Progress on the eh Interaction Region

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IR meeting June 18, 2019

Outline

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

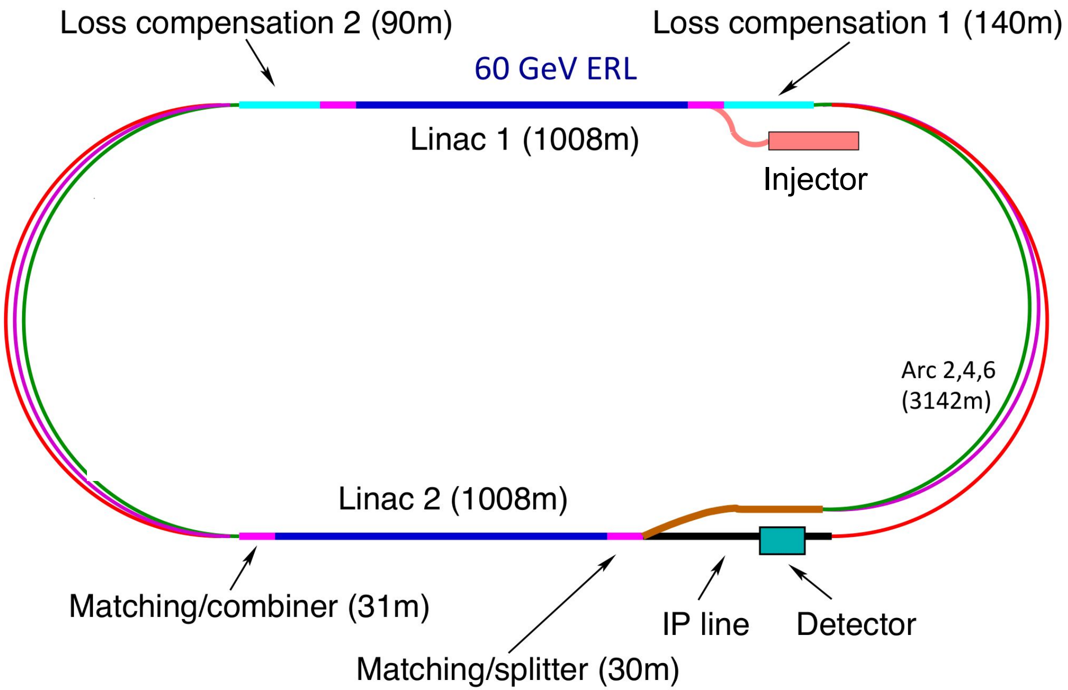
Design parameters

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

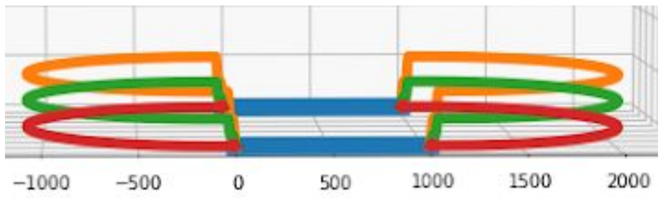
Design	Energy [GeV]	Emittance [nm.rad] e-	Emittance [nm.rad] p	Beam current [mA]	β* [cm] e-	β* [cm] p	IP spot size [µm]	Luminosity
Baseline	50	0.51	0.50	6.4	10.0	10.0	7.20	10^{33}
Upgrade	50	0.34	0.34	20.0	10.0	10.0	5.83	$3.9x10^{33}$
Np = $1.7x10^{11}$		0.24	0.34	20.0	10.0	7.0	4.87	$4.6x10^{33}$
Upgrade	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.

Layout of the Energy Recovery Linac (ERL)



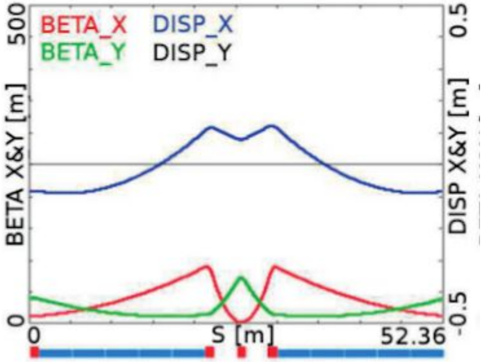
From 2018, LHeC PERLE executive summary - Max Klein



60 GeV design :
⅓ LHC length
9 km circumference

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

Layout of the Energy Recovery Linac (ERL)

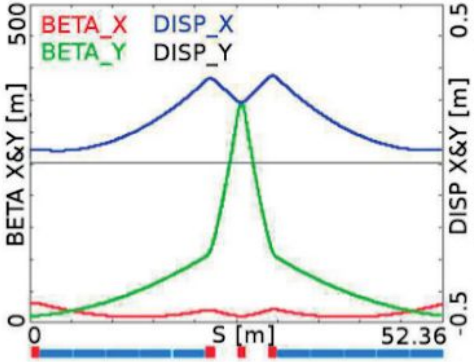


Arc 1 & 2 periodic optics
" Negative momentum compaction "

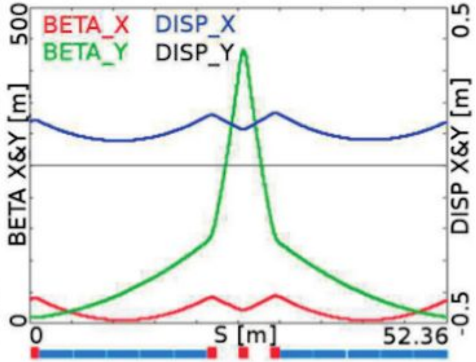
Mitigate the bunch elongation and low beam size.

Arc 3 & 4 periodic optics
" DBA-like "

Compromise between bunch lengthening and emittance dilution.



Plots from D. Pellegrini PhD thesis

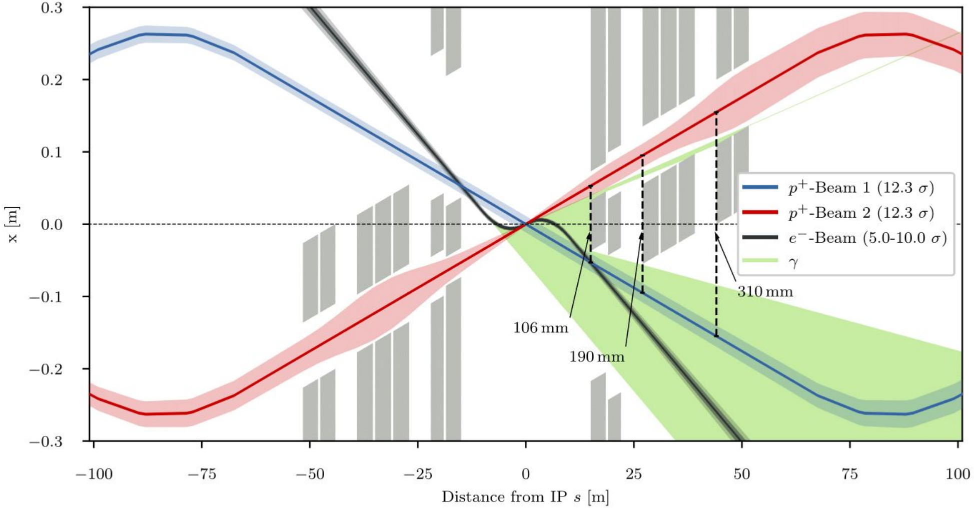


Arc 5 & 6 periodic optics
" TME-like "

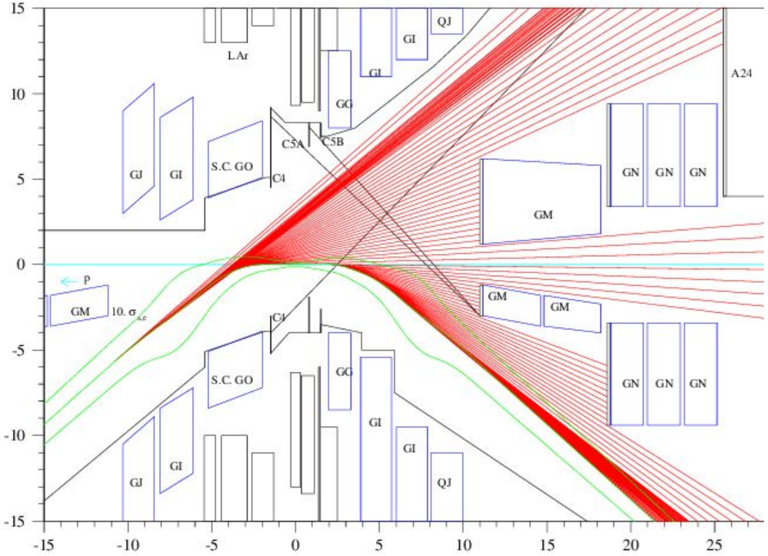
Mitigate the emittance dilution by minimizing the $\mathcal{H}(s)$ function.

Layout of the Interaction Region

Schematic from R. Martin



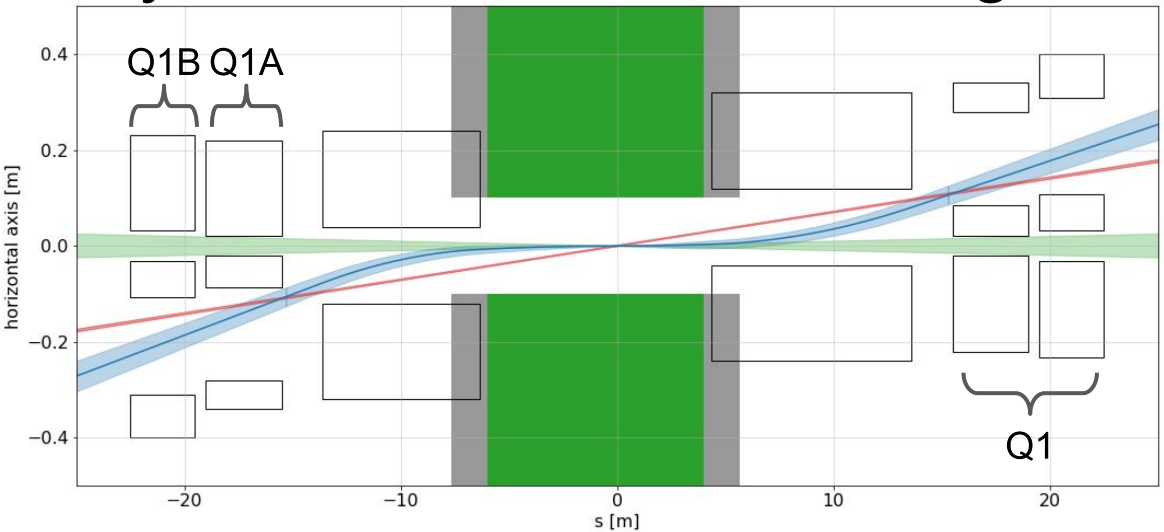
Schematic from *Design of a high power synchrotron radiation absorber for HERA* - M. Bieler et al.

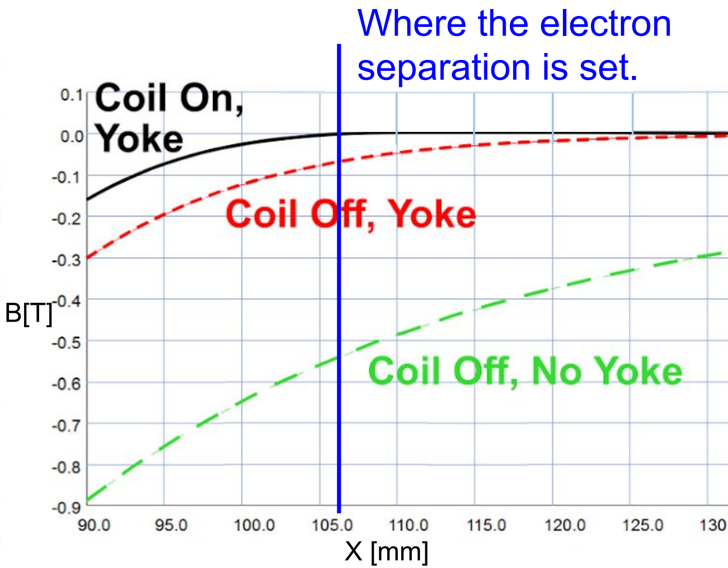


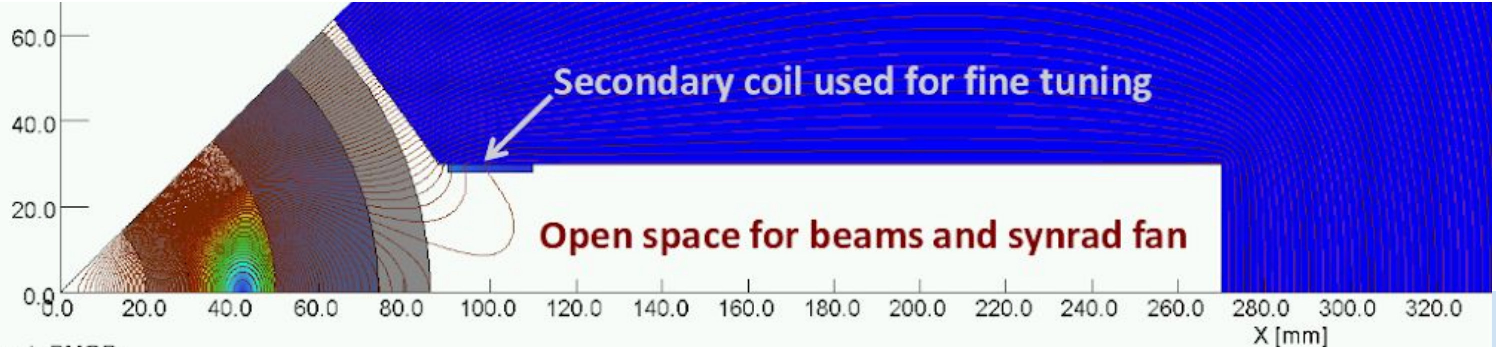
Interaction point characteristics:

- 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

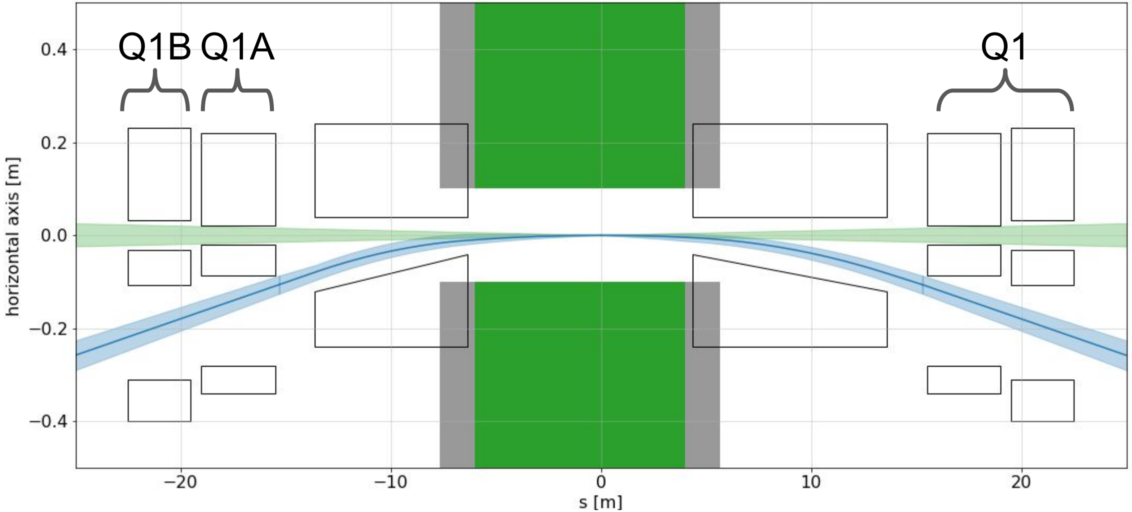




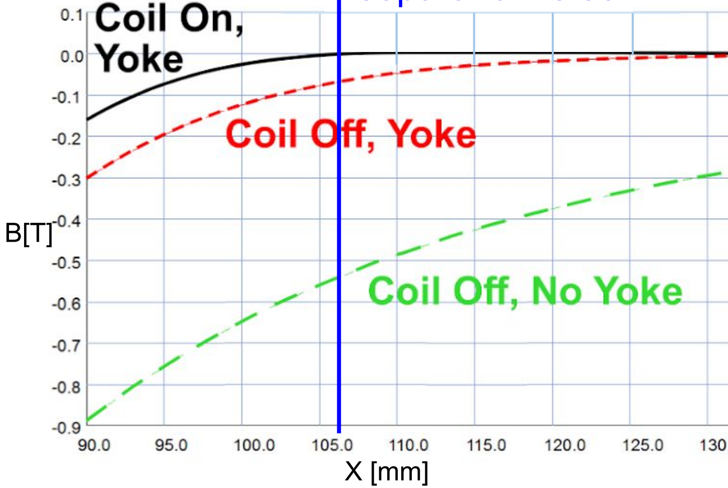


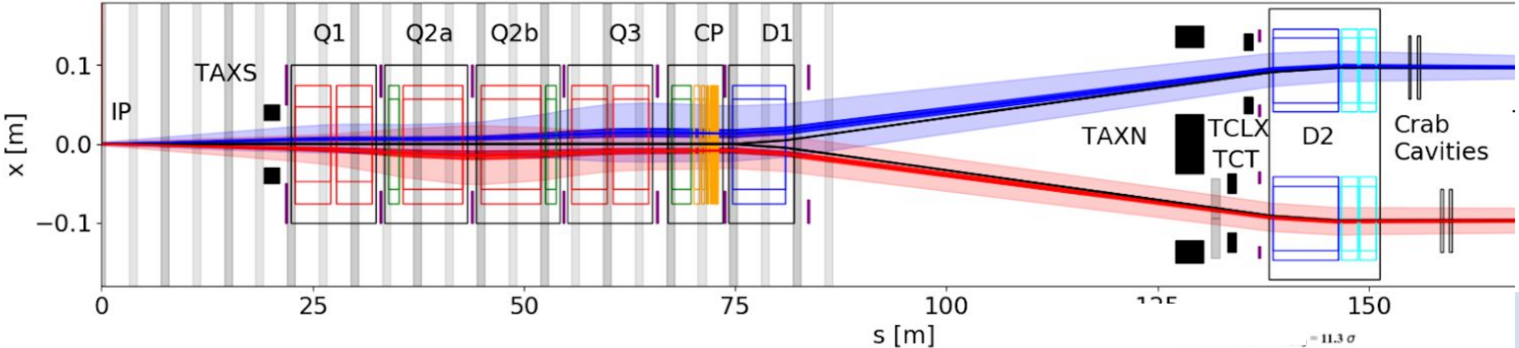
From 2018, LHeC/FCCeh Workshop - Brett Parker

Layout of the Interaction Region



Where the electron separation is set.





From 6/6/19 ABP General group meeting - M. Giovannozzi

Synchrotron radiations

Synchrotron radiations

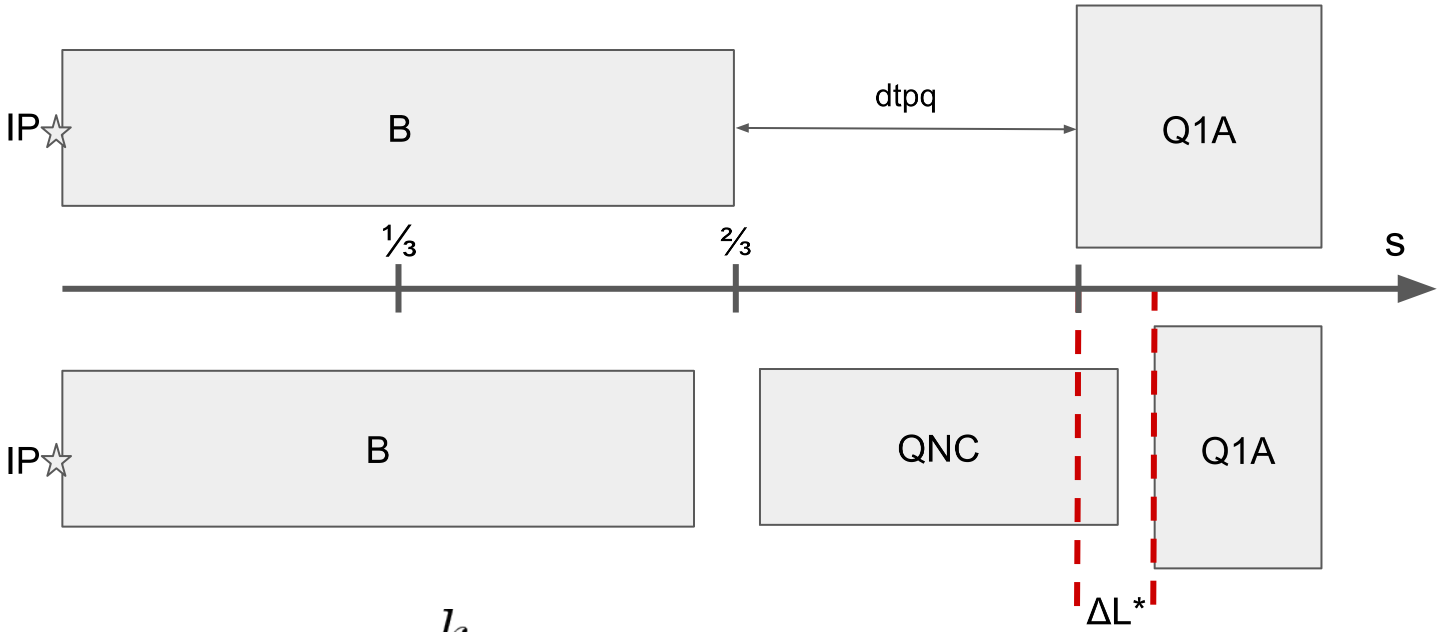
Mainly due to the space required to have a separation between electron and proton before the first proton quadrupole.

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

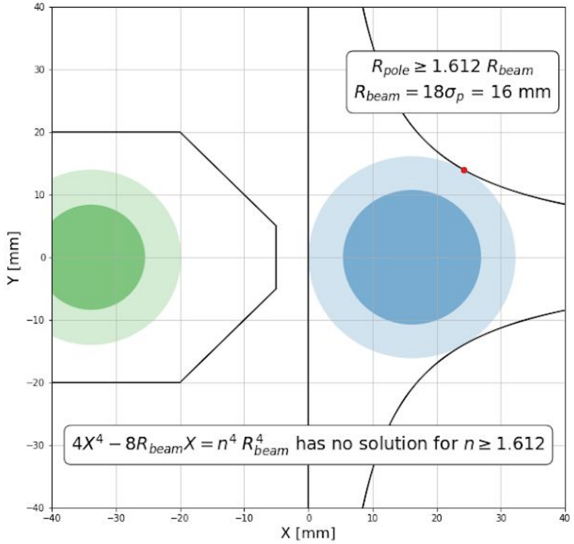
In cooperation with Melvin Liebsch (Stephan's PhD); use of ROXIE to assess the properties of a mirror magnet with a resisting technology. Within the CERN archives there are few magnets with the following characteristics :

- 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/

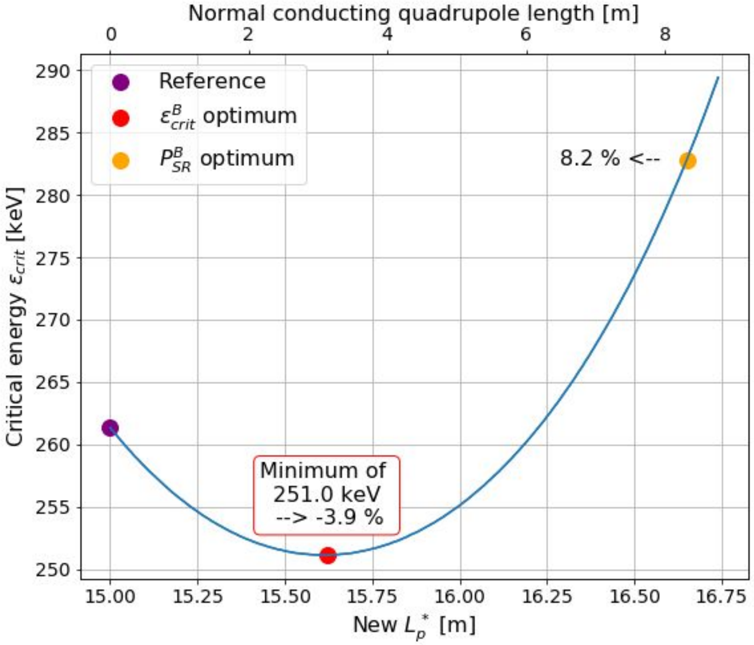
So far 47 T/m has been reached instead of the 49.8 T/m probably due to the different saturation curves of the iron simulated // real.

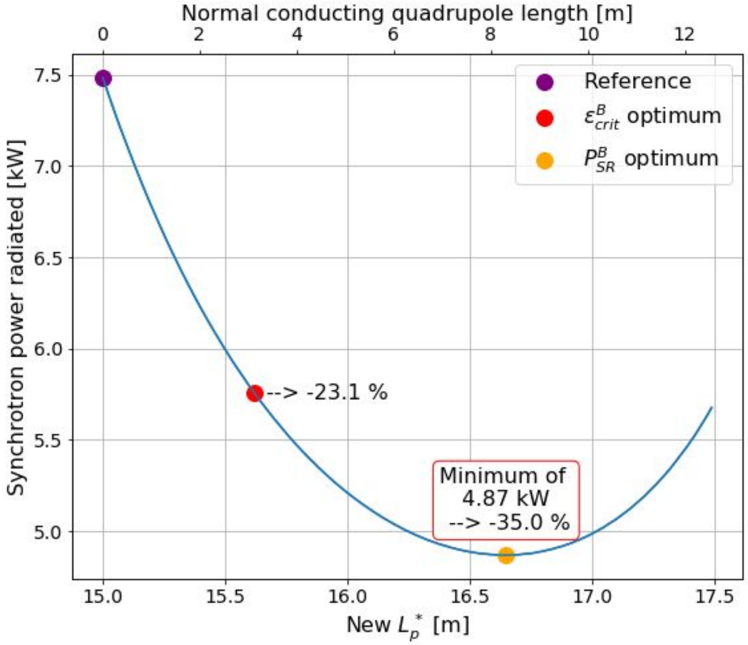
The next steps :

- Mesh size convergence analysis
- Saturation in the iron w.r.t. different excitation currents,
- Field free region versus thickness of the mirror screen,
- Multipole errors versus thickness of the mirror screen,
- Harmonics at the proton beam position at nominal field/current and possible correction/mitigation



Synchrotron radiations - NC quadrupole

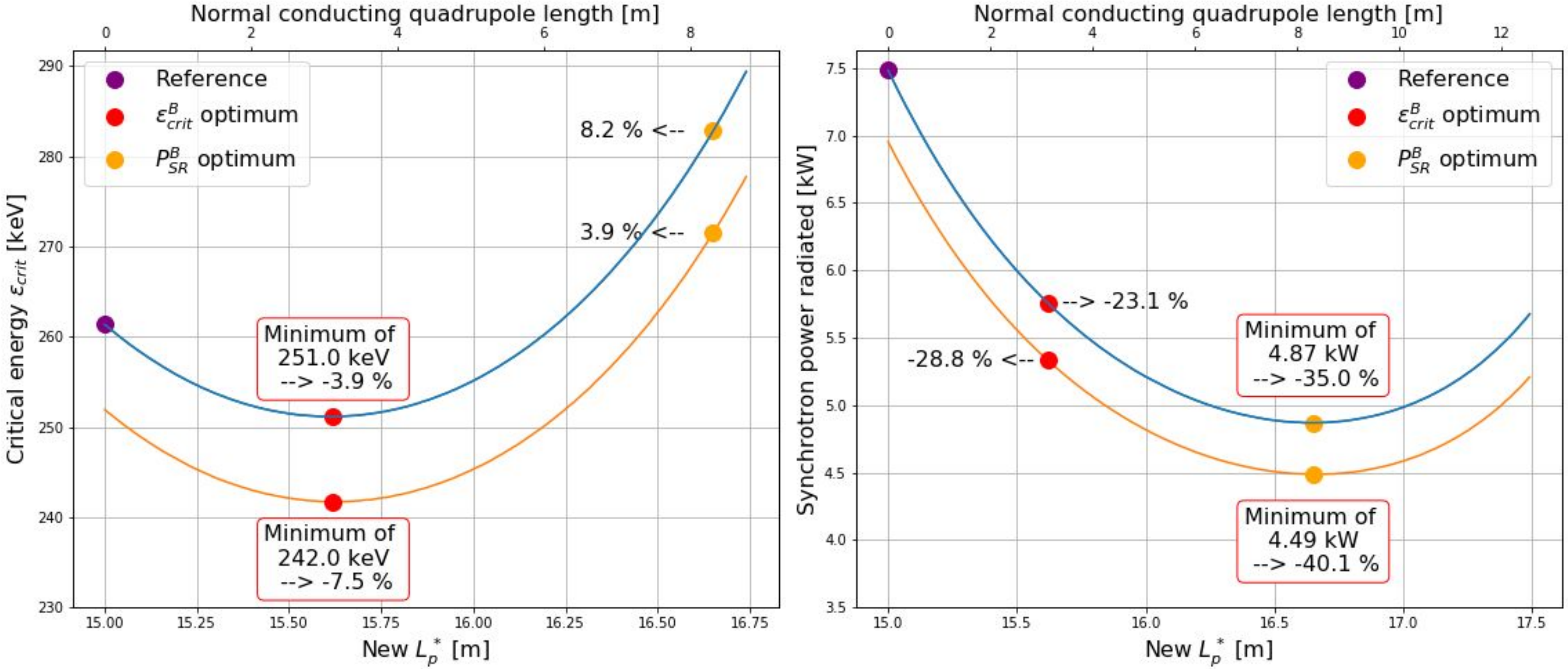




$$\frac{\epsilon}{\epsilon_{ref}} = \frac{9}{8}\,\frac{\Omega^2 - 1}{\Omega^2}$$

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

Synchrotron radiations - NC quadrupole



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

Synchrotron radiations

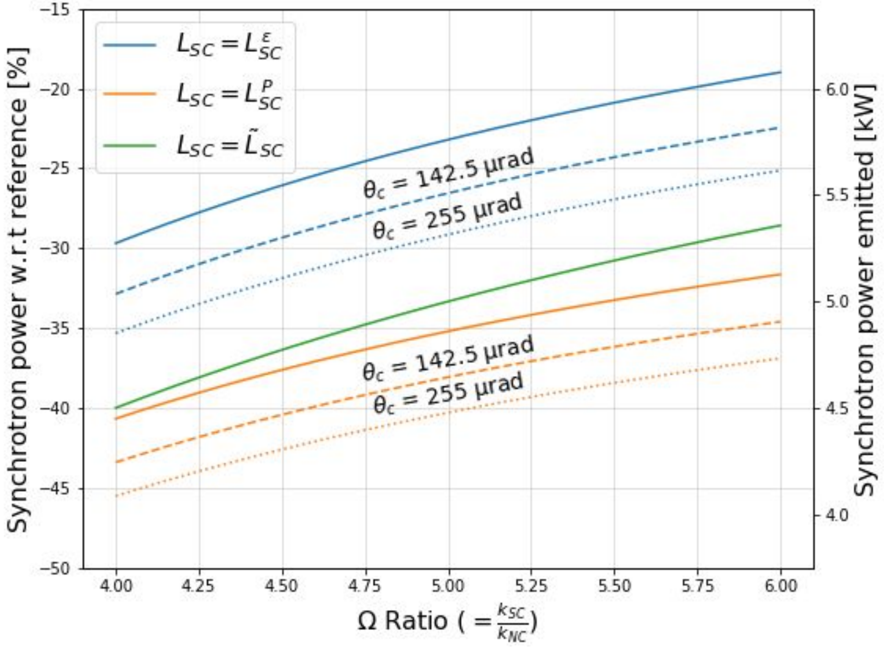
Besides the resisting quadrupole the possibility of adding a crossing angle for the colliding proton beam compensated by crab cavities has been studied.

A crossing angle of 255 µrad gives.

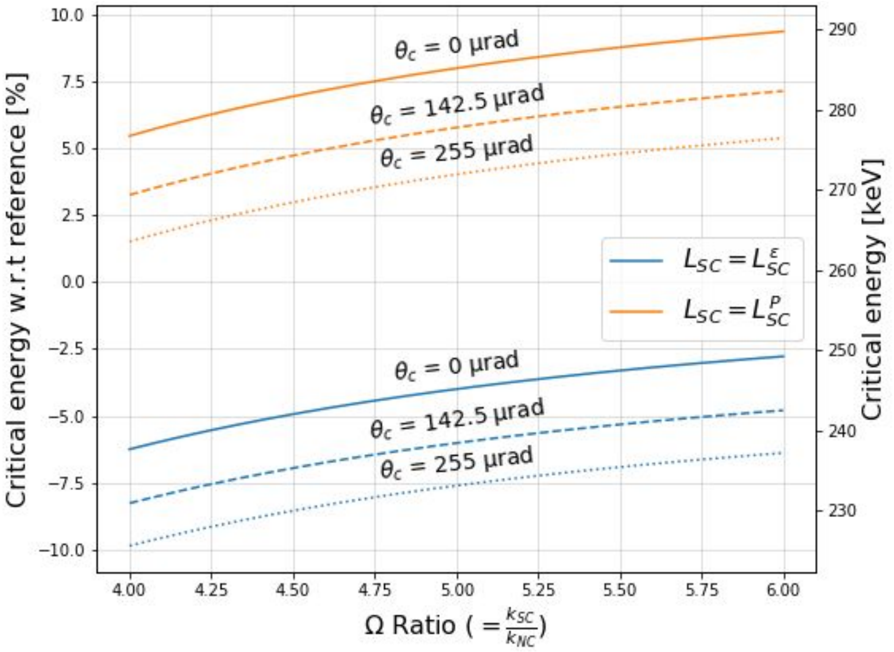
Electron beam energy 50 GeV							
	Baseline with Ie = 6.4 mA			Goal design with Ie = 20 mA			HERA
	⅔ L*	SR opti	ε opti	⅔ L*	SR opti	ε opti	
Synchrotron Power [kW]	12.7	9.0	10.7	39.7	28.1	33.3	28
Critical Energy [keV]	294	267	241	294	267	241	150

Synchrotron radiations

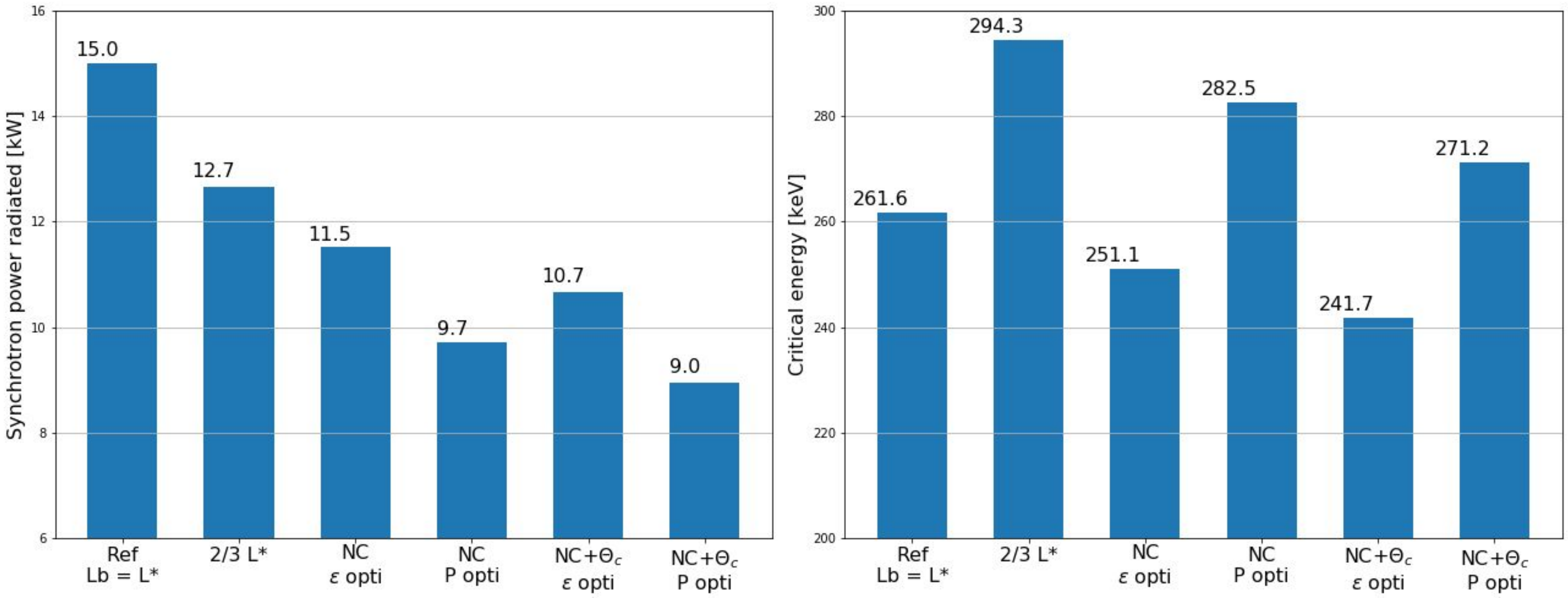
Synchrotron power emitted



Critical energy

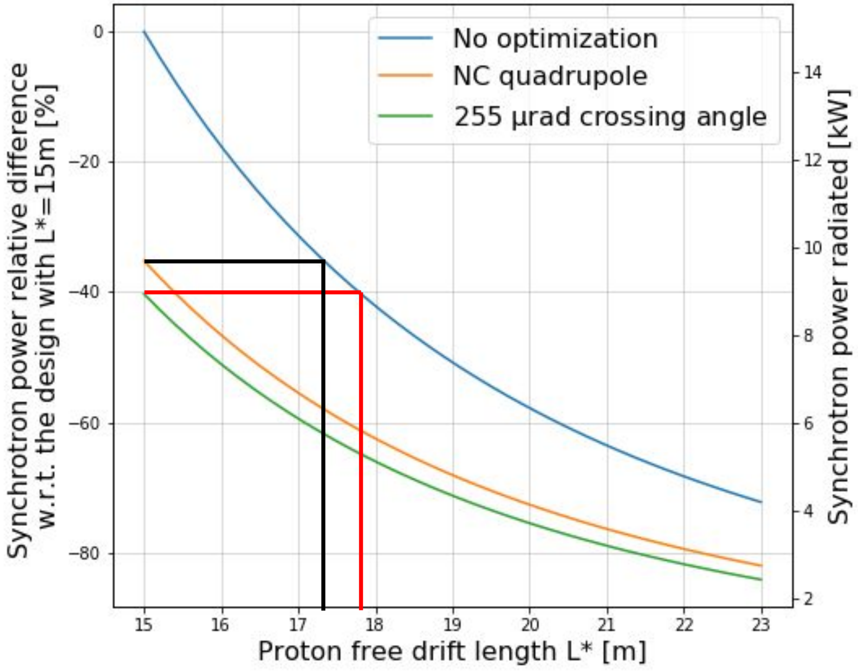


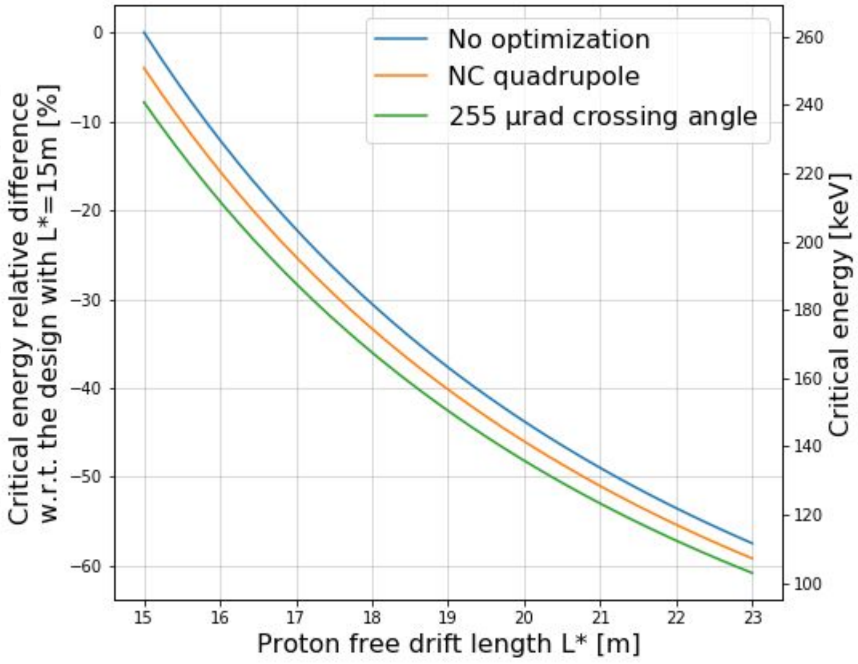
Synchrotron radiations



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

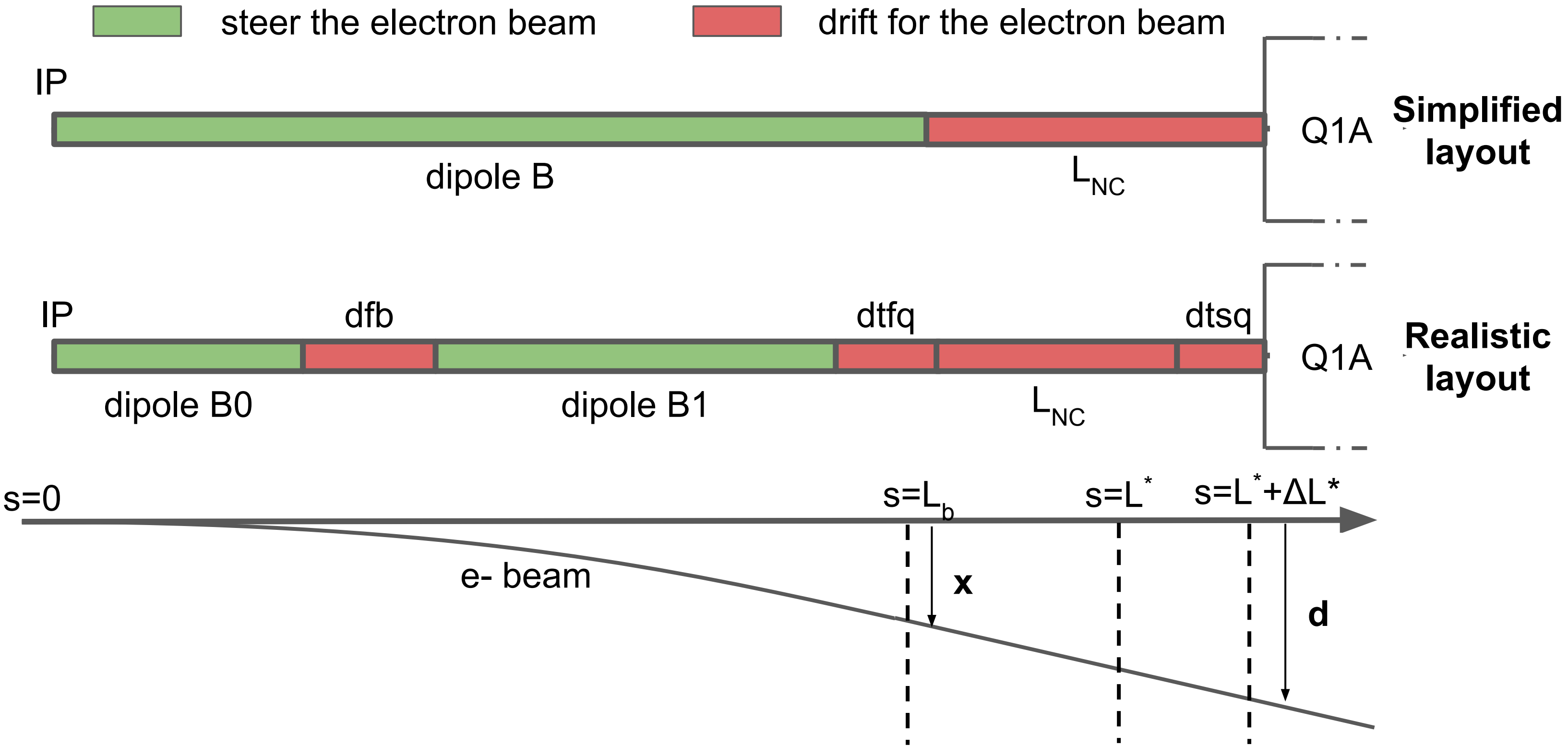
Synchrotron radiations





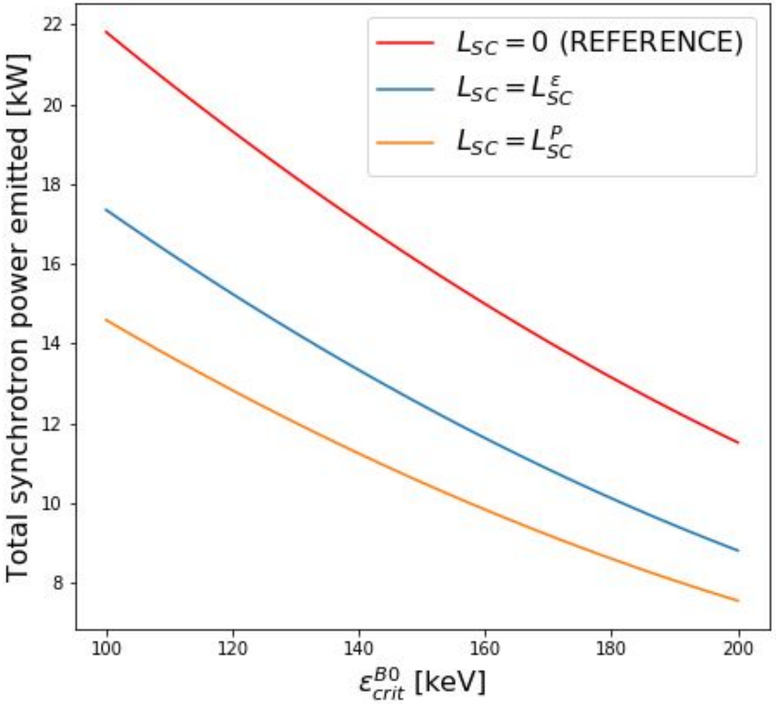
The calculations assume a separation at the first proton quadrupole Q1A of 106 mm

Synchrotron radiations

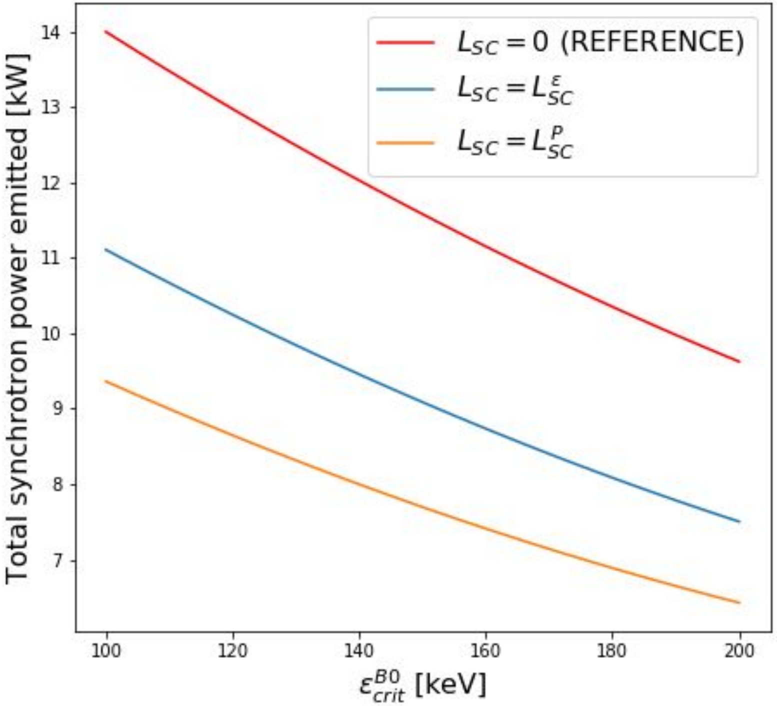


Synchrotron radiations

LEFT HAND SIDE OF THE IP



RIGHT HAND SIDE OF THE IP



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.

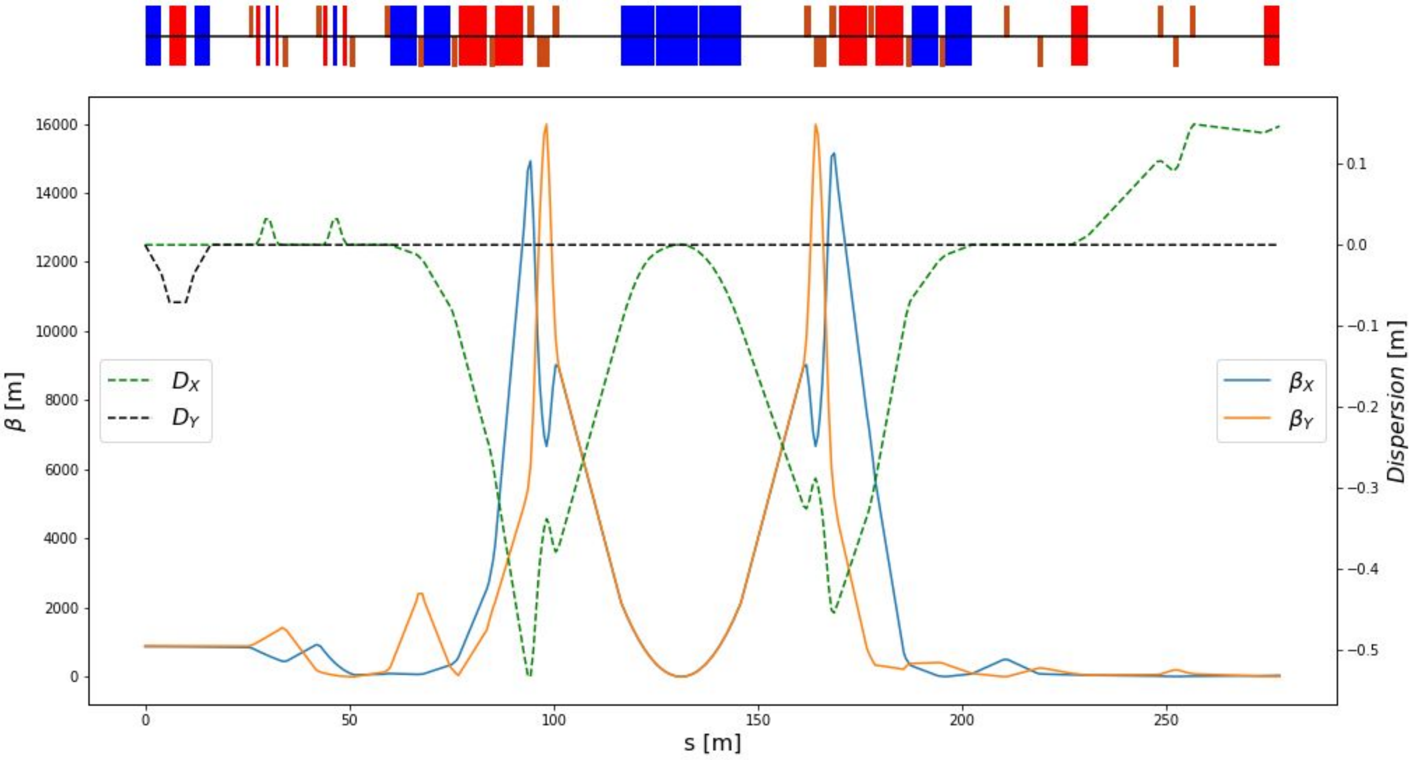
The results of the optimization allows a reduction from 15 kW to 10.7 kW being 29%.

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.

It is possible to consider 60 GeV beam and 200 keV critical energy if L* increases to around 19m. Then adjusting the electron current to have acceptable synchrotron power.

Electron interaction region optics

Electron optics : Interaction region

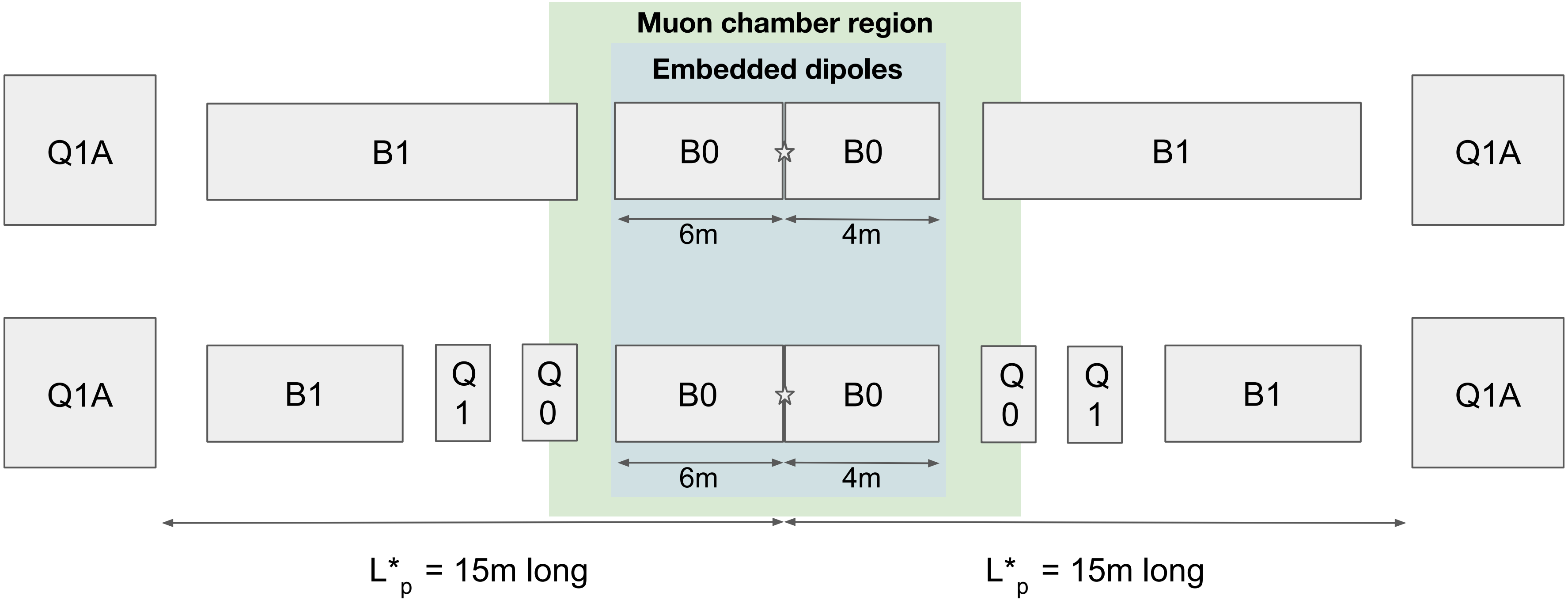


16 km beta max

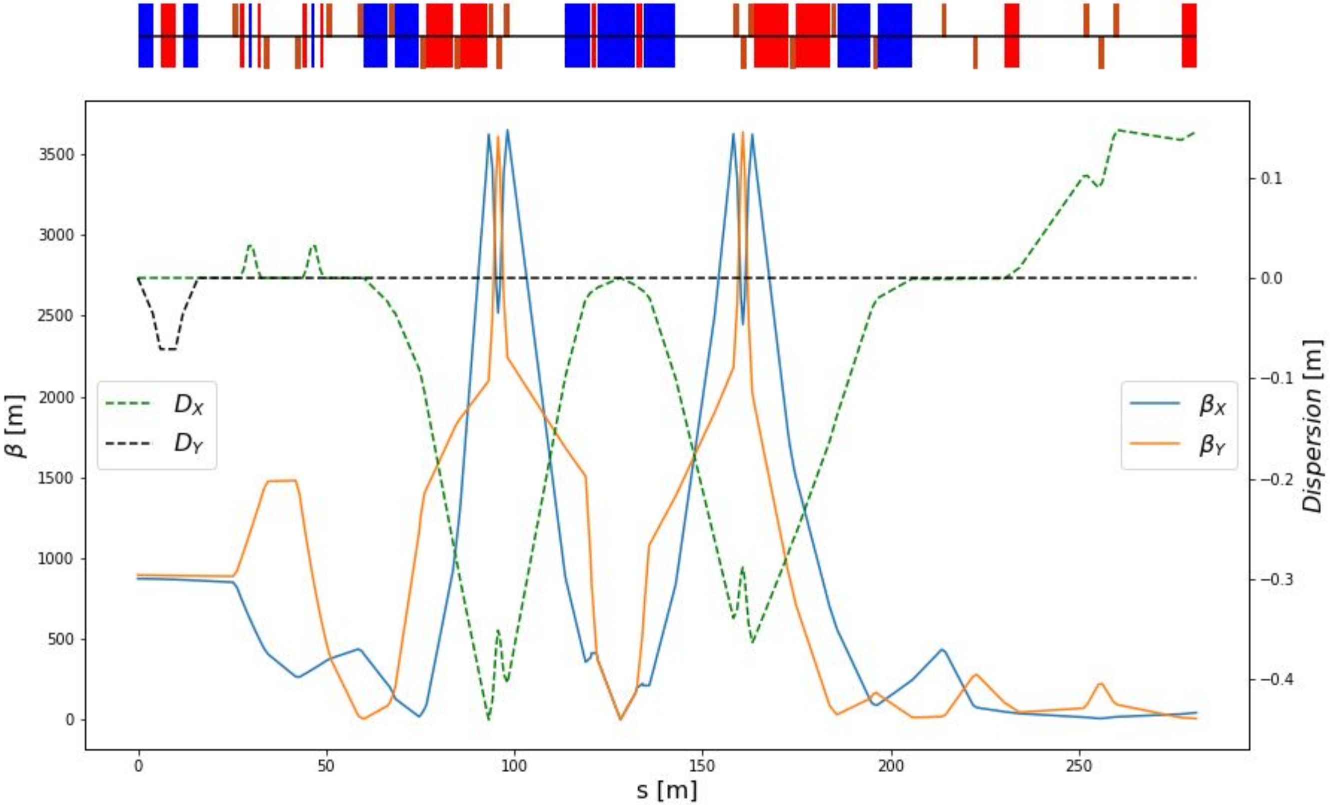
Large beam size in the quadrupoles

Natural chromaticity around -200

Electron optics : Interaction region



Electron optics : Interaction region



Down to 3 km beta max

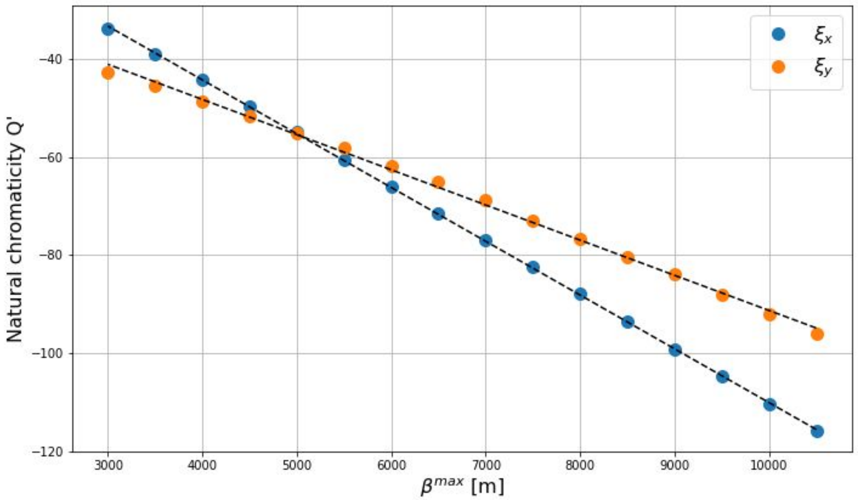
Smaller beam size in the quadrupoles

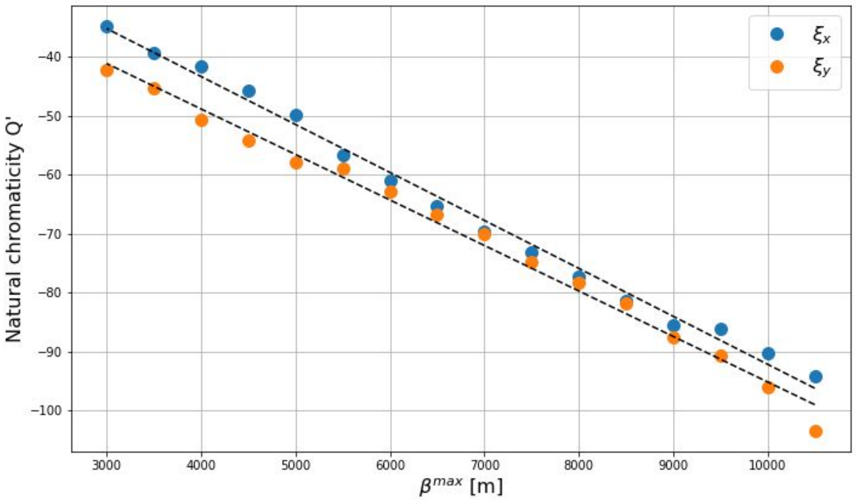
Natural chromaticity down to -80

Electron optics : Chromaticity

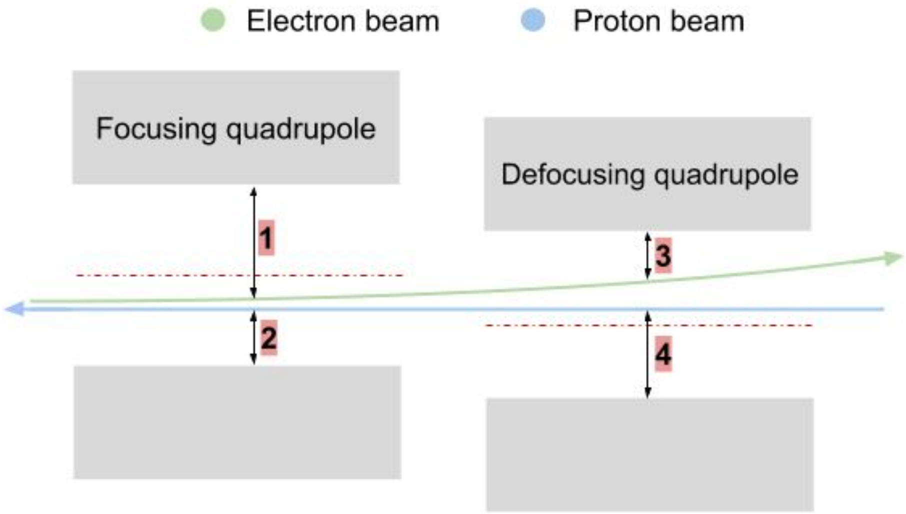
In case of bending magnets only, the beam arrives round in the final focusing quadrupoles.

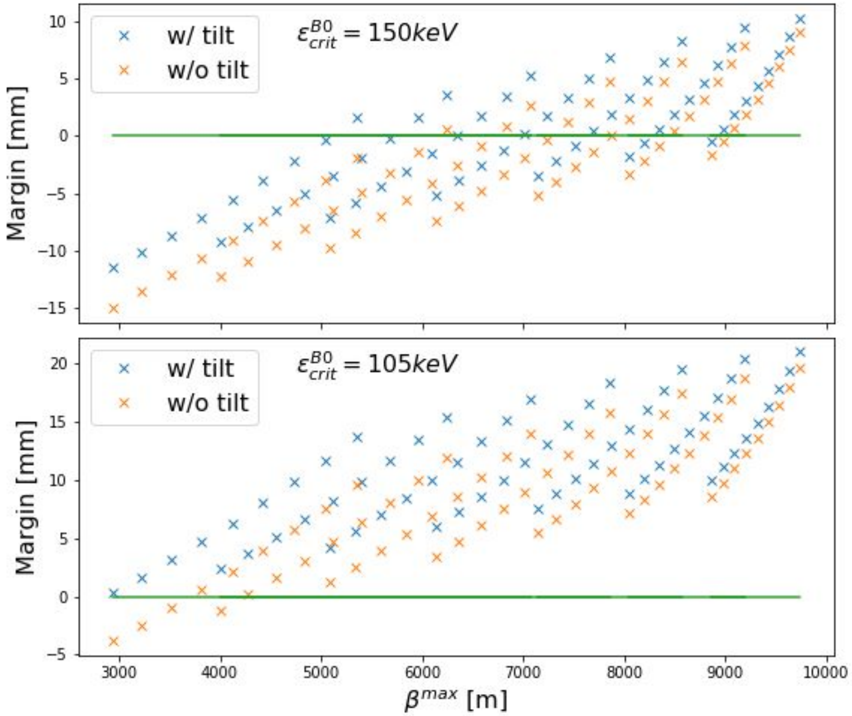
To avoid the bump in one of the transverse plane one could flatten the beam before them.



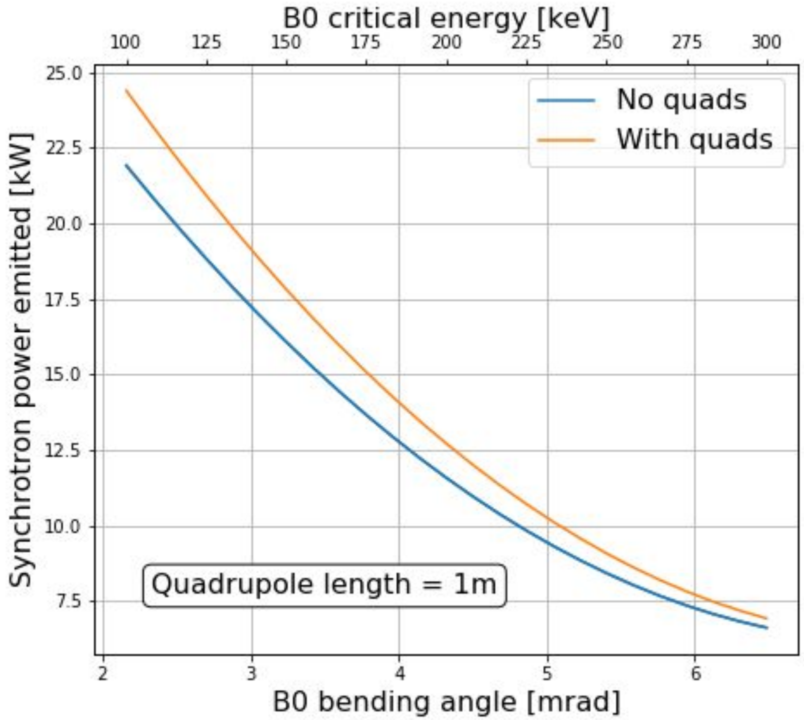


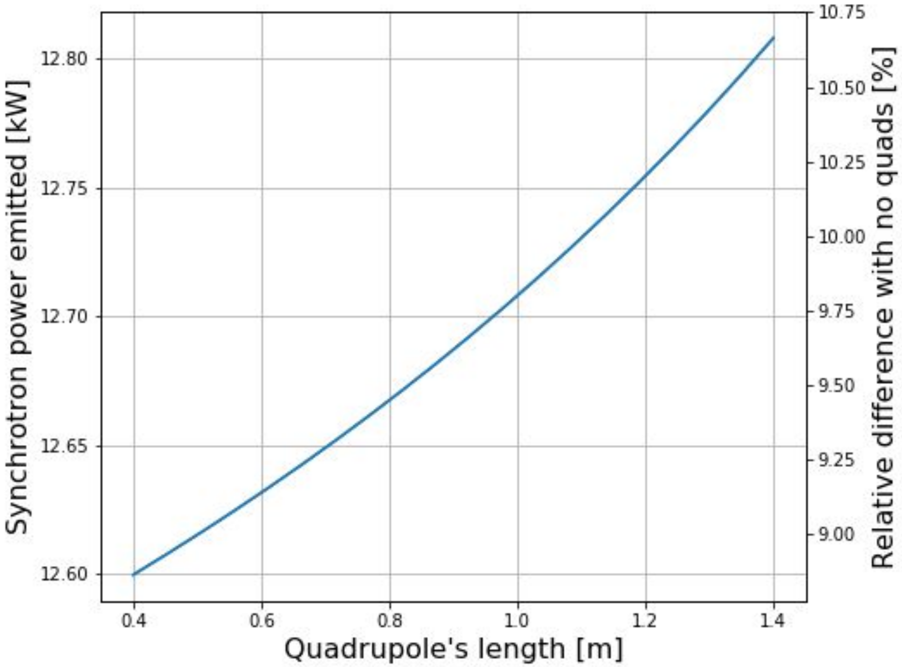
Electron optics : Aperture





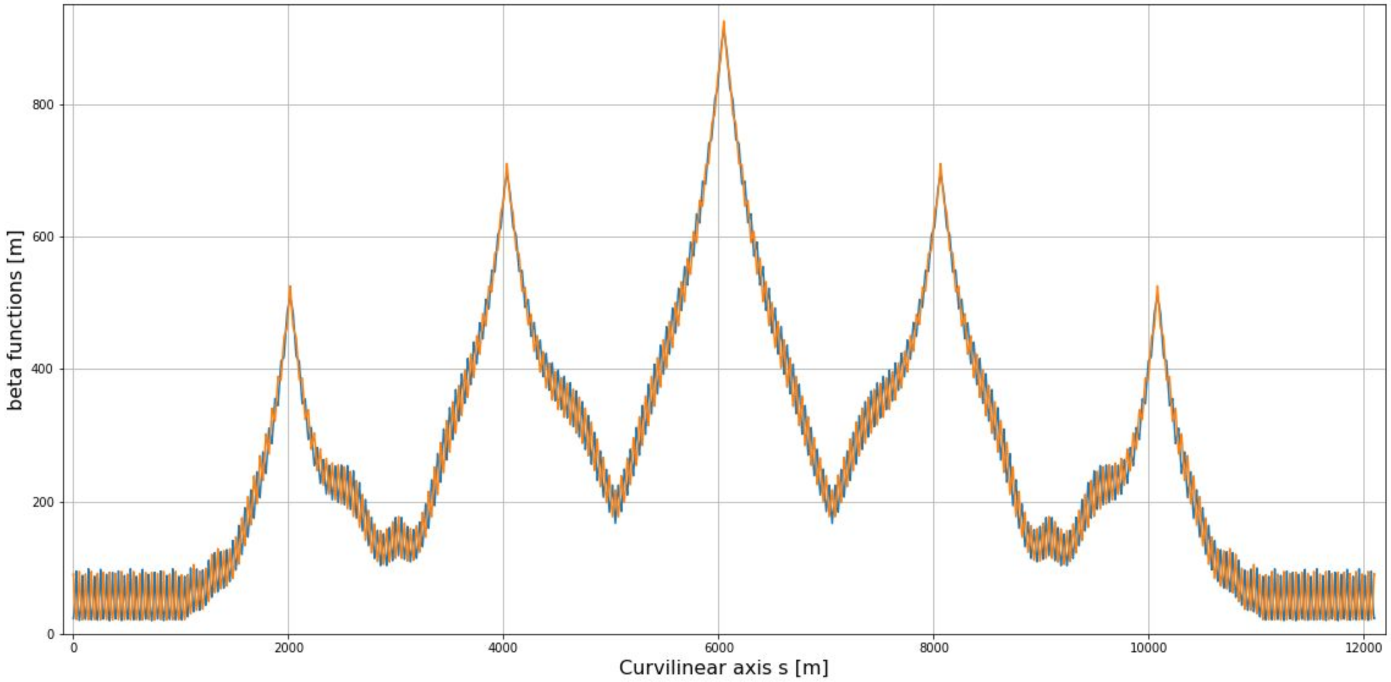
Electron optics : Synchrotron power





Electron Recirculating Linac optics

ERL - Linac optics

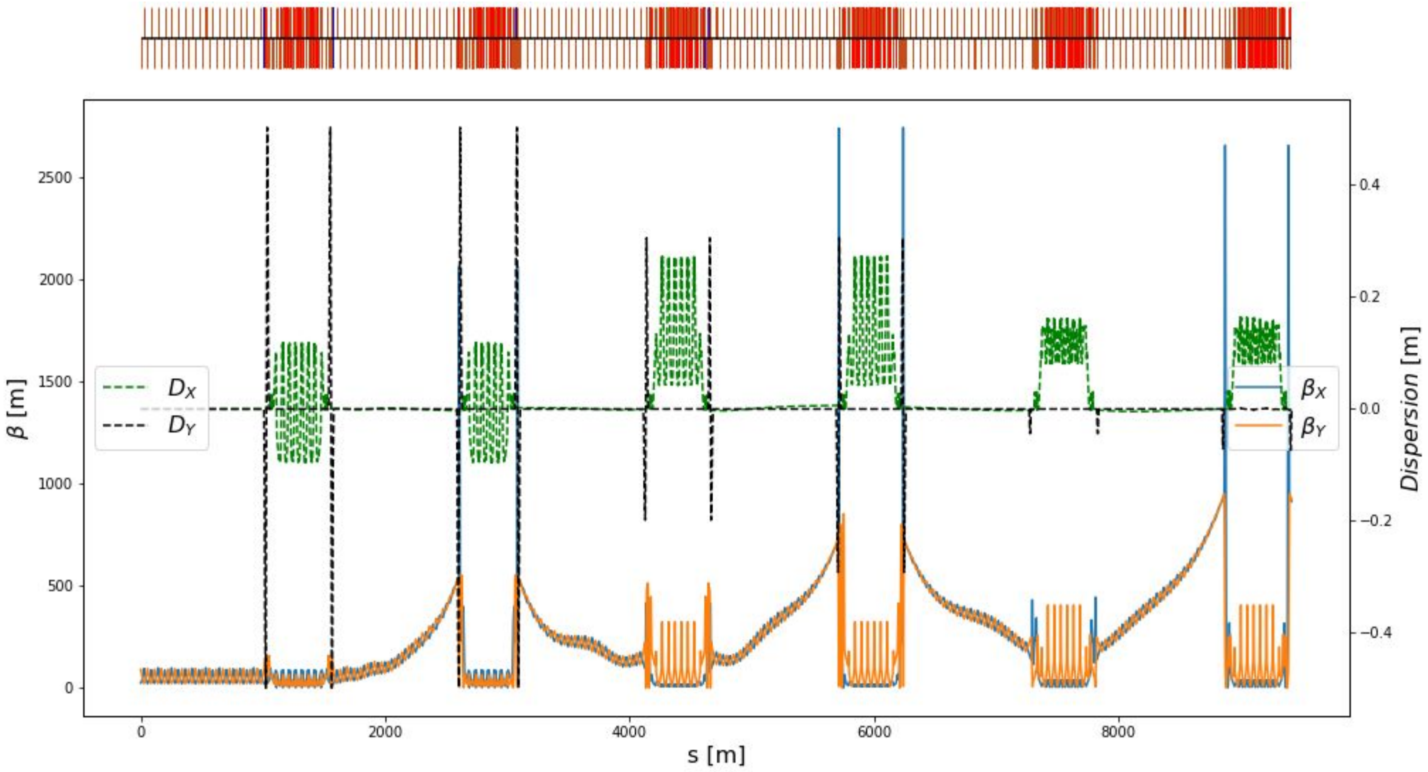


Reproduction of Linac lattice with MAD-X

Symmetric optics of the linacs

Optimized for the interaction of bunches at different turns

ERL optics with arcs included

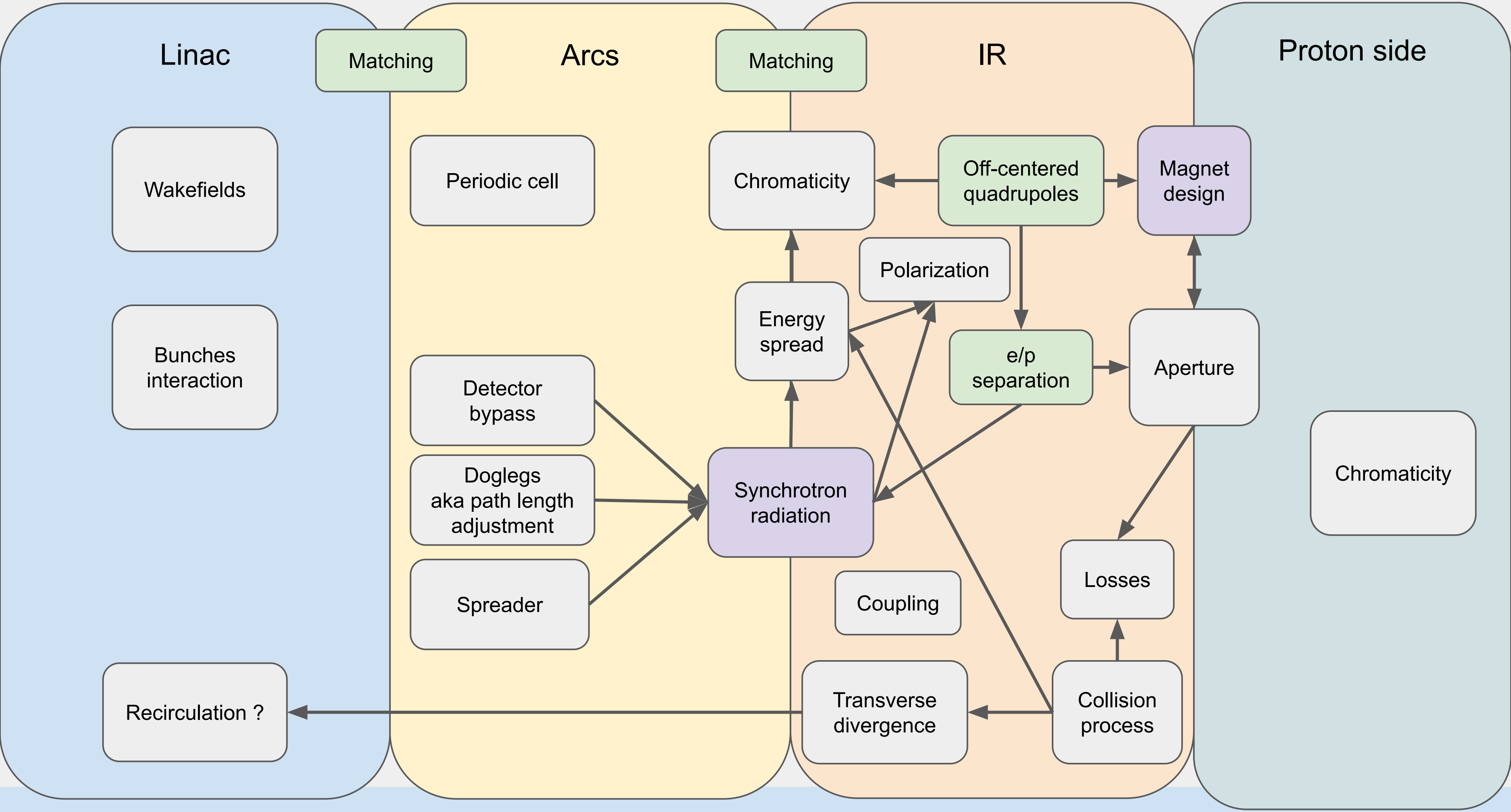


Conclusion : The main challenges

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

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


Linac
Matching
Arcs
Matching
IR
Proton side
Wakefields
Periodic cell
Chromaticity
Off-centered quadrupoles
Magnet design
Polarization
Energy spread
e/p separation
Aperture
Bunches interaction
Detector bypass
Doglegs aka path length adjustment
Synchrotron radiation
Chromaticity
Spreader
Coupling
Losses
Recirculation ?
Transverse divergence
Collision process