A new lattice for the beta-beam decay ring to enlarge the stability limit

A. CHANCÉ
J. PAYET[1]

CEA Saclay IRFU/SACM

4th August 2011

[1]presenter

Why a new lattice?

- High fluxes of (anti) neutrinos imply high intensities to store (several hundreds of Amps peak!)
- Collective effects (space charge, beam loading, wake fields...) must be investigated.
- The head tail effects (excitation of the tail of the beam by the head due to tranversal fields) are one of the big issues for the stability in the decay ring.
- Two solutions have been under study to mitigate this effect:
  - a new lattice with a smaller transition gamma;
  - making an amplitude detuning with octupoles, which sometimes enables to push the intensity limit. For the decay ring, we will see the impact of this solution on the optics.

How to decrease the transition gamma

The momentum compaction α_P is defined by:

$$\alpha_P = \frac{1}{\gamma_T^2} = \frac{1}{L} \oint \frac{D_x(s)\, ds}{\rho}$$

L is the total length, D_x the horizontal dispersion and ρ the curvature radius. α_P can be increased by:

- increasing the average dispersion in the dipoles.
  - $\Rightarrow$ Larger apertures.
  - $\Rightarrow$ Few degrees of freedom.
  - $\Rightarrow$ Difficult to significantly change the value of α_P.
- increasing the integration length.
  - $\Rightarrow$ "Wiggler" scheme: the sign of the curvature radius alternates with the dispersion.
  - $\Rightarrow$ The integrate $\oint \frac{D_x(s)\, ds}{\rho}$ increases.

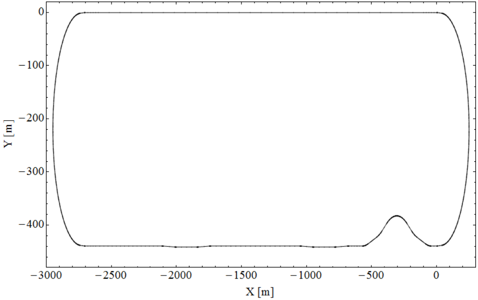
We have chosen the second solution.

An injection out of the arc

The injection is out of the arcs.

- ☺ Simpler arcs: FODO lattices.
- ☺ More compact arcs: enlarged duty factor (39 %).
- ☹ More dipoles needed (208 against 172 before).

General:
Layout:



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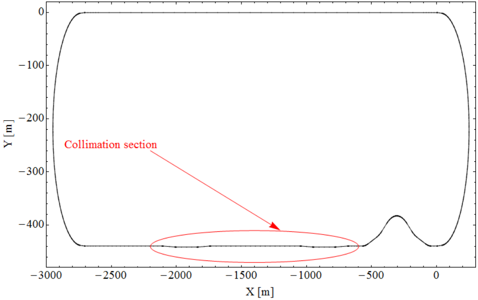

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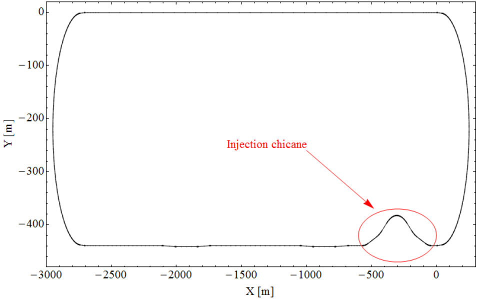

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Injection chicane:
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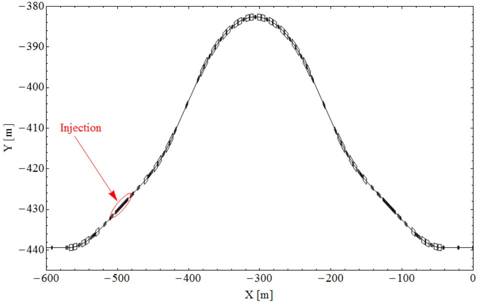
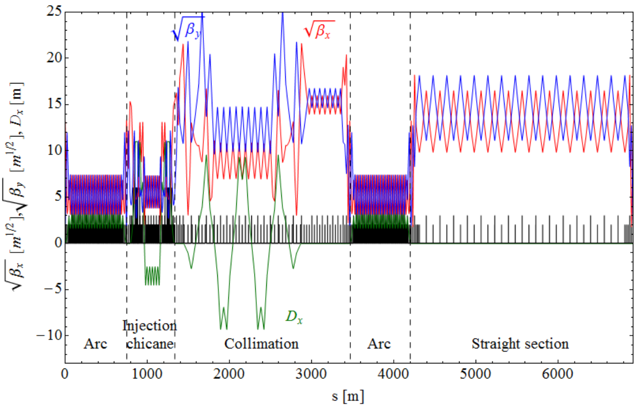
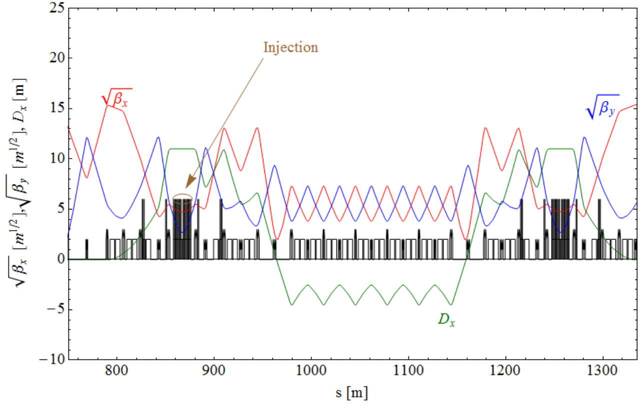


Optical functions in the decay ring



- Straight section length: 2706 m.
- Total length: 2200 π m.
- Dipoles of 7.46 T (for $^{6}He^{2+}$) with an angle of $\pi/84$ rad.

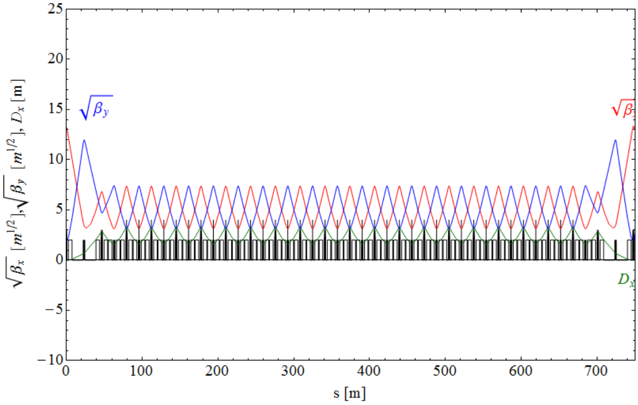
Optical functions in the injection chicane



Optical functions at the center of the chicane:

- $D_x = 11$ m.
- $\beta_x = 22$ m.
- $\beta_y = 7.3$ m.

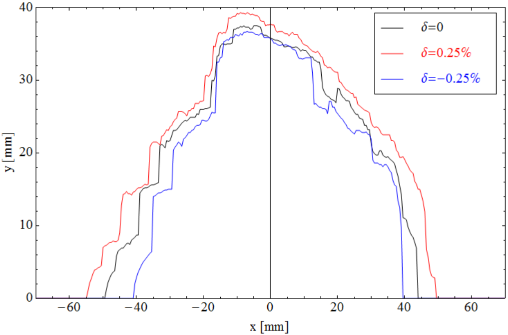
Optical functions in the arcs



- Phase advance of $\pi/2$ in both planes per FODO period.

⇒ Cancels some non linearities brought by the sextupoles.

Dynamic aperture



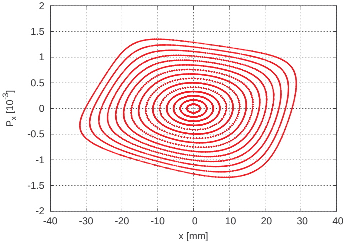
rms beam sizes:
$\sigma_x = 1.83$ mm
$\sigma_y = 0.76$ mm.

Advantages of the new lattice:

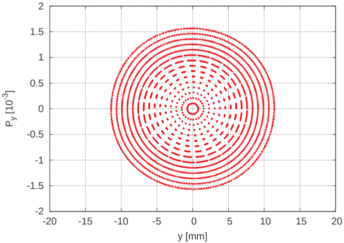
- Very simple arcs.
- Two sextupole families to cancel the chromaticity.
- Large dynamic aperture in the momentum range of the beam.

Tracking with PTC_MADX and $\delta = 0$

Initial position:
$(x = n\sigma_x, P_x = y = P_y = 0)$



Initial position:
$(y = n\sigma_y, x = P_x = P_y = 0)$



- Step of 1 for n
- Beam sizes: $\sigma_x = 1.83$ mm and $\sigma_y = 0.76$ mm.
- The beam stays elliptic up to 10 σ_x.
- Small non linearities.

Summary of the new lattice

- The transition gamma γ_T for the new lattice is 18.7 (to compare with the old value of 27).
- The value of the average betatron functions are :
  $< \beta_x >=$ 125 m (against 134 m before)
  $< \beta_y >=$ 160 m (against 175 m before).
- The fractional part of the tune is kept equal to the one of the reference lattice. We have then:

$$Q_x = 22.228 \text{ and } Q_y = 19.16$$

- The arcs are more compact and much simpler.
- The dynamic aperture is still large (more than 20σ in both planes) and the tracking shows that the beam keeps an elliptic shape for the first 10 sigmas.

Amplitude detuning for the decay ring

- The intensity limit has been pushed by changing the transition gamma.
- BUT the aimed intensities are still over this limit (more than twice).
- A studied solution is to add octupoles in the lattice to make an amplitude detuning. The expected amplitude detuning are:

$$\frac{\partial Q_x}{\partial \varepsilon_x} = 425\ \mathrm{m}^{-1},\ \frac{\partial Q_x}{\partial \varepsilon_y} = -878\ \mathrm{m}^{-1},\ \frac{\partial Q_y}{\partial \varepsilon_y} = 1155\ \mathrm{m}^{-1}$$

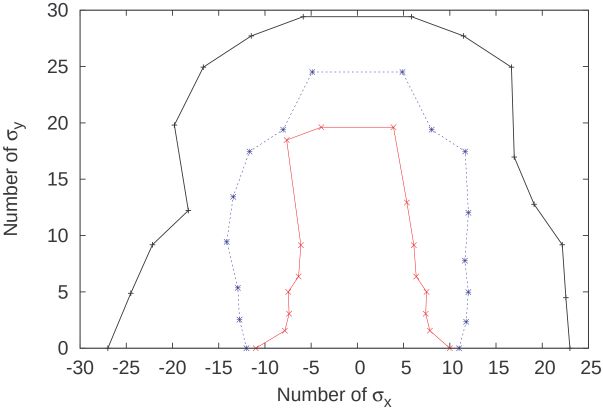
- How to make the amplitude detuning?
  - Where to put the octupoles?
  - Which strength?
  - Which impact on the dynamic aperture?

Location of the octupoles

The intensity limit is mostly sensitive to the derivative $\frac{\partial Q_y}{\partial \varepsilon_y}$.
The two other derivatives are less relevant (possibility to optimize their value with optical reasons).
We will use two octupole families. Two locations were studied:

- The arcs. The phase advance in the FODO lattices in the arcs is $\pi/2$ rad. The octupoles can be compensated and their contribution to the dynamic aperture should be small. The integrated octupole strengthes are 360 T/m^2 and 1000 T/m^2.
- The long straight section. There is plenty of place to insert them there. Larger betatron functions imply weaker octupoles. The integrated octupole strengthes are 32 T/m^2 and 63 T/m^2.

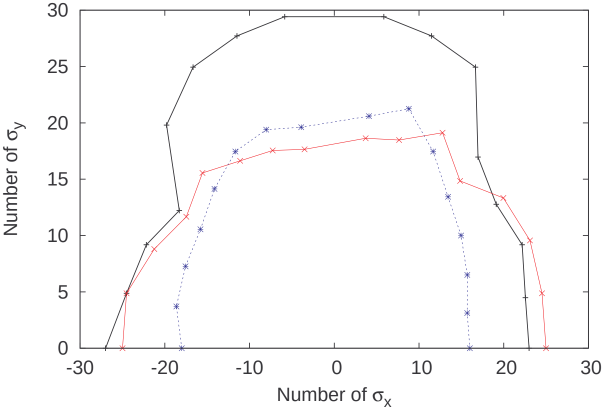
Dynamic aperture with octupoles



$$\frac{\partial Q_x}{\partial \varepsilon_x} = 425\ \mathrm{m}^{-1},\ \frac{\partial Q_y}{\partial \varepsilon_y} = 1155\ \mathrm{m}^{-1}$$

- no octupoles
- octupoles in the arcs
- octupoles in the straight section

Dynamic aperture with another $\partial Q_x/\partial \varepsilon_x$



$$\frac{\partial Q_x}{\partial \varepsilon_x} = -425\ \mathrm{m}^{-1},\ \frac{\partial Q_y}{\partial \varepsilon_y} = 1155\ \mathrm{m}^{-1}$$

- no octupoles
- octupoles in the arcs
- octupoles in the straight section

Summary of the amplitude detuning

- We have studied the impact of an octupole detuning in the decay ring.
- Although the phase advances are not optimal in the long straight section, it is more interesting to put the octupoles in this section. The needed octupoles are much weaker for this solution with a similar (or even larger) dynamic aperture.
- If only the derivative $\partial Q_y/\partial \varepsilon_y$ is significant to reduce the collective effects, it is possible to optimize the octupole strenghtes to enlarge significantly the dynamic aperture.
- Amplitude detuning is affordable if only the dynamic aperture is considered.

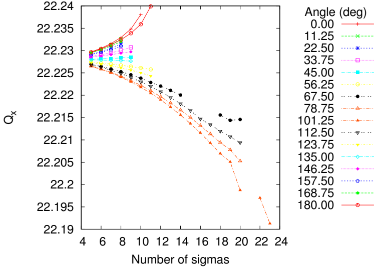
BUT The gain is very small on the intensity limit (see Hansen's presentation).

Thank you for your attention!

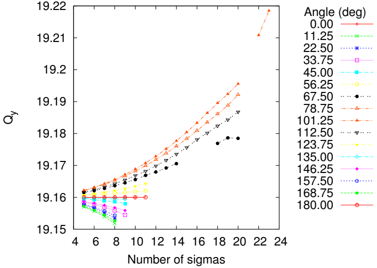
Tune variations (1)

Octupoles in the arcs

Horizontal tune



Vertical tune



Tune variations (2)

Octupoles in the straight section