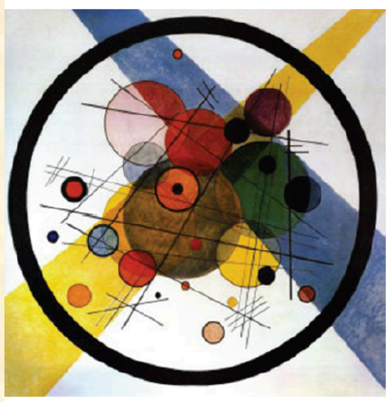
LHeC

"Synchrotron Radiation Scaling"

Optimisation of the IR & Separation Scheme

Kevin André, Bernhard Holzer



LHeC Parameter List

E = 50 GeV

Table 1.1: Parameters of LHeC ERL —for reference

Description	unit	parameters
Injector energy	GeV	0.5
Total number of linacs		2
Number of acceleration passes		3
Maximum electron energy	GeV	49.19
Bunch charge	pC	499
Bunch spacing	ns	24.95
Electron current	mA	20
Transverse normalized emittance	µm	20
Total energy gain per linac	GeV	8.114
Frequency	MHz	801.58

$\beta^* = 10$ cm

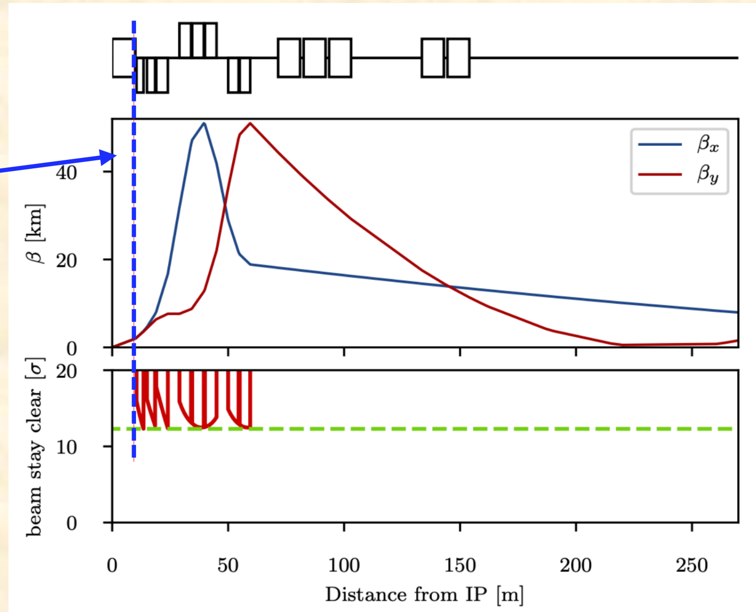
LHeC ***Beam Separation Scheme:***

Magnetic separation via different beam rigidities:

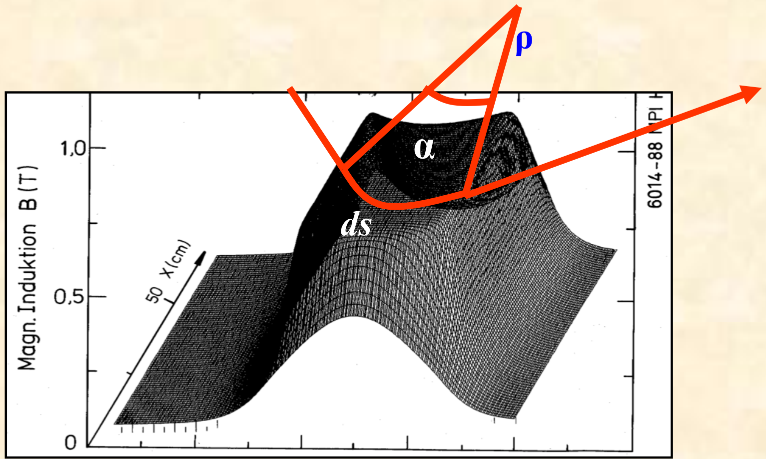
7 TeV / 50 GeV

Fast enough to bypass the sc. proton mini beta quads

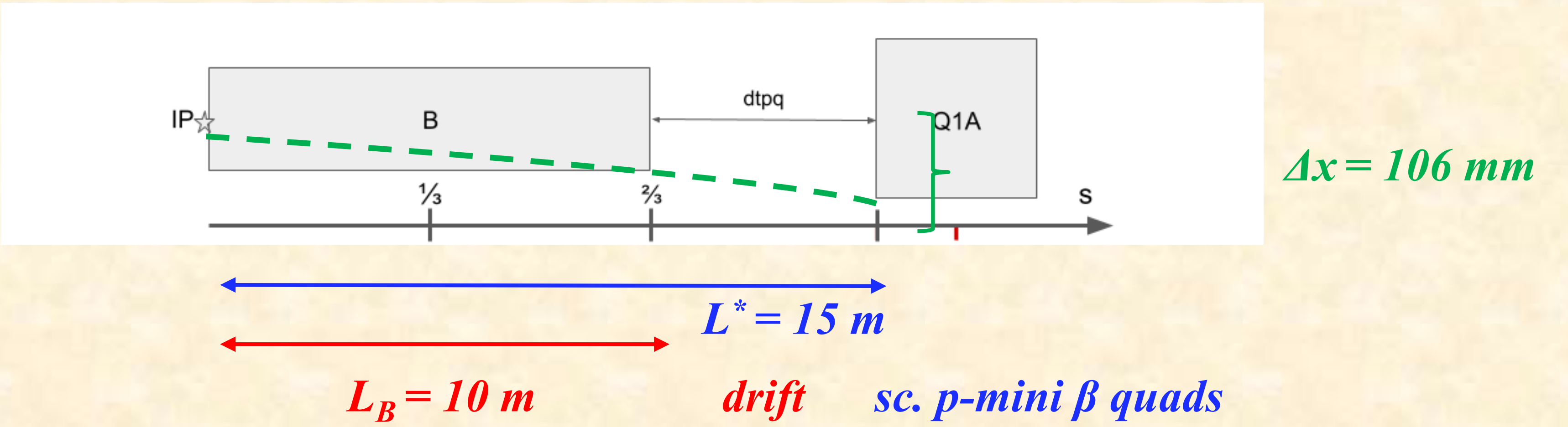
IR Layout for the LHeC p-optics
L^* =15 m



Slow enough to keep 1/ρ as small as possible



LHeC Beam Separation Scheme:
Principle Layout



Everything is defined, i.e. frozen.

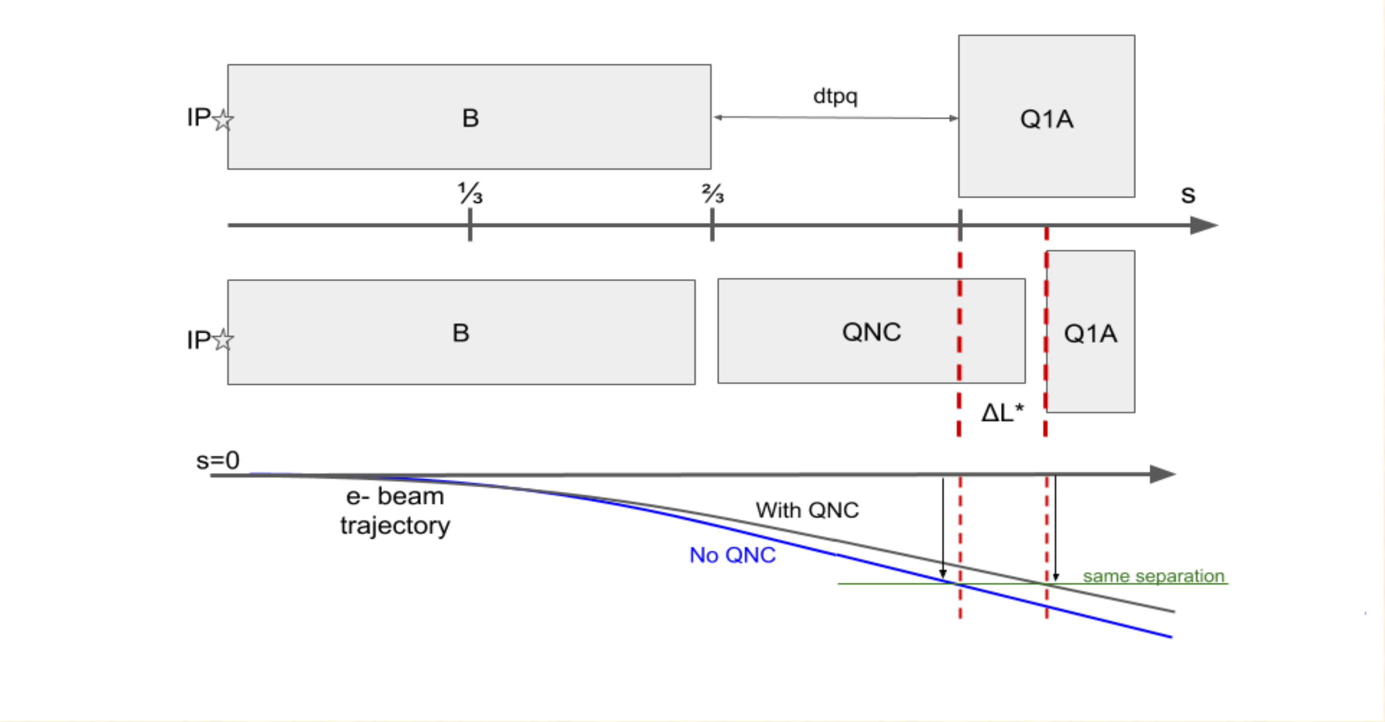
$$P_{syn} = \frac{e^2 c}{6\pi\varepsilon_0}\frac{\gamma^4}{\rho^2}$$

$$E_{crit} = \frac{3\hbar c}{2}\frac{\gamma^3}{\rho}$$

Or … may be not !!

I.) Improved proton lattice

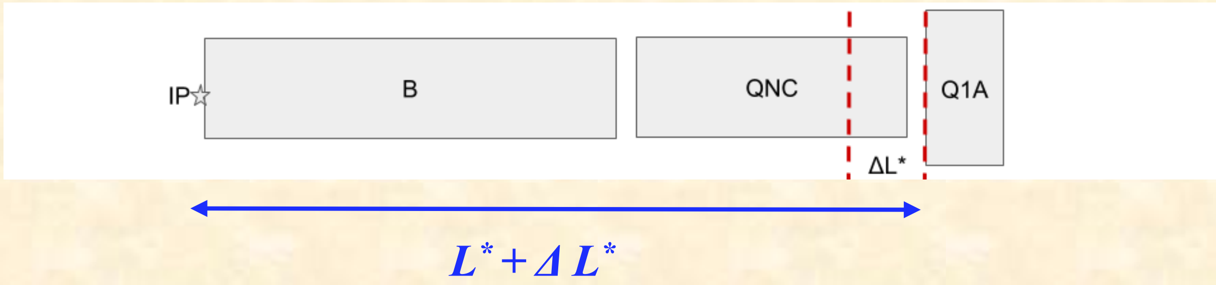
Increase of L^* is possible → shift of the first sc. p-quadrupole,
proton lattice (and optics) is modified slightly by ΔL^*
adding a nc. half quadrupole.



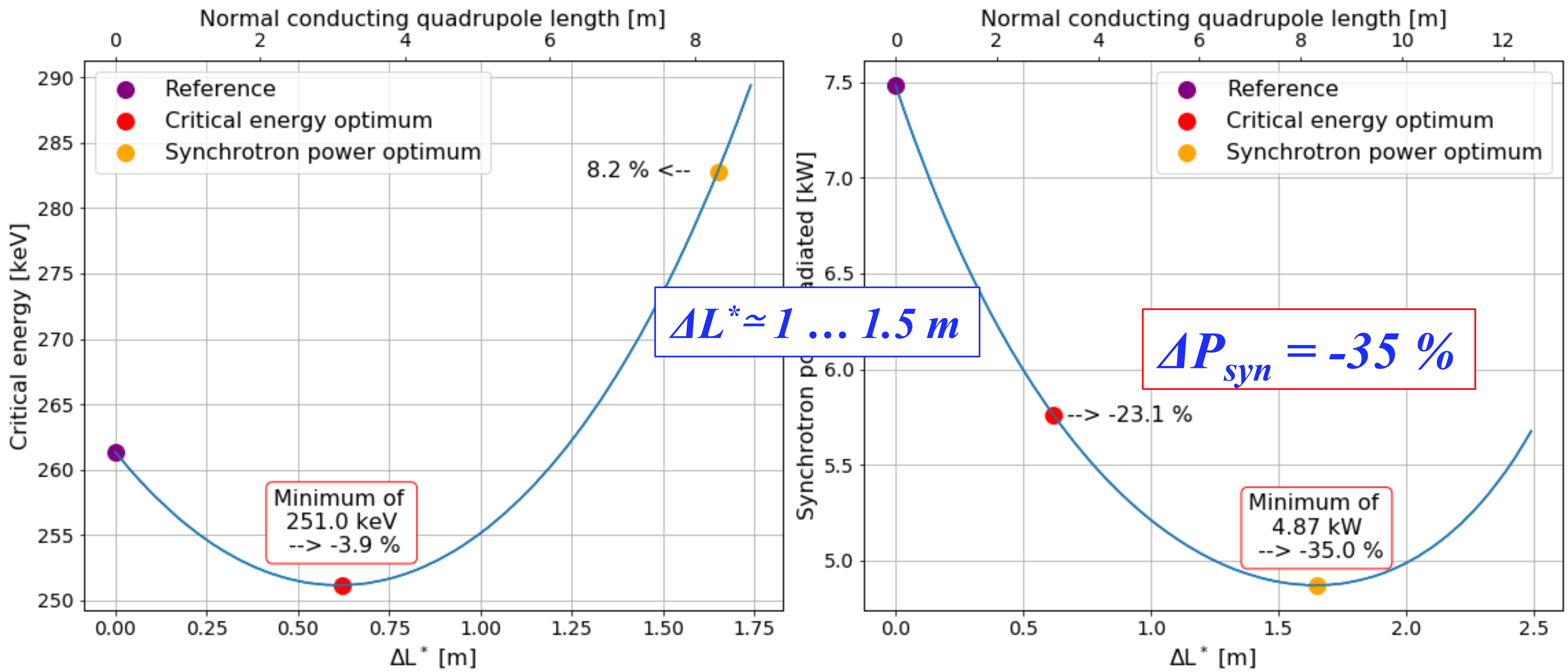
Beam separation fields, i.e. 1/ρ, can be reduced proportionally to L^*.

Limits: defined by gradient & beam size (β-function) of p-beam

nc proton half quadrupole:



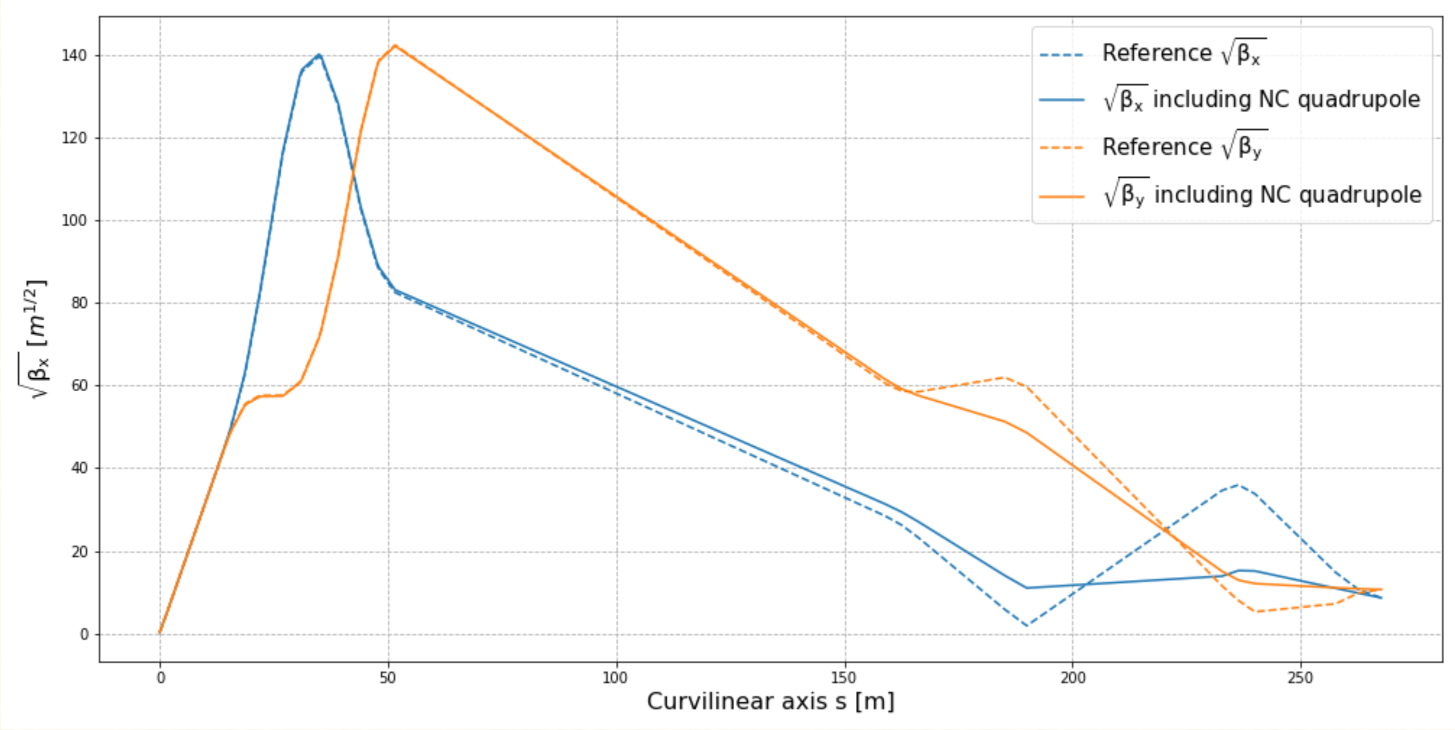
Optimising E_{crit} & P_{syn} via position of Q1A (→ ΔL^*)



$\Delta L^* \simeq 1 \ldots 1.5$ m

ΔP_{syn} = -35 %

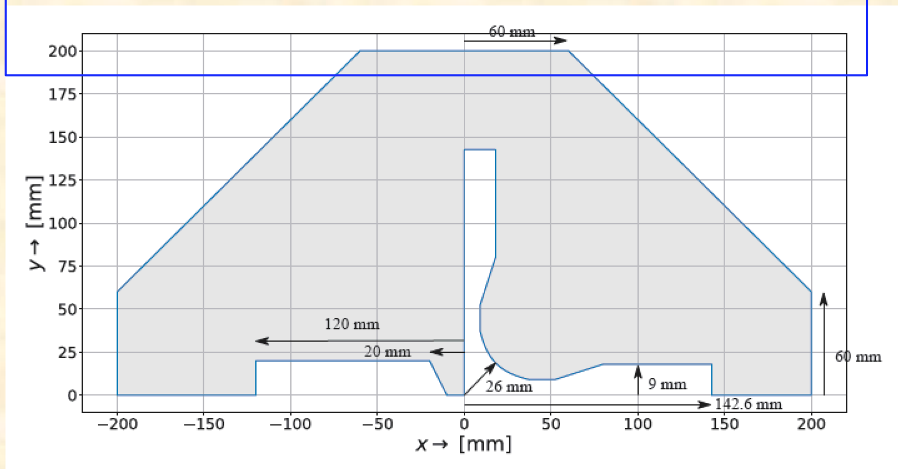
Proton Optics only slightly modified

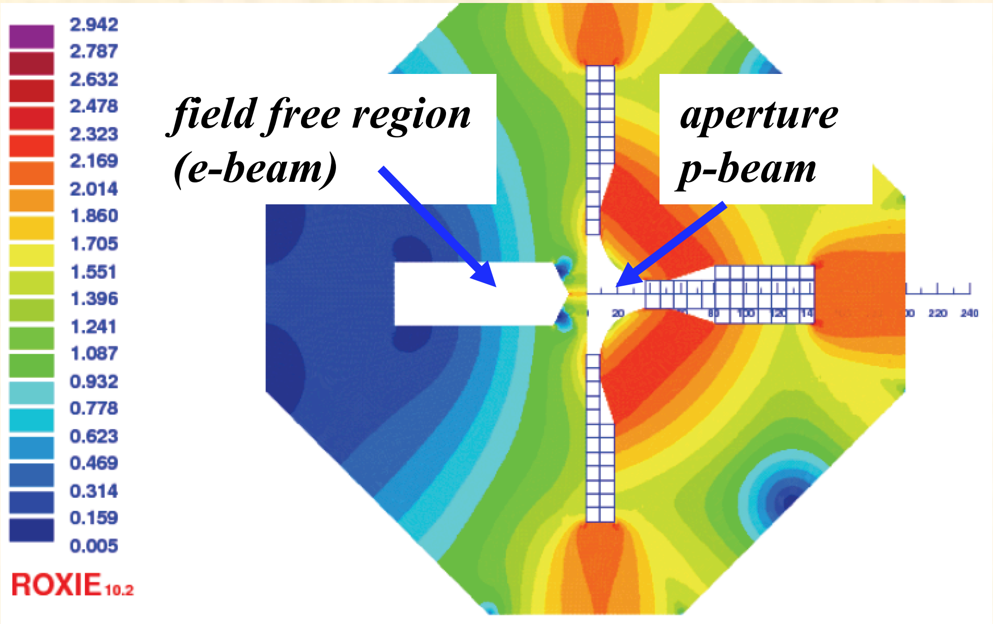


old

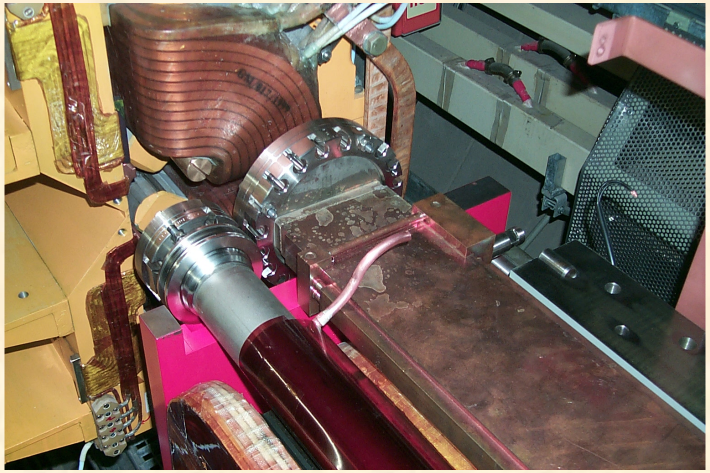
new

Technical design: Melvin Liebsch



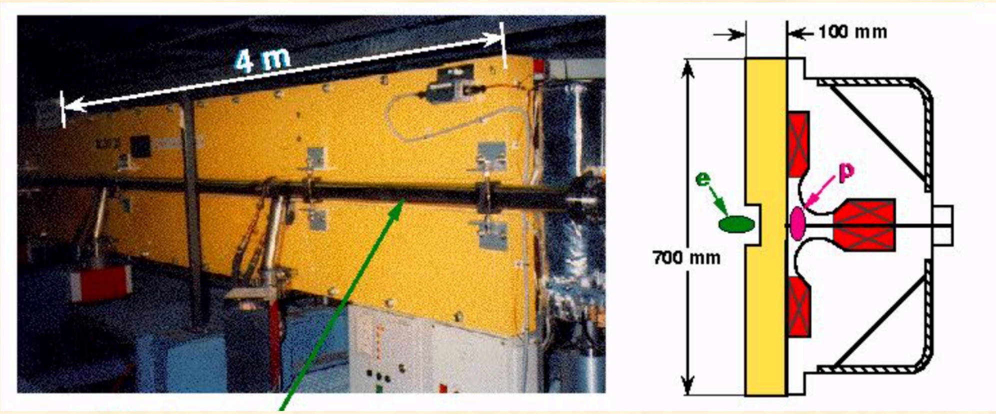


Examples from history:



GM half quad with stabilized mirror plate

GN half quad with full size return yoke



QS design,
with simple mirror plate

… and a meter of magnet steel provides a nice shielding of Q1A against synchrotron radiation.

II.) Improved Electron Lattice:

Beam separation required is defined by

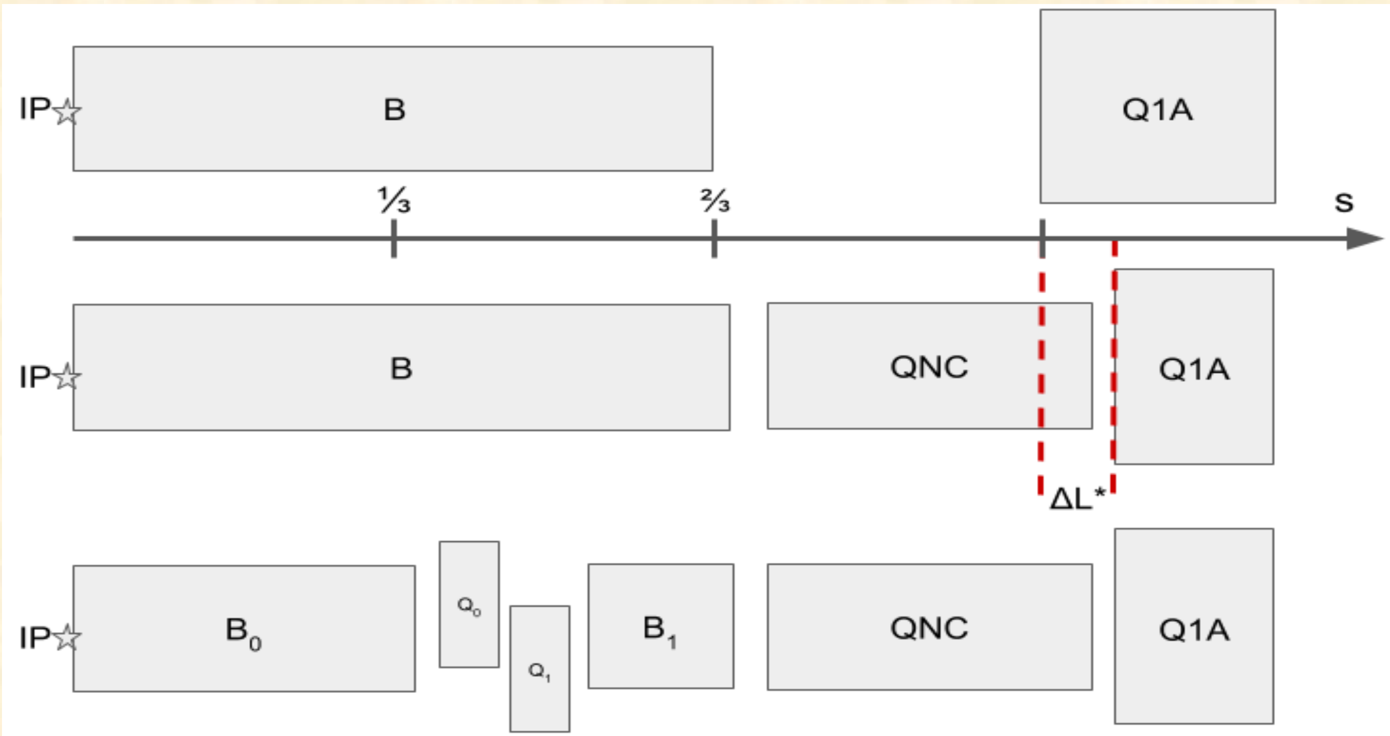
1.) *magnet design of Q1A (technical feasibility)*
2.) *proton beam size … defined by* L^*

$$\beta(s) = \beta^* + \frac{s^2}{\beta^*} \qquad \textit{(Liouville)}$$

3.) *beam size of electron beam*

defined by the e-focusing scheme

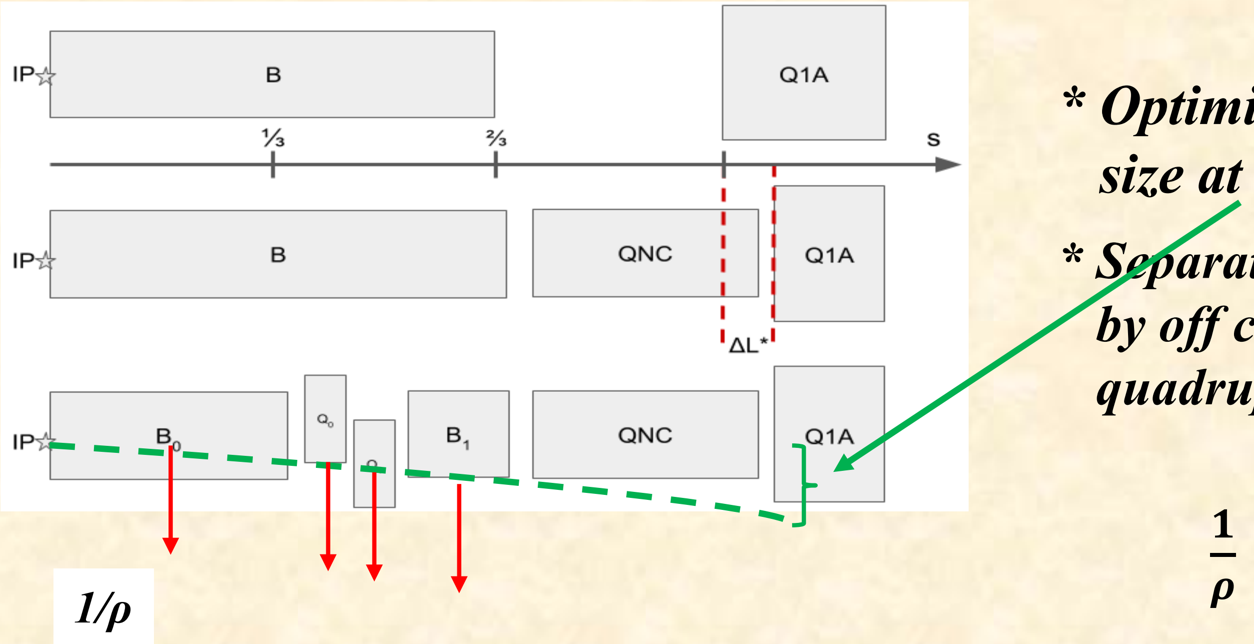
Introduce an early focusing structure before (!) Q1A



II.) Improved Electron Lattice:

$$\beta(s) = \beta^* + \frac{s^2}{\beta^*}$$

… it is again Liouville that counts, but now for the electrons



* *Optimize for smallest electron beam size at s = L**
* *Separation fields 1/ρ kept constant by off centre alignment of the new quadrupoles*

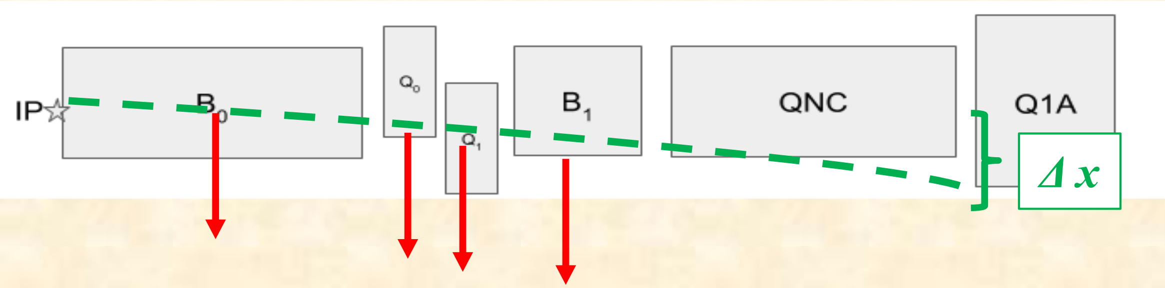
$$\frac{1}{\rho} = \Delta x^* k = const$$

$l_q = 1.5\ m$

Goal:

find a reasonably small β-function for the electron beam at s = 15m

II.) Improved Electron Lattice:



Determine hor. separation
as function of σ_{xe} - - for a given beam stay clear

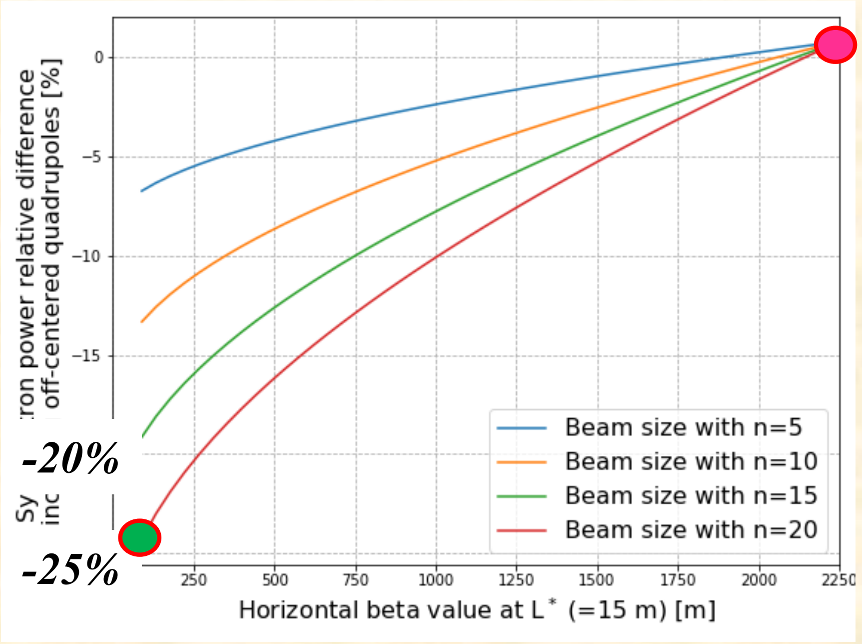
Calculate the 1/ρ needed to reach this Δ x,

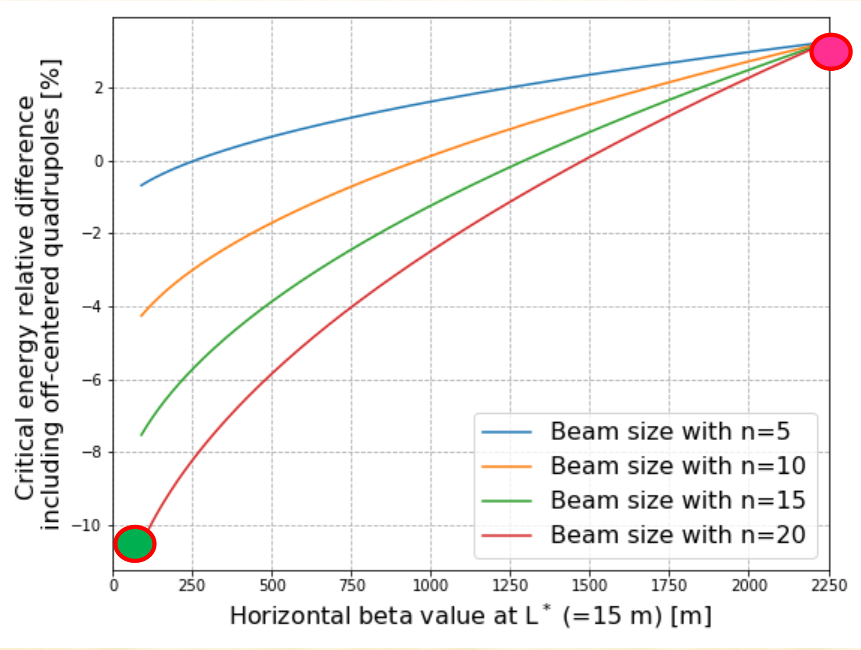
Determine the resulting critical energy & synchr. radiation power

β ≃ 90m

Synchr. radiation power → -24%

Critical energy → -12%

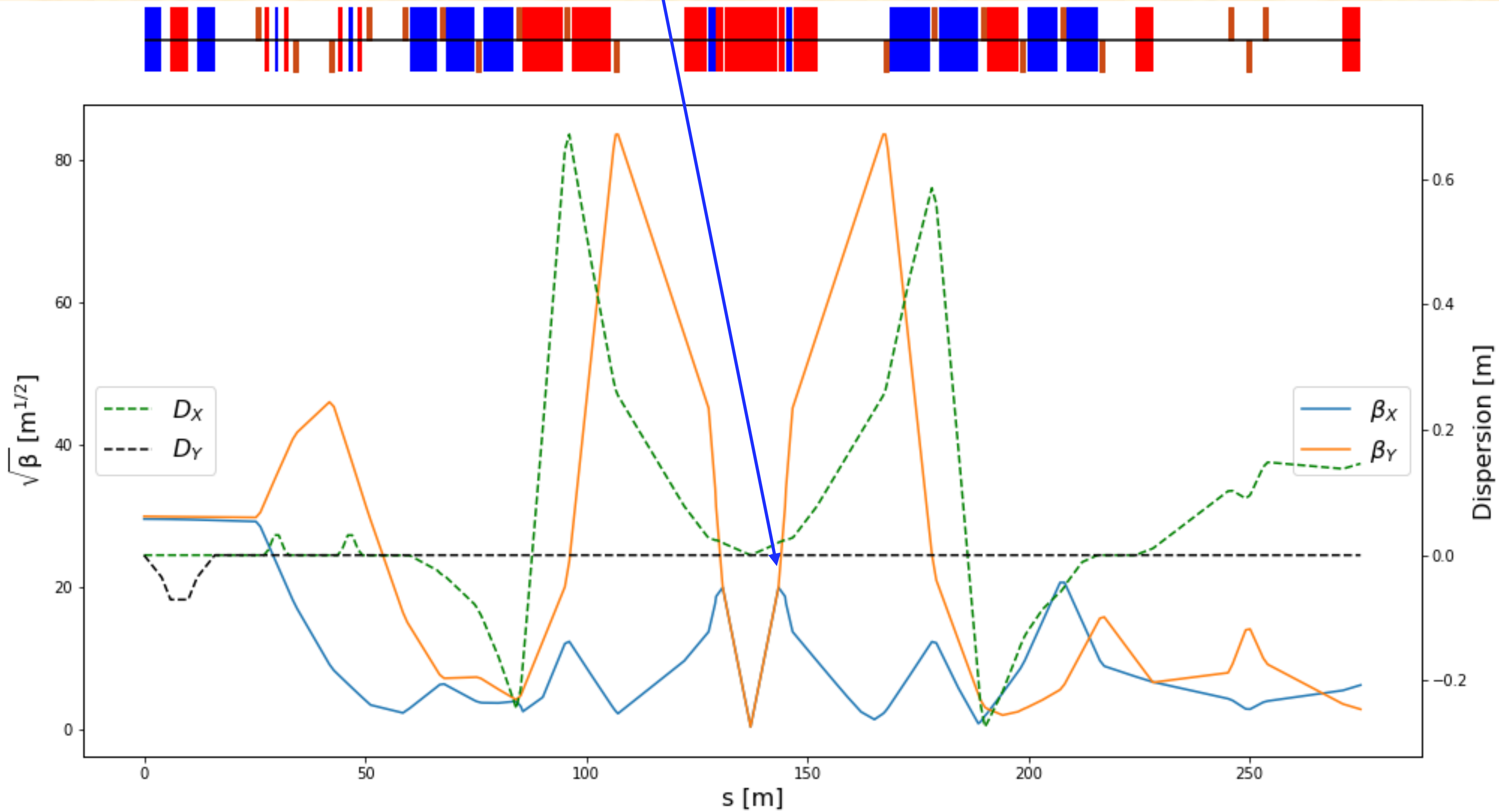




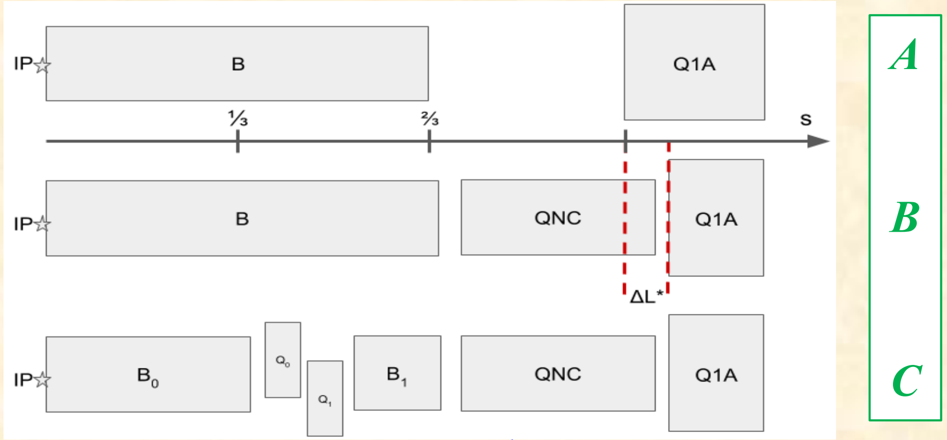
II.) Improved Electron Lattice:

New electron optics: $\beta^* = 10$ cm

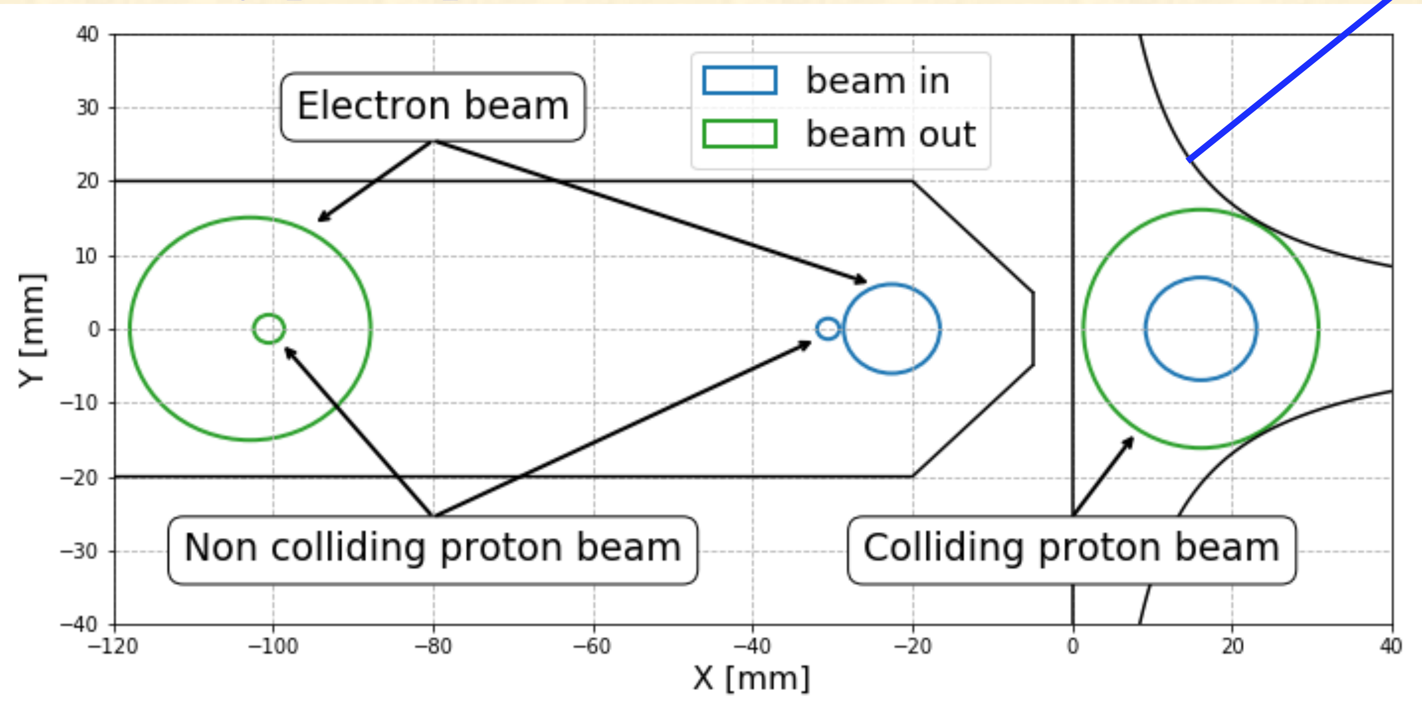
β (15 m) = 90m



Aperture requirements of new quadrupoles:



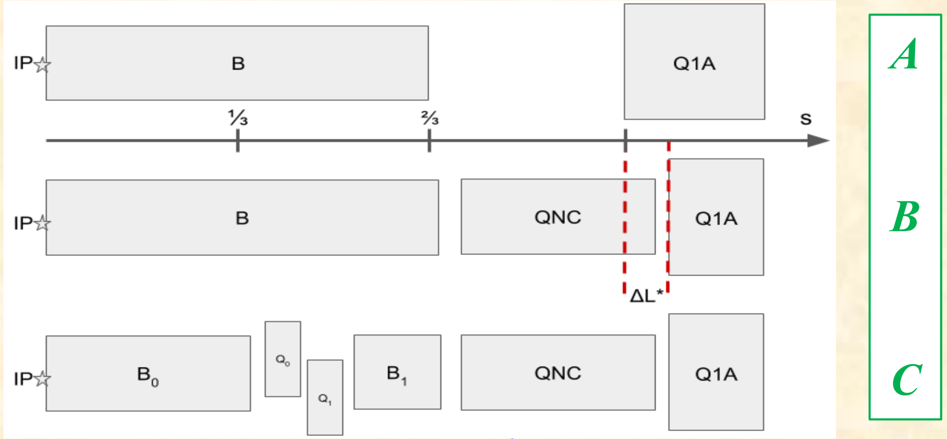
nc. half quadrupole



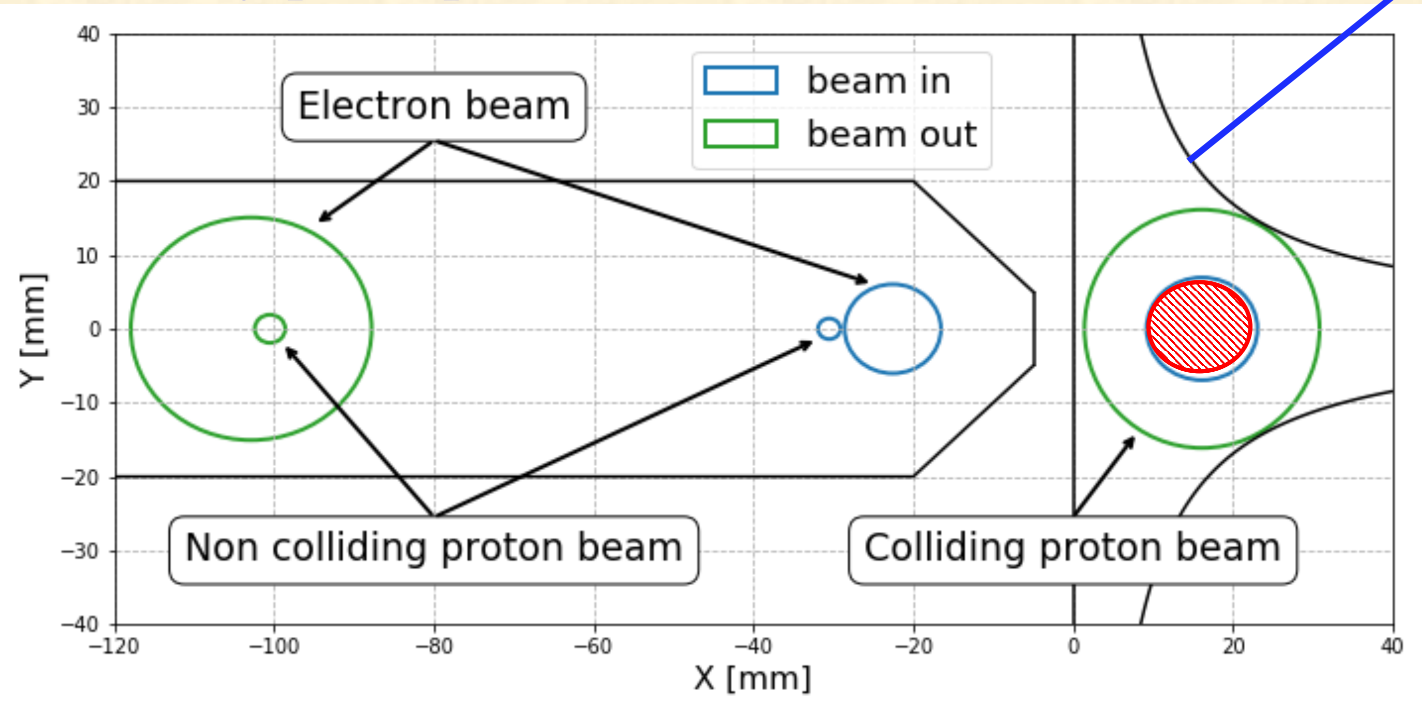
Field free region for electrons and non-colliding proton beam

Focusing of colliding proton beam

Aperture requirements of new quadrupoles:



nc. half quadrupole

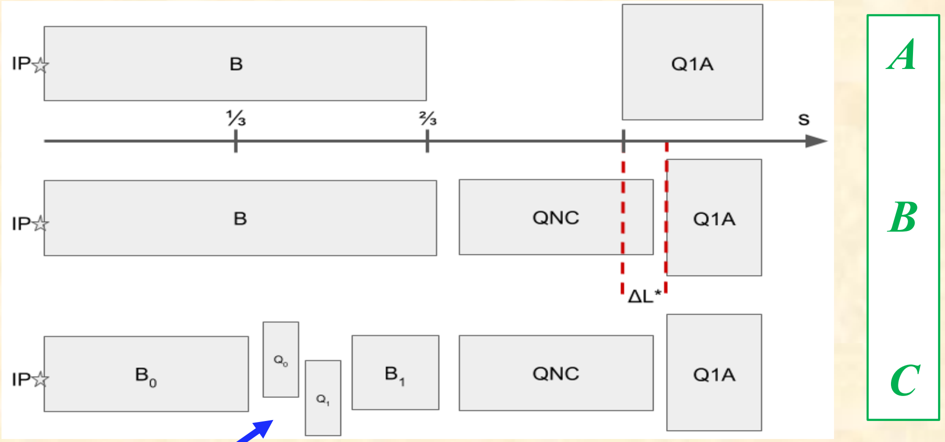


Proton injection optics:
β = 11.2 / 15.0 m

Field free region for electrons and non-colliding proton beam

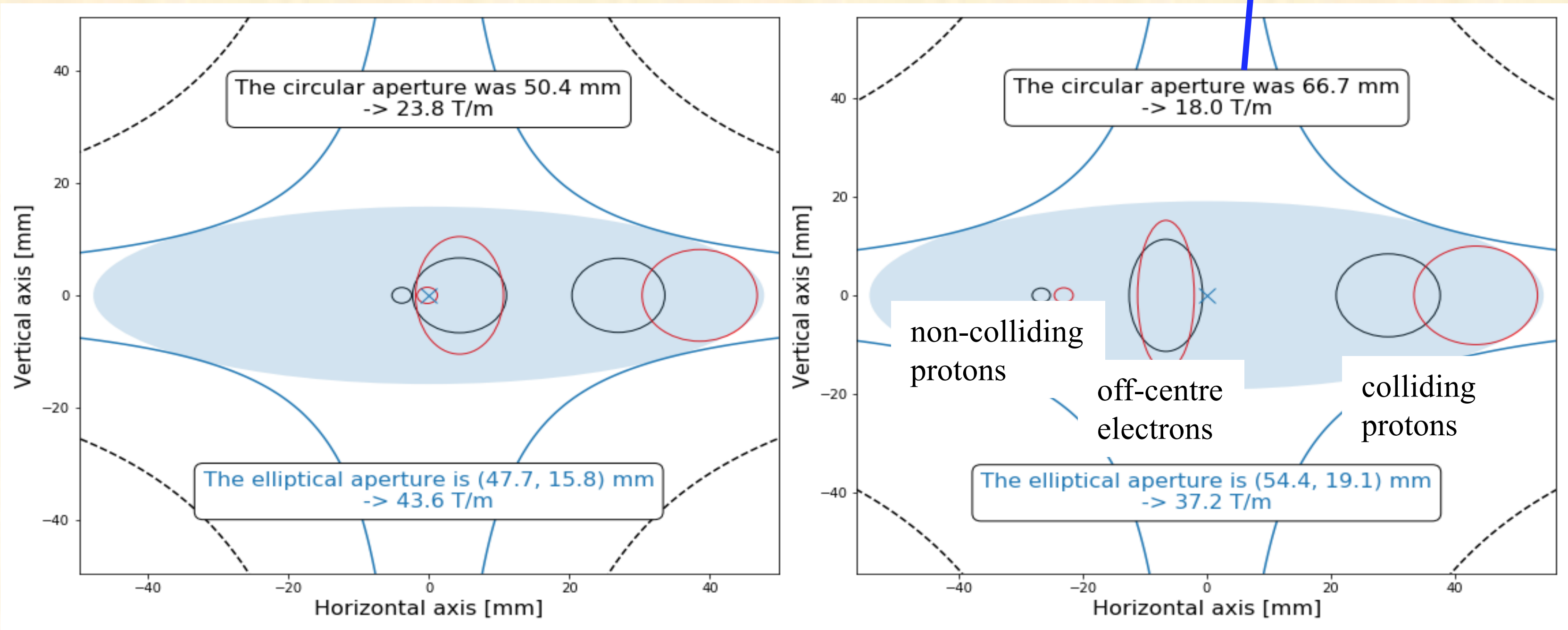
Focusing of colliding proton beam

Aperture requirements of new quadrupoles:

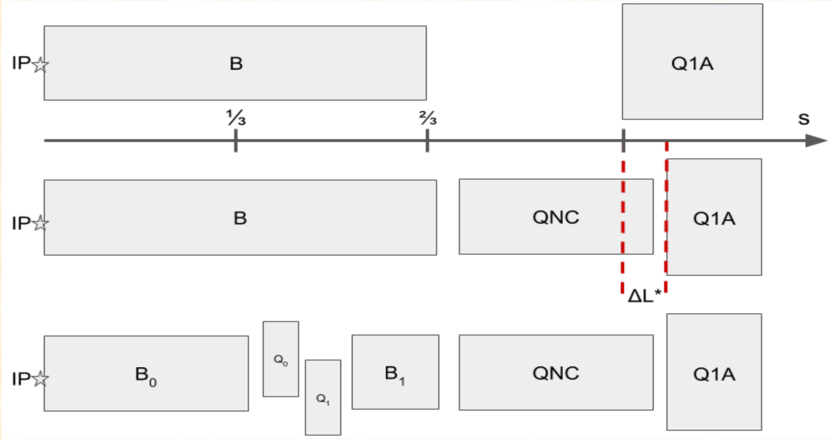


Early focusing electron quadrupoles

We assume … $n_e = 20\ \sigma$, $n_p = 18\ \sigma$



III.) Resumé



A
B
C

Combining the two options …

"B" half quadrupole to increase

+ the effective L^*

"C" early focusing scheme for the electrons

Optimum for smallest Synchr. Rad. Power:

	Synchrotron Radiation Power (kW)			Critical Energy (keV)		
n	Ref. Design	half quad.	half quad+doublet	Ref. Design	half quad.	half quad+doublet
5	24.70	16.04 (-35.1 %)	15.22 (-38.4 %)	267	285 (+6.8 %)	294 (10.0 %)
10	27.11	17.76 (-34.5 %)	15.49 (-42.9 %)	280	299 (+6.8 %)	297 (6.1 %)
15	29.63	19.57 (-34.0 %)	15.76 (-46.8 %)	292	312 (+6.9 %)	300 (2.5 %)
20	32.27	21.47 (-33.5 %)	16.04 (-50.3 %)	305	326 (+6.9 %)	302 (-0.8 %)

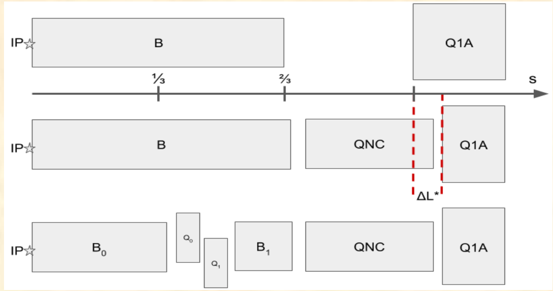
Reduced Chromaticity of the electron lattice:

	dipole based separation	early focusing scheme
ξ_x	-116	-15
ξ_y	-294	-32

β_{max} *= 2250 m → 90 m*

Strong impact on luminosity loss factor and ERL performance

Momentum acceptance & luminosity loss factor



Reduced Chromaticity of the electron lattice:

	dipole based separation	early focusing scheme
ξ_x	-116	-15
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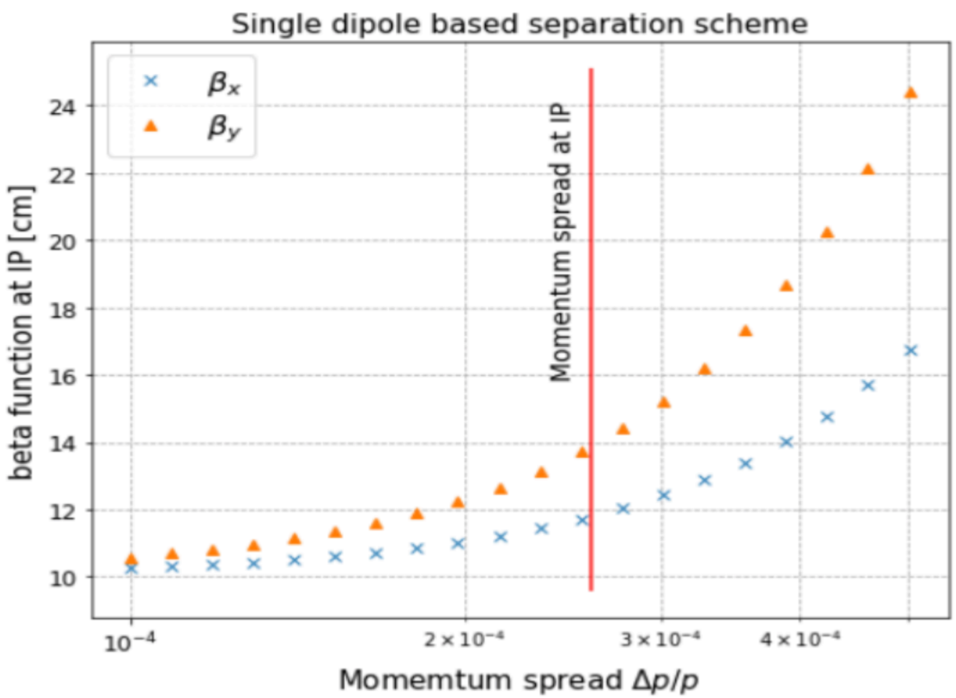
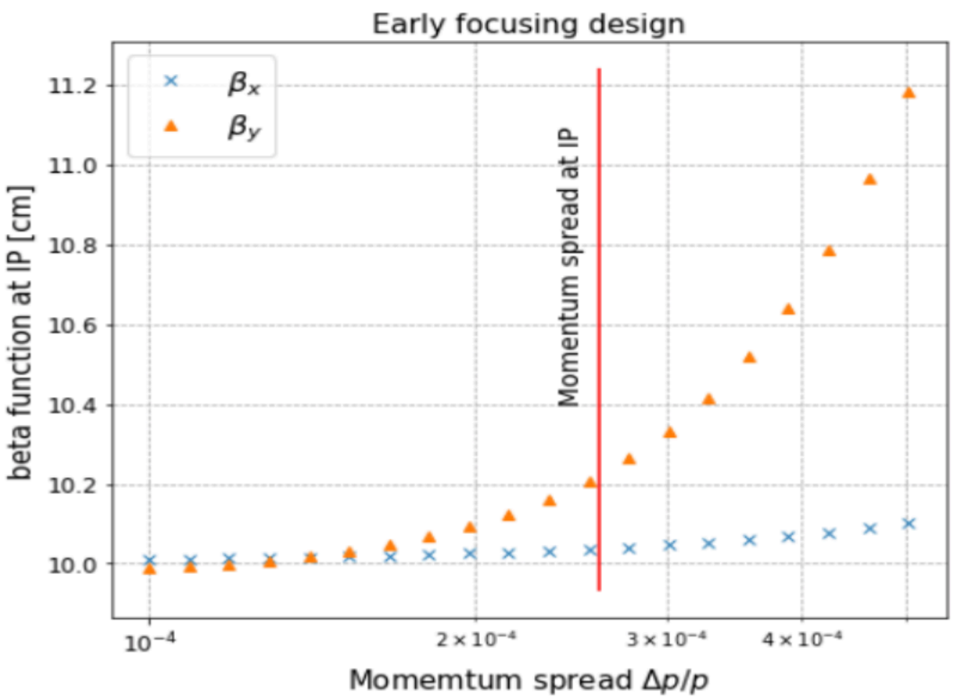
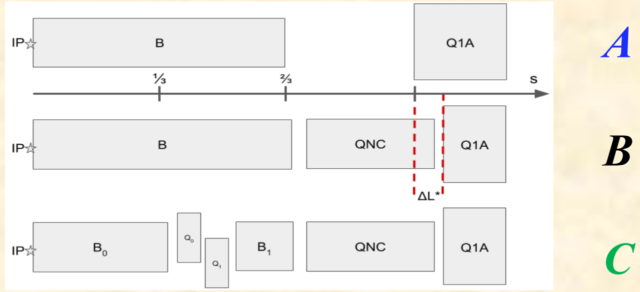
Off-momentum beta-beat $\Delta\beta/\beta_{(\Delta p/p)}$ at IP

design momentum spread $\Delta p/p = 2.6 * 10^{-4}$





Momentum acceptance & luminosity loss factor



Reduced Chromaticity of the electron lattice:

	dipole based separation	early focusing scheme
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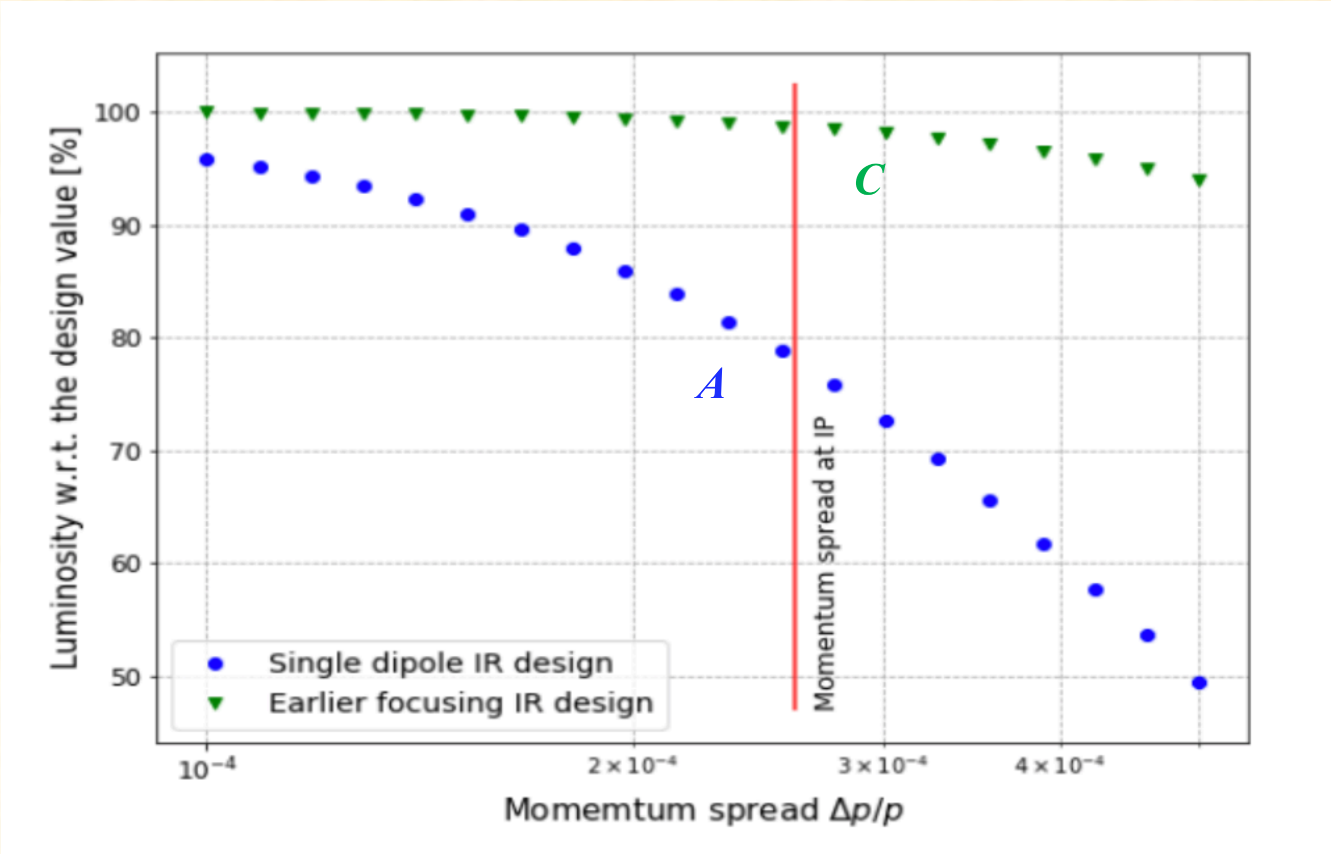
Luminosity loss for off-momentum particles

design momentum spread $\Delta p/p = 2.6 * 10^{-4}$



III.) Resumé

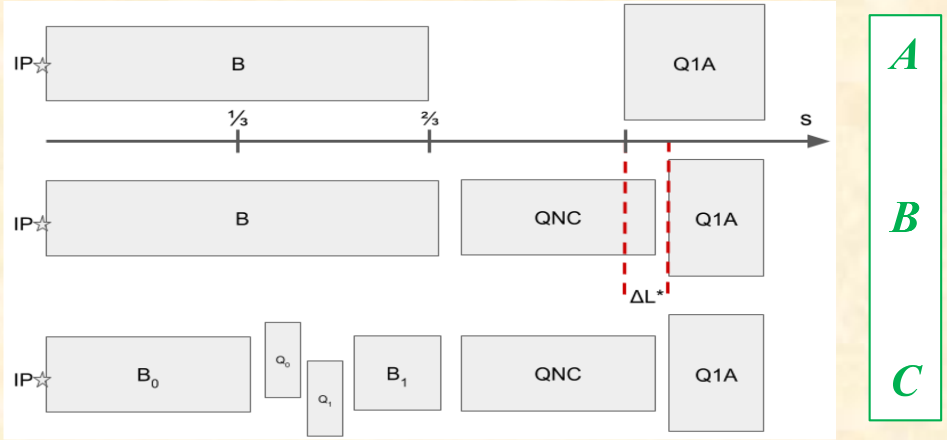
Reduction in critical energy:

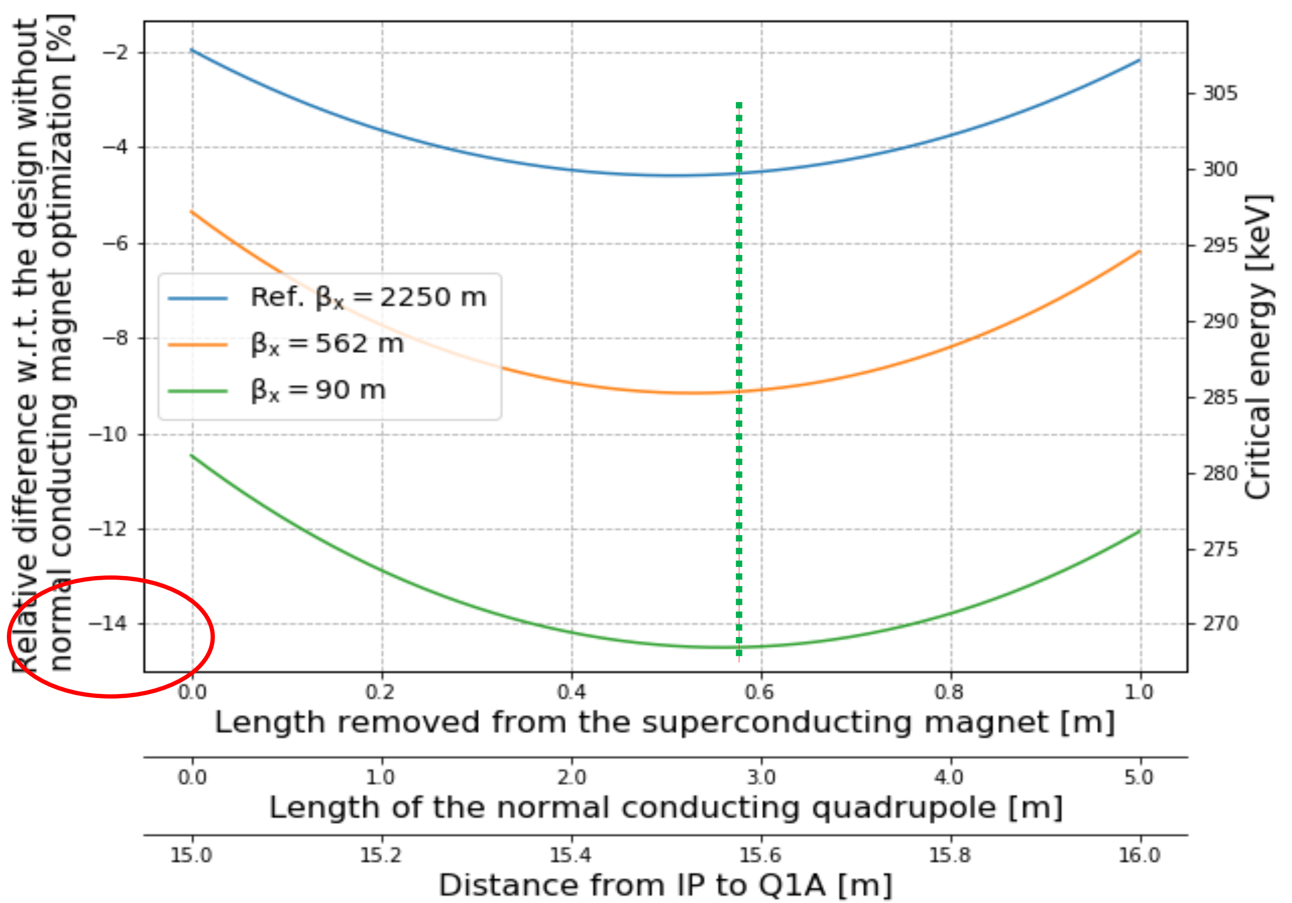
Combining the two options …

"B" half quadrupole to increase

+ the effective L^*

"C" early focusing scheme for the electrons





half quadrupole parameters:

l_q = 2.9 m

g = 50 T/m

r_a = 26 mm

Reduction in critical energy:

ΔP_{Ecrit} = -15 %

III.) Resumé

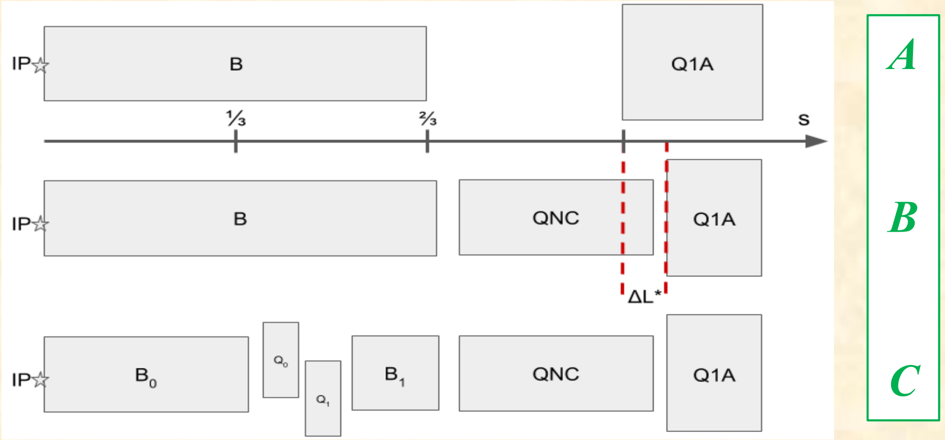
Synchr. Power reduction:

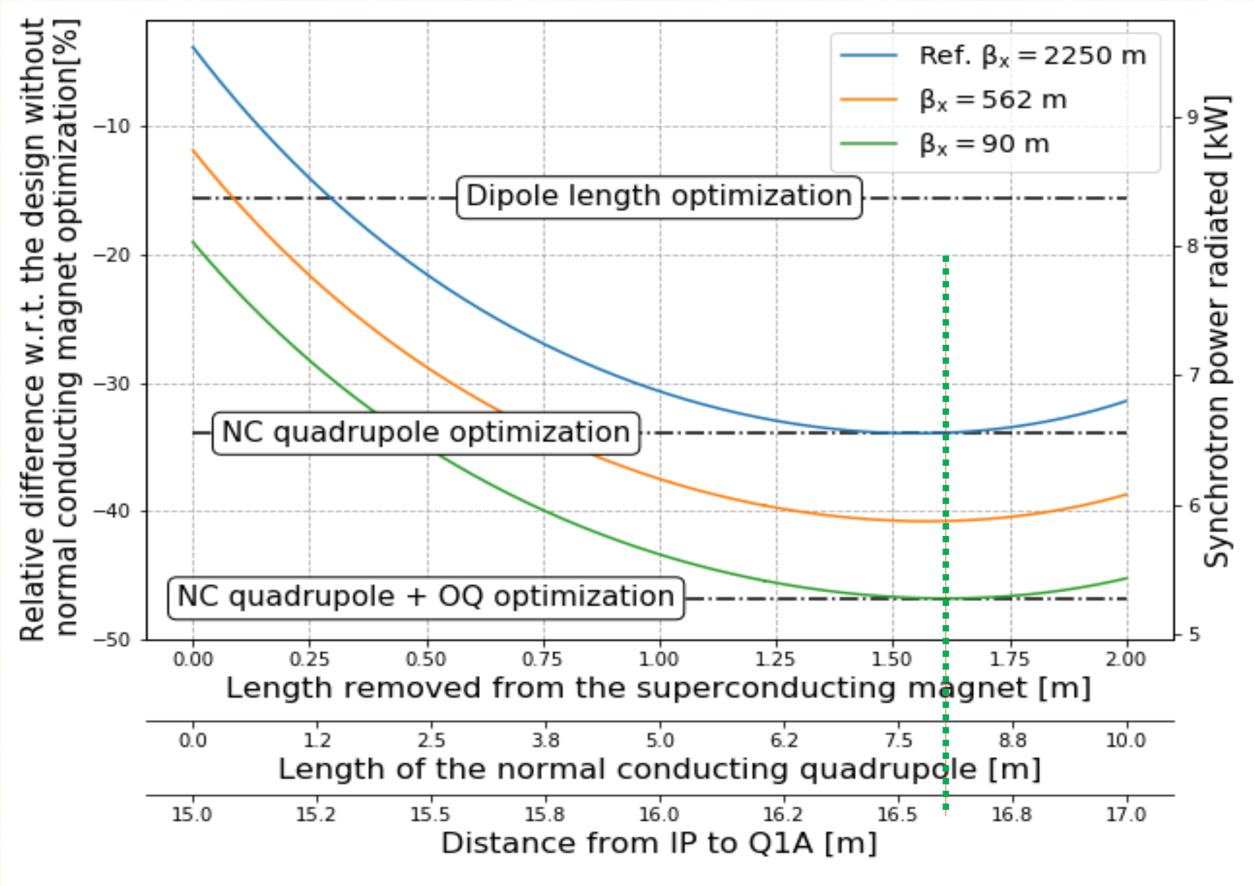
Combining the two options …

"B" half quadrupole to increase

+ the effective L^*

"C" early focusing scheme for the electrons





half quadrupole parameters:

$l_q = 7.6\ m$

$g = 45\ T/m$

$r_a = 26\ mm$

Synchr. Power reduction:

$\Delta P_{syn} = -50\ \%$

Conclusion:

Careful Refinement of the Interaction Region has been studied

Installation of a half quadrupole on the p-lattice

and a doublet in the electron beam

allows to …

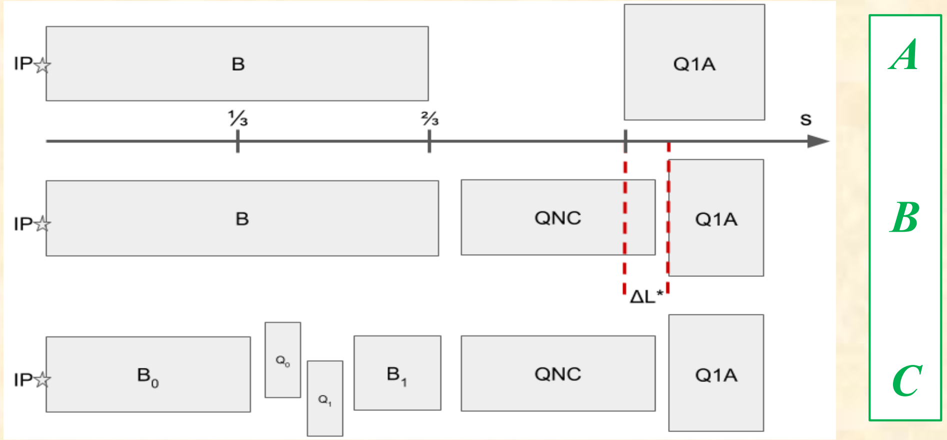
****** reduce the critical energy by 15 %***

****** reduce the synchrotron power by 50 %***

Tbd … which way to go.

… for Helmut:
Critical energies below 250 keV are out of question

III.) Resumé



Combining the two options …

- ***"B" half quadrupole to increase***
- ***\+ the effective L^****
- ***"C" early focusing scheme for the electrons***

Optimum for smallest critical energy:

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15	29.63	23.09 (-22.1 %)	18.99 (-35.9 %)	292	279 (-4.7 %)	262 (-10.4 %)
20	32.27	25.3 (-21.6 %)	19.33 (-40.1 %)	305	291 (-4.6 %)	264 (-13.3 %)

PEP II B-factory IR design