Beta Beam RCS Design Status

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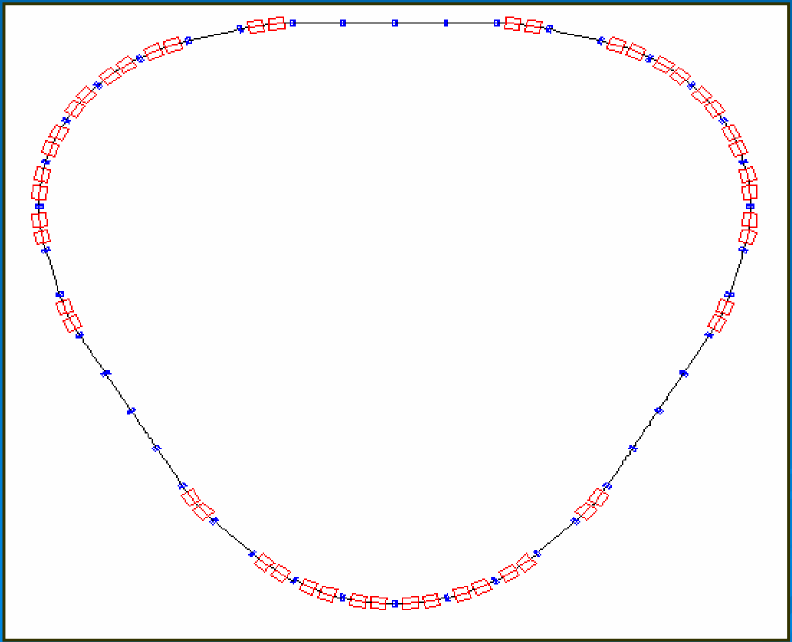
Programme

- Updated parameter list
  (general, optics, magnets, RF)
- Eddy current effects and chromaticity correction
- Field error tolerances and closed orbit correction
- Multiturn injection
- Fast extraction
- Conclusion

Update parameter list (General)

EURISOL

Injection energy	100 MeV/u
Extraction energy	3.5 GeV eq. Proton
Maximum rigidity	14.47 T.m
Number of FODO cells	21
superperiodicity	3
Repetition rate	10 Hz
Transition energy γ	4.502
Ring circumference	237.12m
Revolution time at injection	1.85 μs



Two major modifications after recommandations made at the last meeting (GSI 22/06/06) :

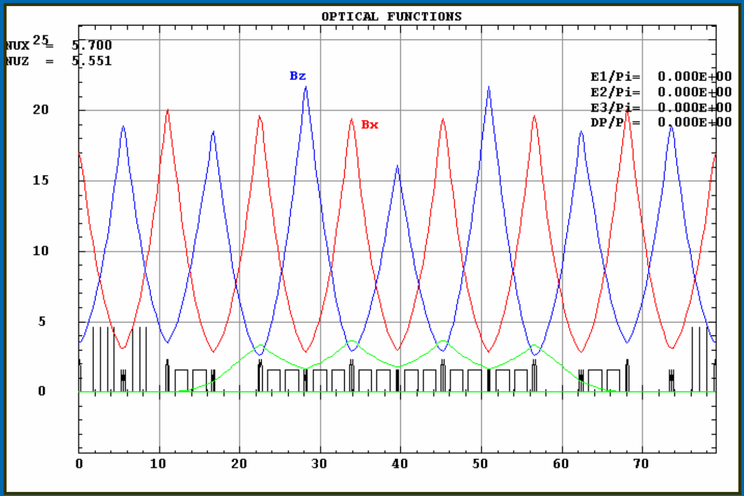
-The ring maximum magnetic rigidity is 14.47 T.m (3.5 GeV proton eq.)

-Dipole magnets have been splitted into two parts separated by a drift space allowing installation of collimators/absorbers for decay products. Dipoles are C-shaped like in light sources in order to get rid of problems due to Ne decay.

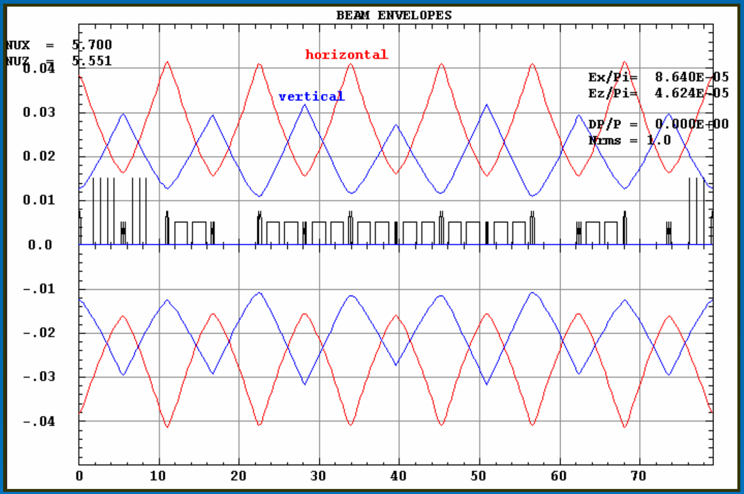
Updated parameters (Optics)

EURISOL

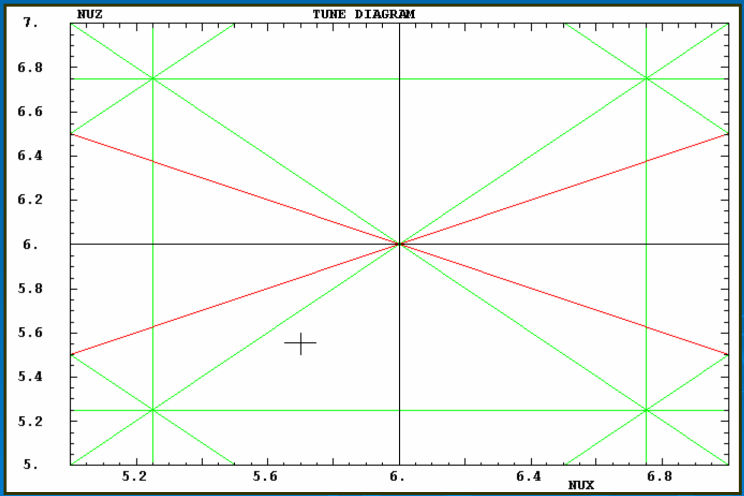
Tunes (H, V)	5.7 5.551
Maximum beta functions (H,V)	22m 20m
Natural chromaticities (H,V)	-1.16 -1.22
Momentum compaction	0.0493
Transtion gamma	4.502
RMS emittances at injection (H,V)	21.6 π.mm.mrad 11.5 π.mm.mrad



Beta functions



Beam envelopes at injection



Tune diagram

Betatron phase advances per FODO cell have been chosen to obtain a working point which avoids low order resonances and to cancel the dispersion function in straight sections with only 2 quadrupole families.

Updated parameters (Magnets)

EURISOL

Dipoles (C-shaped)

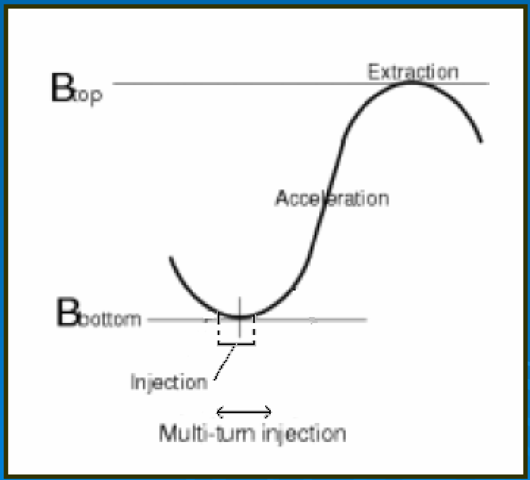
Number	48
Bending radius	12.53 m
Lenght	1.64 m
Maximum field	1.155 T
Gap	100 mm
Time variation	Biased sinusoidal ramp
Field at injection	0.3544 T (He) 0.2126 T (Ne)

Quadrupoles

Number	42
Lenght	0.4 m
Bore diameter	110 mm
Maximum gradient	11 T\m

Time variation of dipole magnetic field

$$B(t) = 0.7546 - 0.4 \cos 20 \pi t \quad (He)$$
$$B(t) = 0.6837 - 0.4711 \cos 20 \pi t \quad (Ne)$$



Magnetic cycle

Updated parameters (RF)

Acceleration

Frequency swing	0.5 to 1.2 MHz
Harmonic number	h=1
Longitudinal beam emittances	1 eV.s (He) 2 eV.s (Ne)
Peak accelerating voltage (constant bucket area $A=3.5\varepsilon_L$)	90 KV (He) 100KV (Ne)
Maximum synchronous phase (constant bucket area $A=3.5\varepsilon_L$)	60° (He) 75° (Ne)

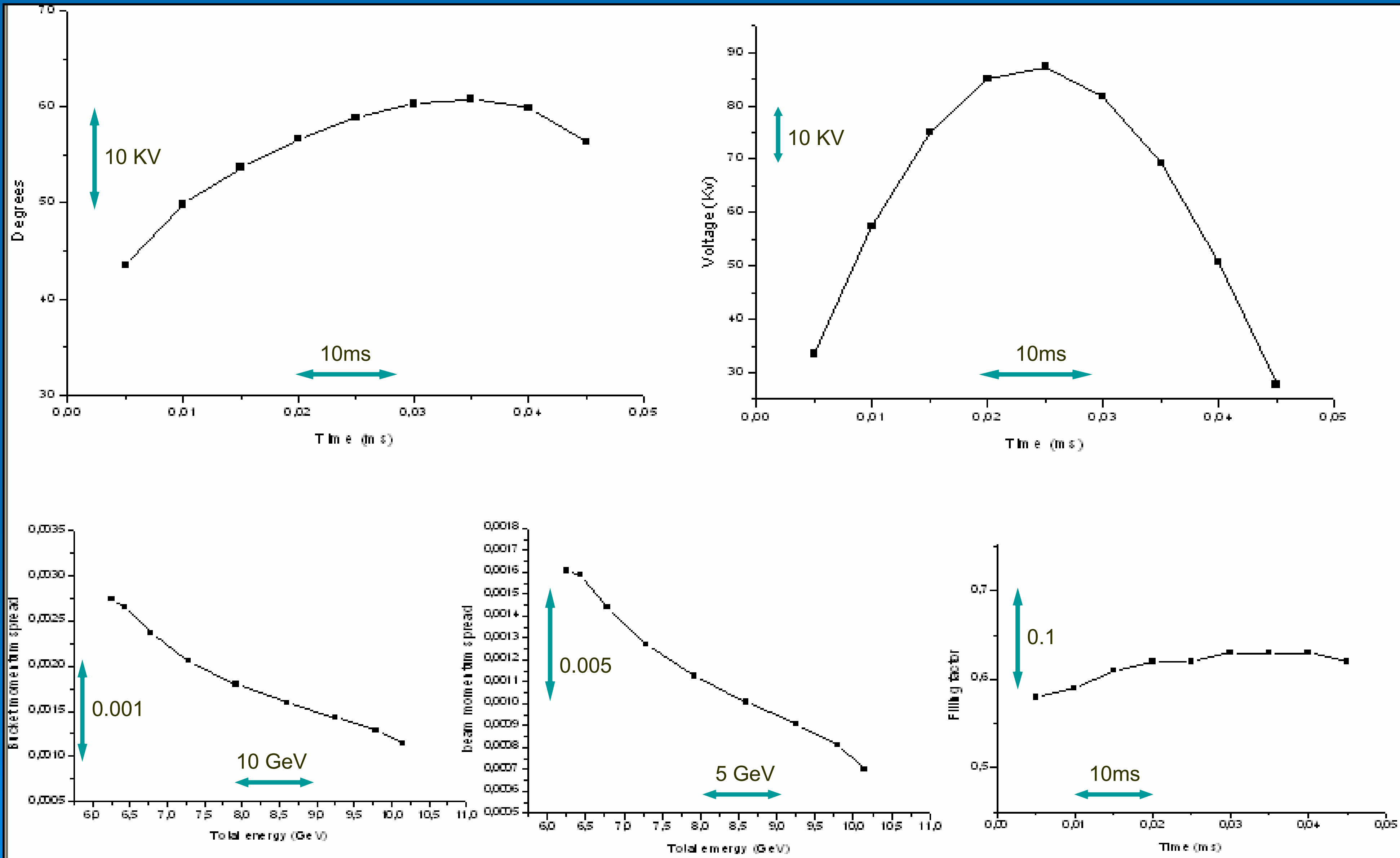
Number of cavities and length required in straight sections for their installation have to be defined according to the state of the art in RF technology.

Preliminary acceleration parameters 1/2

EURISOL

$^{6}He^{2+}$

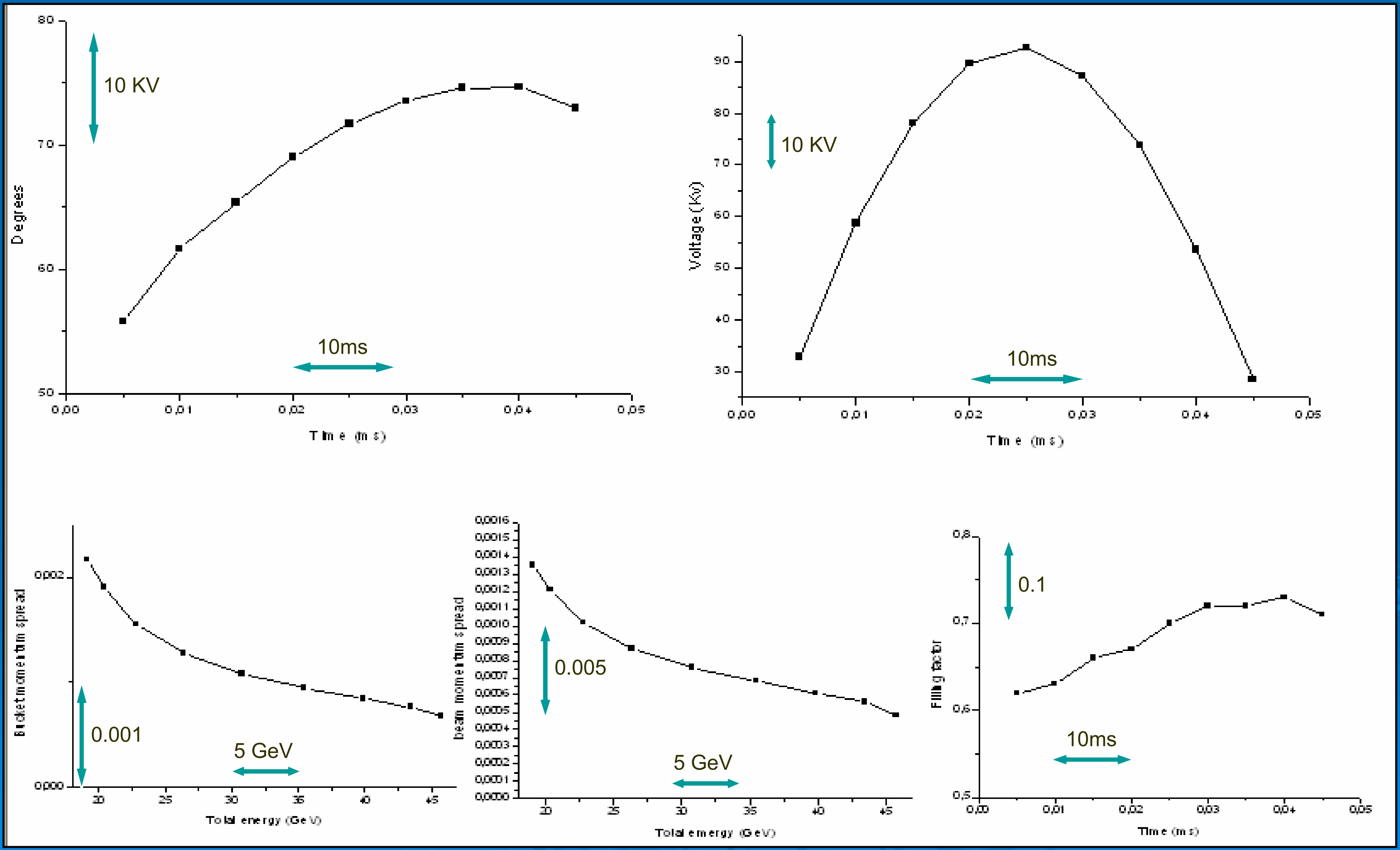
Constant bucket area, h=1



Preliminary acceleration parameters 2/2

$^{18}Ne^{10+}$

Constant bucket area, h=1



Eddy currents effects and chromaticity correction

EURISOL

Time varying fields in RCS magnets induce eddy currents in metallic vacuum chambers which in turn produce various multipole fields acting on the beam.

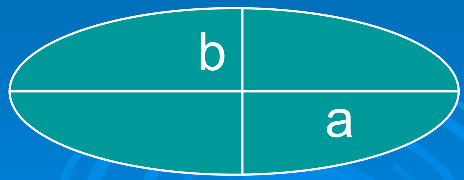
Sextupolar component generated in dipole vacuum chamber.

Assuming an elliptic chamber (there is no big difference with a rectangular chamber) the strength of the generated sextupolar field is given by :

$$m = \frac{1}{2B\rho}\frac{\partial^2 B_z}{\partial x^2} = \frac{\mu_0 \sigma e}{h}\frac{\dot{B}}{B\rho}J(\frac{b}{a})$$

- μ_0 = vacuum permeability
- σ = metallic chamber conductivity
- e = chamber thickness (0.3 mm)
- h = dipole gap

$$J(\frac{b}{a}) = \int_0^{\frac{\pi}{2}} sin\phi\sqrt{cos^2\phi + (\frac{b}{a})^2 sin^2\phi}\, d\phi$$

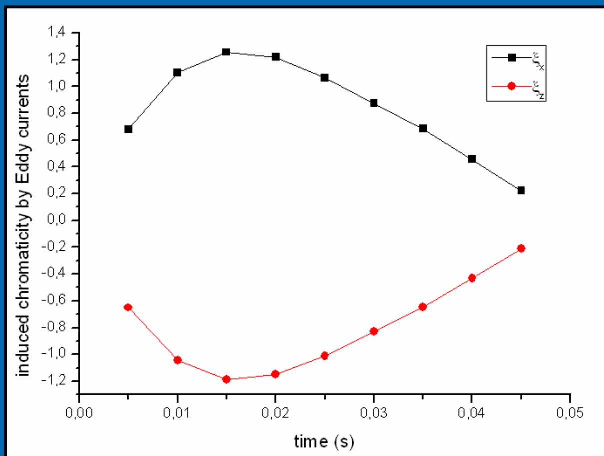


Eddy currents effects and chromaticity correction

EURISOL

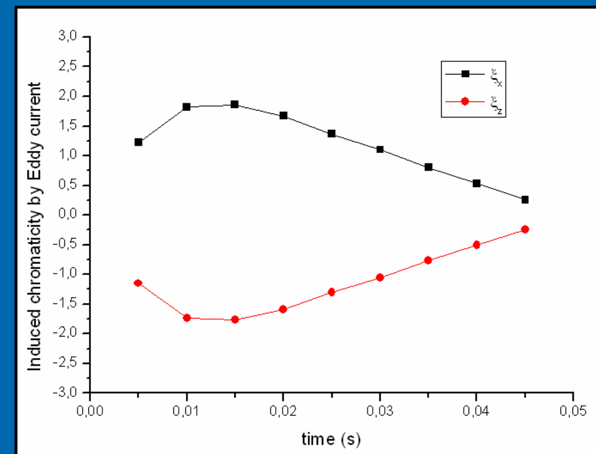
The eddy current sextupole modifies the ring natural chromaticity. In the horizontal plane the chromaticity is compensated while it becomes more negative in the vertical plane.

$^{6}He^{2+}$

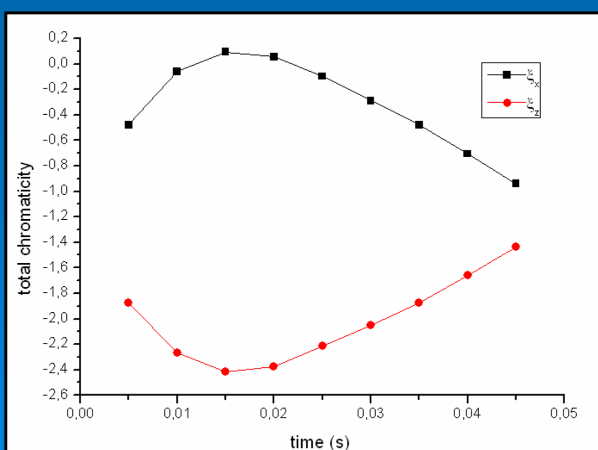


Variation of the induced chromaticity during the ramping

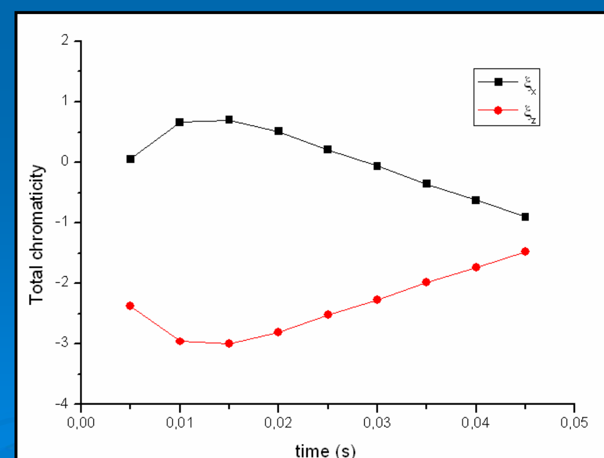
$^{18}Ne^{10+}$



Variation of the induced chromaticity during the ramping



Variation of the total chromaticity during the ramping



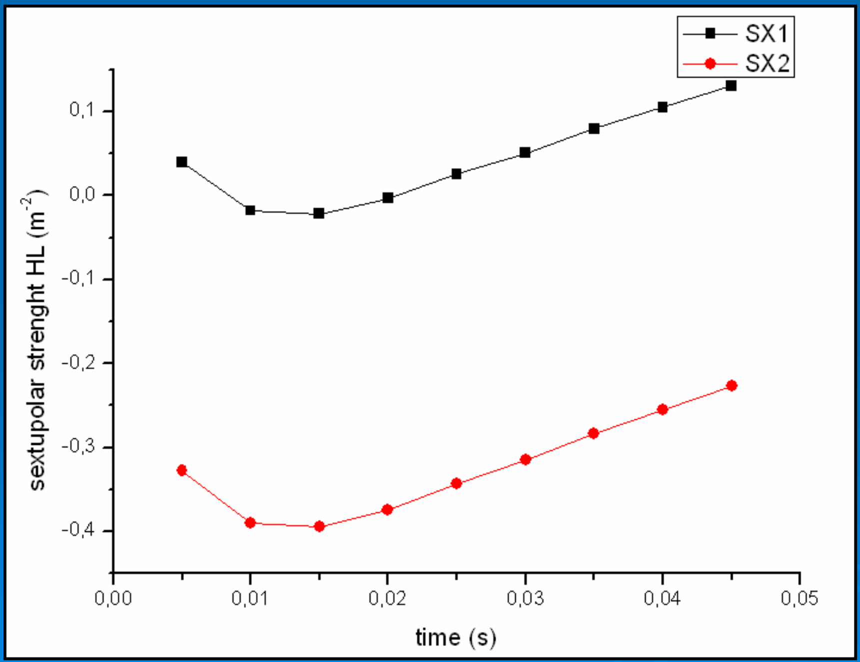
Variation of the total chromaticity during the ramping

Eddy currents effects and chromaticity correction

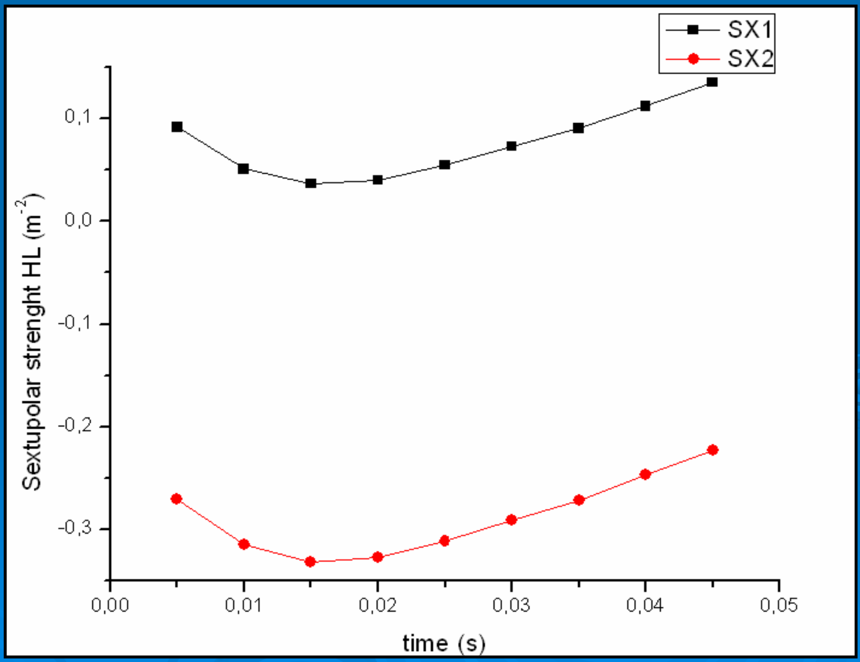
Natural and eddy current induced chromaticities are compensated for by 18 sextupoles magnets (two families) located in dispersive sections of the ring.

Required sextupole strength during the magnetic cycle are summarized in the following figures :

$^{6}\mathrm{He}^{2+}$



$^{18}Ne^{10+}$



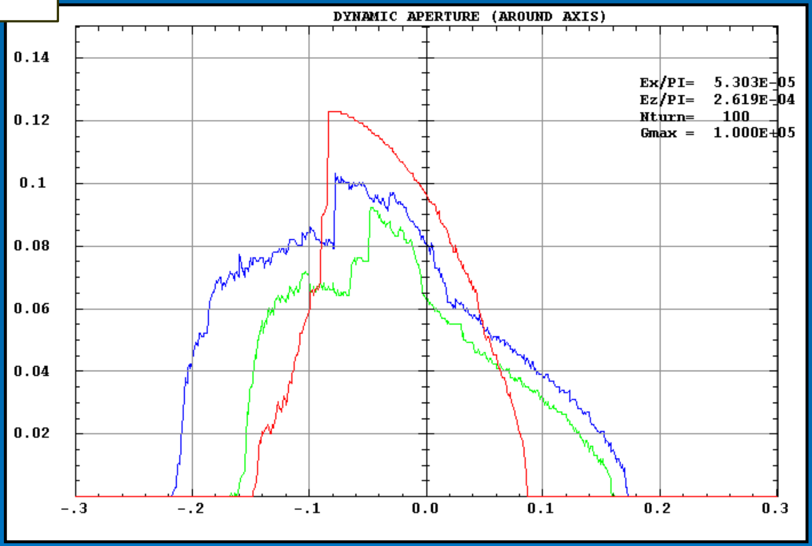
Eddy currents effects and chromaticity correction

EURISOL

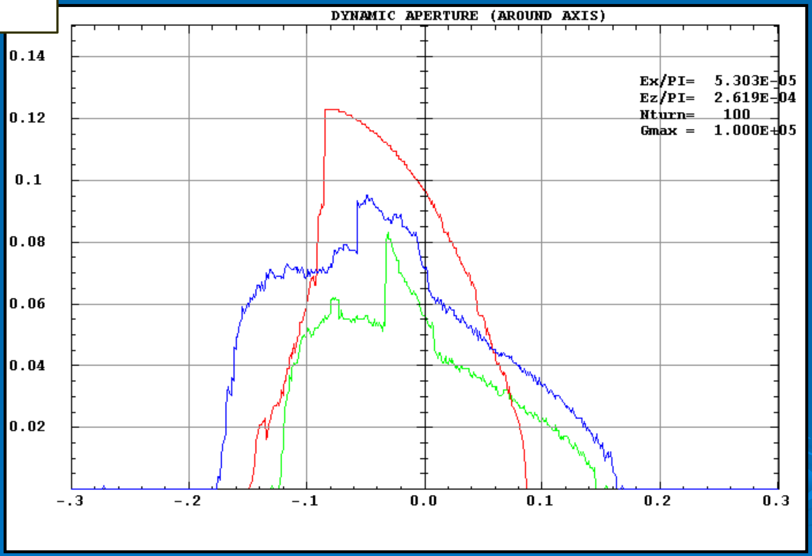
Chromaticity sextupoles introduce non linear perturbations which affect particle motion in the ring (nonlinear resonances excitation, tune variation with amplitude, dynamic aperture limitation).

In order to test our chromaticity correction scheme, the ring dynamic aperture has been calculated with the BETA code.

$^{6}He^{2+}$



$^{18}Ne^{10+}$



As expected (sextupole strength is greater in vertical plane than in horizontal plane) vertical dynamic aperture is reduced while horizontal dynamic aperture is increased

Eddy currents effects and chromaticity correction

EURISOL

Quadrupolar component induced in quadrupole vacuum chamber.

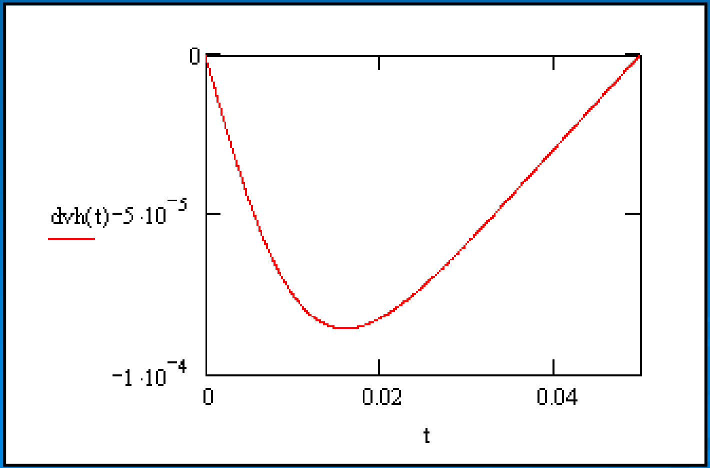
Assuming a circular chamber of radius r, the induced relative gradient change ΔG/G
Is given by :

$$\frac{\Delta G}{G} = -\frac{7}{16}\mu_0 \sigma e \bar{r} \frac{\dot{B}_z}{B_z}$$

The tune variation is thus :

$$\Delta \upsilon = \frac{1}{4\pi}\int \beta \Delta K ds$$

Negligible as shown below



Tune variation for one quadrupole during the magnetic field cycle

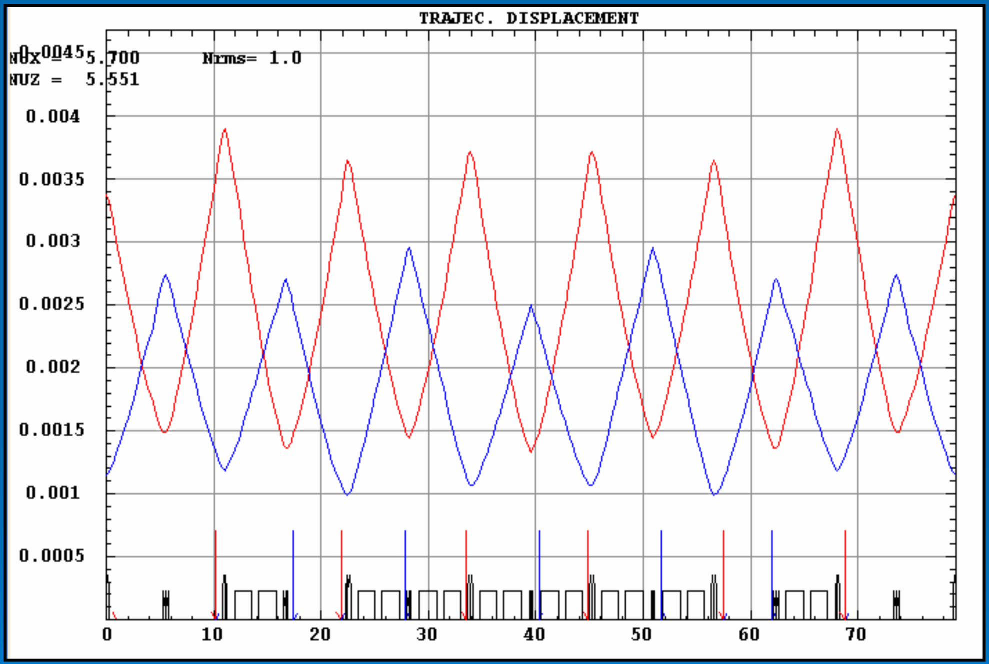
Peak tune variation for one quadrupole is very small

→ The sum of all quadrupole contribution is negligible (less than $0.5*10^{-2}$)

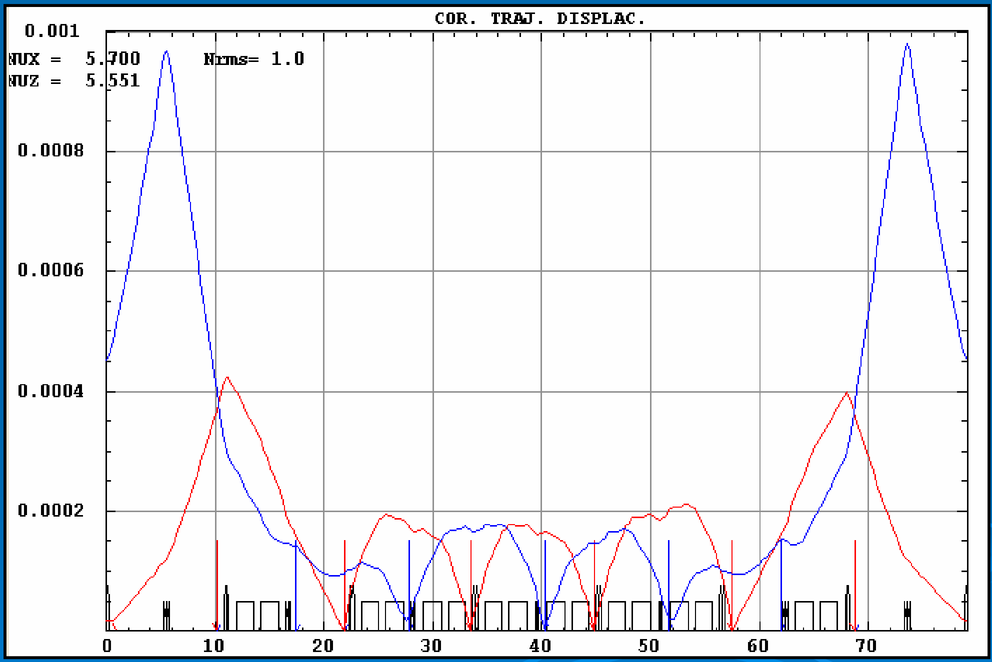
Field errors tolerances and closed orbit correction

EURISOL

Statistical calculation of closed orbit distortions made with the code BETA. Main sources of errors are quadrupoles (0.2mm rms) and bending magnets (1mm rms) misalignments and bending magnets field errors (1E-03 rms).
6 horizontal and 5 vertical correctors coupled with 9 horizontal and 7 vertical BPM per period are used for the COD correction.



Closed orbit before correction



Closed orbit after correction

Multiturn Injection

EURISOL

Septum wall (m)	0.0415 (1.5 π.mm.mrad)
Initial kick in injection bumpers dipoles (mrad)	3.37
Injection bump collapse (turn)	37
Injection efficiency	82% (1.5 π.mm.mrad)

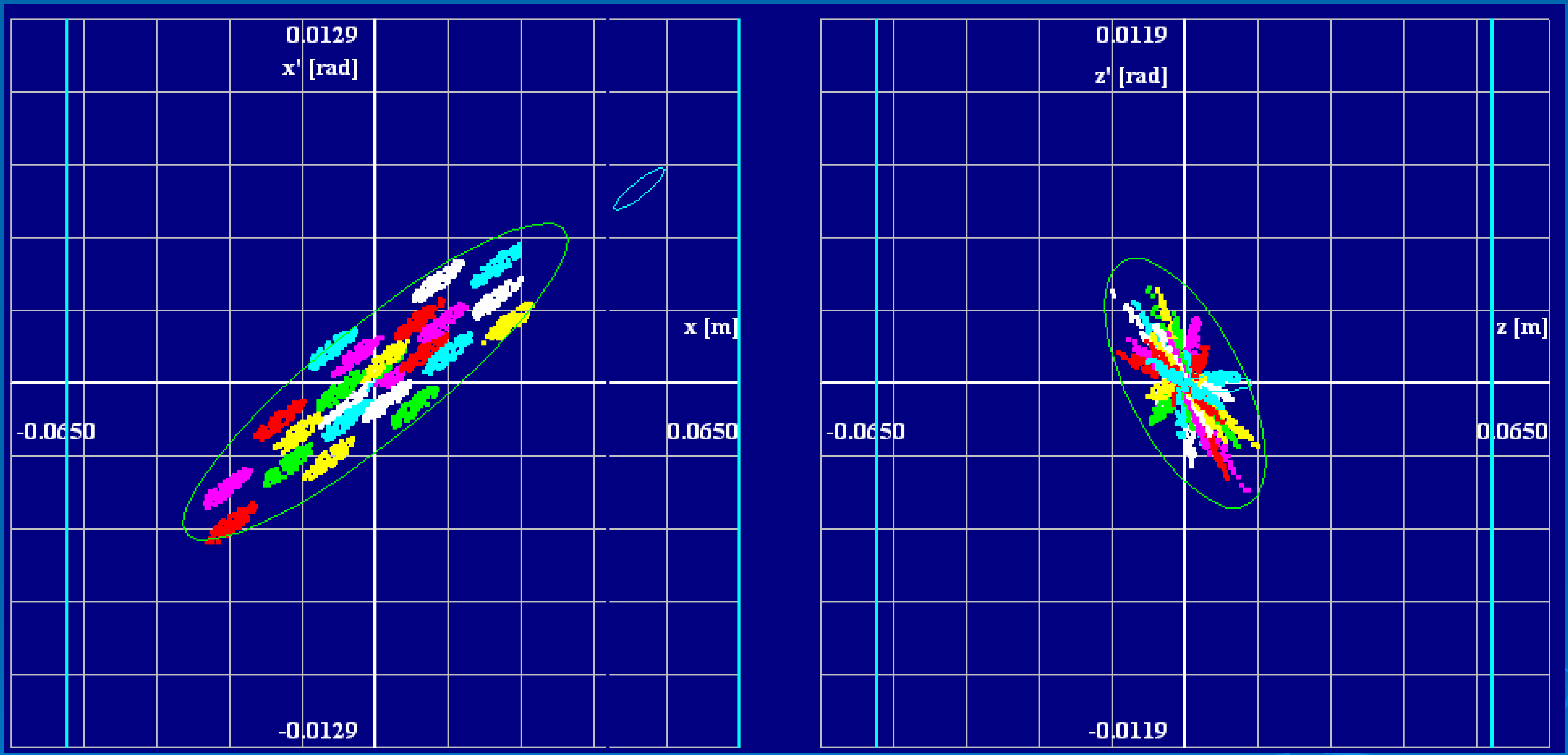
Incoming beam

Horizontal beta fonctions (matched to ring)	$\beta_x = 13.55m$	$\alpha_x = -1.9906m$
Vertical beta fonctions (mismatched to ring)	$\beta_z = 21.36m$ (1.5 π.mm.mrad)	$\alpha_z = 0$
Injected beam at exit of septum	X=0.047m Z=0.006m	X'=0.0069 rad Z'=0

Injection line

Electrostatic deflector	L= 1.6m	Θ=17mrad
Septum magnet	L=0.6m	Θ=100mrad
Septum magnet	L=0.8m	Θ=230mrad

Multiturn Injection



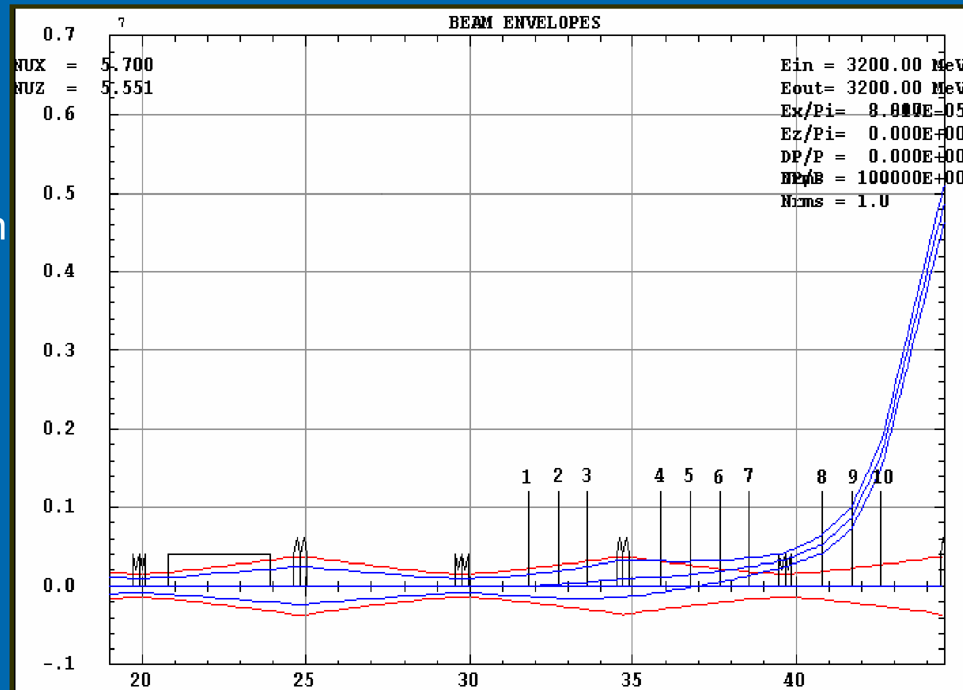
Fast extraction

Extraction system consists of 7 fast kickers and 3 septum magnets.

The kicker layout is designed to produce sufficient separation between the circulating and the extracted beams.

Then septum magnets produce the needed deviation angle to eject the beam from the ring

	Kick angle (mrad)	Length (m)	Field (T)
1	1.5	0.6	
2	1.5	0.6	
3	1.5	0.6	
4	1.5	0.6	
5	1.5	0.6	
6	1.5	0.6	
7	1.5	0.6	
8	20	0.6	0.482
9	50	0.7	1.03
10	80	0.9	1.29



Extracted beam in blue and injected beam in red

Conclusion

The RCS maximum magnetic rigidity has been increased up to14.47 T.m (3.5 GeV protons).

The lattice has been modified in order to facilitate the installation of the collimation system

Multiturn injection, acceleration and extraction parameters have been updated.

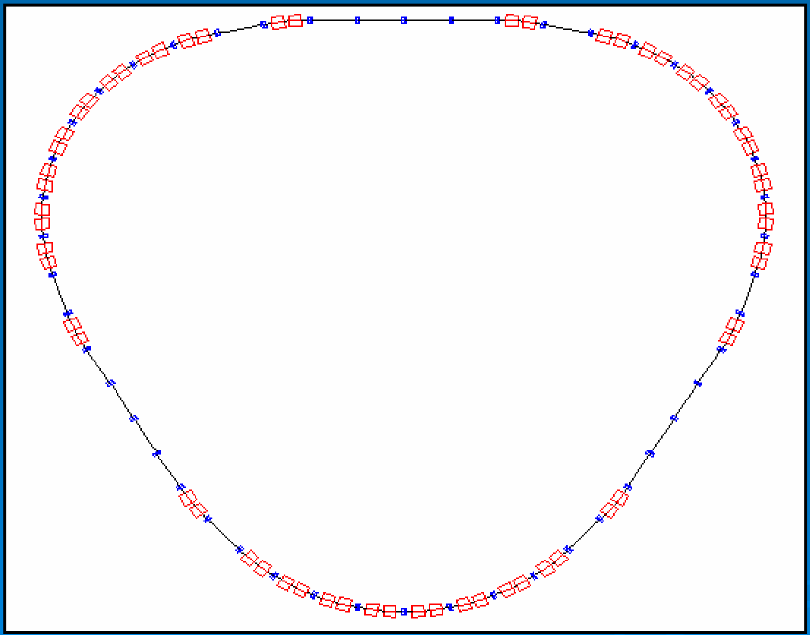
Eddy Currents effects have been investigated.

Alternative solution

Present ring transition gamma : 4.502

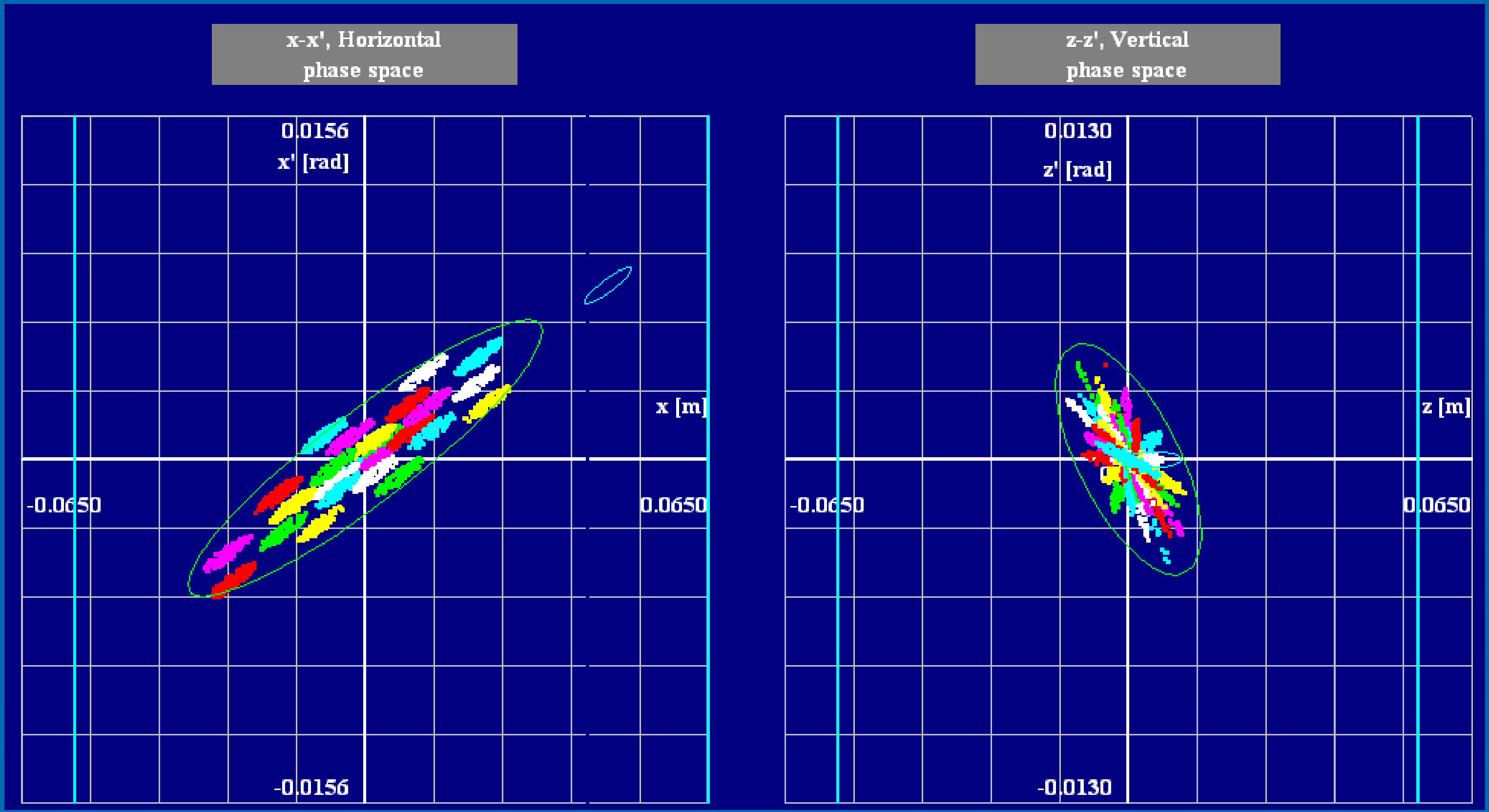
Proton gamma at 3.5 GeV : 4.73

Proton beam acceleration up to 3.5 GeV without transition crossing is possible with a modified lattice having one more FODO cell per superperiod.



Injection energy	100 MeV/u
Extraction energy	3.5 GeV eq. Proton
Maximum rigidity	14.47 T.m
Number of FODO cells	24
superperiodicity	3
Repetition rate	10 Hz
Transition energy γ	5.34
Ring circumference	243.12m
Revolution time at injection	1.9 μs

Alernative solution



No problems for multiturn injection, efficiency of 90%

Updated parameters (general, optics, accélération, corrections) could be presented at the next meeting if necessary