Beta Beam RCS Design Update

A.Lachaize

IPN Orsay, CNRS/IN2P3

3 May 2007, MSL

5th Beta-Beam Task Meeting

Programme

- New RCS parameters
- Multiturn injection, vacuum chamber aperture, fast extraction
- Magnets, eddy current effects and chromaticity correction
- RF acceleration system
- Conclusion

New RCS parameters

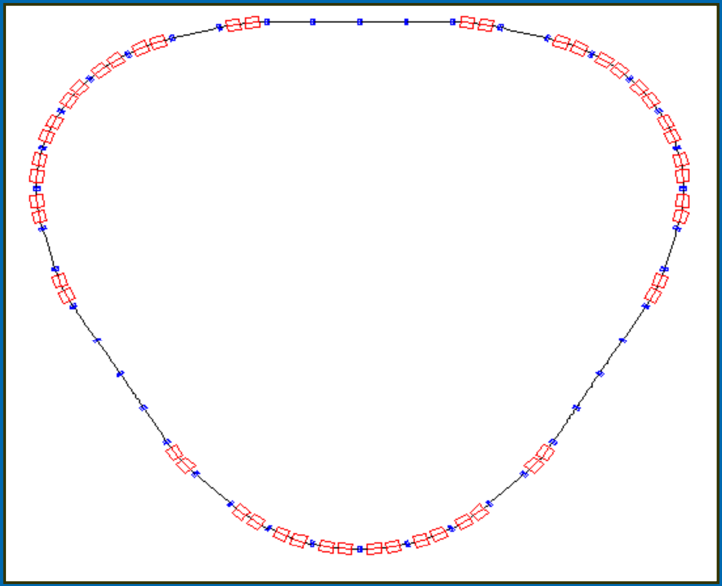
After our last meeting at CERN (30th october 2006) the RCS lattice has been modified once again in order to satisfy two new requirements :

- Potentiality of accelerating protons up to 3.5GeV without transition crossing.
- Adjustement of the physical radius to 40m to facilitate the synchronization between the RCS and the PS.

These requirements have been achieved by increasing the number of dipole magnets (and thus reducing the dispersion function) and by changing the length of straight section by a few percents.

Update parameter list (General)

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	5.35
Ring circumference	251.327m
Revolution time at injection	1.95 µs

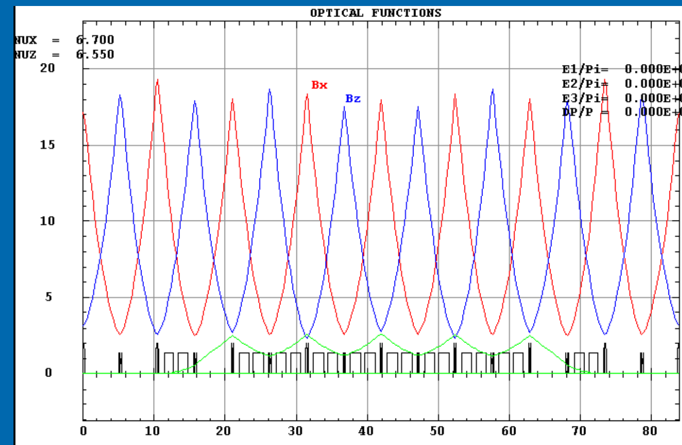


Transition crossing for protons acceleration up to 3.5 GeV is avoided
With the modified lattice having one more FODO celle per superperiod

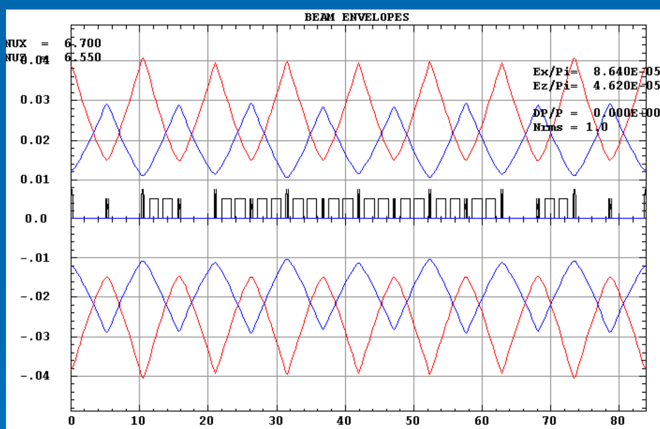
$\rightarrow \gamma t = 5.35$ (Ep = 4.08 GeV)

Updated parameters (Optics)

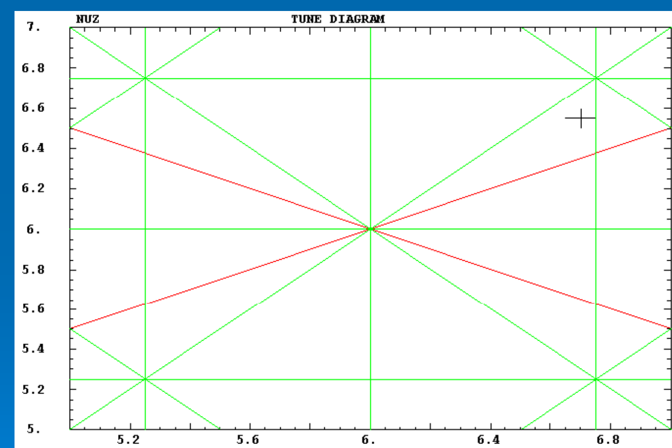
Tunes (H, V)	6.7 6.551
Maximum beta functions (H,V)	19m 18m
Natural chromaticities (H,V)	-1.24 -1.27
Momentum compaction	0.0349
Transtion gamma	5.35
RMS emittances at injection (H,V)	21.6 π.mm.mrad 11.5 π.mm.mrad



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	72
Bending radius	13.369m
Lenght	1.64 m
Maximum field	1.08 T
Gap	100 mm
Time variation	Biased sinusoidal ramp
Field at injection	0.3321T (He) 0.1992 T (Ne)

Quadrupoles

Number	48
Lenght	0.4 m
Bore diameter	110 mm
Maximum gradient	11 T\m

Sextupoles

Max integrated strength H	0.3 m-2
Max integrated strength V	-0.9 m-2

Time variation of dipole magnetic field

B(t) = 0.707233 -0.3751212 cos 20 π t (He)
B(t) = 0.6408104 -0.441544 cos 20 π t (Ne)

Dipolar corectors

Max deviation angle Horizontal correctors	1.8 mrad
Max deviation angle Vertical correctors	1.1 mrad

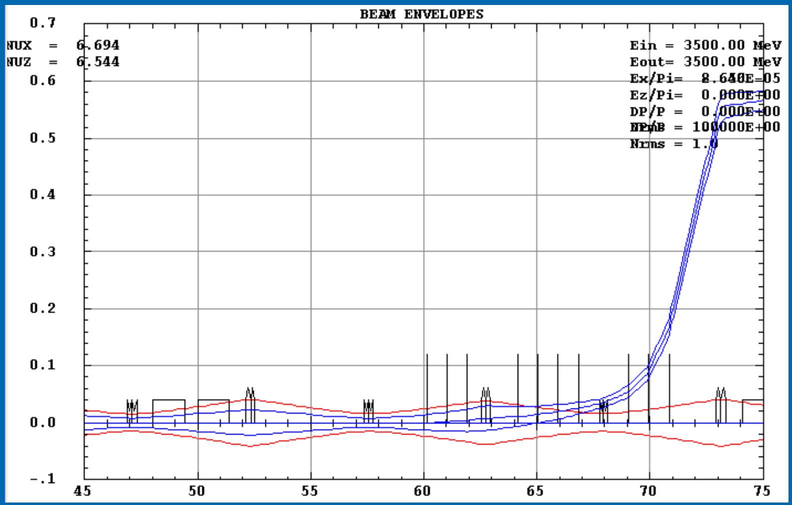
Fast extraction

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	0.619
9	50	0.7	1.04
10	80	0.9	1.29



Extracted beam in blue and injected beam in red

Multiturn Injection

Septum wall (m)	0.0401 (1.5 π.mm.mrad)
Initial kick in injection bumpers dipoles (mrad)	4.2
Injection bump collapse (turn)	37
Injection efficiency	82% (1.5 π.mm.mrad)

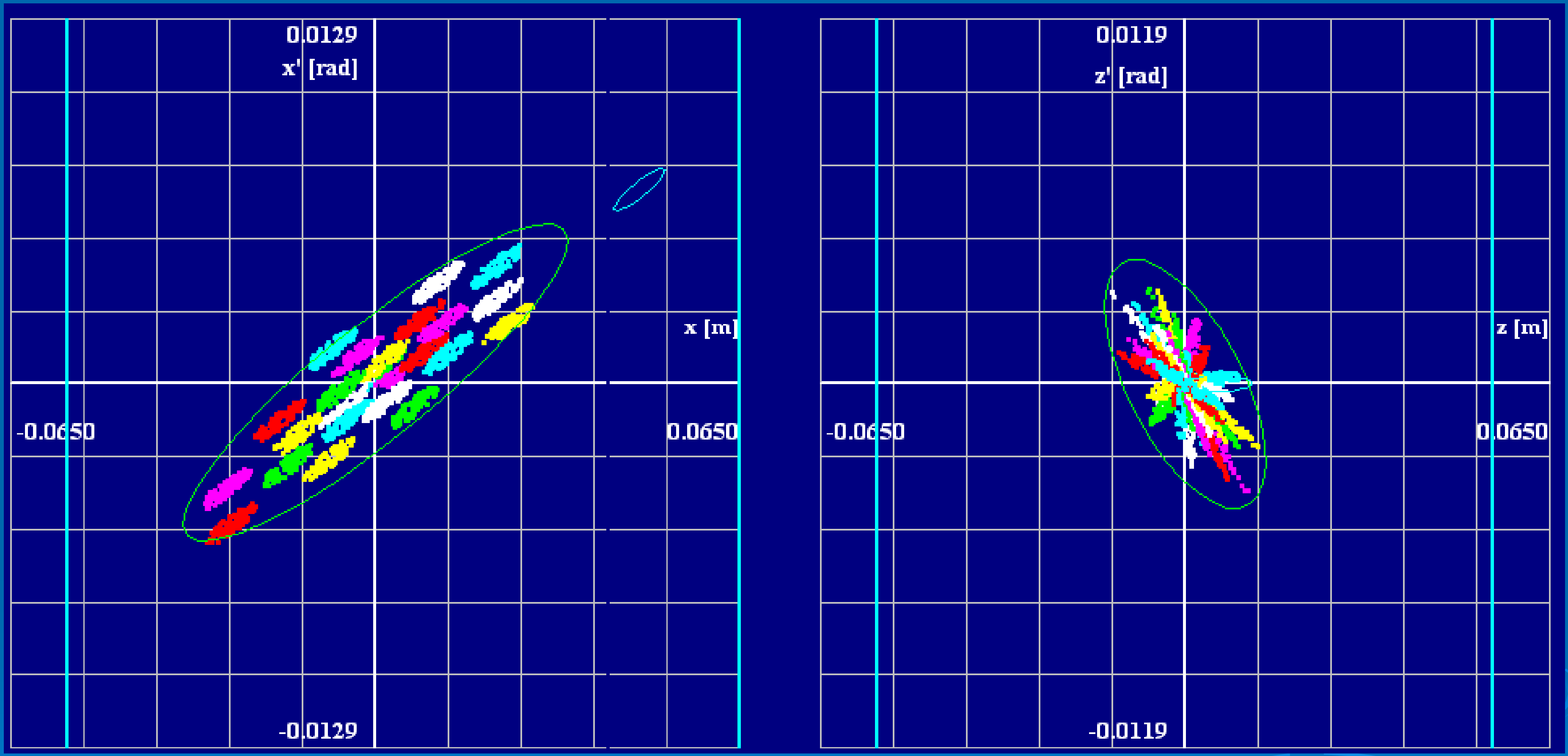
Incoming beam

Horizontal beta fonctions (matched to ring)	$\beta_x = 13.3m$	$\alpha_x = -2.1918m$
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=0.0466m Z=0.005m	X'=0.00763 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



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.

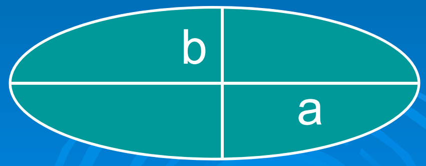
Sextupolar component generated in dipole vacuum chamber.

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

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



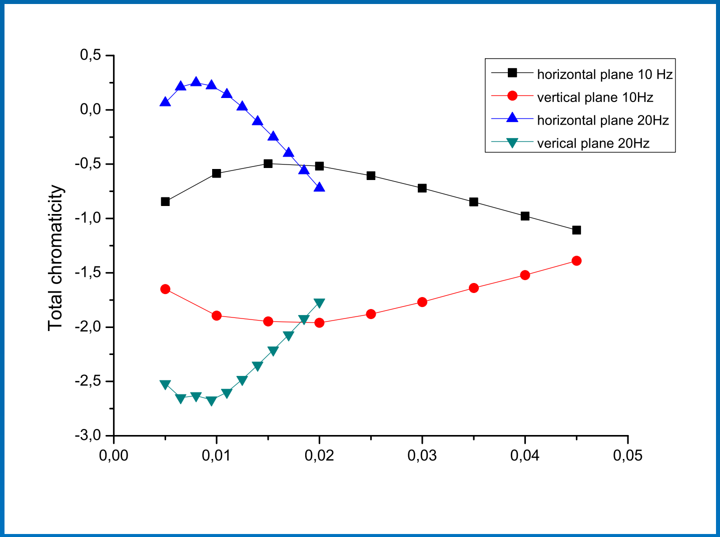
Eddy currents effects and chromaticity correction

EURISOL

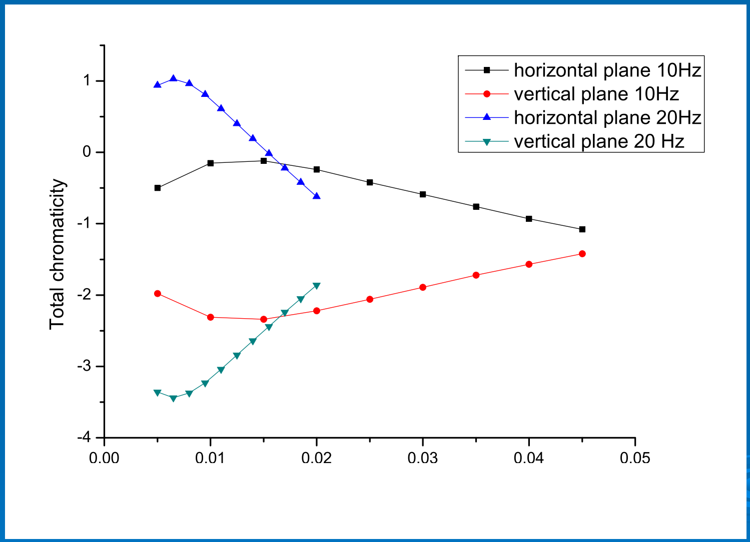
The eddy current sextupole modifies the ring natural chromaticity. In the horizontal plane the chromaticity is compensated while it becomes more negative in the vertical plane.

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

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



Variation of the total chromaticity during the ramping



Variation of the total chromaticity during the ramping

Eddy currents effects and chromaticity correction

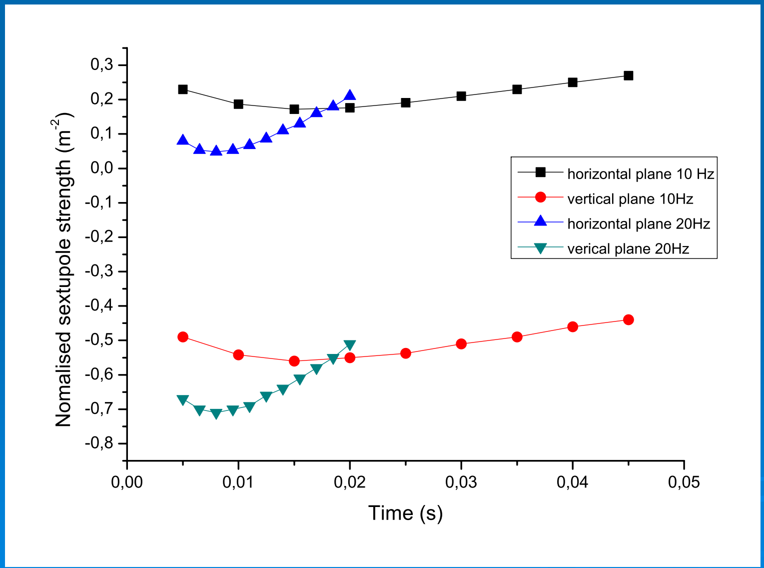
EURISOL

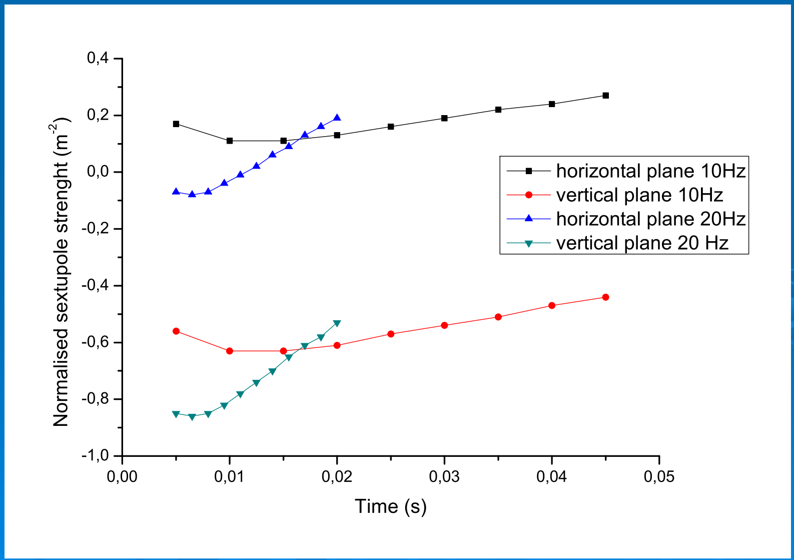
Natural and eddy current induced chromaticities are compensated for by 27 sextupoles magnets (two families) located in dispersive sections of the ring.

Required sextupole strengths during the magnetic cycle are summarized below

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

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



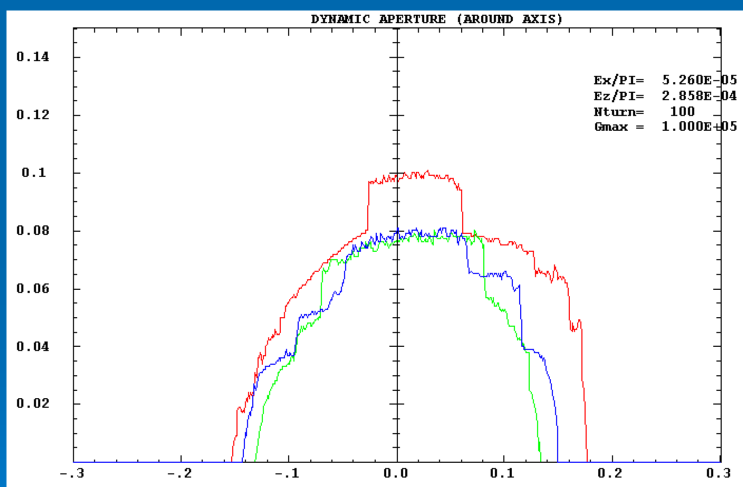


Eddy current effects and chromaticity correction

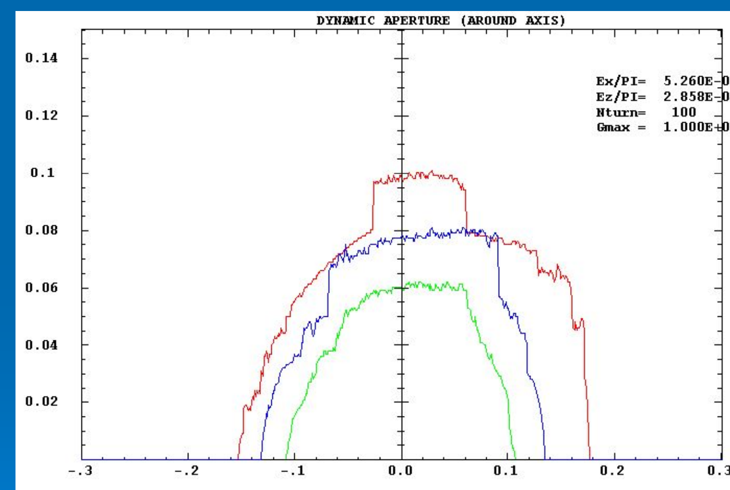
EURISOL

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.

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



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

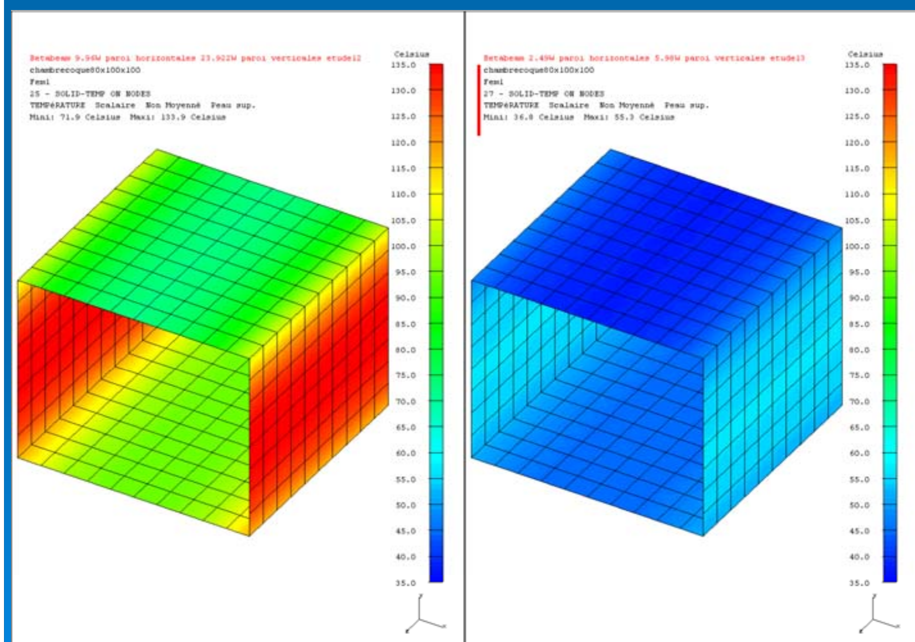


Estimate of eddy current power dissipation

Rectangular chamber 5cm half-width, 4cm half-height, 0.3mm thickness

Highest power dissipation for Ne operation.

Time average dissipated power per unit of length : 87.4W /m at 10Hz for Ne
338.9W /m at 20Hz for Ne



Max chamber temperature :

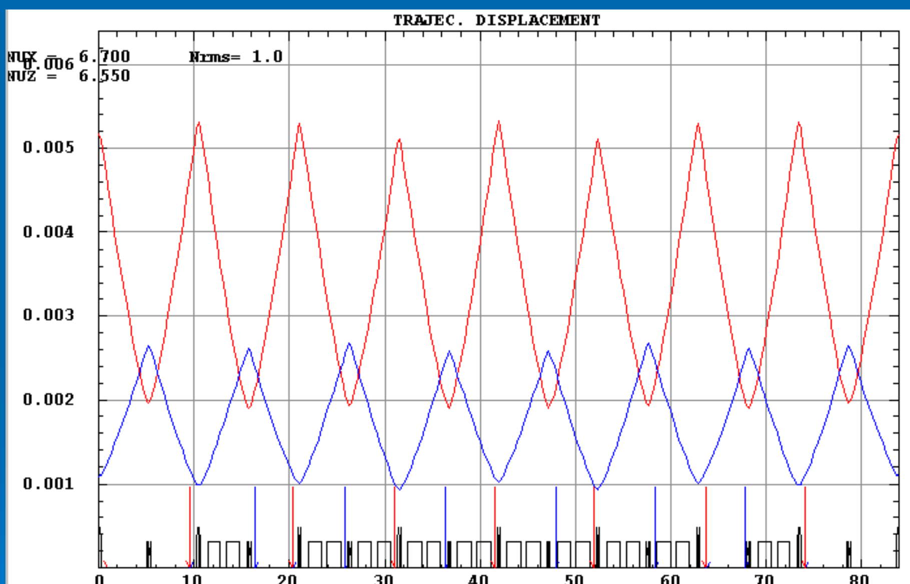
-below 60°C at 10Hz
-above 130°C at 20 Hz !!

Detailed studies on vacuum chamber have to be made to assess the consequences of such temperatures.

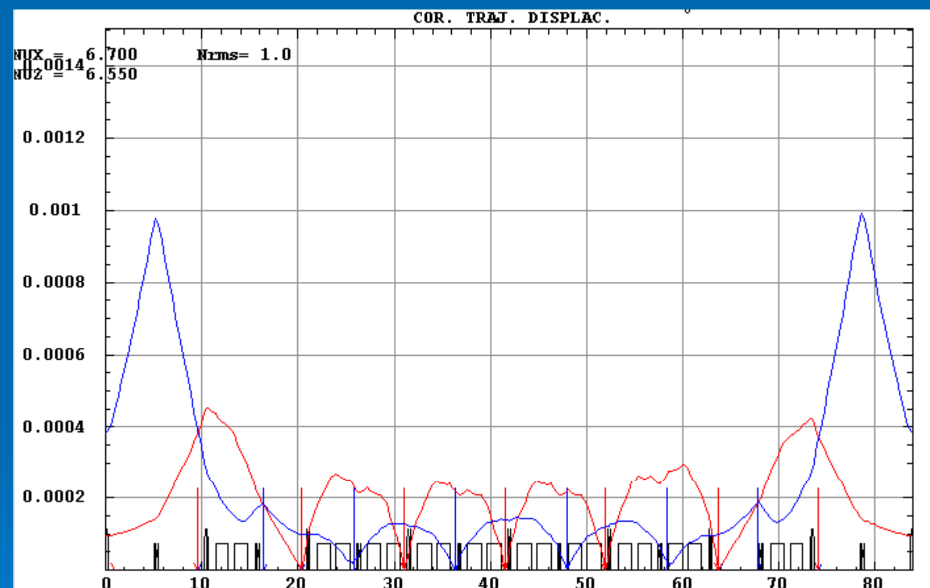
Field error tolerances and closed orbit correction

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).
7 horizontal and 6 vertical correctors coupled with 10 horizontal and 8 vertical BPM per period are used for the COD correction.



Closed orbit before correction



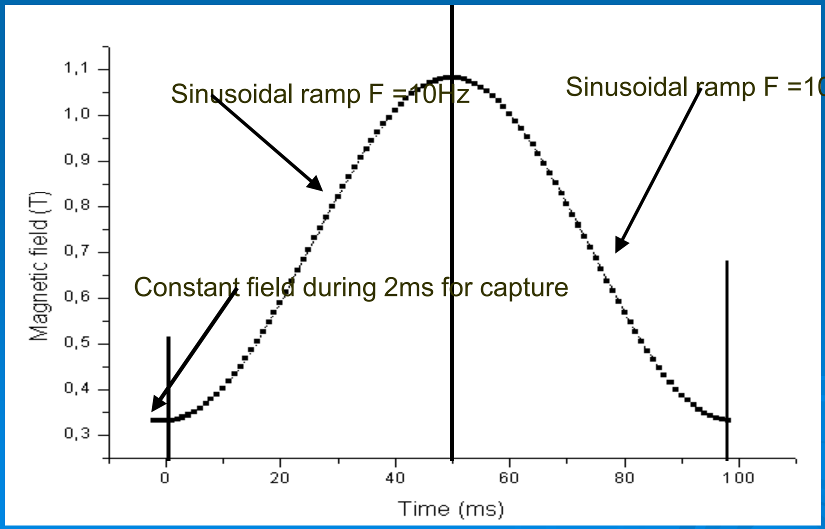
Closed orbit after correction

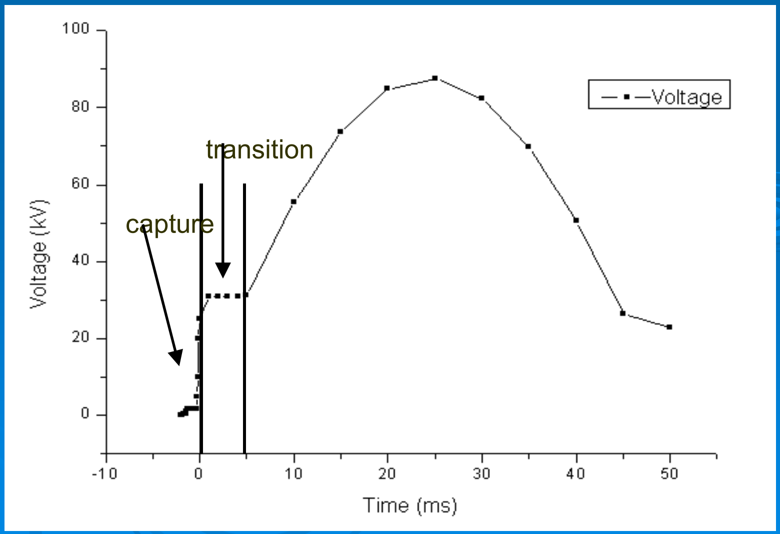
RF simulations

Simulations with ACCSIM during march at CERN for capture and acceleration.
At injection : uniform beam ε_L=0.45 eV.s (dp/p=10^{-4} !)

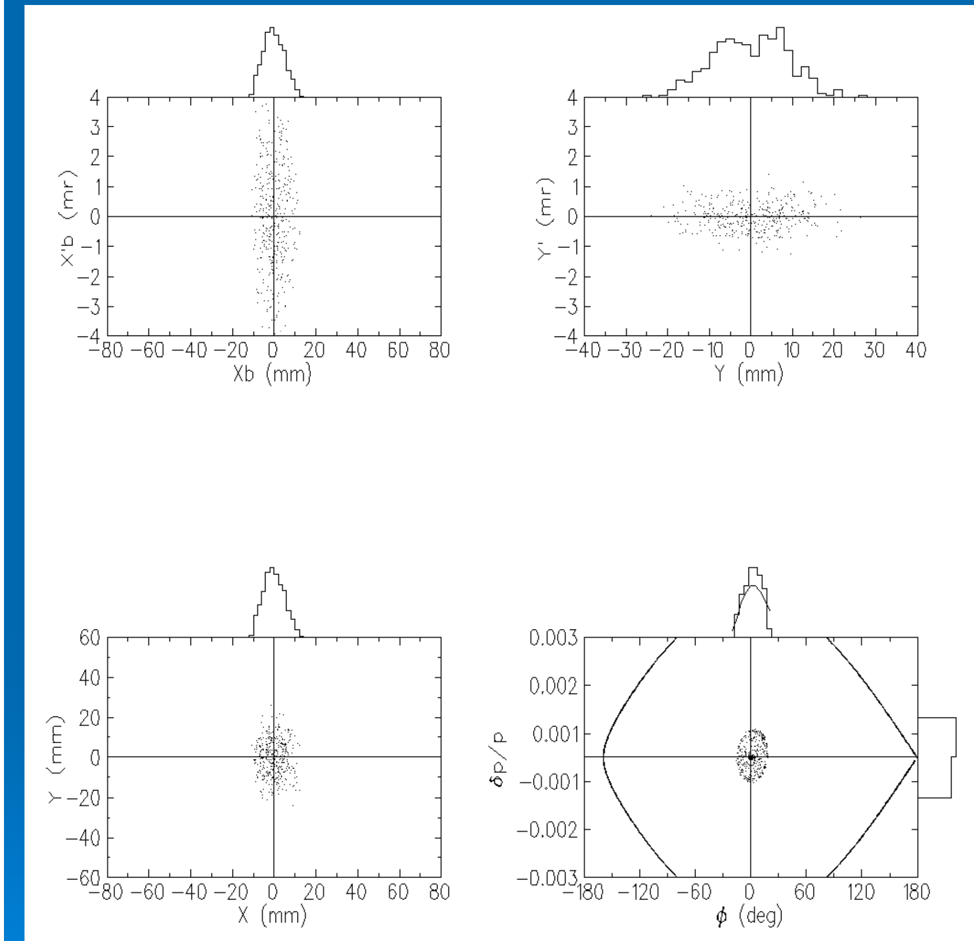
Requirements at extraction : ε_L=0.64 eV.s
V=23 kV

To obtain the required emittance at extraction with good capture efficiency I use a dual-frequency magnetic cycle.





RF cycle simulations



ε_L=0.64 eV.s at extraction

~ 20% losses

Possibility of dual-frequency cycle with high repetion rate has to be confirmed.

Beam momentum spread at injection (10^{-4}) has to be confirmed too.

Cavity performances :

J-parc 2m long 45kV , 0.9 to 1.67 MHz
GSI 2.5m long 40kV , 0.43 to 2.8 MHz

19.2m (4*4.8m) availaible in straight section

➡ Enough length to install 3(6) cavities for 10(20) Hz operation

Conclusion

The RCS maximum magnetic rigidity has been increased up to14.47 T.m (for 3.5 GeV protons) and the ring circumference has been modified.

Multiturn injection, acceleration and extraction parameters have been updated.

Eddy currents effects have been investigated, induced chromaticity correction is not an issue from the point of view of dynamic aperture.