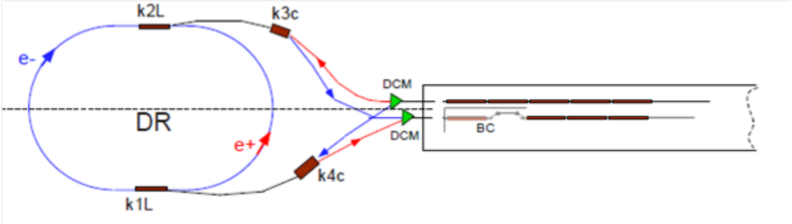
Bunch compressor and transfer lines

Antoine CHANCÉ

CEA Saclay IRFU/SACM

18th March 2010

The injection scheme



- The e^+ are produced at low energy before the damping ring (DR).
- The e^+ and e^- are injected in the same DR at 1 GeV and damped.
- They are ejected and transported until a bunch compressor (BC).
- They are accelerated in a second linac up to their nominal energy.

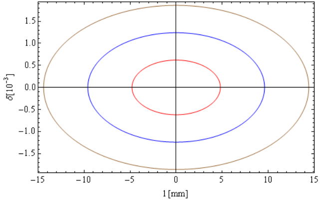
Parameter table

	Units		electrons	positrons
After the damping ring				
Total Energy	GeV	E_d	1	1
rms bunch length	mm	$\tilde{l}_d$	4.8	4.8
rms phase extension	rad	$\tilde{\theta}_d$	0.287	0.287
rms energy spread	10^{-4}	$\tilde{\delta}_d$	6.2	6.2
After the linac				
Total Energy	GeV	E_l	4.18	6.7
Total voltage	GV	V_l	3.18	5.7
RF frequency	GHz	f_l	2.856	2.856
LER/HER				
Total Energy	GeV	E_S	4.18	6.7
Slipping factor	10^{-4}	η	4.86	4.33
RF voltage	MV	V_{RF}	4.0	5.7
Synchronous phase	rad	θ_S	0.156	0.372
RF frequency	MHz	f_{RF}	476	476
Harmonic number	-	h	2015	2015
Synchrotron period	ms	-	0.35	0.40
Longitudinal damping time	ms	-	13.4	28

Why a bunch compressor

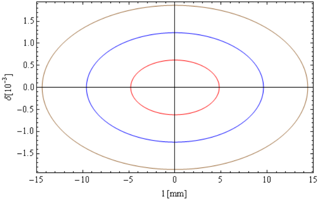
Without compression: C=1

After the DR:



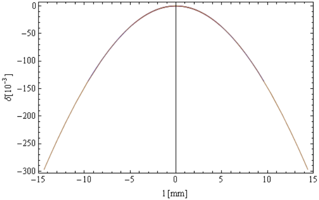
→ Compression

After the BC:



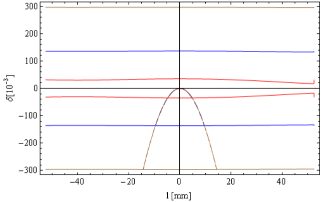
↓

After the Linac:



← Injection

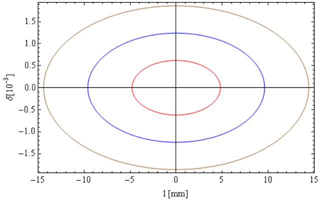
After a few turns:



Why a bunch compressor

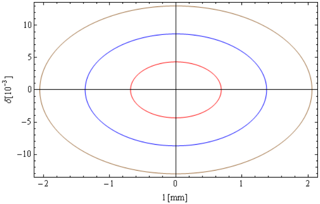
With compression: C=7

After the DR:



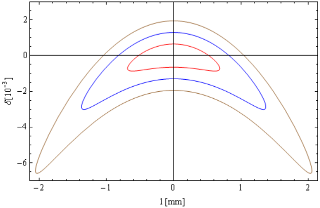
⟶ Compression

After the BC:



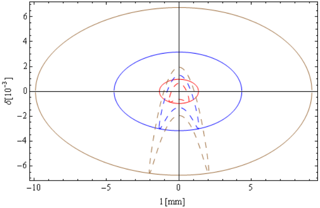
↓

After the Linac:



⟵ Injection

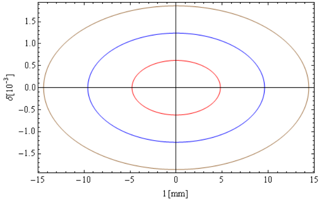
After a few turns:



Why a bunch compressor

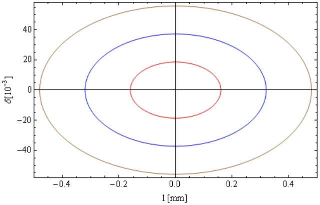
With compression: C=30

After the DR:



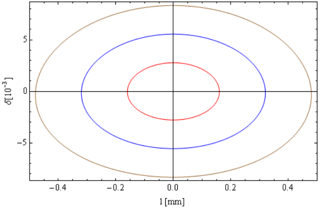
→ Compression

After the BC:



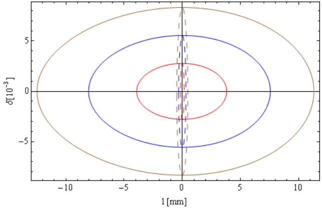
↓

After the Linac:



← Injection

After a few turns:



Choice of the compression factor

Compromise to find:

- Too small compression factor: the phase extension of the beam is too large at the injection in the linac. $\Rightarrow$ "Sausage-like beam"
- Too large compression factor: the energy spread of the beam is large and we keep the large energy spread after the acceleration.

The dynamic aperture shrinks significantly with energy in the HER and LER.
The criteria is to minimize the rms energy maximum of the beam after a few turns in the main rings.

Choice of the compression factor (2)

rms energy maximum after a few turns in the main rings:

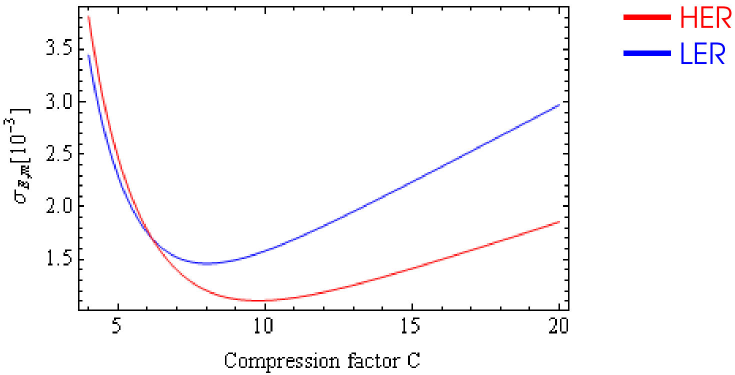
$$\sigma_{E,m}^2 = \frac{C^2 E_d^2}{E^2}\tilde{\delta}_d^2 + \alpha \cos\theta_S \left(1 - e^{-\frac{\beta^2 \tilde{\theta}_d^2}{2C^2}}\right) + \frac{3 + e^{-\frac{2\tilde{\theta}_d^2}{C^2}} - 4e^{-\frac{\tilde{\theta}_d^2}{2C^2}}}{2E^2}$$

$$\alpha = \frac{V\beta^2}{\pi h \eta E} \qquad \beta = \frac{f}{f_l}$$

$$\tilde{\delta}_d^2 = \left\langle \delta^2 \right\rangle_d \qquad \tilde{\theta}_d^2 = \left\langle \theta^2 \right\rangle_d$$

l for the values in the linac, d for the values in the DR.
⚠ It is the rms energy maximum and not the energy spread.

Choice of the compression factor (3)



The best point for the LER (HER) is $C = 8.0$ (9.8) and then $\sigma_{E,m} = 1.5‰$ (1.1‰).

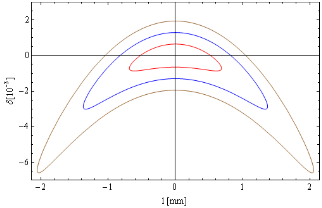
A good range for C is then (8,9).

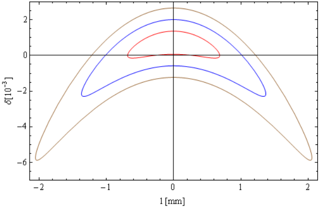
⇒ Choice of $C = 9$ for the bunch compressor.

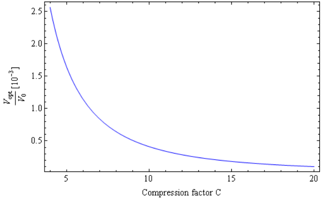
An idea to decrease the energy spread

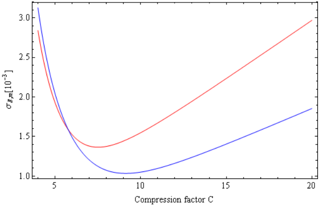
Idea: to use a higher voltage in the linac to optimize the energy distribution after injection.

$C = 7 : V = V_I$ $\quad$ $+\overrightarrow{\Delta V}$ $\quad$ $C = 7 : V = V_I + \Delta V$









The best point for the LER (HER) is then $C = 7.5$ (9.1) and then $\sigma_{E,m} = 1.4‰$ (1.0‰).

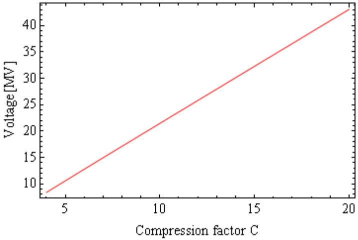
$\Rightarrow$ A decrease by 10 % has been obtained.

RF Matrix:

$$R = \begin{pmatrix} 1 & 0 \\ R_{65} & 1 \end{pmatrix}$$

$$R_{65} = \frac{eV_c}{E_d}\frac{2\pi f_c}{c} = \frac{\tilde{\delta}_d}{\tilde{l}_d}\sqrt{C^2 - 1}$$

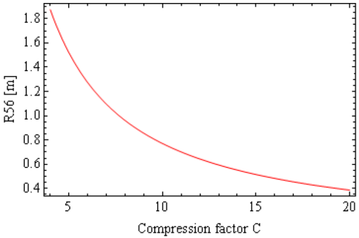
$$f_c = 2.856 \text{ GHz}$$



Chicane Matrix:

$$R = \begin{pmatrix} 1 & R_{56} \\ 0 & 1 \end{pmatrix}$$

$$R_{56} = \frac{R_{65}\tilde{l}_d^2}{R_{65}^2\tilde{l}_d^2 + \tilde{\delta}_d^2}$$



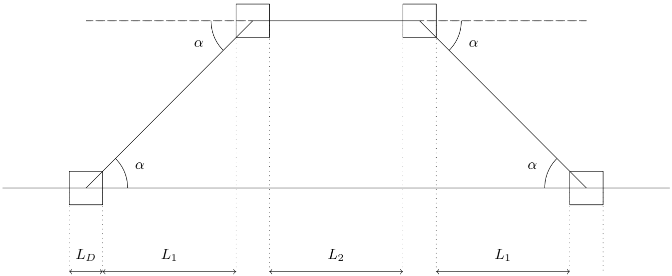
For C=9, V=19.3 MV and $R_{56} = 0.855$ m.

Choice of a C-chicane: Its big advantage is to be achromatic.

Use of PEP II magnets: $B_{\text{max}} = 0.93T$ and $L = 0.45$ m.

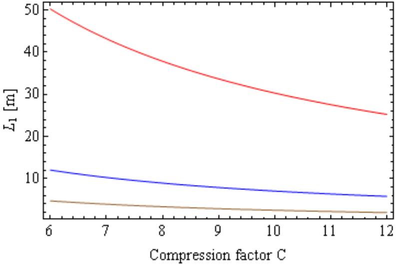
→ Margin on the field: B=0.83 T.

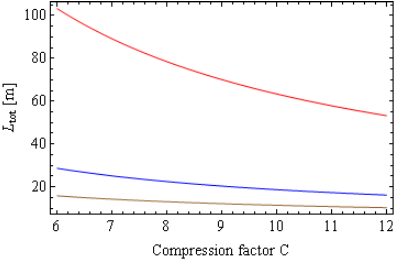
First dipole and last dipole of the chicane used to separate electron and positron beams.



Choice of the number of dipoles

For the chicane, we can choose 1, 2, … dipoles for each group in the C-chicane.



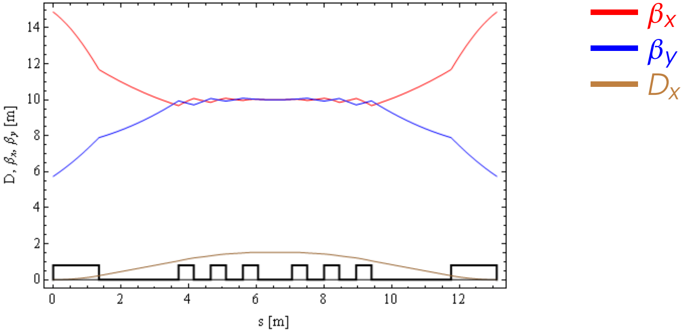


— 1 dipole — 2 dipoles — 3 dipoles

The best is to use 3 dipoles in each group.

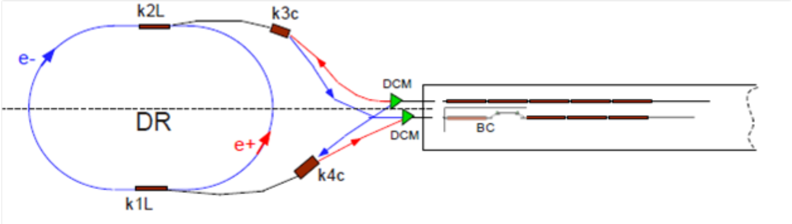
Length of the separator: 1.35 m for a field of 0.83 T.

⚠ The optical functions are here arbitrary (chosen to have a waist at the center).



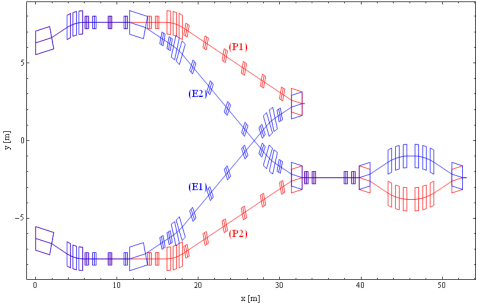
The optical functions are quite low.
⇒ No need to insert quadrupoles to keep the betaton functions low.
Total length of the chicane: 13.1 m.

The transfer lines



- Four transfer lines.
- The e^+ and e^- are injected in the same DR at 1 GeV.
- Two beam separators to separate the e^+ and e^- beams.
- Two kickers (k2L and k1L) for the injection into the DR.
- Two kickers (k3c and k4c) to differentiate the e^+ path from the one of the e^-.
- The BC is after the DR and before the second linac.

Geometrical constraints



Same separator as for the BC.
Same angle for the injection (extraction) septum: $3\pi/28$ rad.
$\Rightarrow$ a 0.56-T 2-m-long septum.
DR width: 12.59 m
Distance between both linacs: $\approx$ 5 m (4.76 m in the actual layout)

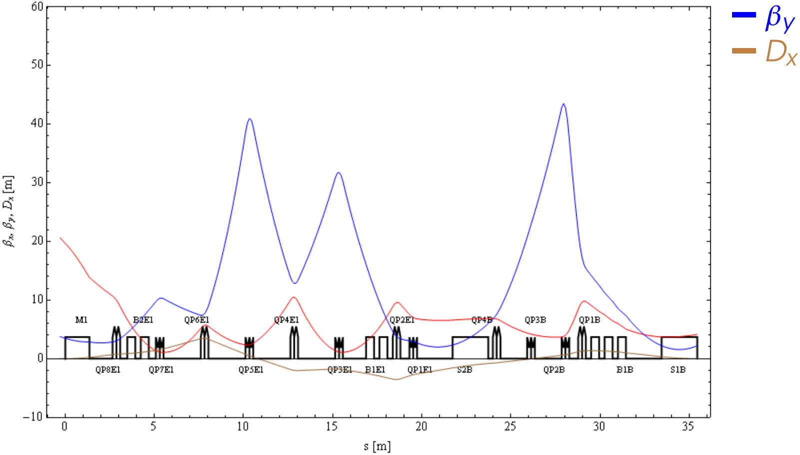
Optical constraints

- The transfer lines must be achromatic.
- Use as much as possible the PEP II magnets.
- In the linacs, a defocusing quadrupole for the e^+ is focusing for the e^-. The constraint on the optical functions at the entry or end of the transfer lines is then:

$$
\begin{array}{llll}
\beta_{x,i}^{(E1)} = \beta_{y,i}^{(P1)} & \beta_{y,i}^{(E1)} = \beta_{x,i}^{(P1)} & \alpha_{x,i}^{(E1)} = \alpha_{y,i}^{(P1)} & \alpha_{y,i}^{(E1)} = \alpha_{x,i}^{(P1)} \\
\beta_{x,f}^{(E1)} = \beta_{y,i}^{(P2)} & \beta_{y,f}^{(E1)} = \beta_{x,i}^{(P2)} & \alpha_{x,f}^{(E1)} = -\alpha_{y,i}^{(P2)} & \alpha_{y,f}^{(E1)} = -\alpha_{x,i}^{(P2)} \\
\beta_{x,f}^{(P1)} = \beta_{y,i}^{(E2)} & \beta_{y,f}^{(P1)} = \beta_{x,i}^{(E2)} & \alpha_{x,f}^{(P1)} = -\alpha_{y,i}^{(E2)} & \alpha_{y,f}^{(P1)} = -\alpha_{x,i}^{(E2)} \\
\beta_{x,f}^{(E2)} = \beta_{y,f}^{(P2)} & \beta_{y,f}^{(E2)} = \beta_{x,f}^{(P2)} & \alpha_{x,f}^{(E2)} = \alpha_{y,f}^{(P2)} & \alpha_{y,f}^{(E2)} = \alpha_{x,f}^{(P2)}
\end{array}
$$

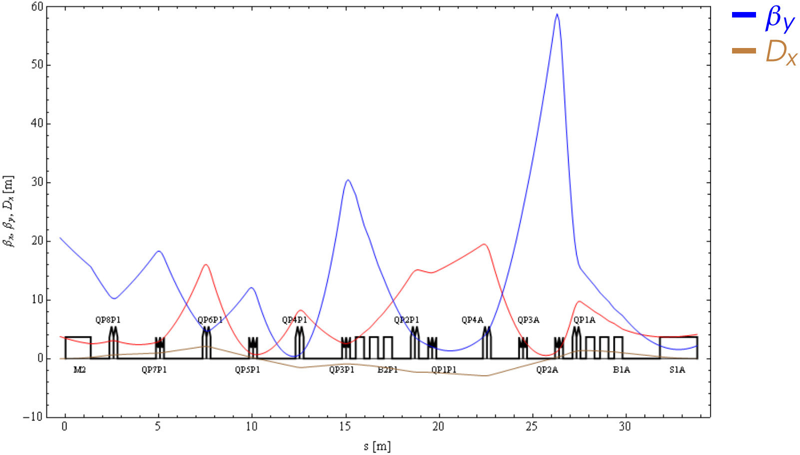
Lattice of the TL (E1)

Transfer line (E1):



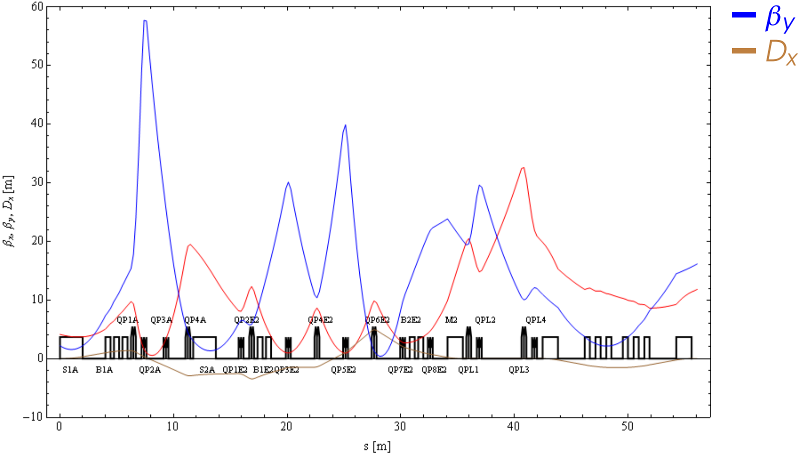
Lattice of the TL (P1)

Transfer line (P1):

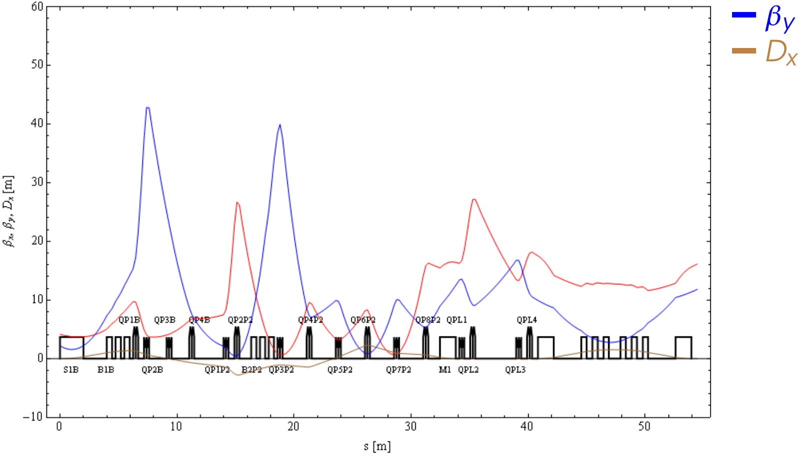


Lattice of the TL (E2)

Transfer line (E2):



Transfer line (P2):



Resume for the four TL

	Units	(E1)	(E2)	(P1)	(P2)
Total length	m	35.749	56.077	34.108	54.436
Max Dipole field	T	0.832	0.832	0.832	0.832
Max QP gradient	T/m	4.756	6.607	6.607	7.124
Max β_X	m	20.612	32.594	19.513	27.158
Min β_X	m	1.072	0.533	0.533	0.625
Max β_Y	m	43.496	57.655	58.787	42.809
Min β_Y	m	1.5603	0.418	0.389	0.460
Max D_X	m	3.450	4.940	2.073	2.290
Min D_X	m	-3.559	-3.469	-2.927	-2.793
ϵ_X	nm	23	23	23	23
Momentum spread	‰	0.62	0.62	0.62	0.62
Max σ_X	mm	2.22	3.07	1.85	1.787

⚠ For the moment, the momentum spread and the emittances before the DR are unknown: the beam size may be much larger for a bigger momentum spread.

Conclusion

- A compression factor of about 8-9 seems to be a good compromise.
- It is possible to make a BC with PEP II dipoles. The length of the chicane is about 13.1 m for a voltage of 19.3 MV.
- A first design of the transfer lines between the DR and the linac has been done. The maximum gradient in quadrupoles is 7.2 T/m. The PEP II dipoles and quadrupoles can be used. The betatron functions stay quite low (maximum $\approx$ 60 m minimum $\approx$ 0.4 m).
- The dispersion in the TL may be a problem.
- The design of the transfer lines between the linac and the main rings has not been done yet (TO DO).

Thank you for your attention!