Progress on the eh Interaction Region

K. Andre, B. Holzer, M. Klein

Outline

- Design parameters for LHeC
- Layout of the Energy Recovery Linac (ERL)
- Layout of the Interaction Region
- Synchrotron radiations
- Electron interaction region optics

Design parameters

Luminosity with the baseline design of 10^{33} $cm^{-2}s^{-1}$ and up to $6x10^{33}$ $cm^{-2}s^{-1}$

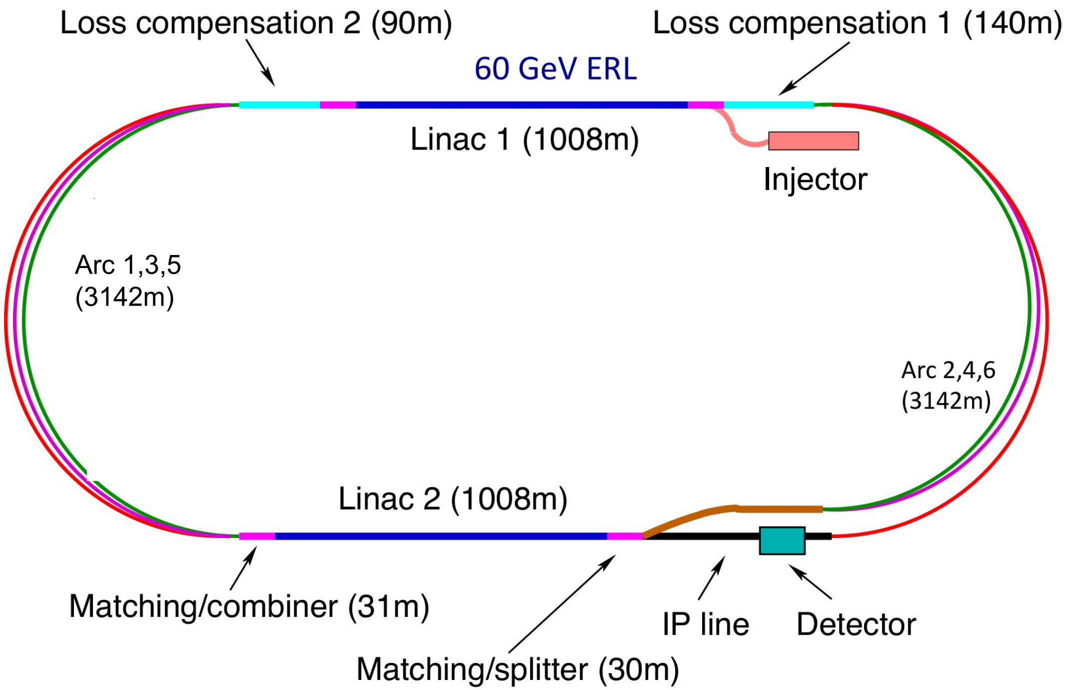
Design	Energy [GeV]	Emittance [nm.rad] e-	Emittance [nm.rad] p	Beam current [mA]	β* [cm] e-	β* [cm] p	IP spot size [μm]	Luminosity
Baseline	50	0.51	0.50	6.4	10.0	10.0	7.20	10^{33}
Upgrade	50	0.34	0.34	20.0	10.0	10.0	5.83	$5.0x10^{33}$
Np = $2.2x10^{11}$		0.24	0.34	20.0	10.0	7.0	4.47	$6.0x10^{33}$

0.50 and **0.34** nm.rad corresponds to **3.75** and **2.5** μm.rad normalized emittance for the proton beam.

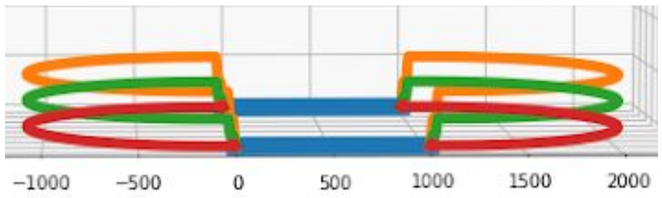
0.51 and **0.24** nm.rad corresponds to **50** and **23** μm.rad normalized emittance for the electron beam.

FCC eh	60	0.17	0.04	20	3.6	15.0	2.45	$15.0x10^{33}$

Layout of the Energy Recovery Linac (ERL)



From 2018, LHeC PERLE executive summary - Max Klein

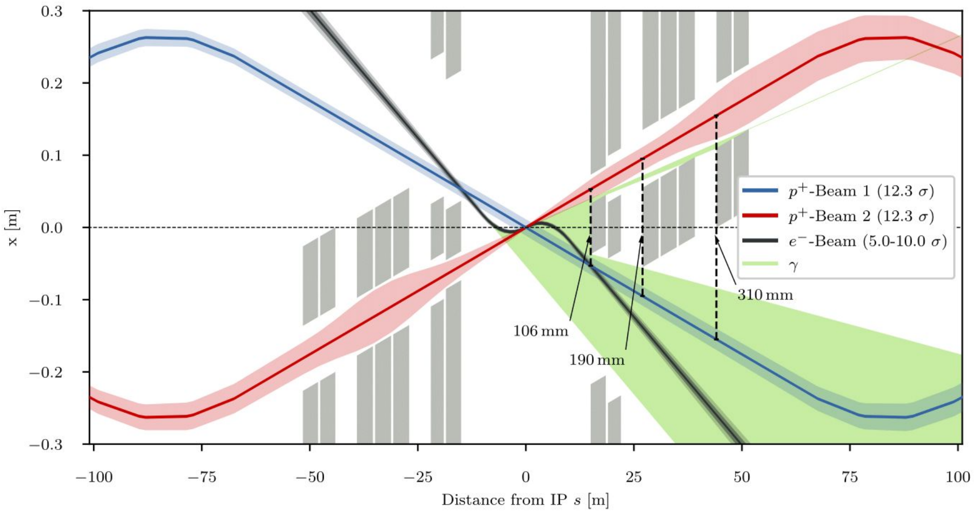


60 GeV design :
⅓ LHC length
9 km circumference

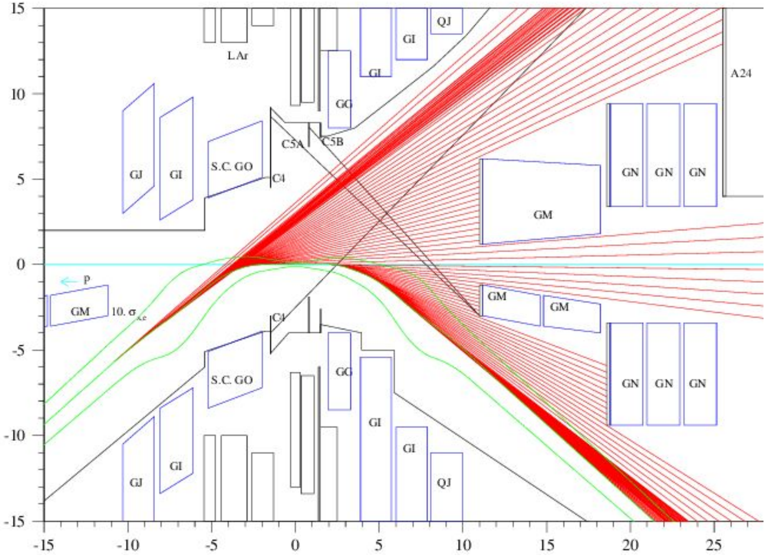
50 GeV design :
¼ LHC length ≈ SPS
6.7 km circumference

Layout of the Interaction Region

Schematic from R. Martin



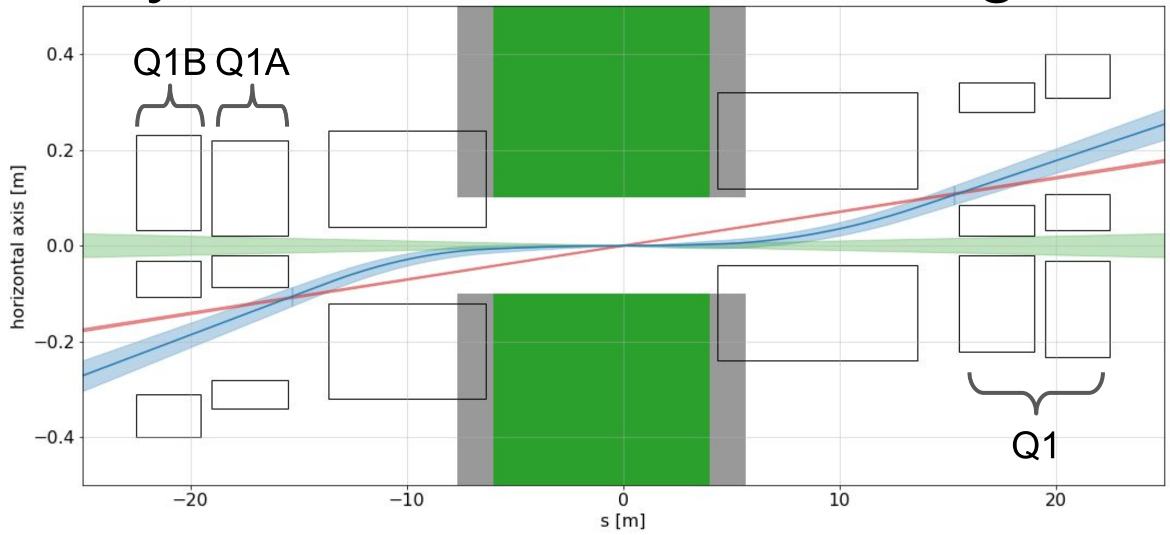
Schematic from *Design of a high power synchrotron radiation absorber for HERA* - M. Bieler et al.

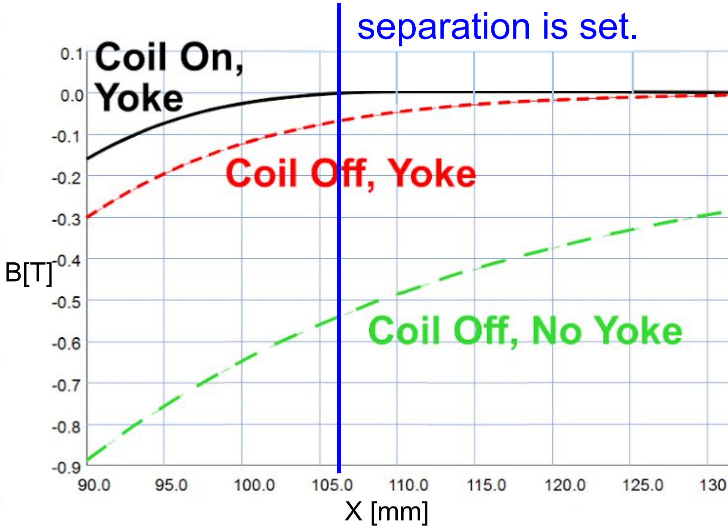


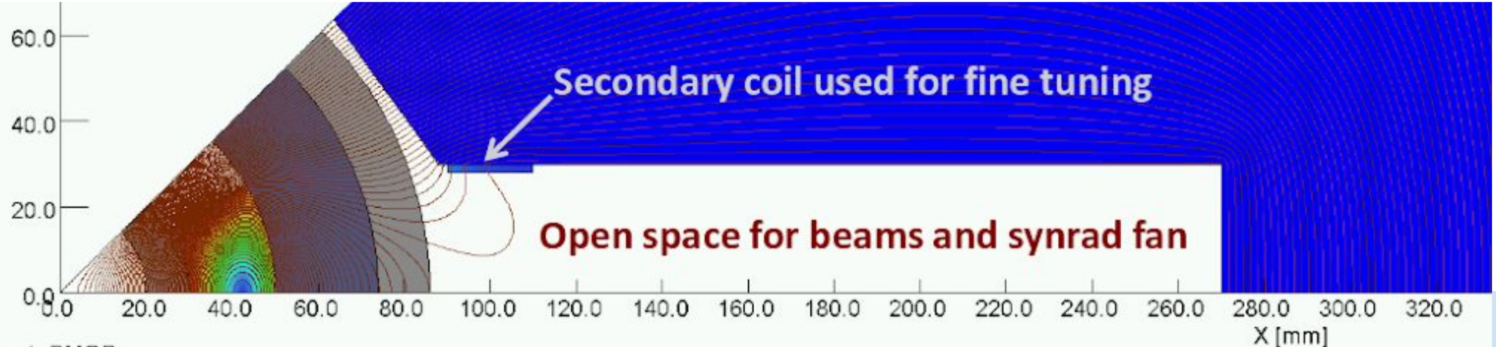
Interaction point characteristics:

- Besides head-on collision, 3 beams among which one is not colliding,
- Concurrent collision ep and pp for the colliding proton beam,
- Tens of kilowatts of synchrotron power to shield.

Layout of the Interaction Region







From 2018, LHeC/FCCeh Workshop - Brett Parker

Synchrotron radiations

Synchrotron radiations

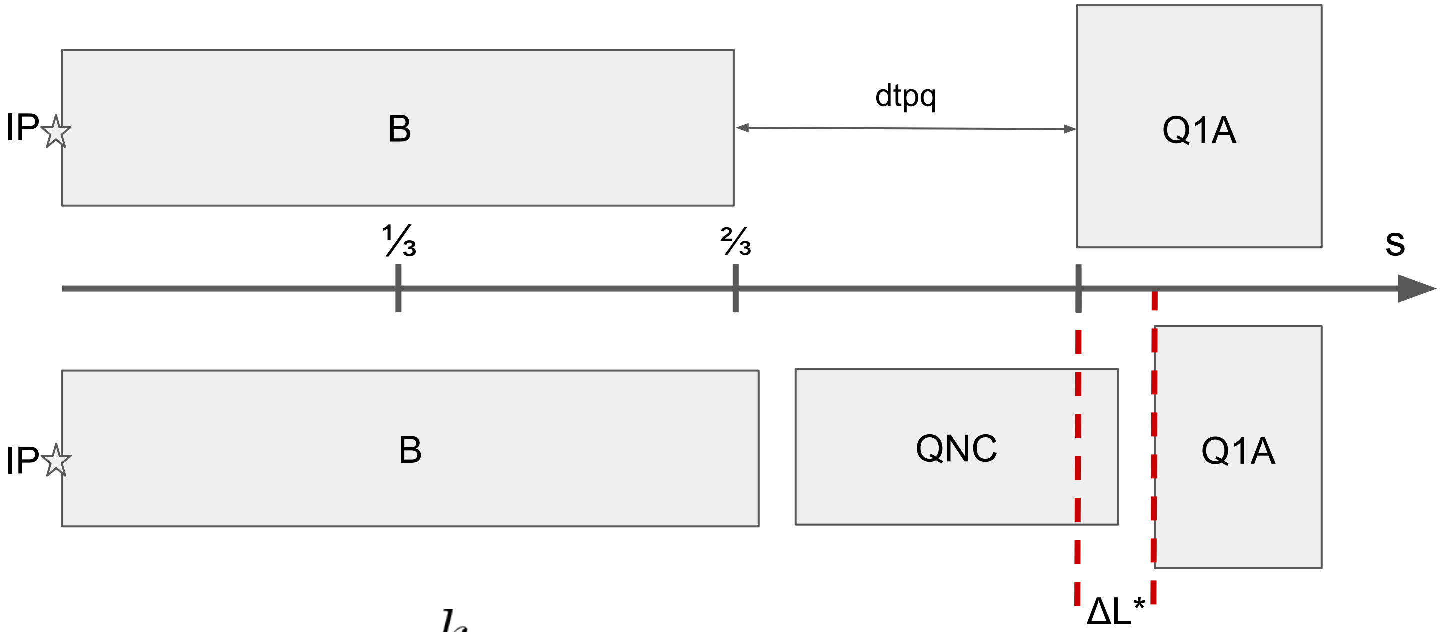
Mainly due to the space required to have a separation between electron and proton beams before the first proton quadrupole.

The **synchrotron radiation power** is proportional to : $I_e E_e^{4} \theta^2 / L$,

while the **critical energy** is proportional to : $E_e^{3} \theta / L$

	Design with L^*_p=15m, E_e = **60 GeV**				Design with L^*_p=15m, E_e = **50 GeV**				HERA
	Lbend = ⅔ L^*_p		Lbend = L^*_p		Lbend = ⅔ L^*_p		Lbend = L^*_p		
Electron current [mA]	6.4	20	6.4	20	6.4	20	6.4	20	58
Synchrotron Power [kW]	26.7	82.0	30.9	97.2	12.7	39.6	15.0	46.9	28
Critical Energy [keV]	508.6		445.0		294.3		261.6		150

Synchrotron radiations - NC quadrupole

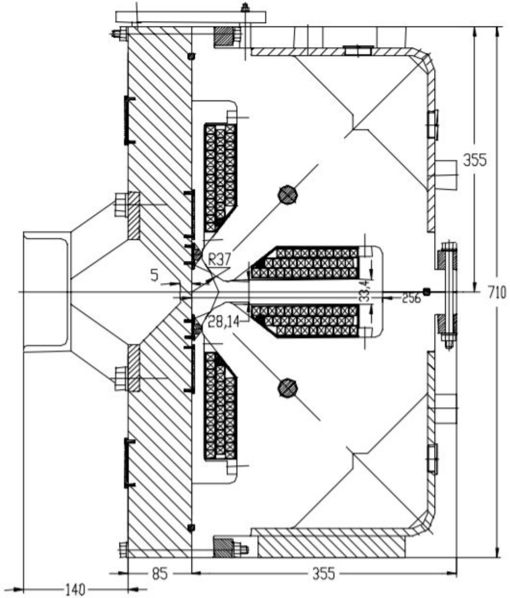


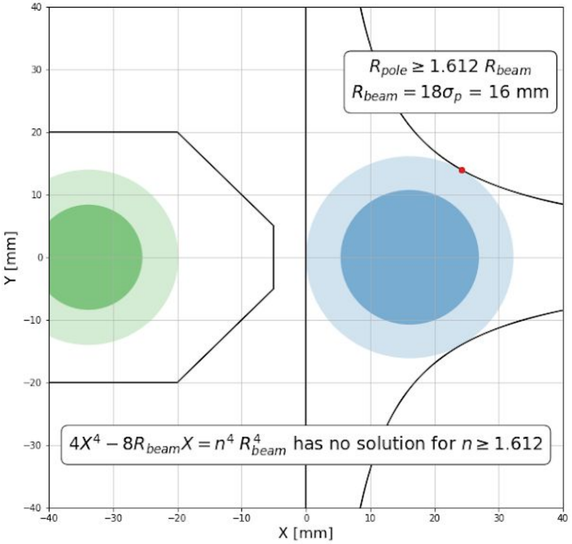
$$L_{NC} = \frac{k_{SC}}{k_{NC}} \times L_{SC} = \Omega \times L_{SC}$$

Synchrotron radiations - NC quadrupole

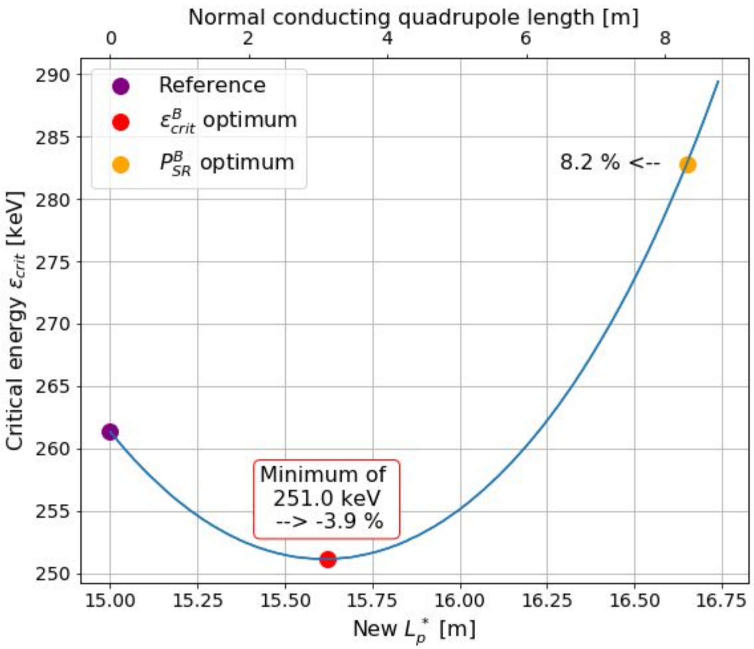
In cooperation with M. Liebsch, use of ROXIE to assess the properties of such mirror magnet with a resisting technology. Within the CERN archives there are few magnets with the following characteristics :

- 52.5 T/m Quadrupole (r = 25 mm) : https://norma-db.web.cern.ch/magdesign/idcard/312/
- 49.8 T/m Quadrupole (r = 25 mm) : https://norma-db.web.cern.ch/magdesign/idcard/311/

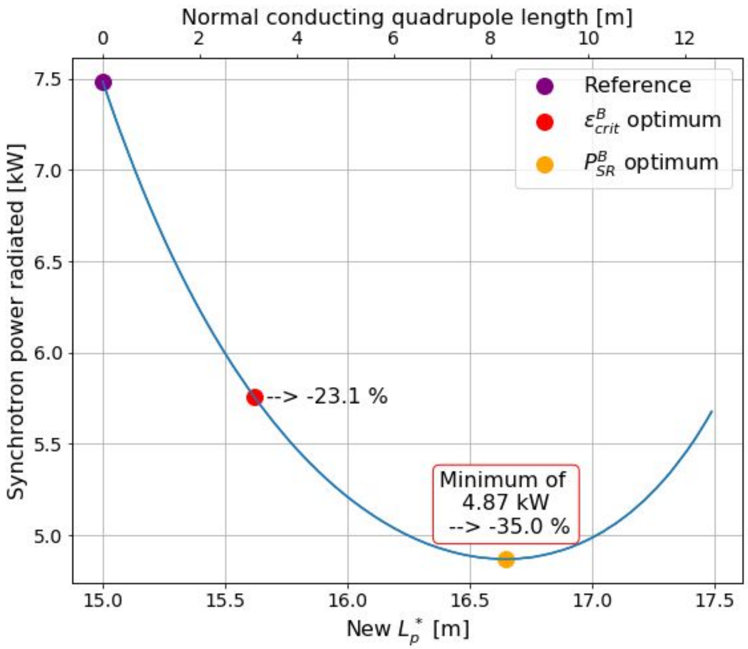




Synchrotron radiations - NC quadrupole

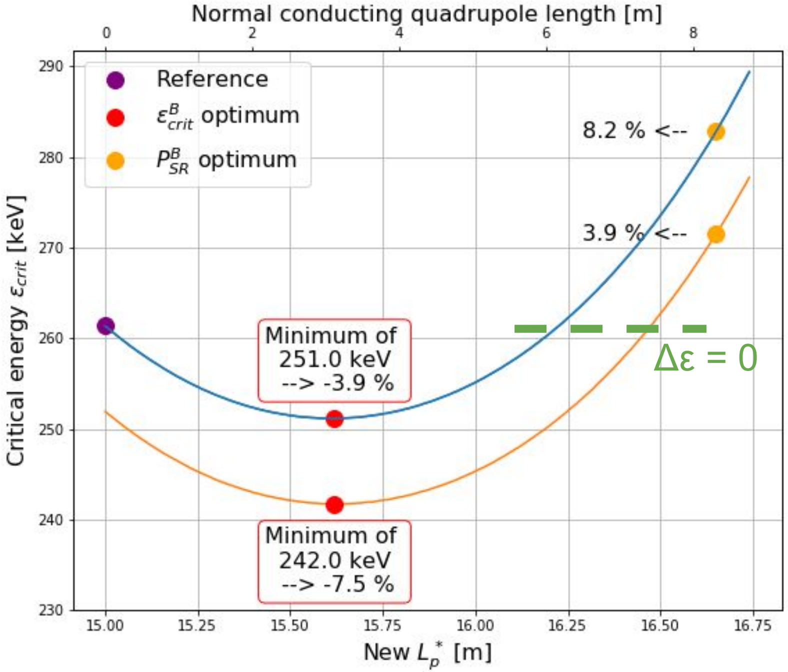


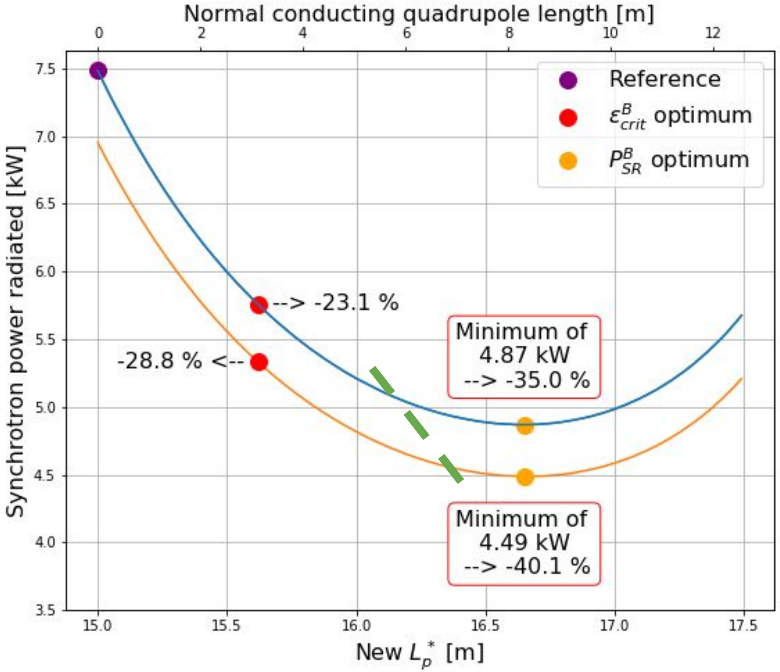
$$\frac{\epsilon}{\epsilon_{ref}} = \frac{9}{8}\frac{\Omega^2 - 1}{\Omega^2}$$



$$\frac{P}{P_{ref}} = \frac{27}{32}\frac{(1+\Omega)(\Omega-1)^2}{\Omega^3}$$

Synchrotron radiations - NC quadrupole + crossing





0 to 255 µrad crossing angle span for the colliding proton beam ➤ gain up to 3.8 mm separation.

Synchrotron radiations optimization

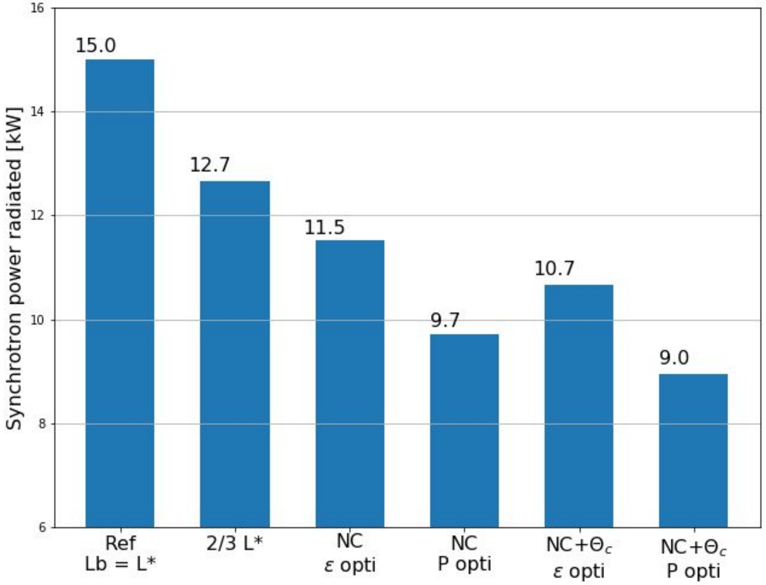
Besides the resisting quadrupole the possibility of adding a crossing angle for the colliding proton beam compensated by crab cavities has been studied.

A crossing angle of 255 µrad gives.

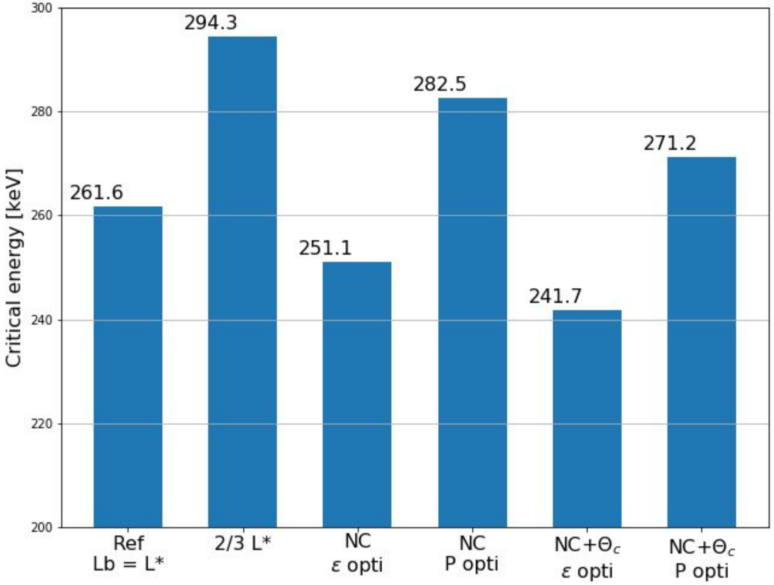
Electron beam energy 50 GeV							
	Baseline with Ie = 6.4 mA			Goal design with Ie = 20 mA			HERA
	⅔ L*	SR opti	ε opti	⅔ L*	SR opti	ε opti	
Synchrotron Power [kW]	12.7	9.0	10.7	39.7	28.1	33.3	28
Critical Energy [keV]	294	267	241	294	267	241	150

Synchrotron radiations optimization

Synchrotron power emitted

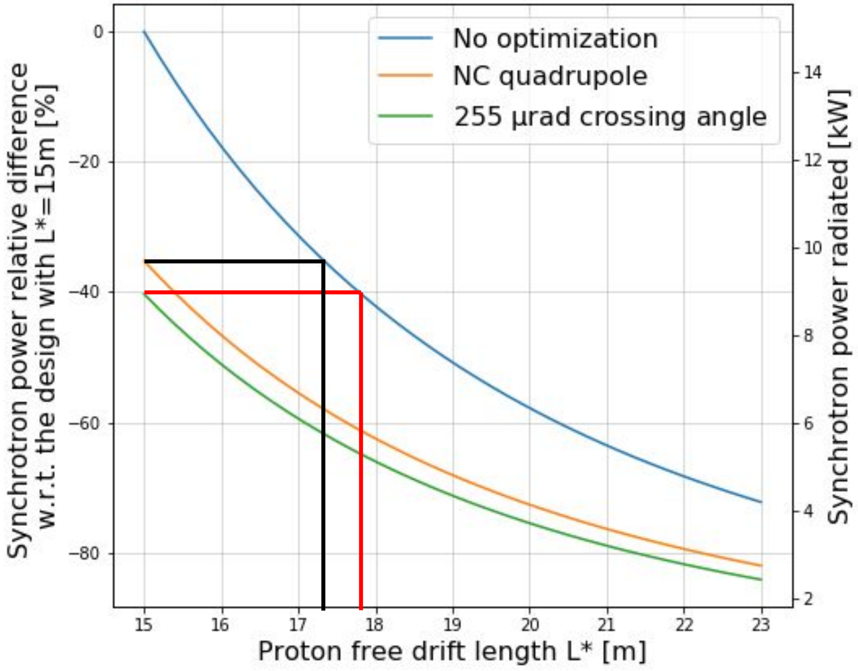


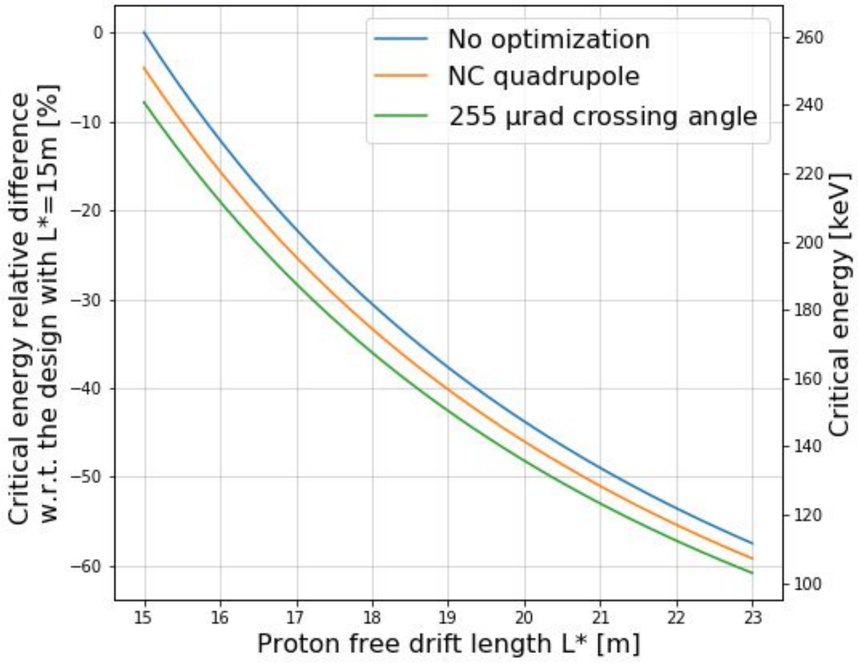
Critical energy



$$\frac{P}{P_{ref}} = \frac{27}{32}\frac{(1+\Omega)(\Omega-1)^2}{\Omega^3}\left[1-\frac{\theta_c}{d}(L^*+L_{SC})\right]^2$$

Synchrotron radiations - Comparison





The calculations assume a separation at the first proton quadrupole Q1A of 106 mm

Synchrotron radiations - Conclusions

To reduce efficiently (tens of percents) the critical energy either a decrease of the electron beam energy or an extension of the proton free drift length (*i.e.* L*) is required.

The results of the optimization allows a decline from 260 keV to 240 keV being 8%.

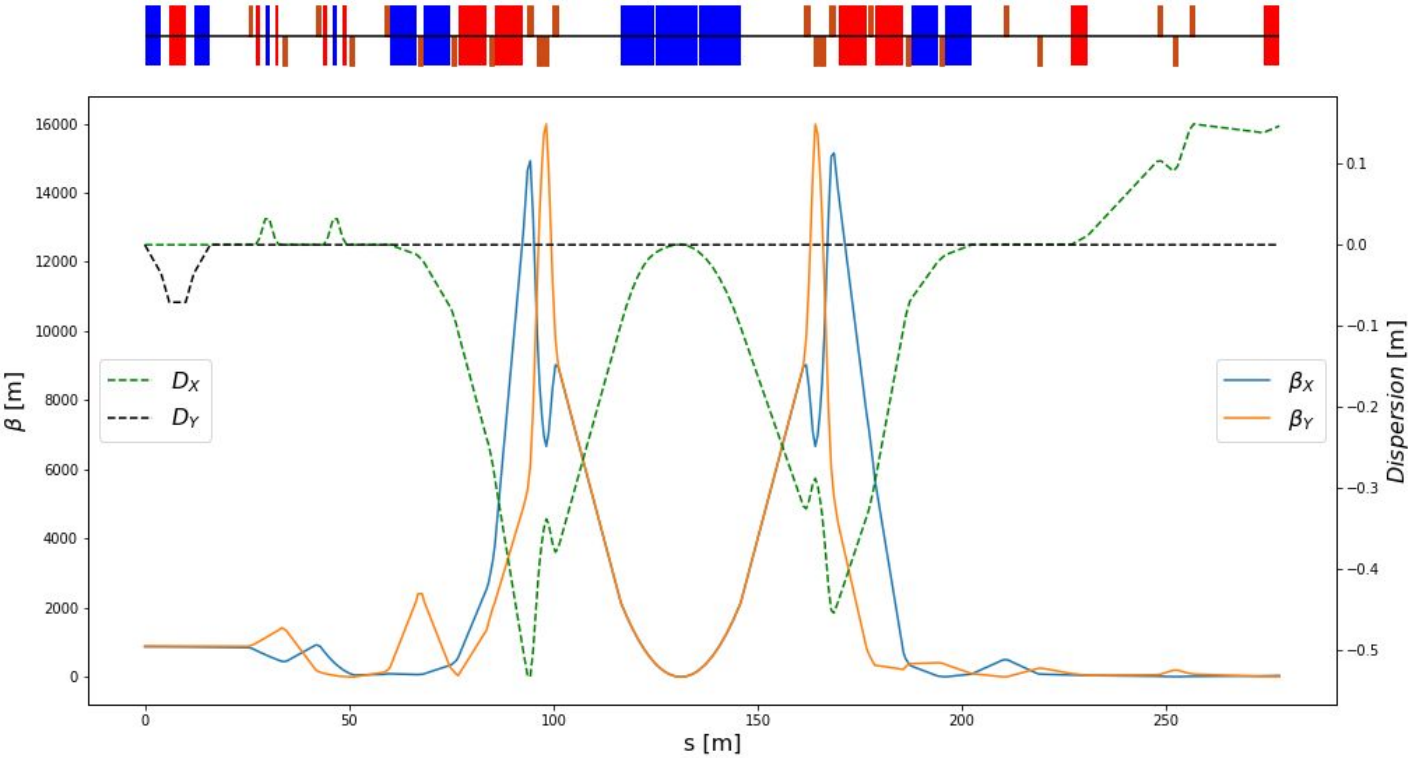
The electron current is an additional leverage in regard to the synchrotron power.

The results of the optimization allows a reduction from 15 kW to 10.7 kW being 29%.

All in all, the results presented offer a decrease of both critical energy and synchrotron power that was not possible with the dipole optimization only.

Electron interaction region optics

Electron optics : Interaction region



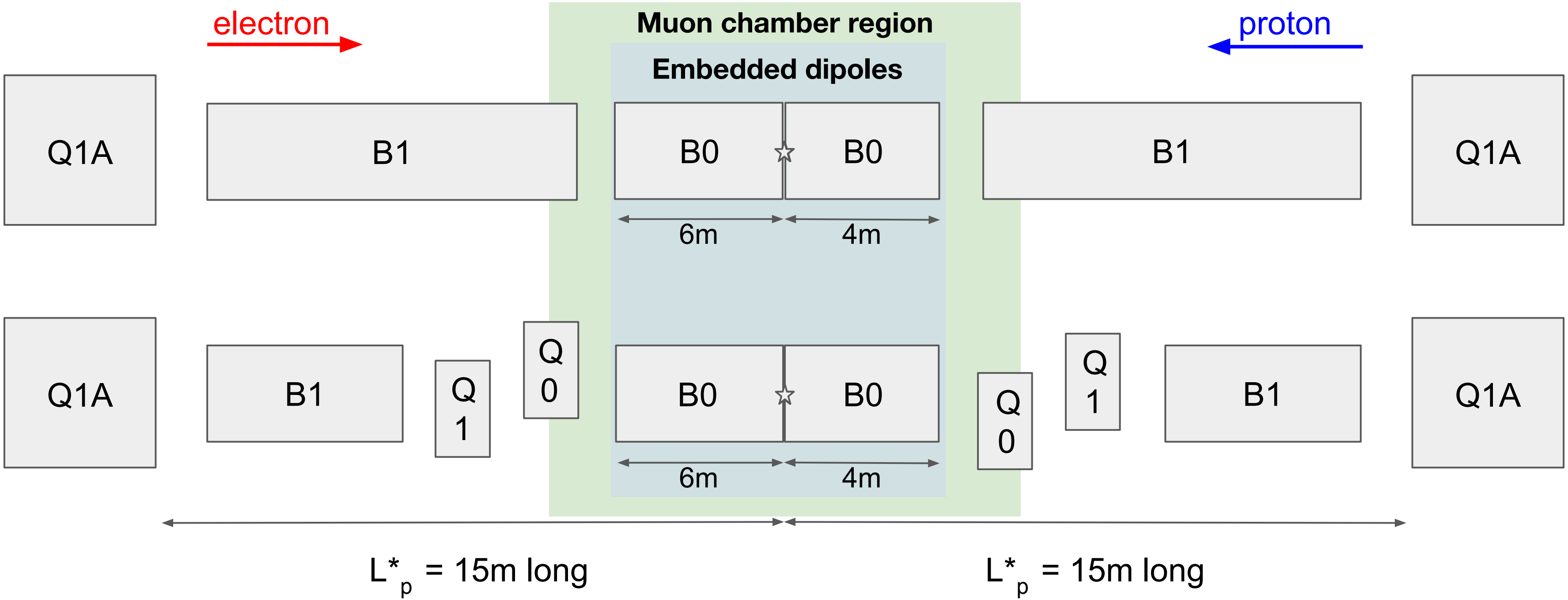
16 km beta max

Large beam size in the quadrupoles

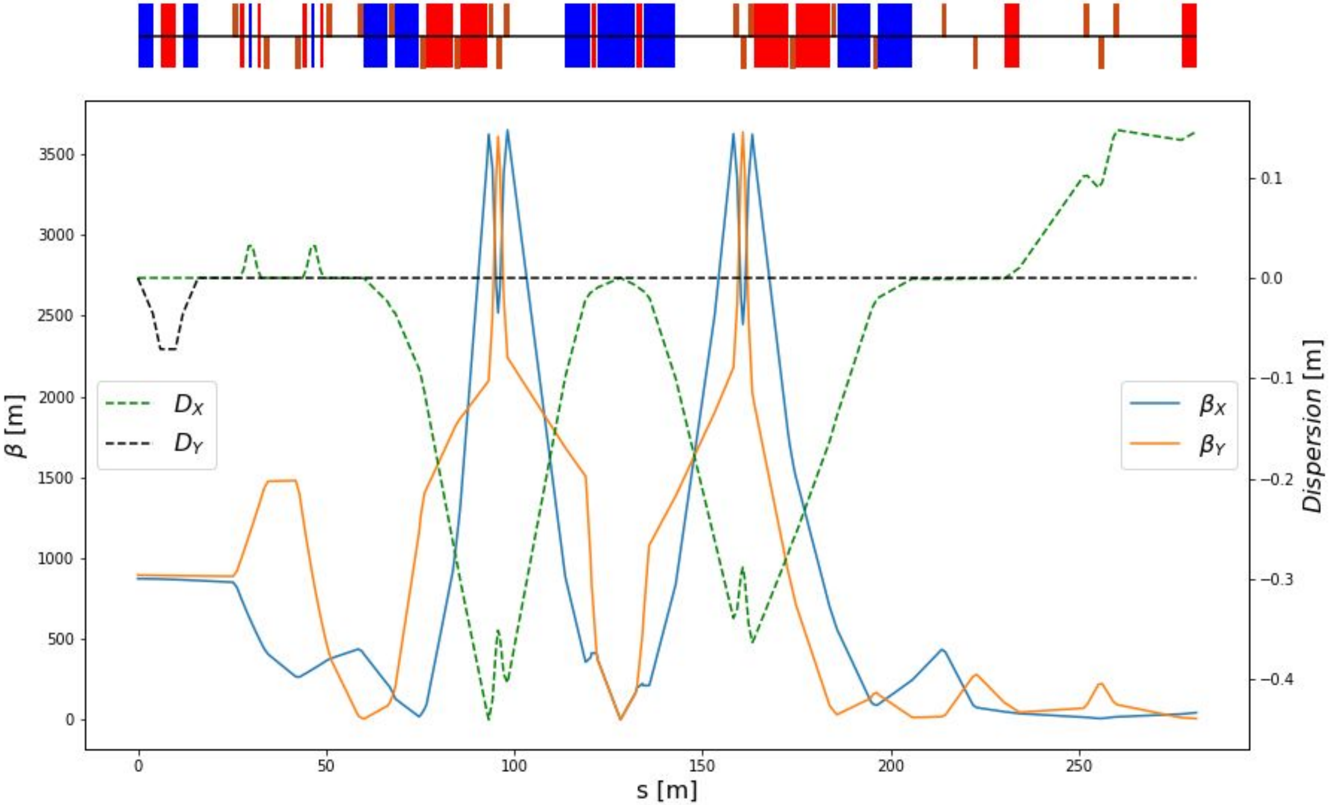
Long quadrupoles

Natural chromaticity around -200

Electron optics : Interaction region



Electron optics : Interaction region



Down to 3 km beta max

Smaller beam size in the quadrupoles

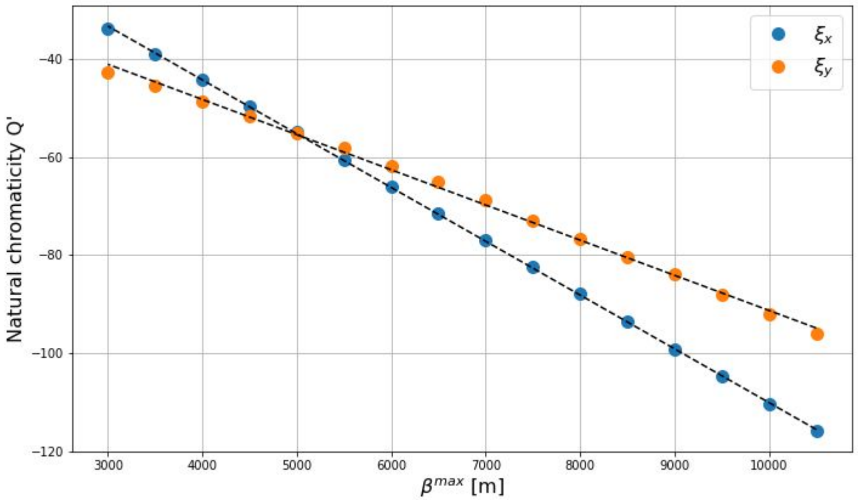
Shorter quadrupoles

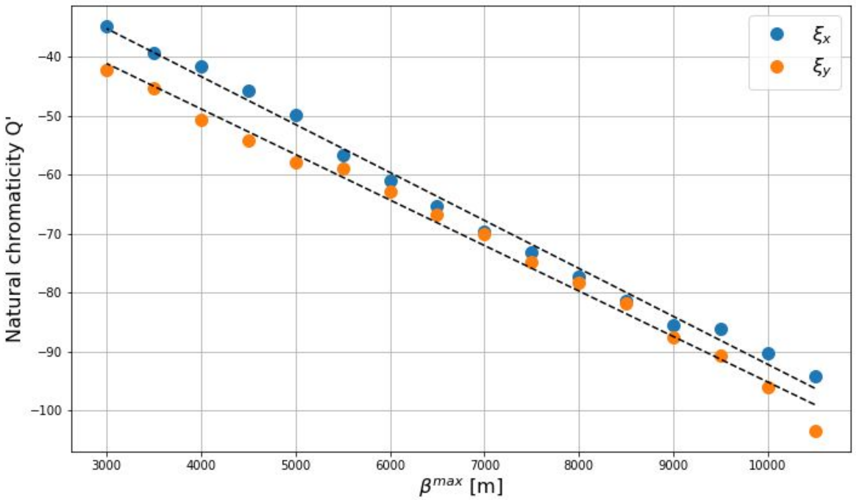
Natural chromaticity down to -80

Electron optics : Chromaticity

In case of bending magnets only, the beam arrives round in the final focusing quadrupoles.

To avoid the bump in one of the transverse plane one could flatten the beam before them.





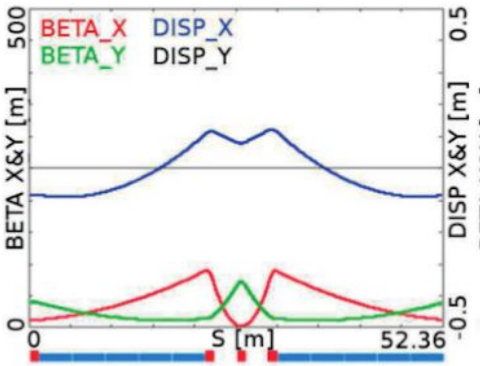
Conclusion : The main challenges

Having 3 beams within the interaction region represent an important challenge in term of magnet design in order to succeed a separation as soft as possible while the proton optics can still be corrected and matched to the LHC lattice.

The synchrotron radiation emitted in the neighborhood of the detector and magnets.

The control of the disrupted electron beam to perform the energy recovery loops.

Layout of the Energy Recovery Linac (ERL)

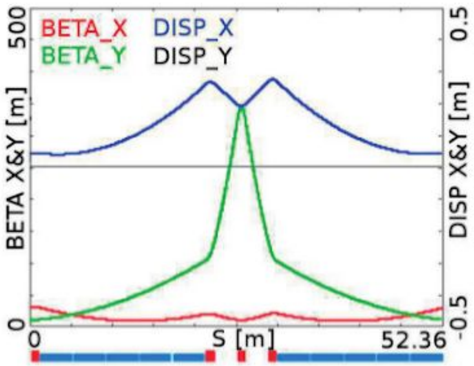


Arc 1 & 2 periodic optics
" Negative momentum compaction "

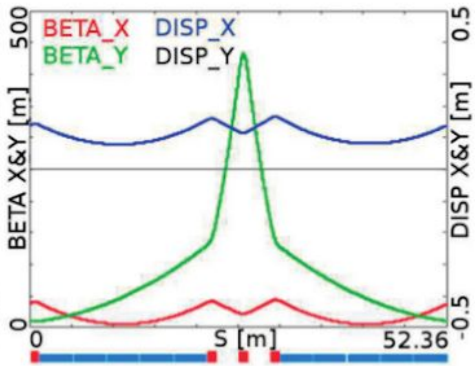
Mitigate the bunch elongation and low beam size.

Arc 3 & 4 periodic optics
" DBA-like "

Compromise between bunch lengthening and emittance dilution.



Plots from D. Pellegrini PhD thesis



Arc 5 & 6 periodic optics
" TME-like "

Mitigate the emittance dilution by minimizing the $\mathcal{H}(s)$ function.