Beta Beam RCS Design Status

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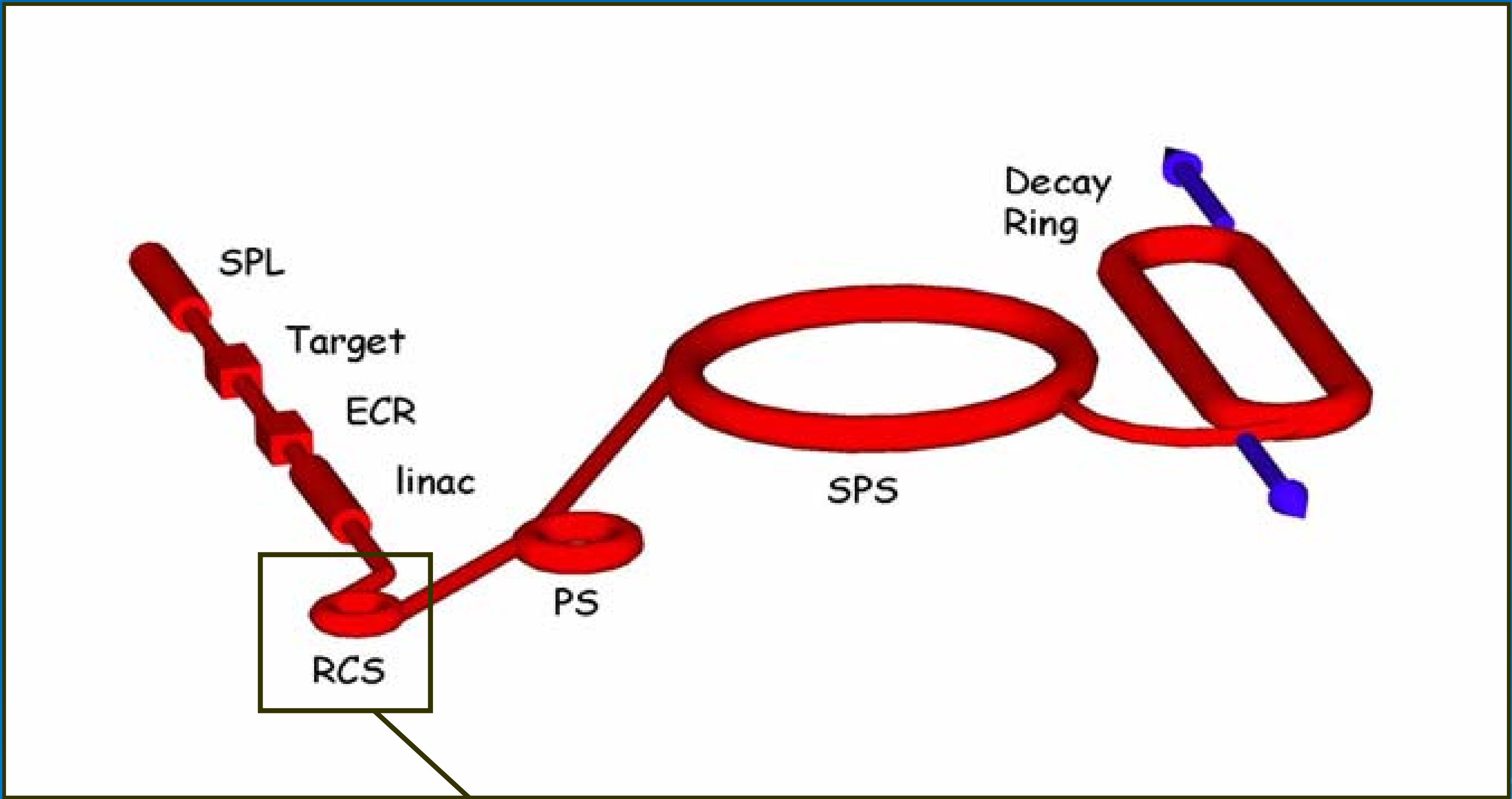
3rd Beta-Beam Task Meeting

Programme

- Overview of proposed new parameters
- Dipole magnetic field cycle and preliminary acceleration parameters
- Closed orbit and chromaticity correction
- Multiturn injection
- Fast extraction
- Conclusion

The Beta-Beam facility



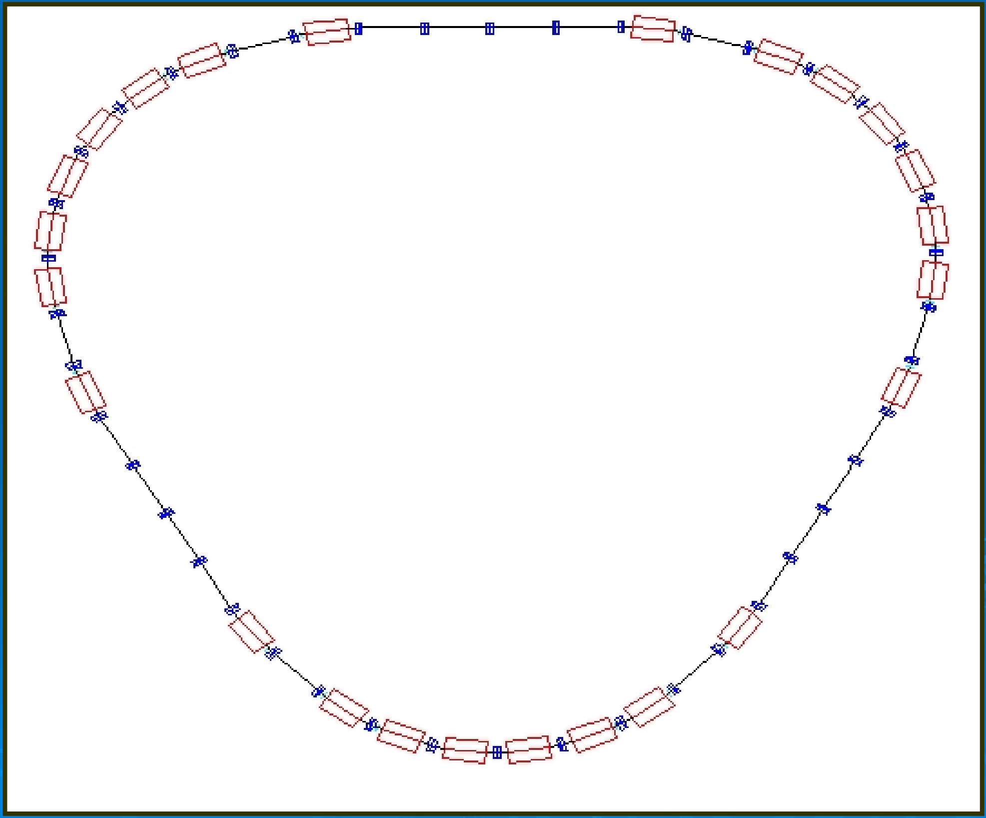
Subject of my talk

Overview of proposed new parameters 1/3

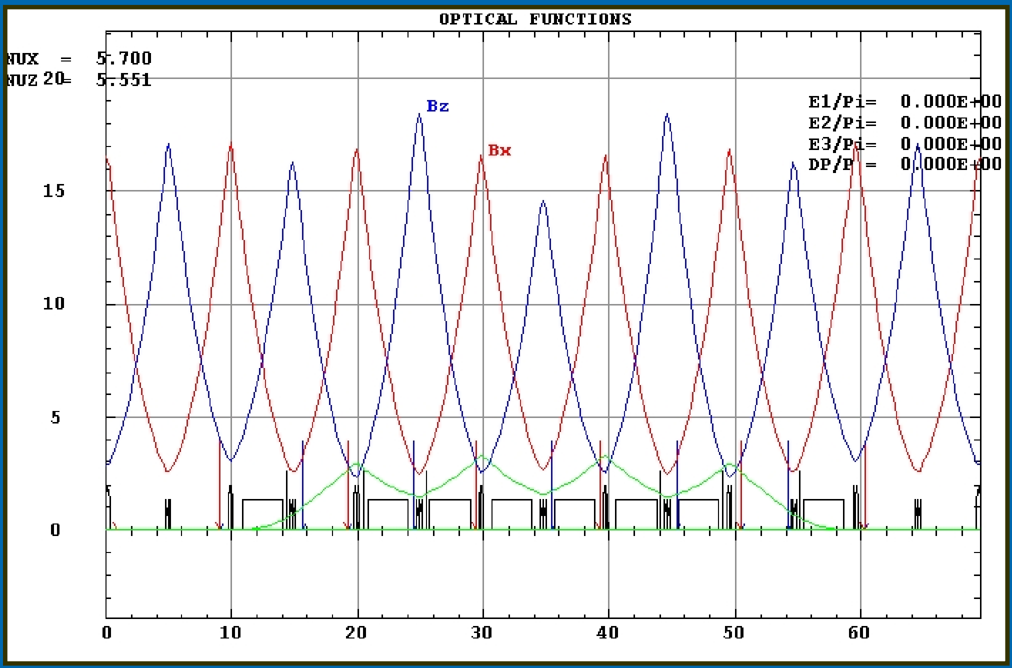
EURISOL

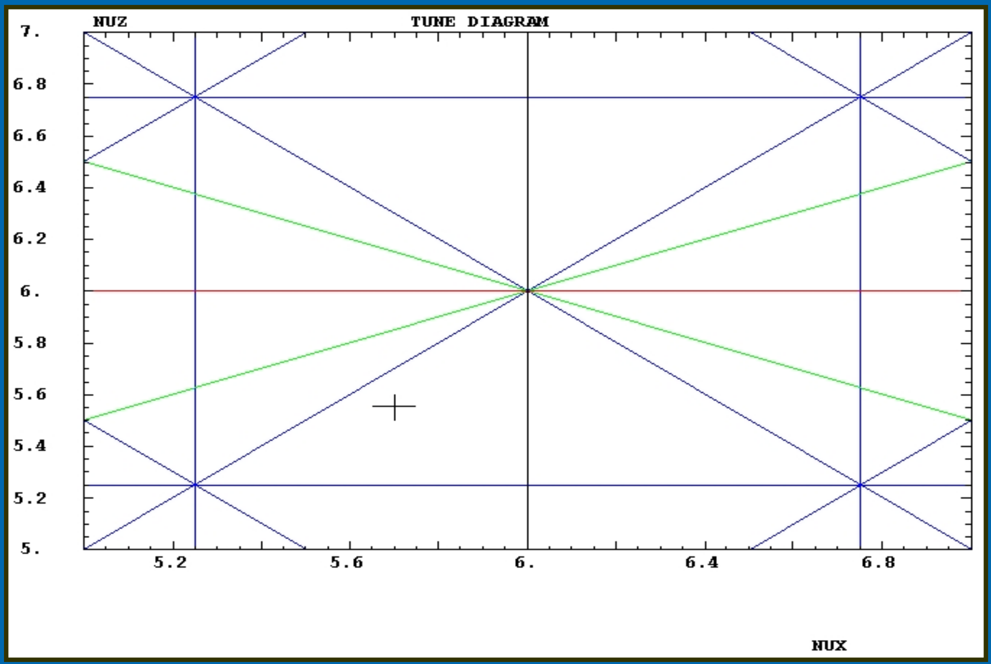
Taking into account the recommendations made during the last meeting at Saclay, the RCS maximum magnetic rigidity has been pushed to 13.44 T.m (3.2 GeV protons).
The proposed ring has a three-fold symmetry, a circumference of 208.14 m and a missing magnet FODO structure providing 3 dispersion free straight sections (EURISOL DS/TASK12/TN-06-02).

Injection energy	100 MeV/u
Extraction energy	3.2 GeV eq. Proton
Maximum rigidity	13.4 T.m
Number of FODO cells	21
Horiz/vert. Tunes	5.7 5.55
Repetition rate	10 Hz
RMS horizontal emittance at injection	20 π.mm.mrad
RMS vertical emittance at injection	10.72 π.mm.mrad
Natural normalized chromaticities	-1.15 , -1.22
Transition energy γ	4.48
Dipole bending radius	12 m
Maximum bending field	1,1203 T
Quadrupole length	0,4 m
Maximum gradient	<11 T/m



Overview of proposed new parameters 2/3





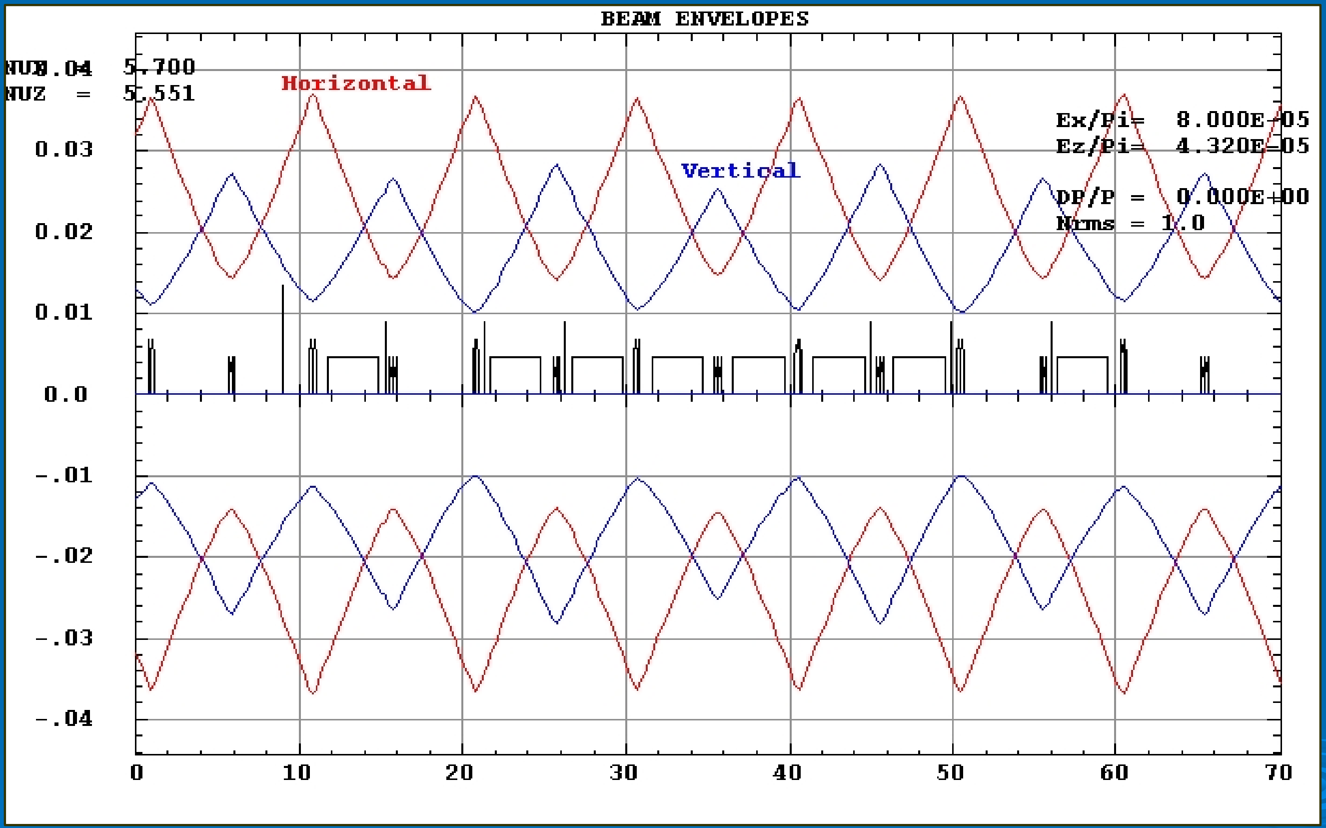
Nux= 5.7 Nuz=5.551

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.

Overview of proposed new parameters 3/3

$\varepsilon_x = 80\pi.\text{mm.mrad} = 4\varepsilon_{RMS}$

$\varepsilon_z = 43.2\pi.\text{mm.mrad} = 4\varepsilon_{RMS}$



Beam envelopes at injection without momentum spread

Dipole magnetic field cycle

The dipole bending radius have been fixed to 12 m in order to obtain a peak magnetic field value of 1.12T at extraction.
Bending and focusing magnets are supposed to be excited with resonant circuits.

Magnetic field at injection

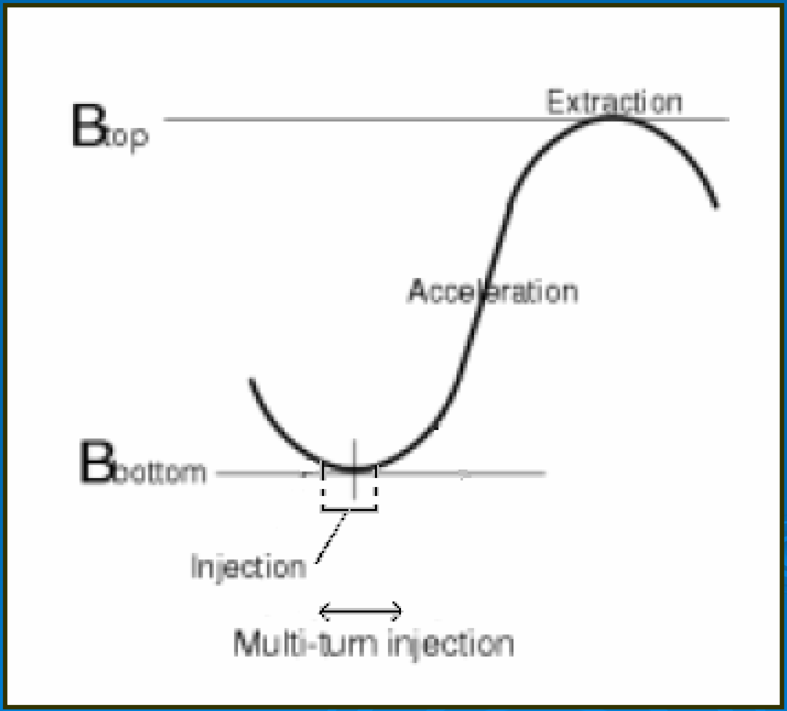
$(B\rho)$= 4.44 T.m for 6He2+ and
Bmin= 0.37 T

$(B\rho)$= 2.66 T.m for 18Ne10+ and
Bmin= 0.222 T

Magnetic field cycle for 10 Hz operation

$B(t) = 0.745-0.375 \cos 20\pi t$ and
$(dB/dt)_{max}$ = 23.57 T/s for 6He2+

$B(t) = 0.671-0.449 \cos 20\pi t$ and
$(dB/dt)_{max}$ = 28.22 T/s for 18Ne10+



Magnetic cycle of the RCS

Preliminary acceleration parameters 1/5

After capture, beam acceleration requires an accelerating voltage given by

$$\hat{V} \sin \varphi_s = C \rho \dot{B}$$

in order to maintain the central trajectory on the reference orbit and to provide a large enough bucket area A for enclosing the longitudinal beam emittance ε_L (1eV.s for He and 2 eV.s for Ne)

Preliminary calculations have been performed for 2 possible acceleration cycles :

- Constant bucket area equal to 3.5 ε_L .
- Variable bucket area with partially constant voltage.

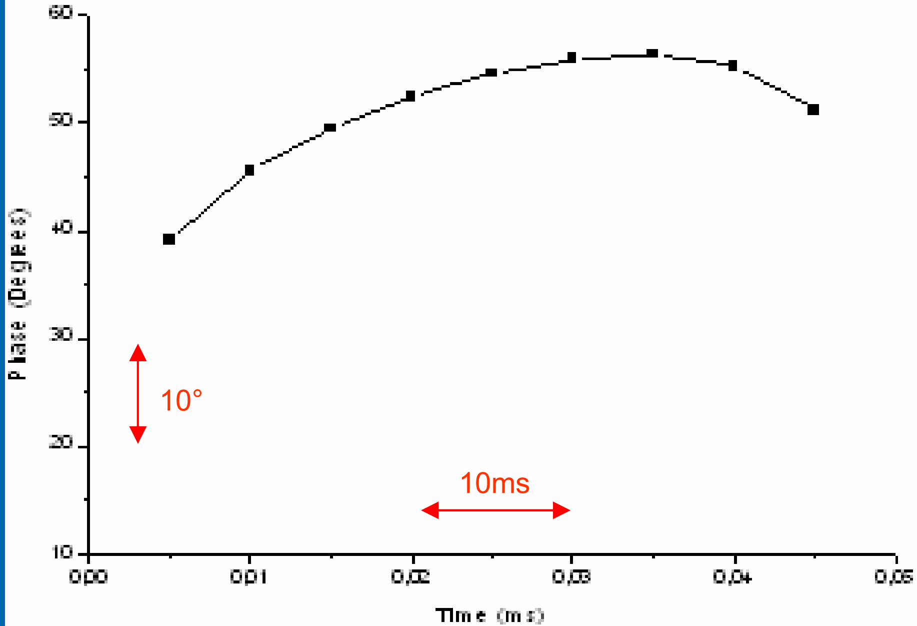
The bunch matching to the PS bucket at extraction not taken into account.

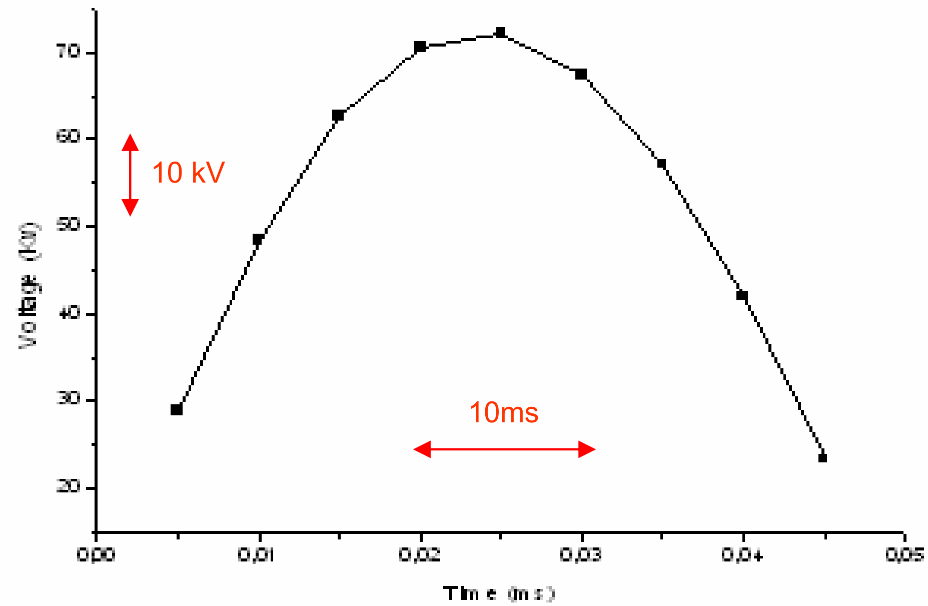
Preliminary acceleration parameters 2/5

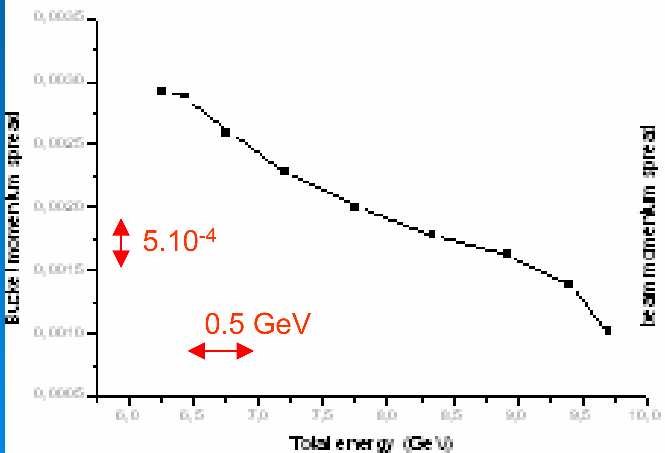
EURISOL

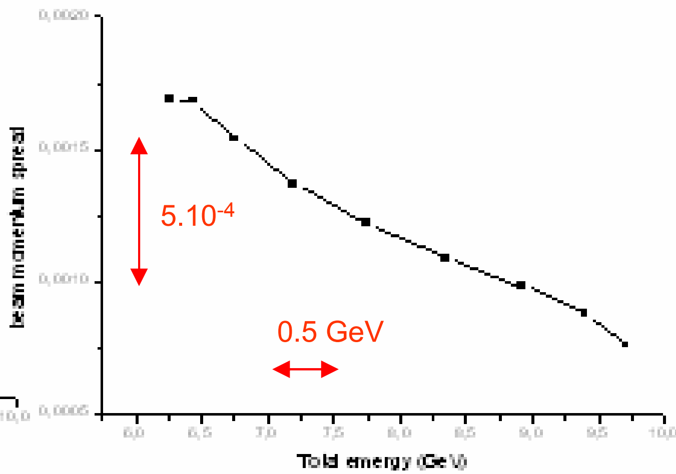
$^{6}He^{2+}$

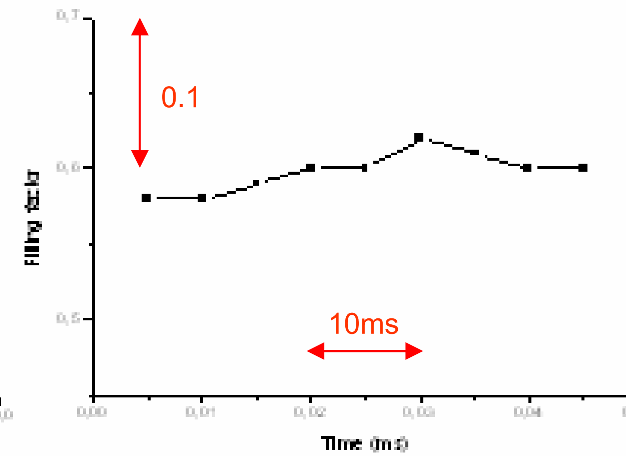
First case : constant bucket area, h=1







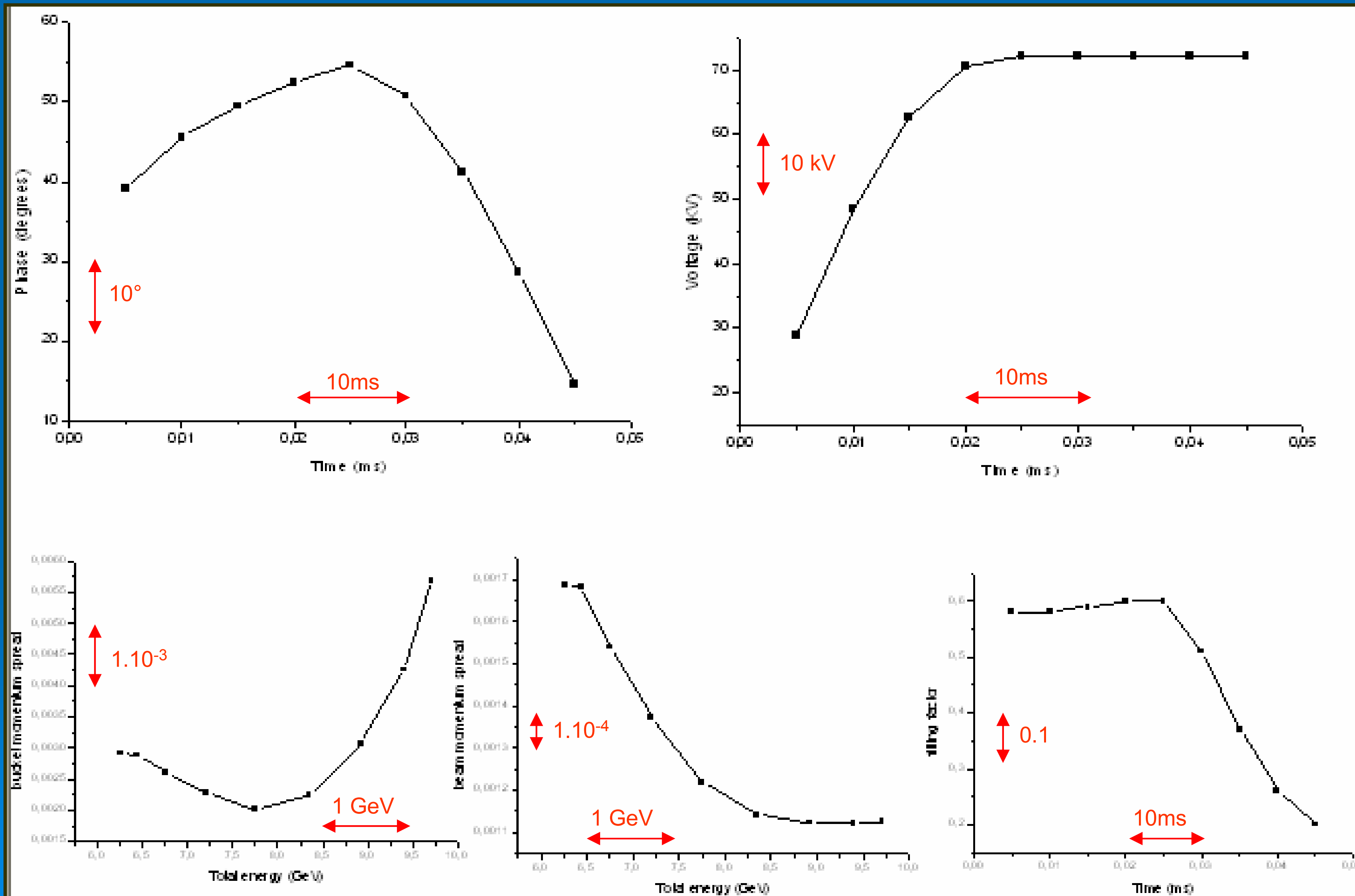




Preliminary acceleration parameters 3/5

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

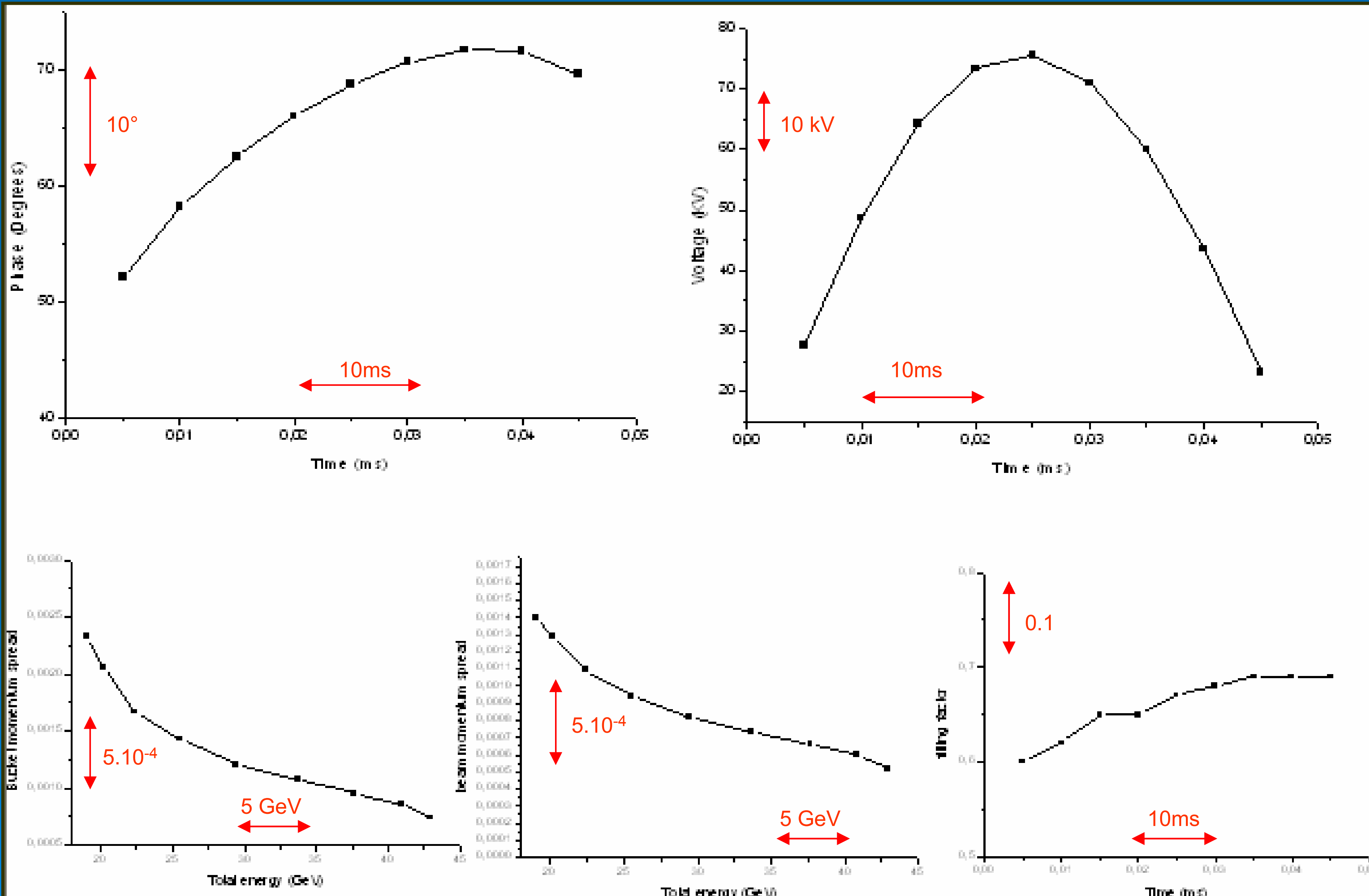
Second case : partially constant voltage, h=1



Preliminary acceleration parameters 4/5

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

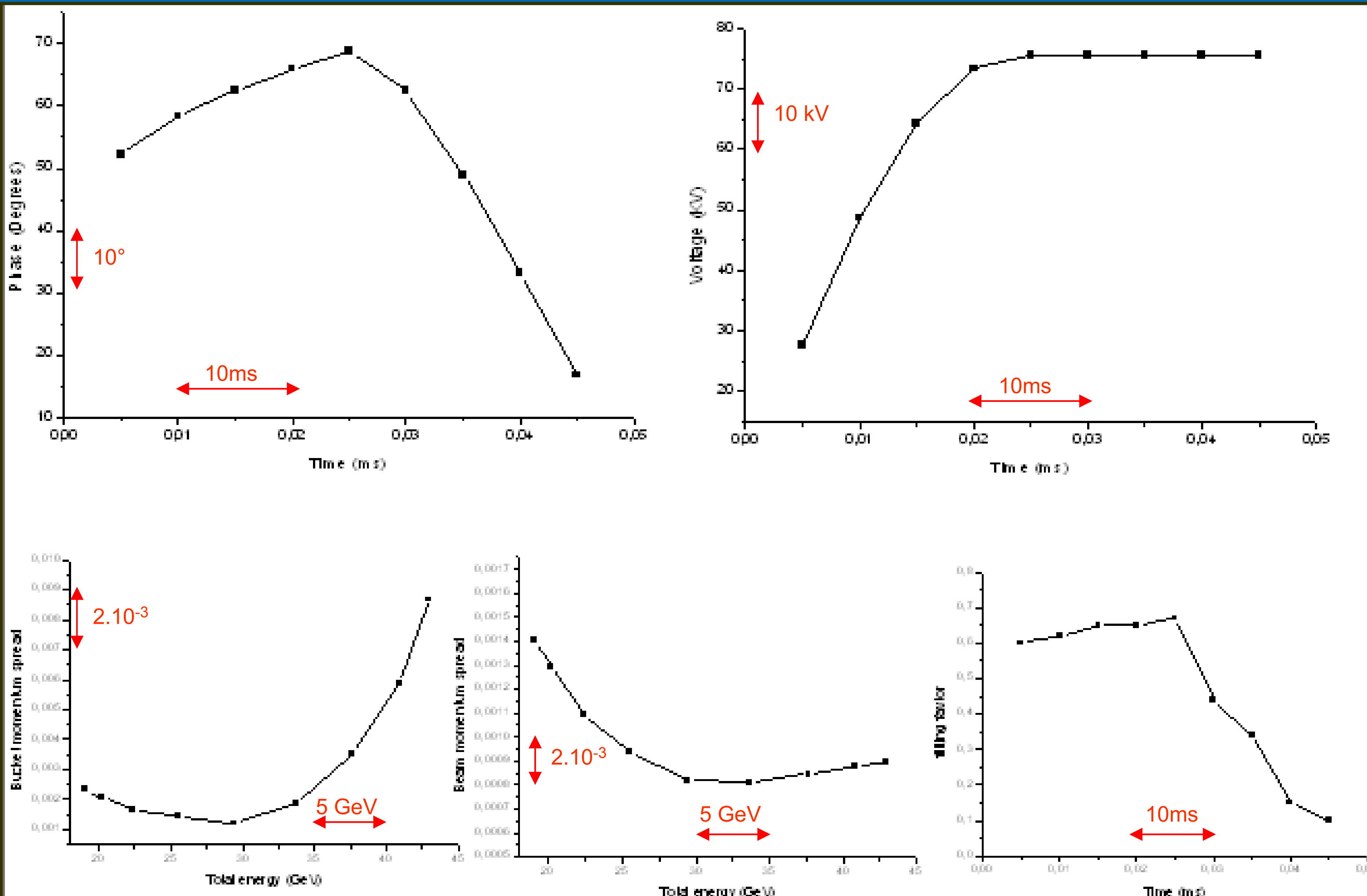
First case : constant bucket area, h=1



Preliminary acceleration parameters 5/5

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

Second case : partially constant voltage, h=1



Summary of preliminary RF parameters

- Peak voltage 80 to 100 kV
- Maximum synchronous phase ~ 70°
- Harmonic number h=1
- Frequency swing 0.6 to 1.33 MHz

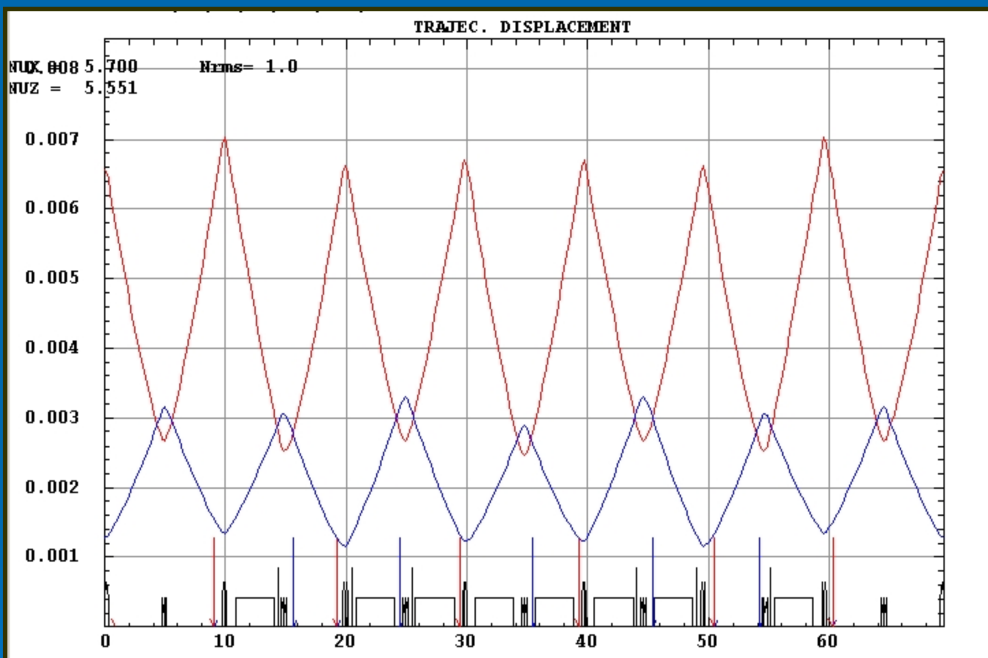
Number of cavities and length required in straight sections for their installation have to be defined according to the state of the art in RF technology.

Recent design : J-PARC 2m long cavities 42 kV each, F = 1.23 to 1.67 MHz

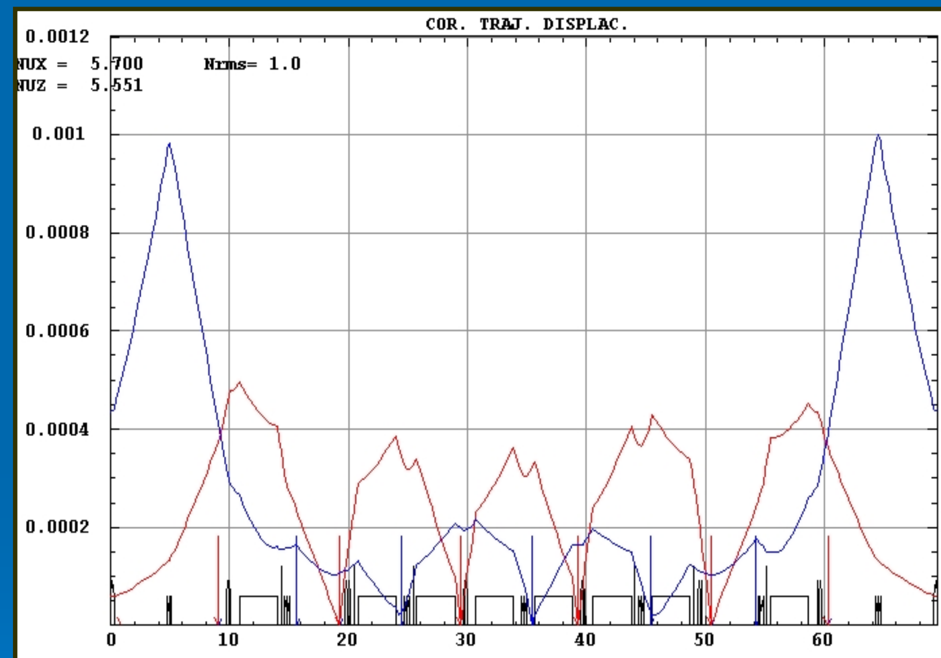
Older design : ISIS 3m long cavities 22.5 kV each, F = 1.34 to 3.1 MHz

Closed orbit correction

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

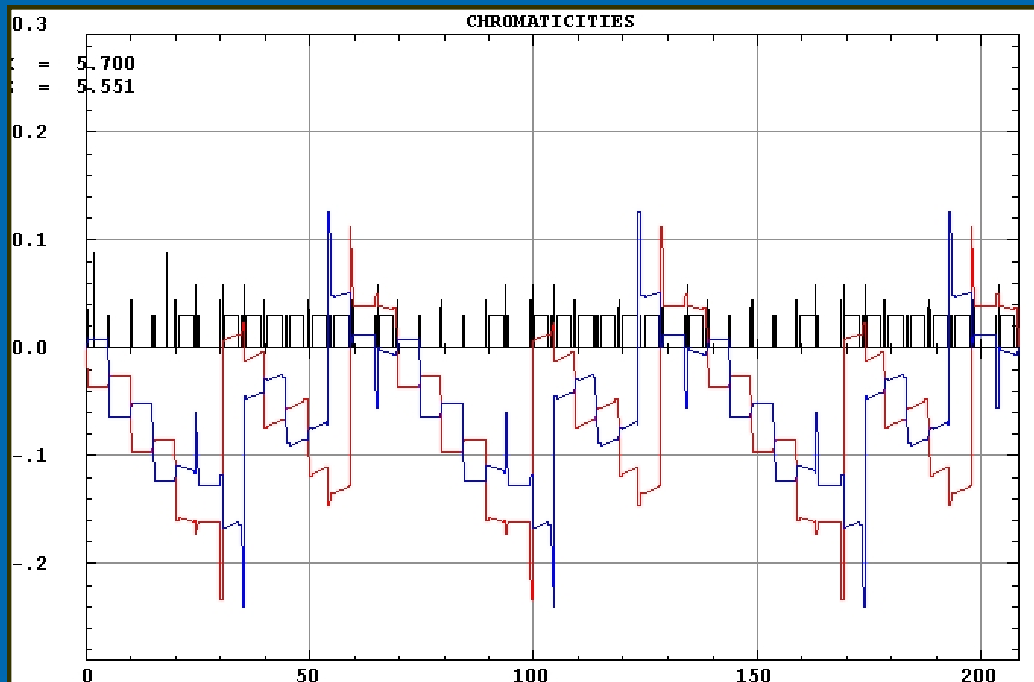


Closed orbit after correction

The maximal strength of correctors is around 0.3 mrad that is 13 Gauss.m in terms of integrated magnetic field at 100 MeV/A

Chromaticity correction

Correction of the natural chromaticity is performed with sextupoles inserted in the arcs.



Natural chromaticity after correction

The integrated maximal sextupole strength is 1.2 T.m/m² at injection.
Chromaticity due to eddy currents in bending magnet chambers is not taken into account

Multiturn Injection 1/5

- Simulations have been performed with the WinAgile code, neglecting the small variation of the magnetic field during the injection time ($\Delta B/B \sim 5.10^{-6}$)

- The revolution period of ions at 100 MeV/A is 1.6 μs. A source pulse of 50 μs corresponds to 31 turns.

-The transverse emittance of the injected beam is taken equal to 1.5 π.mm.mrad which is in agreement with the value of 1 π.mm.mrad given in the EURISOL report.

The Courant and Snyder invariant $\varepsilon=\gamma x^2+2\alpha x x'+\beta x'^2$ of an injected particle is minimum if the following equation holds during all the injection time :

$$-\frac{\alpha}{\beta}=\frac{x'_{inj}-x'_{CO}}{x_{inj}-x_{CO}}$$

Multiturn Injection 2/5

EURISOL

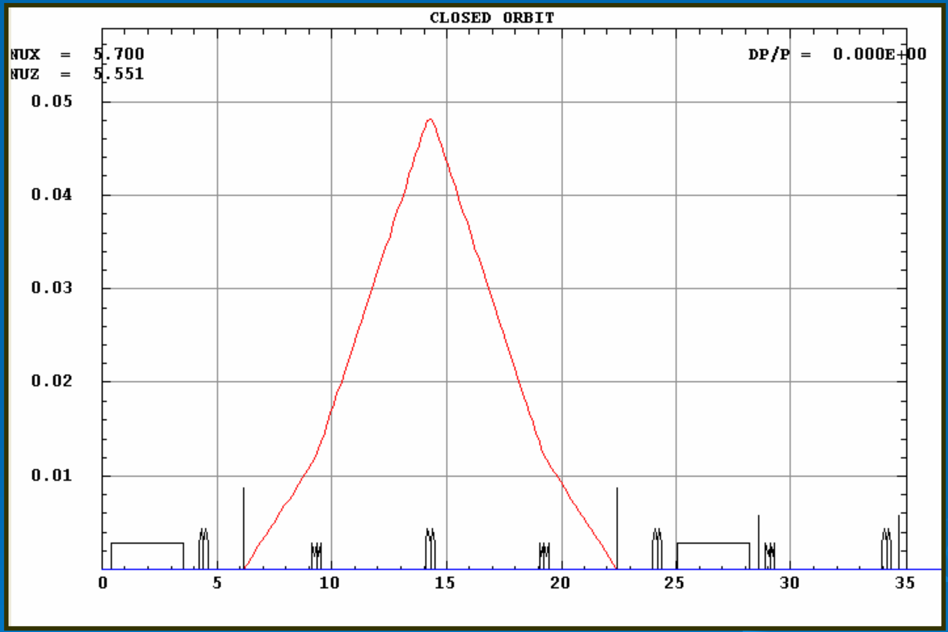
This is possible if $x_{CO} = Kx'_{CO}$ and $x_{inj} = Kx'_{inj}$

In this case : $\dfrac{x'_{inj} - x'_{CO}}{x_{inj} - x_{CO}} = \dfrac{1}{K} = -\dfrac{\alpha}{\beta}$

Injected beam is parallel to the matched envelope

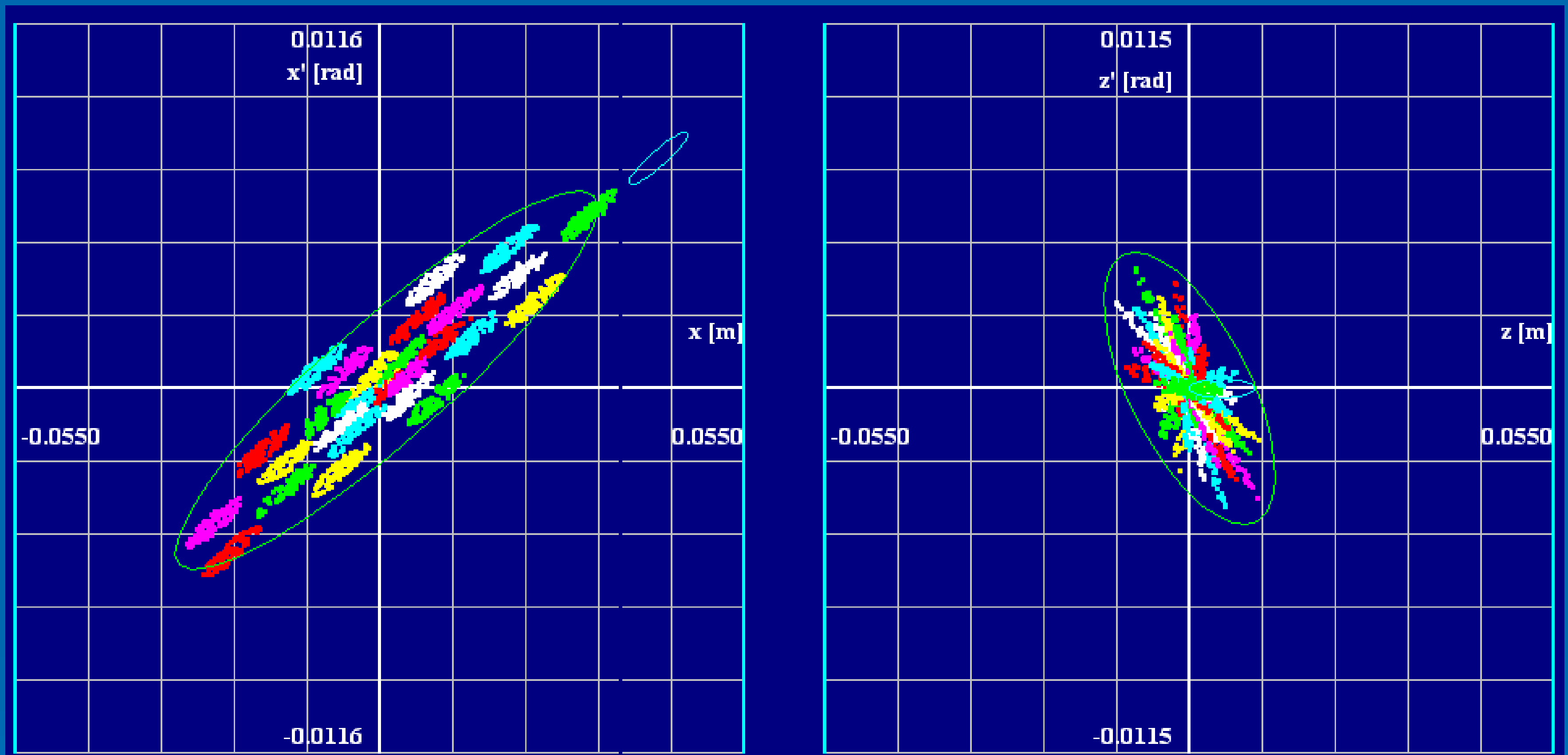
Triangle shaped closed orbit bump with :

$x_{CO} = Kx'_{CO}$



Optimum filling of phase space has been achieved with a closed orbit bump having a triangular shape produced by two pulsed dipoles of 3.8 mrad maximal strength.
(in practice 3 or 4 bumpers will be required)

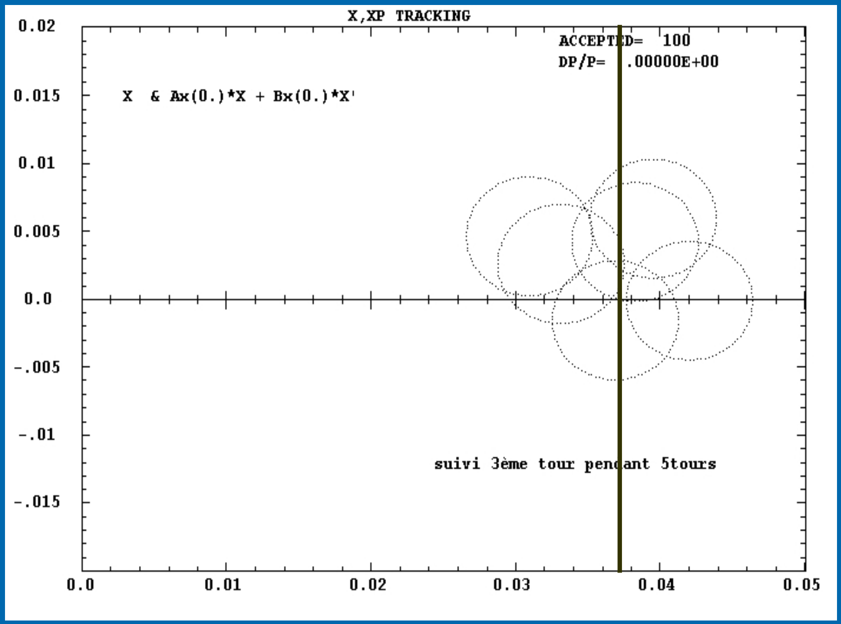
Multiturn Injection 3/5

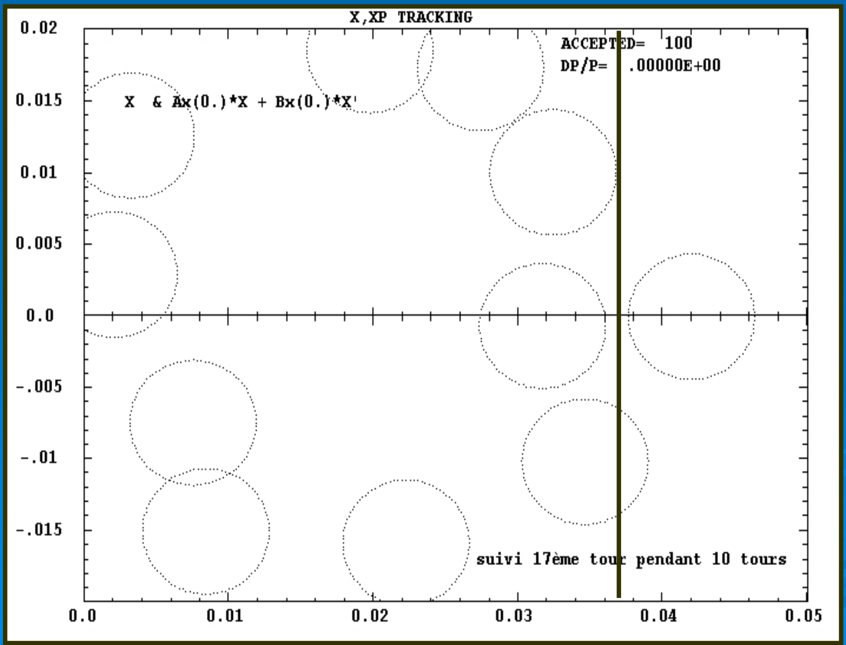


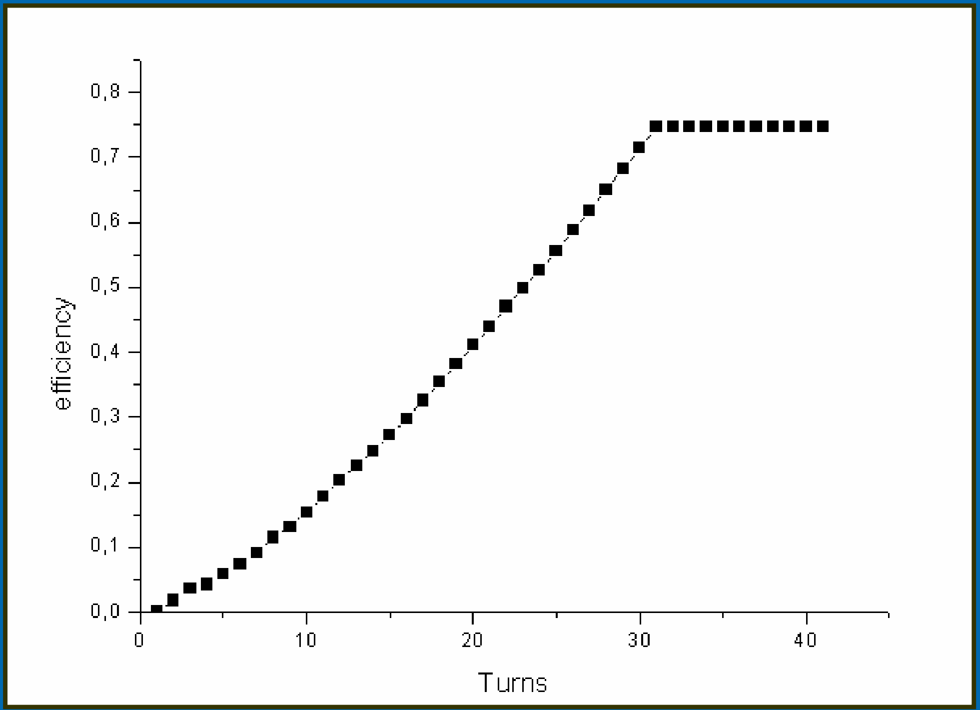
Injected beam at the end of injection in horizontal phase space (left) and vertical phase space (right)

Incoming beam emittance of 1.5 π.mm.mrad, 31 injection turns for a source pulse of 50 μs
Vertical emittance dilution is obtained by a betatron function mismatch and beam offset.
The end of the septum wall is approximately set 40mm from the central orbit of the ring so that the number of turns for the bump to collapse is 41.

Multiturn Injection 4/5







percentage of injected ions versus the number of turns

Multiturn Injection 5/5

Septum wall (m)	0.0365 (1.5 π.mm.mrad) 0.0373 (1 π.mm.mrad)
Initial kick in injection bumpers dipoles (mrad)	3.8
Injection bump collapse (turn)	41
Injection efficiency	75% (1.5 π.mm.mrad) 85% (1 π.mm.mrad)

Injection efficiency reaches 85% for an incident beam emittance of 1πmm.mrad
It is thus important to fix precisely this emittance value.

Incoming beam

Horizontal beta fonctions (matched to ring)	$\beta_x = 12.747m$	$\alpha_x = -2.1867m$
Vertical beta fonctions (mismatched to ring)	$\beta_z = 16.66m$ (1.5 π.mm.mrad) $\beta_z = 25m$ (1 π.mm.mrad)	$\alpha_z = 0$
Injected beam at exit of septum	X=0.042 m Z=0.005m	X'=0.00735 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

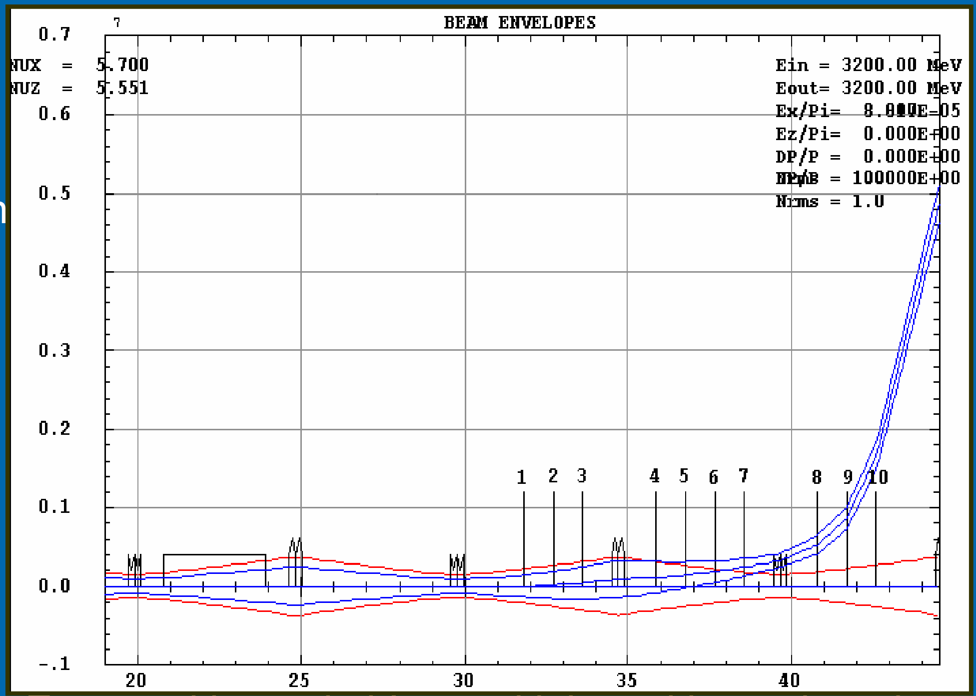
Fast extraction

EURISOL

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



Extracted beam in blue and injected beam in red

	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	0.573
9	50	0.7	0.96
10	80	0.9	1.19

Conclusion

Based on a FODO lattice structure, the newly proposed RCS has been designed to accelerate ion beams up to a maximum rigidity of 13.44 T.m (3.2 GeV protons)

Multiturn injection, acceleration and extraction parameters have been investigated

No major problems have emerged but the whole design has to be optimized taking into account the ring hardware characteristics, the decay losses estimation and the beam parameters imposed by the post-accelerator linac at injection and by the Cern PS at extraction