Decay ring - status and further plans at CEA

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Outline

Outline

Summary of the constraints on the optics

- In order to maximize the flux going to the detector, we need :
  - ⇒ large betatron functions in the long straight sections (FODO latices). The rms angle $\sqrt{\gamma_x \epsilon_x}$ must be low compared with $1/\gamma \approx 10$ mrad.
- The injection system needs :
  - ⇒ a low β_x and high dispersion insertion. This insertion is in one of the arcs : dispersive areas with low betatron functions and dipoles are already present.
  - ⇒ a collimation of the ions which are not accepted anymore in energy.
- All injected ions are lost in the ring. We have to :
  - ⇒ extract the decay products when possible.
  - ⇒ restrict their deposition in the magnetic elements.

Optical functions of the decay ring

A. Chancé et al, EPAC'06 WEPCH008

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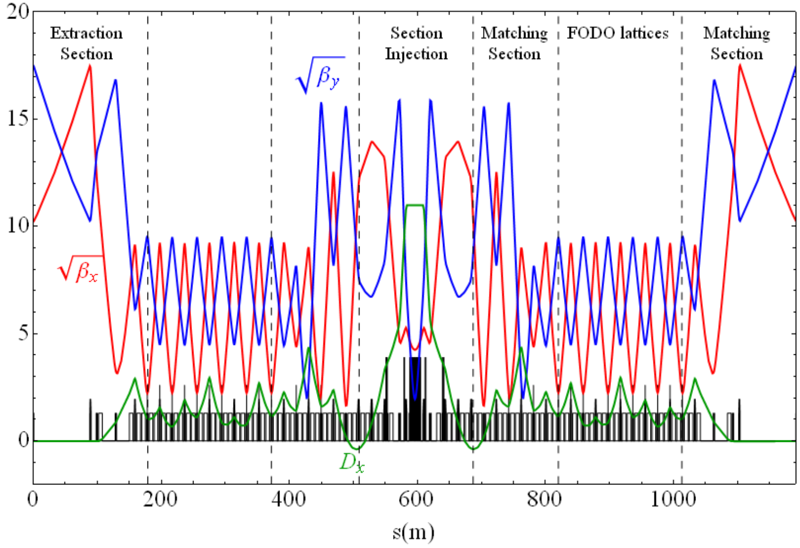

Outline

Beam evolution injection after injection

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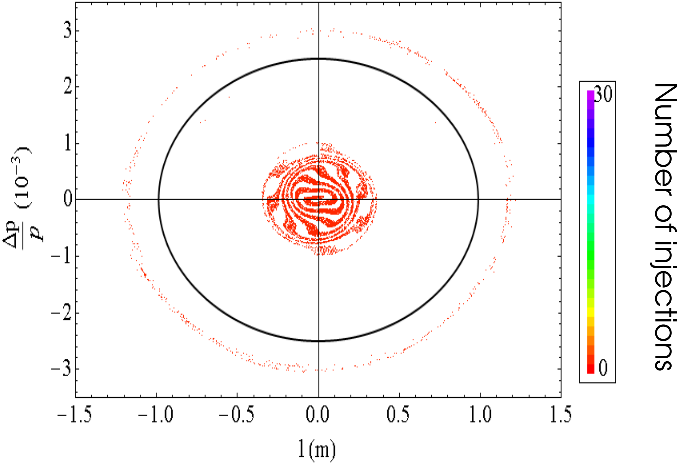
The RF merging program has been applied to an entering beam to simulate its evolution injection after injection.

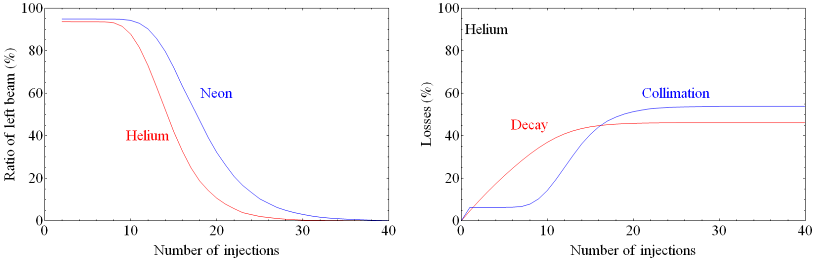


Losses due to the injection system

Two loss sources have been identified :

1. Some ions of the injected beam are not in the capture bucket and form a halo around the beam
2. Blow-up in the space (l, δ) injection after injection. After 15-20 injections, the ions are not accepted anymore.

The survival of the beam after each step has been drawn :



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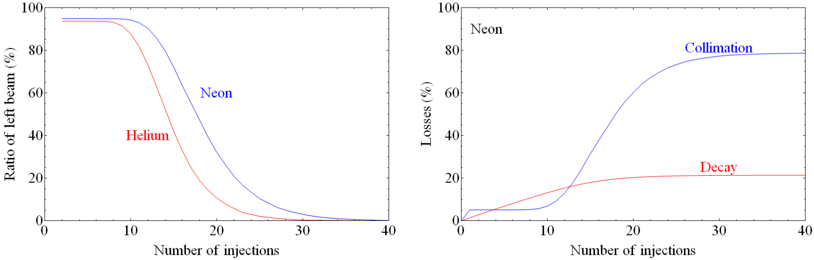
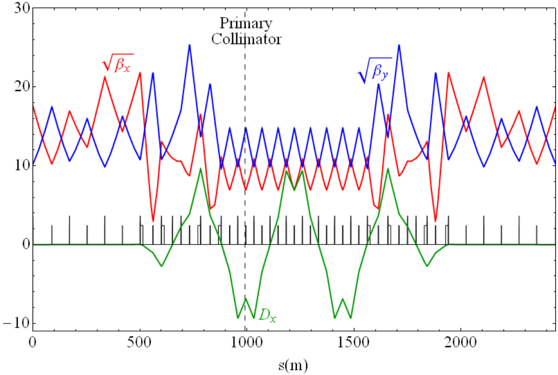


The energy collimation system

The mean power to collimate in the ring has been evaluated to 74 kW for $^{6}He^{2+}$ and 248 kW for $^{18}Ne^{10+}$.
$\Rightarrow$ A two-step collimation system has been designed to perform the collimation in energy. It has been located in the long straight section which is not directed toward the detector.



Status and recommendation

1. The beam has been transported in the phase space (l,δ) for several merging steps.
2. Different loss sources during the merging have been identified and evaluated. After 15-20 injection cycles, the whole beam can be considered as lost.
3. A dedicated collimation section in energy has been realized in one of the long straight sections.

4. The accuracy on the phase and the voltage of the cavities must be evaluated. Until now, the cavities are considered as ideal. The beam loading effects should be considered.
5. A 6D tracking in the collimation section is needed to optimize the collimation section.

Outline

Random errors in the magnetic elements

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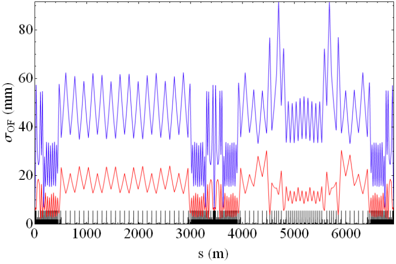
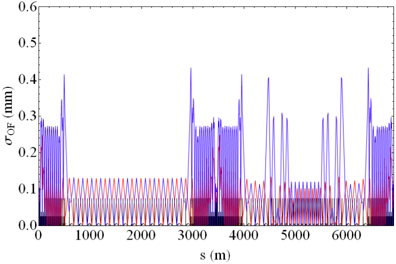
Defect type	rms value	units
DIPOLES		
$\frac{\Delta B}{B}$	0.1	10^{-3}
Horizontal misalignment	0.2	mm
Vertical misalignment	0.2	mm
Rotation error/s axis	0.1	mrad
QUADRIPOLES		
$\frac{\Delta B}{B}$	0.1	10^{-3}
Horizontal misalignment	0.2	mm
Vertical misalignment	0.2	mm

The misalignment errors can be corrected by inserting 83/85 horizontal /vertical correctors with a maximum integrated field of 0.18 T.m in the decay ring.
More precise values on these errors are needed.

Before correction :

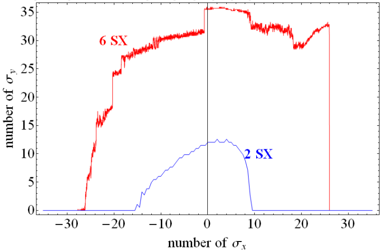


After correction :



Dynamic aperture without any defect

Since the ions run a large number of turns in the ring before being lost, the long term transverse stability must be taken into account.



Neon case

$\sigma_x = \sqrt{\beta_x \epsilon_x} \approx 2$ mm.

$\sigma_y = \sqrt{\beta_y \epsilon_y} \approx 0.9$ mm.

$\epsilon_x = 0.22$ mm.mrad.

$\epsilon_y = 0.22$ mm.mrad.

The dynamic aperture has been optimized by using 6 sextupole families. **Without any defect in the structure**, the obtained dynamic aperture is very large. The dipoles are at large aperture (±80 mm). The design of the dipoles cannot be perfect and multipole defects are unavoidable.

Systematic multipole defects in the dipoles

C. Vollinger, E. Wildner

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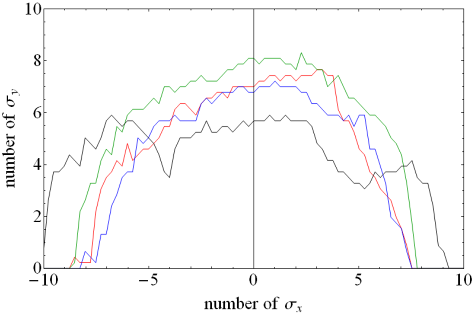
Multipoles	$b_n\left(10^{-4}\right)$	$K_nL = \frac{b_n\theta}{R^{n-1}}\left(\mathrm{m}^{1-n}\right)$
1 (main field)	10^4	$\theta = \frac{\pi}{86}$ rad
3	-1.68	-0.00171
5	33.02	9.307
7	-50.12	-3924.5
9	29.58	643400



Neon case

$\sigma_x = \sqrt{\beta_x \epsilon_x} \approx 2$ mm

$\sigma_y = \sqrt{\beta_y \epsilon_y} \approx 0.9$ mm

$n = 5$

$n = 7$

$n = 9$

all multipoles

The dynamic aperture dramatically decreases in presence of the multipole defects in the dipoles.

Status and recommendation

1. The linear contribution of the errors in the elements have been considered. Adding correctors make the errors on the closed orbit available.
2. An automatic code of enlargement of the dynamic aperture has been implemented in BETA according to WEPCH085, EPAC'06, E. Levichev, P. Piminov
3. Several working points have been studied to compare their optical properties. FRPMN011, PAC'07, A. Chancé et al . The dynamic aperture is up to 6 σ.
4. The coupling between the different planes is still important and could have an effect on the collimation efficiency.

5. The optimization program of the dynamic aperture could be improved (best criteria to choose the sextupoles to change or the path to correct the chromaticity, calculation at different momenta, . . .)

Outline

Losses due to the β decays in the ring

The decay of the stored ions implies a continuous power loss with a mean value of :

$$P = 10.8 \text{ W/m for } {}^{6}\text{He}^{2+}$$
$$P = 11.8 \text{ W/m for } {}^{18}\text{Ne}^{10+}$$

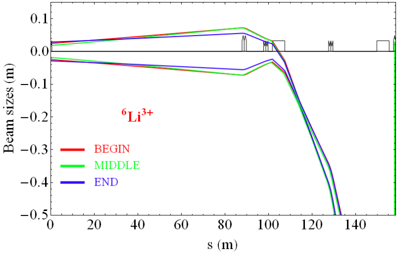
The relative rigidity difference is :

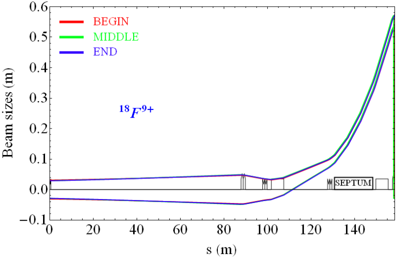
$$\delta \approx -33\% \text{ for } {}^{6}\text{He}^{2+} \quad \delta \approx +11\% \text{ for } {}^{18}\text{Ne}^{10+}$$

The rigidity difference is too large to accept the decay products in the arcs : they are lost after crossing a few dipoles.
$\Rightarrow$ Deposition maxima after the long straight sections : several tens of kilowatts ! Needed extraction.
$\Rightarrow$ The deposition inside the superconducting magnets in the arcs must be low enough to avoid quenching.

Extraction of the decay products coming from the long straight sections

The beam sizes have been considered up to 6 σ and the transport of the decay products has been realized at different points of the straight section.





The first dipole is used to separate the decay products from the reference beam.
For $^{6}He^{2+}$, the magnetic rigidity difference is sufficient to extract the decay products. For $^{18}Ne^{10+}$, a 12-m-long 0.5 T extraction septum is needed.

Evaluation of the energy deposition

An algorithm was implemented in BETA to evaluate quickly the energy deposition in the magnetic elements. Its advantages are :

- Quick.
- Easy to use.

Unfortunately,

- It does not take into account the interactions with the walls.
- The beam is assumed elliptic and decoupled.

To handle the energy deposition in the arcs, two solutions were proposed :

- Use of absorbers. Large apertures in the dipoles ($\pm 80\ mm$).
- Use of open mid plane dipoles.

New treatment of the transport in the dipoles

The relative magnetic rigidity difference for the decay products is very large. A development at 1st or 2nd order could not be accurate enough to describe properly their trajectory in the magnetic elements. So, a new treatment of the transport in the dipoles has been developed.

Reminder : equation of a particle in a magnetic field :

$$m\frac{\partial^2\vec{r}}{\partial t^2} = q\vec{v} \times B$$

In the case of **pure dipole** magnets, the trajectory of any charged particle is an circle arc in the plane normal to $\vec{B}$.

The idea is to use geometric considerations to calculate the exact trajectory of the particle in the dipole instead of using a Taylor-Lagrange development, which is an approximation by polynoms of the trajectory.

Principle of the model

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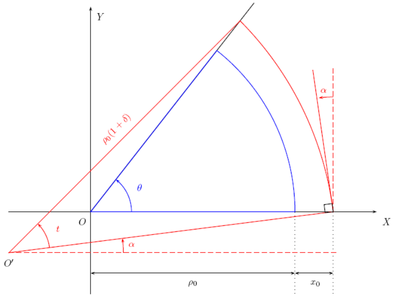


ρ_0	: curvature radius of the dipole
θ	: angle of the dipole
δ	: relative difference of magnetic rigidity
x_0	: position of the ion at the begin
$x'_0 = \tan\alpha$	: angle of the ion at the begin
x_f	: position of the ion at the end
x'_f	: angle of the ion at the end

$$\rho_1 = \rho_0(1+\delta)\sqrt{\frac{1+x_0'^2}{1+x_0'^2+y_0'^2}}$$

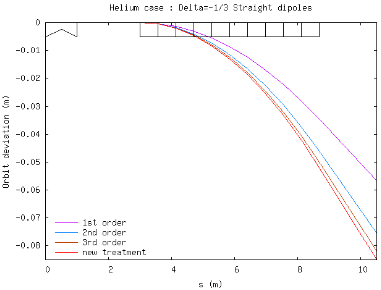
$$\phi = \arcsin\left(\frac{\rho_0+x_0}{\rho_1}\sin\theta - \sin(\theta-\alpha)\right)$$

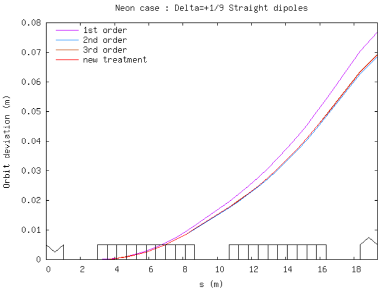
$$x_f = \rho_1\left(\sqrt{(\sin(\theta+\phi)-\sin\alpha)^2+\left(\cos(\theta+\phi)+\left(\frac{\rho_0+x_0}{\rho_1}-\cos\alpha\right)\right)^2}-1\right)$$

$$x'_f = \frac{(1+\phi')\left(\sin(\theta+\phi-\alpha)-\left(\frac{\rho_0+x_0}{\rho_1}\right)\cdot\sin(\theta+\phi)\right)}{(\sin(\theta+\phi)-\sin\alpha)^2+\left(\cos(\theta+\phi)+\left(\frac{\rho_0+x_0}{\rho_1}-\cos\alpha\right)\right)^2}$$

By the same way, the dipole edges have been considered with a geometric approach.

Comparison of the model with TRANSPORT

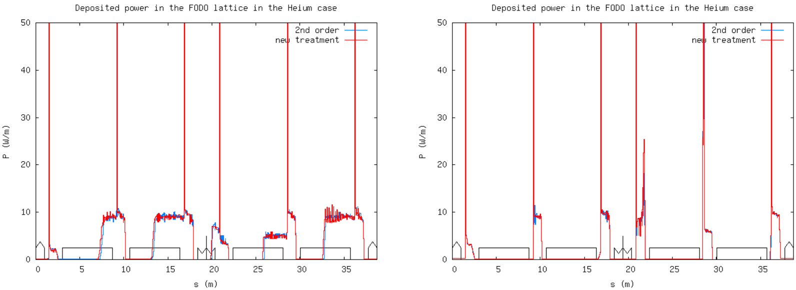




The results at first order are clearly false for the transport of both decay products. The second order is sufficient for the transport of Fluorine but calculations at third order or farther should be made for Lithium.

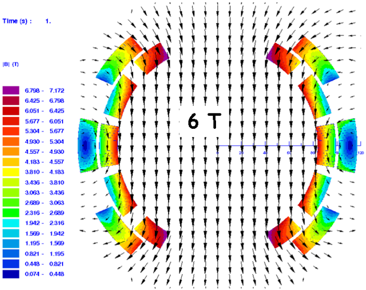
The new treatment of the transport in the dipoles seem to be the asymptote of the curves if we increase the order of calculation.

Results from BETA



In both cases, the differences with the second order are very low.
According to BETA code, the average power lost in the dipoles is under 10 W/m. To improve the model and to verify these results, a simulation with ACCSIM and FLUKA was run by E. Wildner and F. W. Jones. By this way, a 3 D model has been realized.

First feasibility study of 180 mm 6 T dipoles

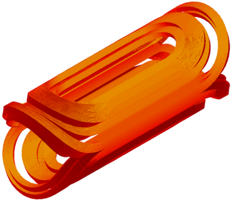


E. Wildner et al, PAC'07,MOPAN088

LHC « costheta » design

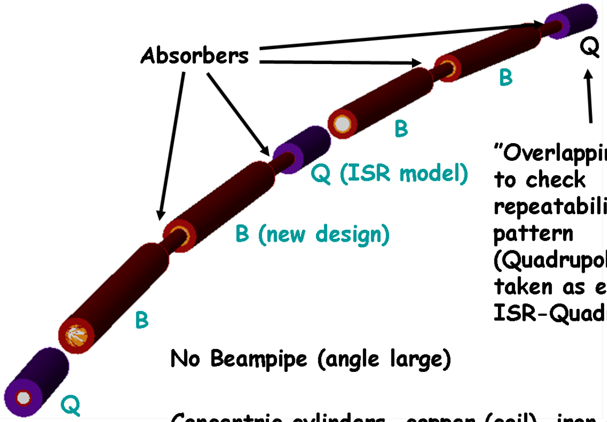
Courtesy Christine Vollinger

Compact coil end :
Aim is a compact coil end to reduce impinging particles.



Heat Deposition Model, one cell

Courtesy : Elena Wildner



"Overlapping" Quad to check repeatability of pattern (Quadrupole is taken as existing ISR-Quadrupole)

No Beampipe (angle large)

Concentric cylinders, copper (coil), iron (yoke)

Results from ACCSIM/FLUKA

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Two aspects of the global heat deposition for Helium

1. Compare to Limits (10 W/m) : not exceeding
2. Compare to Loss Pattern : similar with BETA

Magnet	Quadrupole (max)	Dipole (max)
Average over magnet (W/m)	3	2.1

Absorber	Abs 1	Abs 2	Abs 3	Abs 4
Average (W)	57.8	35.7	45.9	31.3

Normalized to a decay rate in cell :
He : 5.37×10^9 *decays/s*
Ne : 1.99×10^9 *decays/s*

Courtesy : Elena Wildner

Neon about twice the values.
Very different from the BETA results. Reasons ?

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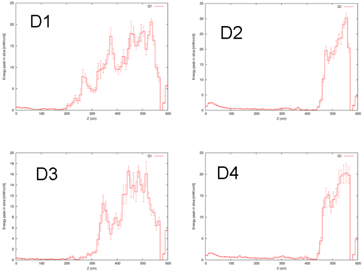
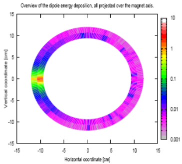
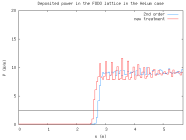
F. W. Jones et al, PAC'07, THPAN006





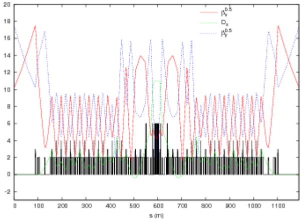
Peaks exceed recommended limit, 4.3 mW/cm3 for dipoles, quadrupoles are below limit

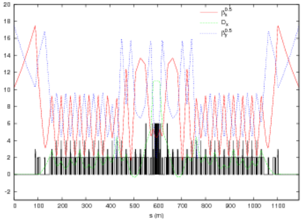
BETA results :



Courtesy : Elena Wildner

Solution with open mid plane dipoles





The optics of the decay ring is very similar in both cases.
The advantages of the open mid plane dipoles are :

1. The dipoles can be lengthened which decreases their magnetic field (5 T instead of 6 T).
2. The aperture is smaller.
3. The impedance of the decay ring should be lower.
4. The structure needs less changes if other ions are used.

Status and recommendation

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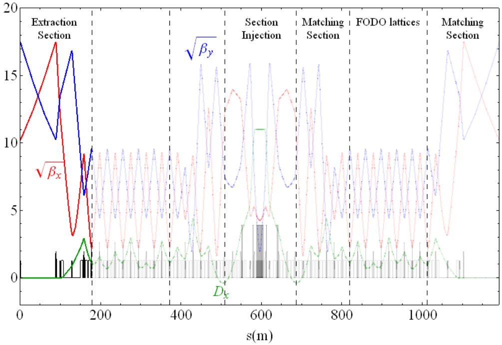
1. The extraction of the decay products from the long straight sections should be possible.
2. The transport of the decay products in the dipoles is better treated.
3. Local heat deposition exceeding for the dipole both He and Ne in the case of absorbers.
4. Open midplane design exists, planned calculations for Fall 2008 (E. Wildner).
5. Liners can be inserted in the existing dipole design, idem for evaluation.
6. Impedance in present model can be handled with beam screens.
7. Calculations with B ions for open midplane case.

Outline

To sum up

Some solutions to handle the main problematics in the arcs have been proposed :

- Extraction section at the entry of the arcs.



To sum up

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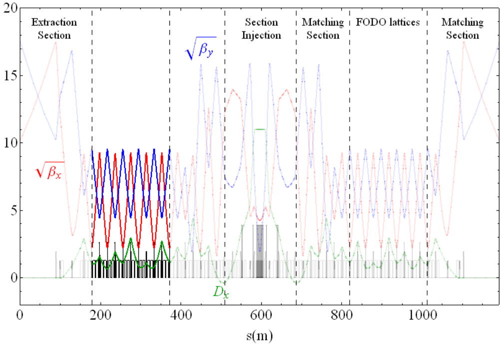
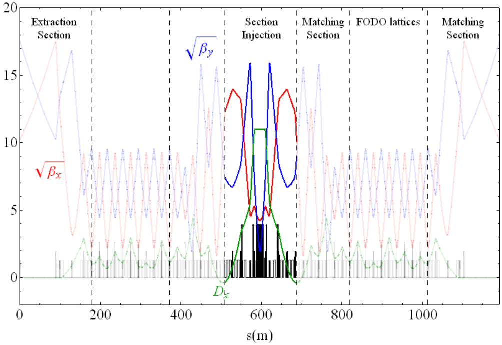
- Extraction section at the entry of the arcs.
- Use of absorbers or open mid-plane dipoles in the arcs.



To sum up

Some solutions to handle the main problematics in the arcs have been proposed :

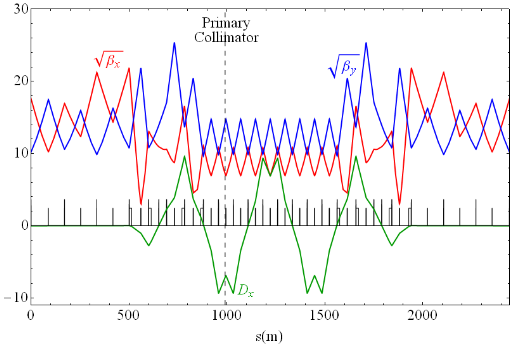
- Extraction section at the entry of the arcs.
- Use of absorbers or open mid-plane dipoles in the arcs.
- Realization of a dedicated injection section.



To sum up II

The specific RF program was developed too :

- Simulation of the merging of the injected and stored beams.
- Evaluation of the losses due to this system.
- A collimation system in energy was then defined.



To sum up III

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An optics of the decay ring was then realized and its optical properties have been evaluated.

Without any defects :
The properties at the first and second orders are sufficient.

With multipole defects in the dipoles :
The dynamic aperture has to be enlarged.
$\Rightarrow$ An automatic optimization program of the dynamic aperture was written.
$\Rightarrow$ Several working points were tested in order to limit the effect of the multipolar resonances.

What can be done

- Simulate the transport of the beam in the collimation section. The interaction with the walls and the beam 6D distribution must be taken into account.
- Go on the study on the field defects in the magnetic elements and find some solutions to reduce their effects.
- Improve the simulations of energy deposition in the elements.
- Study the effect of the high intensities stored on the beam dynamics (beam loading, space charge, impedances, . . .).
- Give a precise evaluation of the allowed errors on the phases and voltages of the RF cavities.
- Realize a lattice for the ions ^{8}B and ^{8}Li but we need parameters.