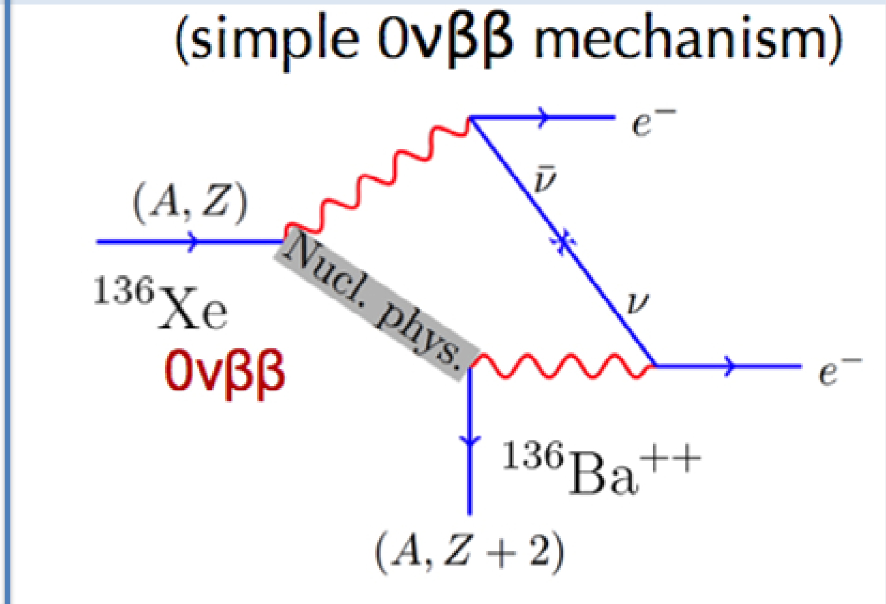


The source-cyclotron matching needs to be improved

Beam transport along the injection line is now being considered, following the MSU, JYFL, KVI methods

Physics case demanding high intensity: double β decay





$$1/T^{0\nu}_{1/2}(0^+ \rightarrow 0^+) = G_{01}\left|M^{\beta\beta 0\nu}\right|^2 \left|\frac{\langle m_\nu \rangle}{m_e}\right|^2$$

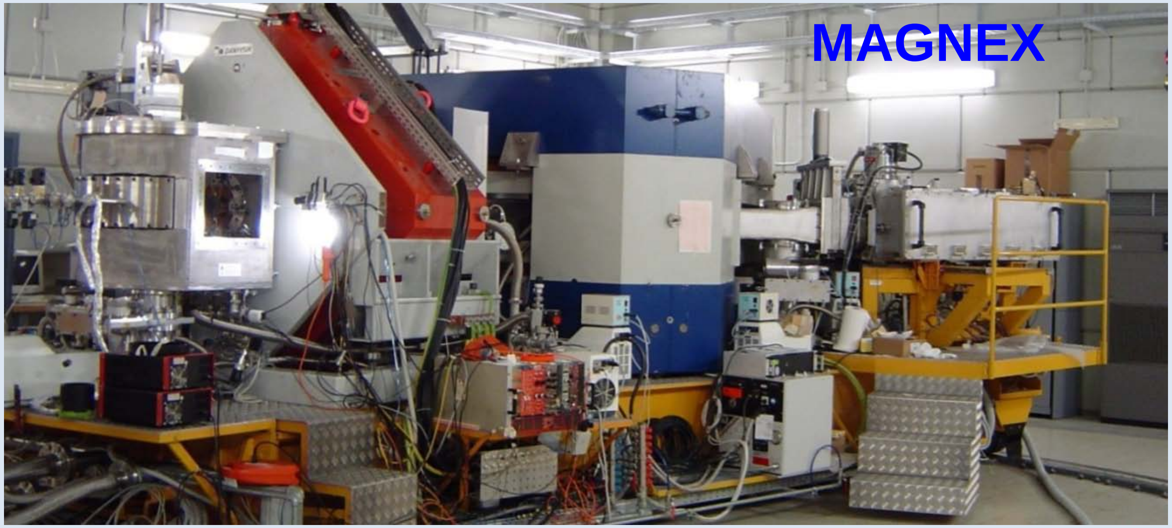
A lot of new physics inside

$$\langle m_\nu \rangle = \sum_i \left|U_{ei}\right|^2 m_i e^{i\alpha_i}$$

but one should know **Nuclear Matrix Element** (NME)

$$\left|M_\varepsilon^{\beta\beta 0\nu}\right|^2 = \left|\left\langle 0_f \left\| \hat{O}_\varepsilon^{\beta\beta 0\nu} \right\| 0_i \right\rangle\right|^2$$

Physics case demanding high intensity: double β decay



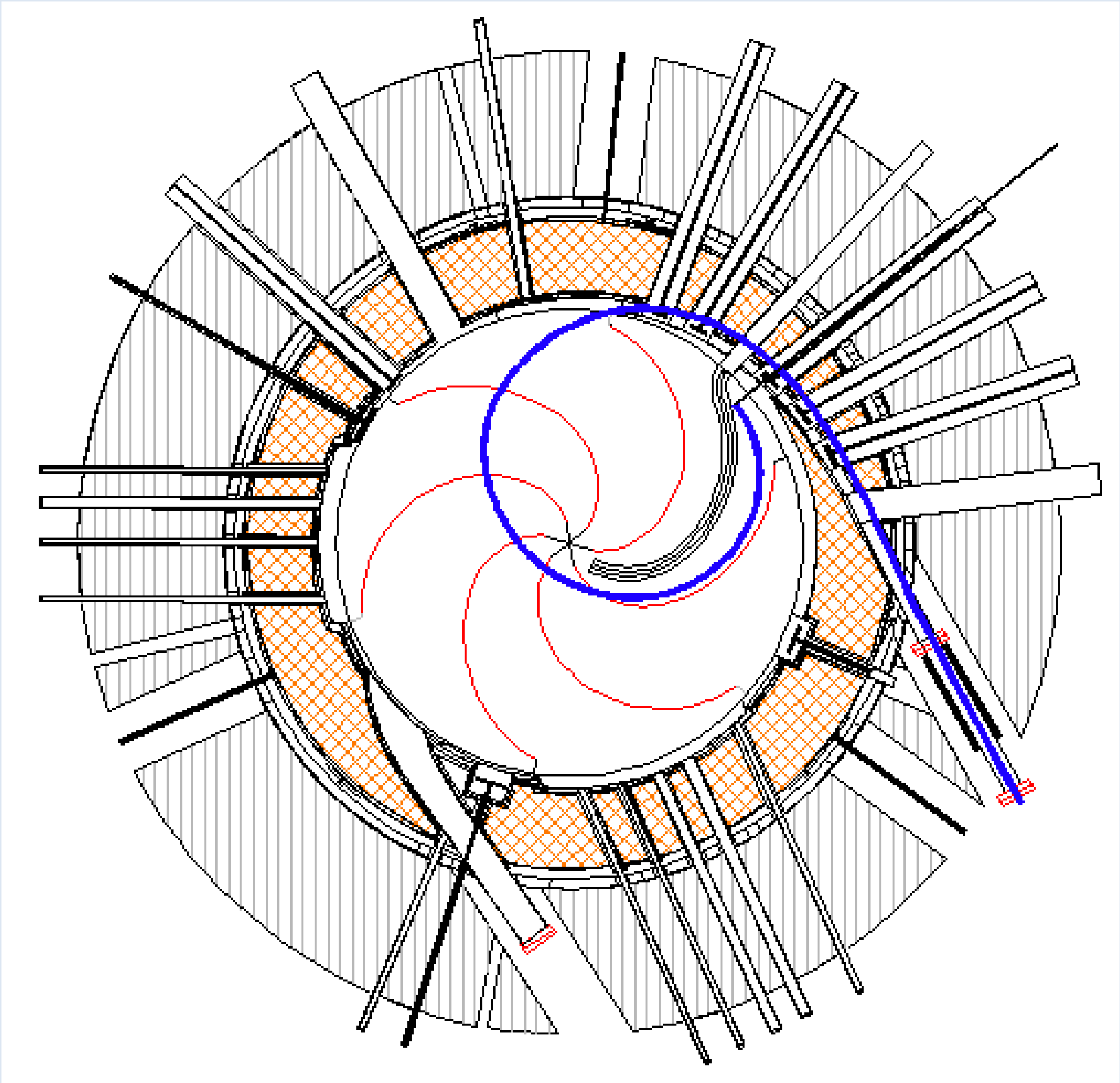
- Large angular acceptance
- Possibility of measuring at 0°
- Possibility of detection of ^{16}O, ^{18}F, ^{18}Ne, ^{20}Ne
- High resolution spectra
- Angular distributions up to10 nb/sr

Double charge exchange reactions (^{18}O,^{18}Ne) and (^{20}Ne,^{20}O) towards the determination of the nuclear matrix element of the double β decay

$^{40}Ca(^{18}O,^{18}Ne)^{40}Ar$ – exp. DOCET nov.2012

Extraction by stripping: high efficiency

Extraction trajectory
Ne20, q=6+ → 10+ E=29 MeV/amu



Extraction by stripping is based on the reduction of magnetic rigidity of the accelerated ion, caused by an increase of charge state or decrease of mass, after crossing a thin carbon foil (stripper).

For light ions at high energies the charge state fraction for q=Z after a stripper with thickness bigger than the equilibrium thickness is >99%

Extraction by stripping: high efficiency >99%

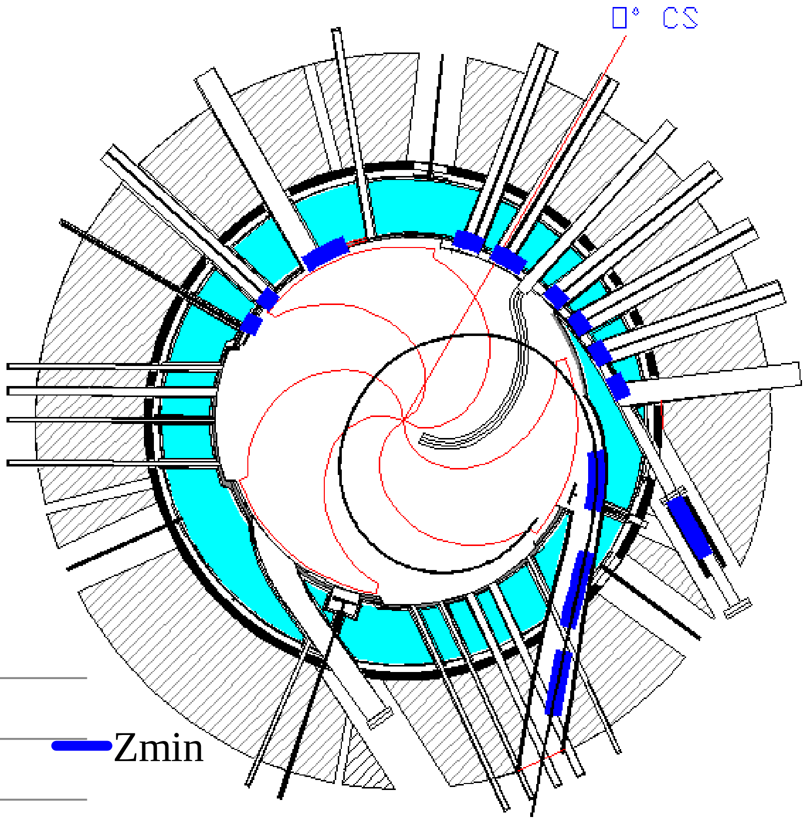
Atomic Data and Nuclear Data Tables, Vol. 51, No. 2, July 1992, Table 2 pag.187

Carbon:	E=15 MeV/u	F(4)=1.74e-7	F(5)=8.35e-4	F(6)=0.99917
	E=20 MeV/u	F(4)=2.56e-8	F(5)=3.20e-4	F(6)=0.99968
Oxygen:	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=20 MeV/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

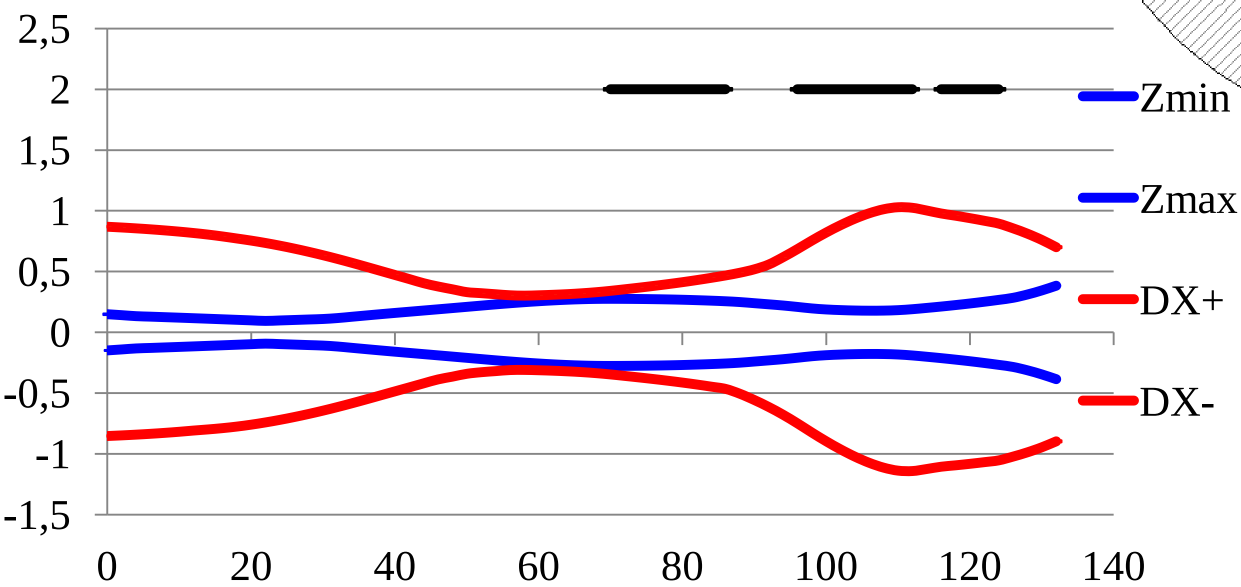
Ion	Energy	Isource	Iacc	Iextr	Iextr	Pextr
	MeV/u	eμA	eμA	eμA	pps	watt
^{12}C q=4+	30	300	45(4+)	66.8(6+)	$6.9 \cdot 10^{13}$	4009
^{18}O q=6+	60	150	22.5 (6+)	30 (8+)	$2.3 \cdot 10^{13}$	4050
^{20}Ne q=4+	20	500	75(4+)	185.6(10+)	$1.1 \cdot 10^{14}$	5569

Beam dynamics in extraction by stripping

Beam dynamics calculations are necessary to ascertain the feasibility of extraction by stripping. In particular the beam envelope has to be evaluated

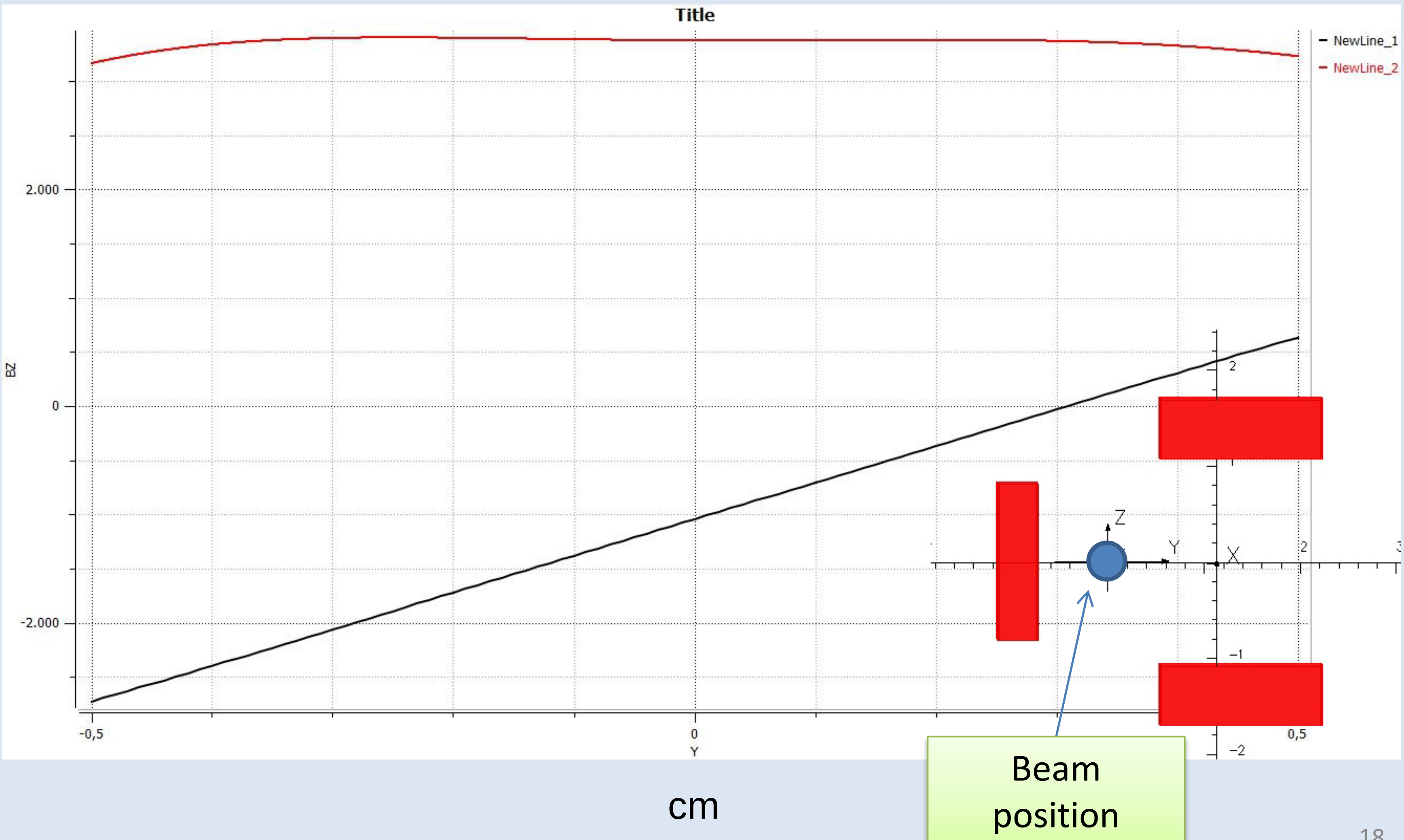


Fast extraction □18, 6+ at teta=96°



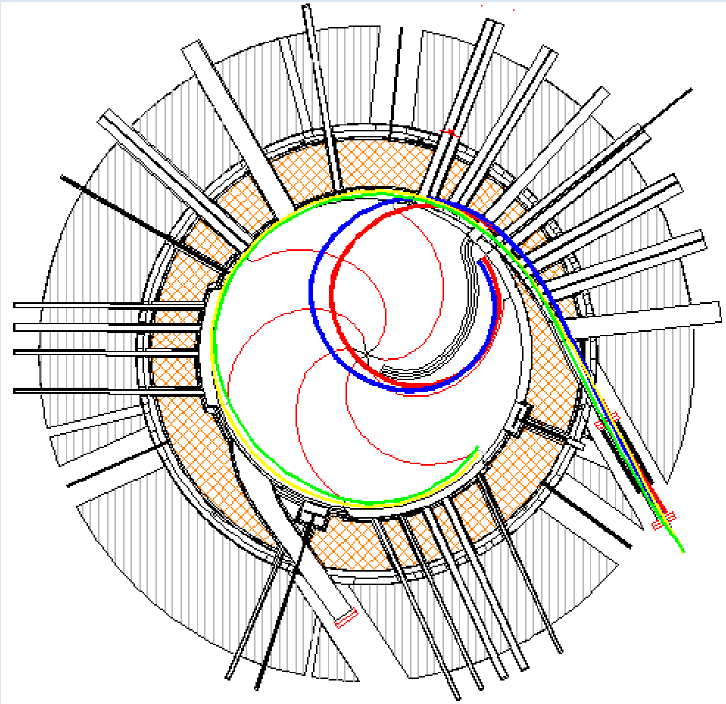
Design of magnetic channels for beam focusing

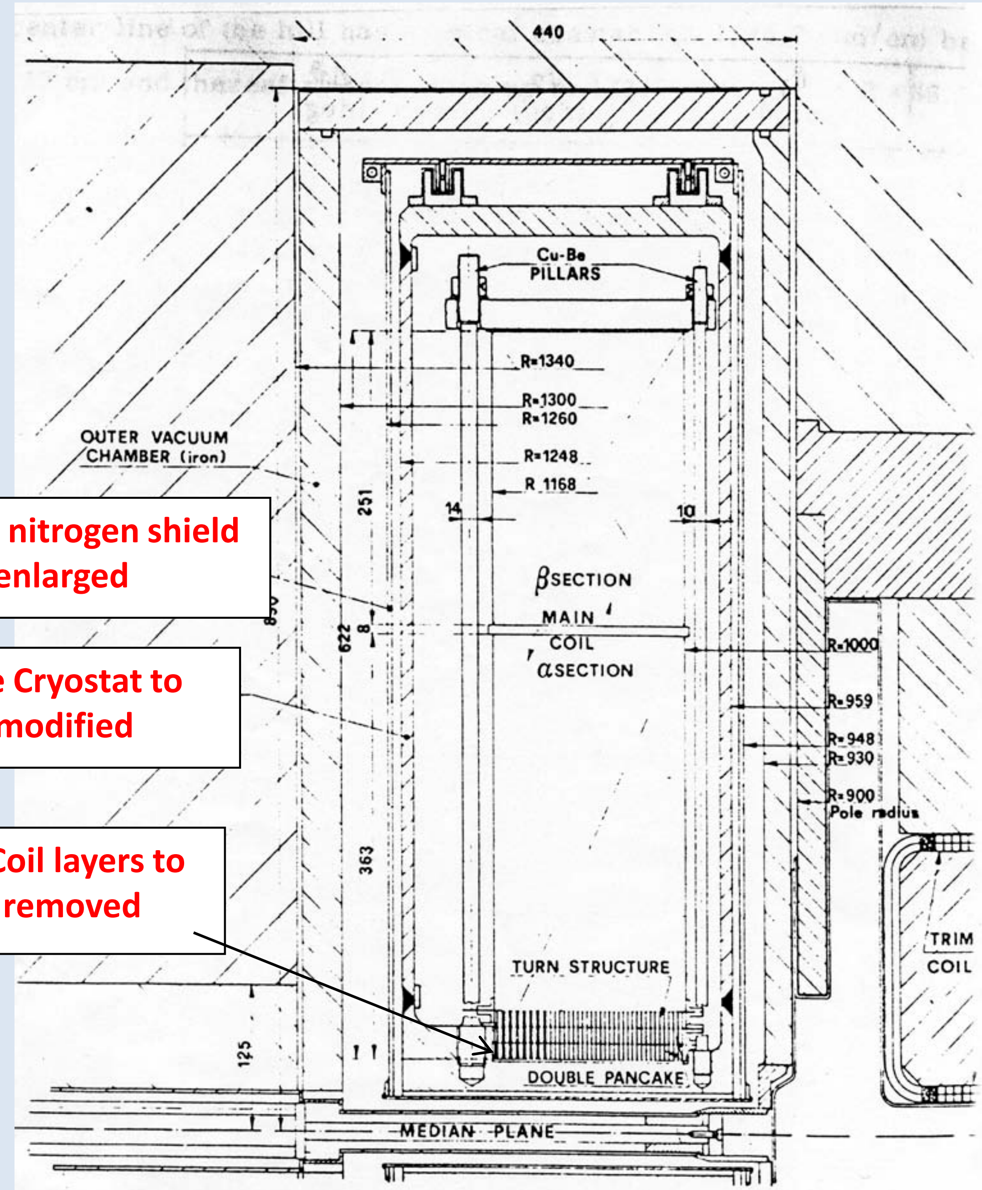
kguass



cm

From electrostatic extraction to extraction by stripping





Liquid nitrogen shield to be enlarged

LHe Cryostat to be modified

α-Coil layers to be removed

A new cryostat

Conceptual design study accomplished in collaboration with MIT.

Report delivered on Oct. 31

Agreement with MIT

PSFC
Technology & Engineering Division

Statement of Work

for

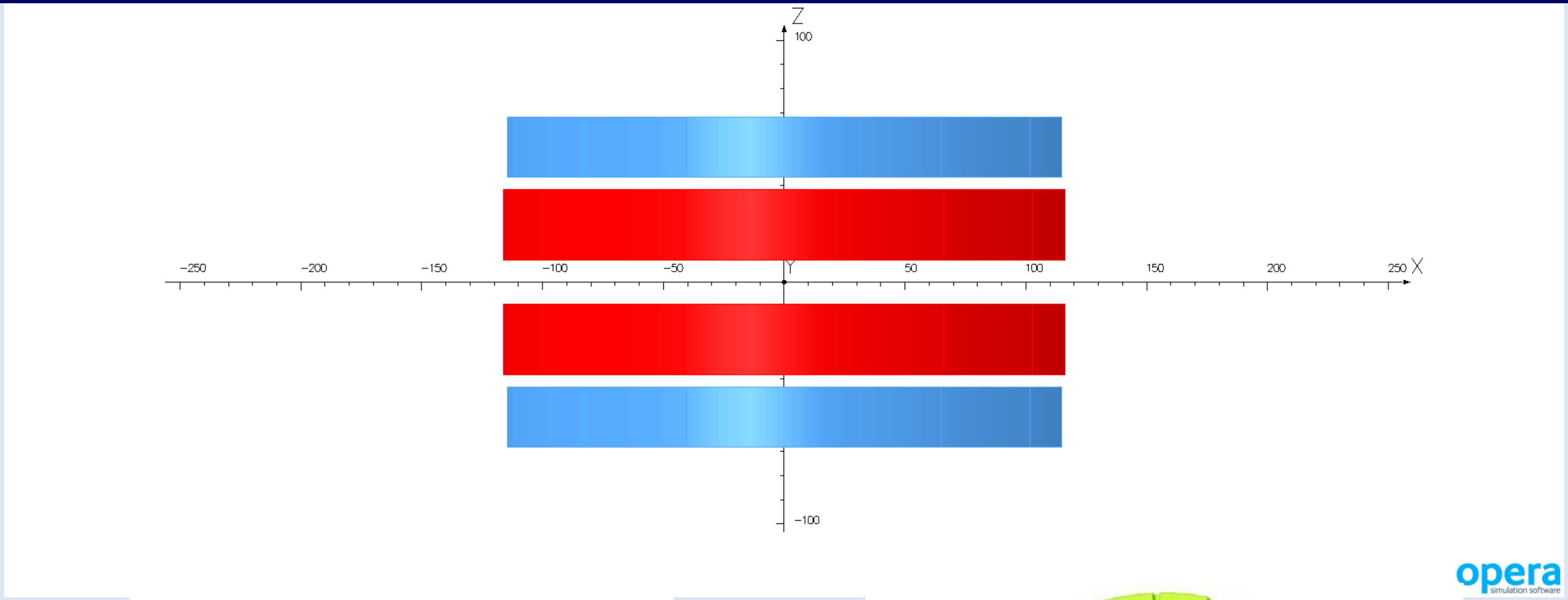
Laboratori Nazionali del Sud of the Istituto Nazionale di Fisica Nucleare (INFN)

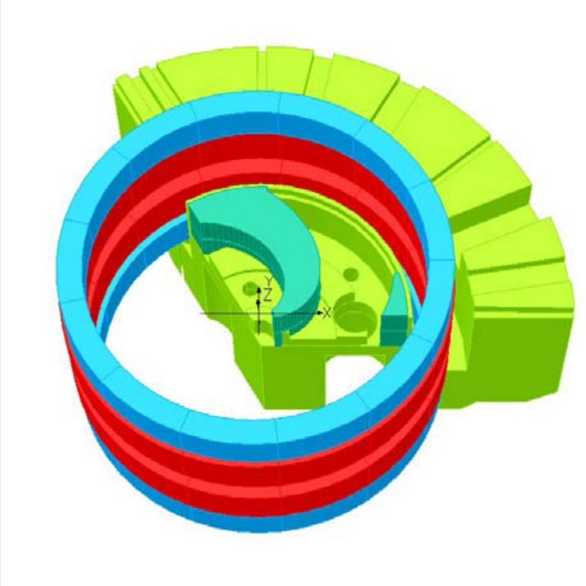
Title: Conceptual Design of a Superconducting Magnet for the LNS Cyclotron

Tasks

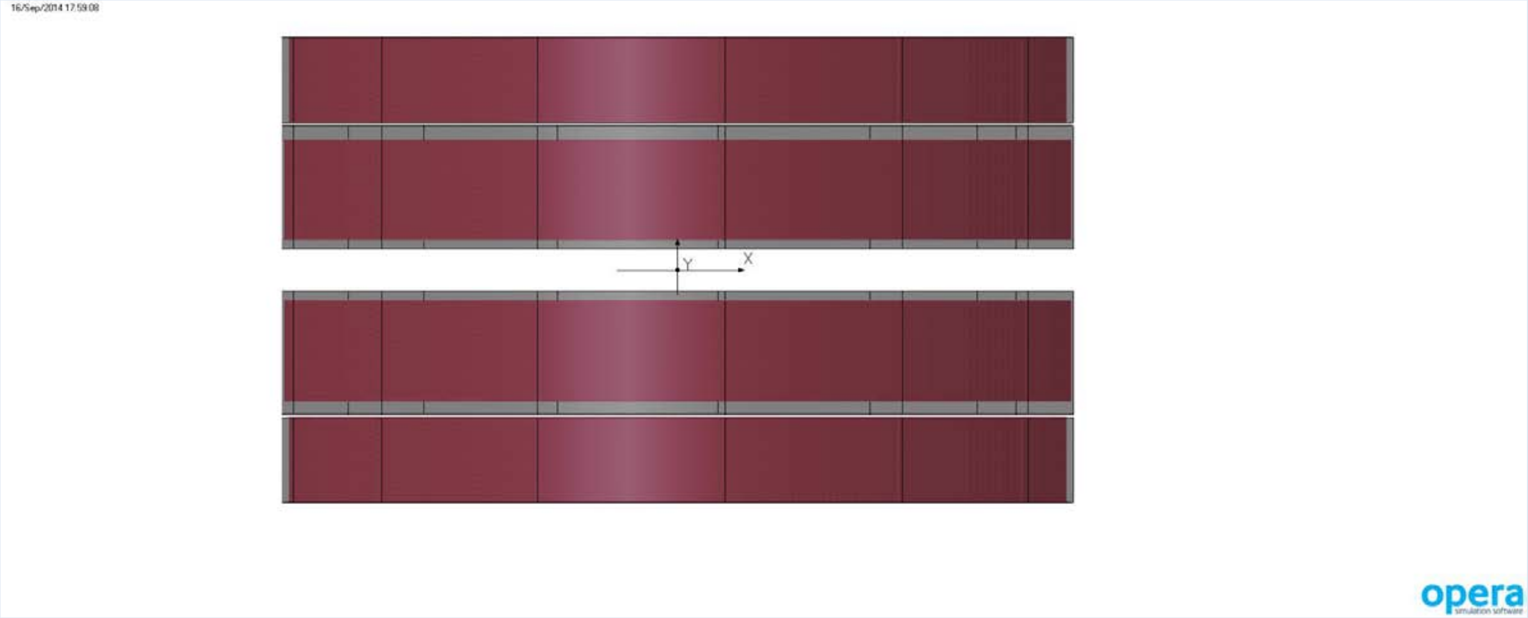
- Magnetic design
  - deviation from the present form factors of the alpha and beta coils
- Conceptual design
  - NbTi cable ans superconducting coils
  - Cryostat
  - Structural analysis
  - Cryogenic consumption
- Preliminary schedule and cost estimate for design and manufacturing

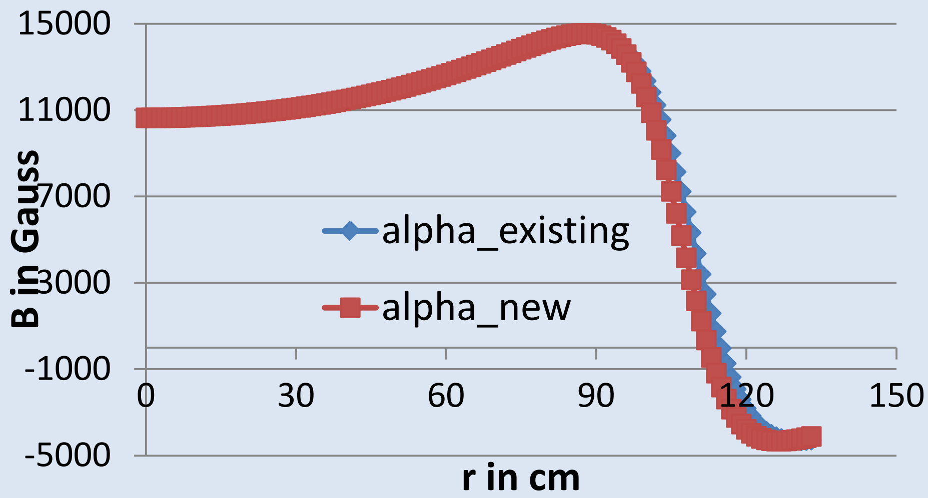
Study of a new superconducting magnet

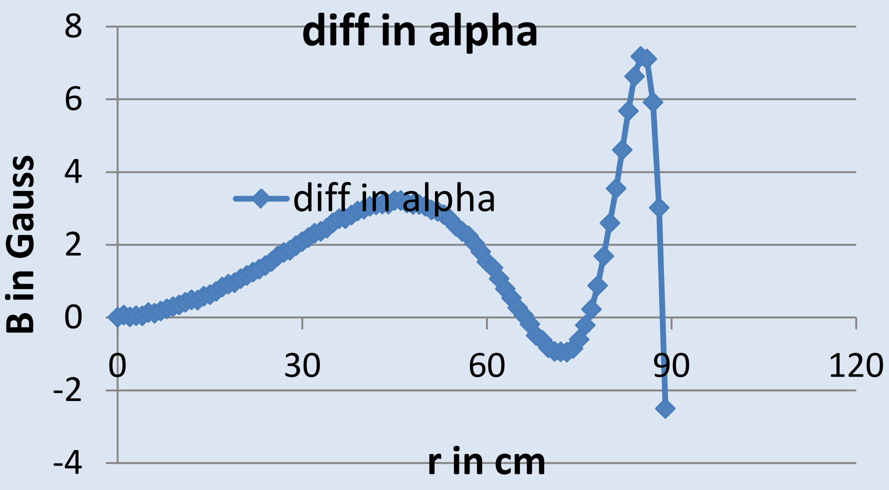




Study of a new superconducting magnet







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

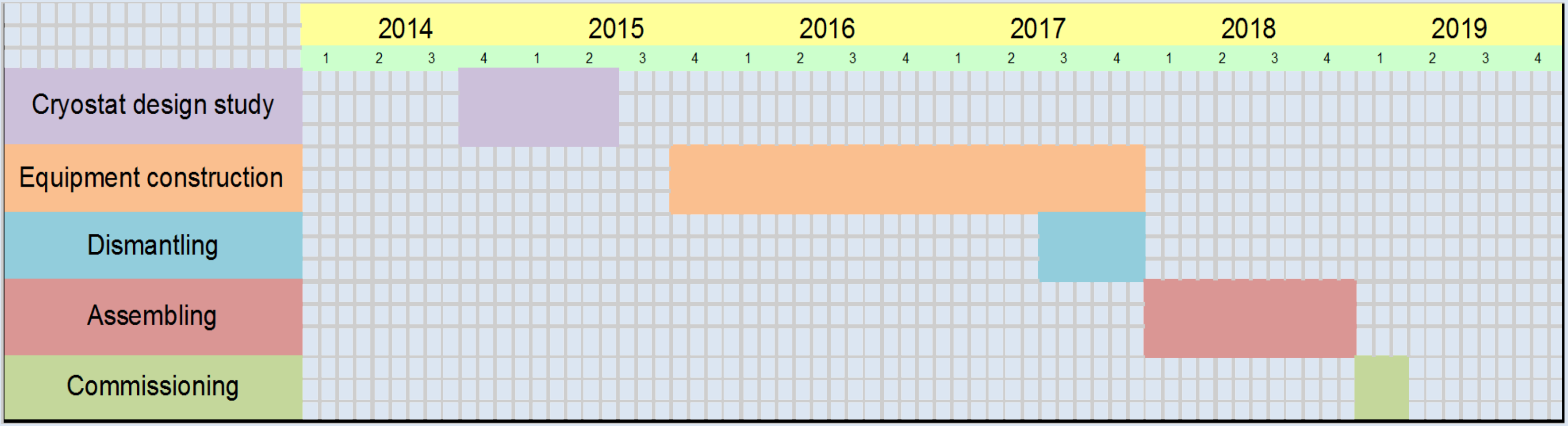
Looking for reliability

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

Roughly estimated cost

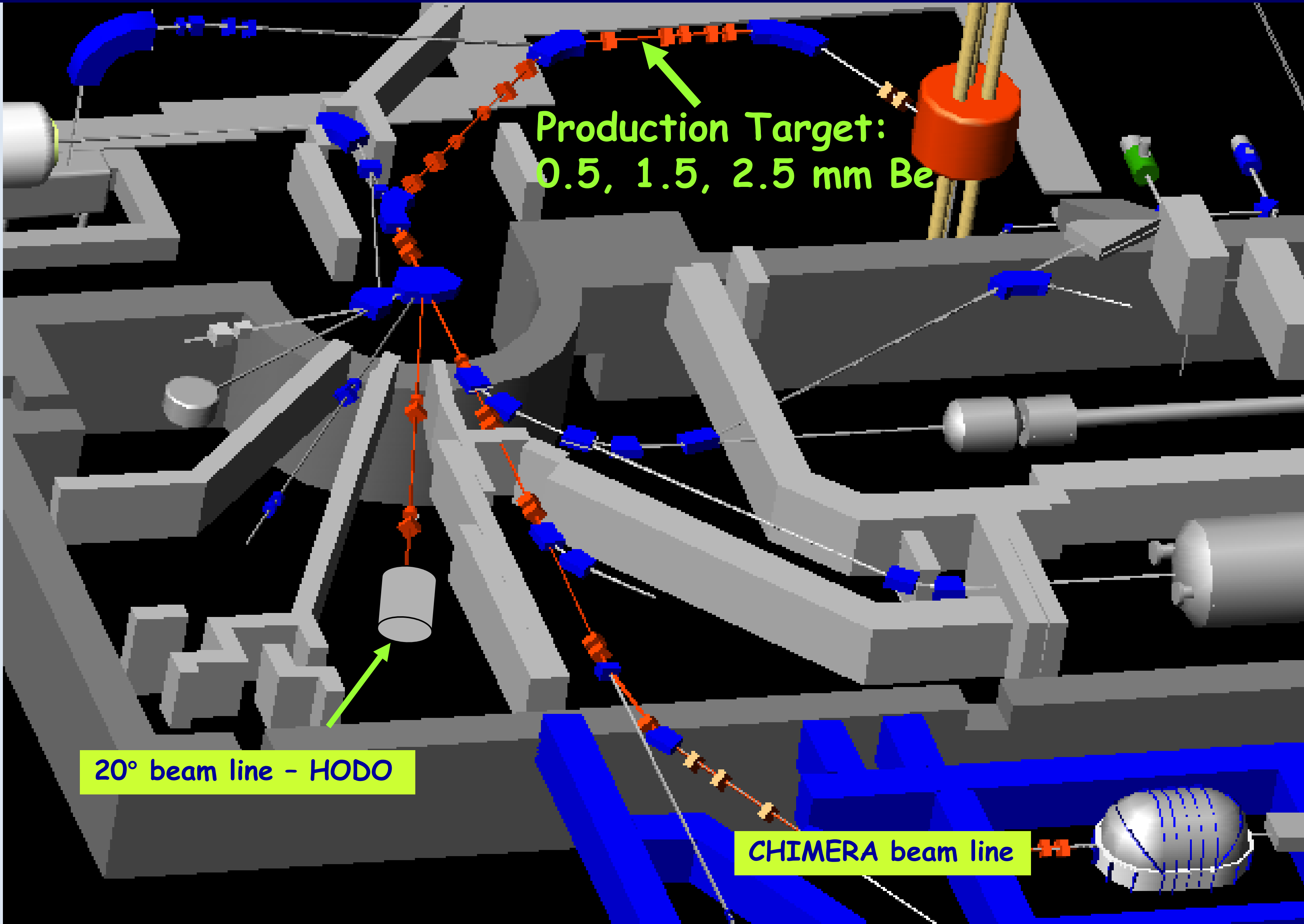
Superconducting magnet	5.4 M€
“Intensity” equipment	2.2 M€
“Reliability” equipment	4.5 M€
Total	12.1 M€

Estimated time



	Start	End
Cryostat design study	09/2014	06/2015
Equipment construction	10/2015	12/2017
Dismantling	07/2017	12/2017
Assembling	01/2018	12/2018
Commissioning	01/2019	04/2019

FRIBS@LNS: in Flight Radioactive Ion BeamS



Beams developed at FRIBS@LNS

primary beam	beam	intensity (kHz/100W)
18O 55 AMeV	16C	120
setting 11Be	17C	12
	13B	80
	11Be	20
	10Be	60
	8Li	20
18O 55 AMeV	14B	3
setting 12Be	12Be	5
	9Li	6
	6He	12
13C 55 AMeV	11Be	50
setting 11Be	12B	100
36Ar 42 AMeV	37K	100
setting 34Ar	35Ar	70
	36Ar	100
	37Ar	25
	33Cl	10
	34Cl	50
	35Cl	50
20Ne 35 AMeV	18Ne	50
setting ne18	17F	20
	21Na	100
70Zn 40 AMeV		
setting 68Ni	68Ni	20

Beams to be delivered in 2014-2015 to approved experiments

^{16}C (CHIMERA)

^{68}Ni (CHIMERA)

^{8}He (CHIMERA) new

^{14}Be (test experiment) new

^{38}S (MAGNEX) new

Thank you