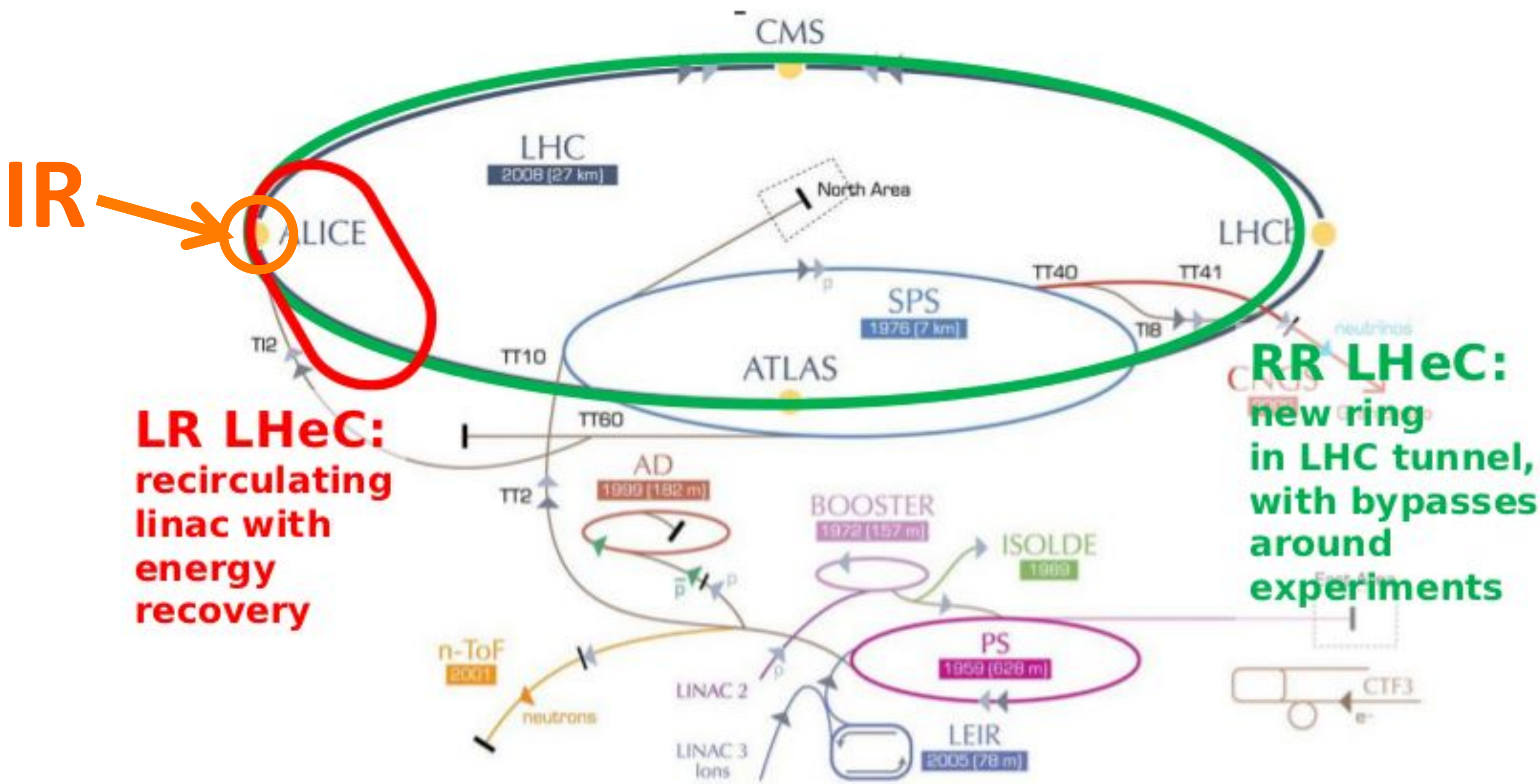
LHeC Interaction Region Design

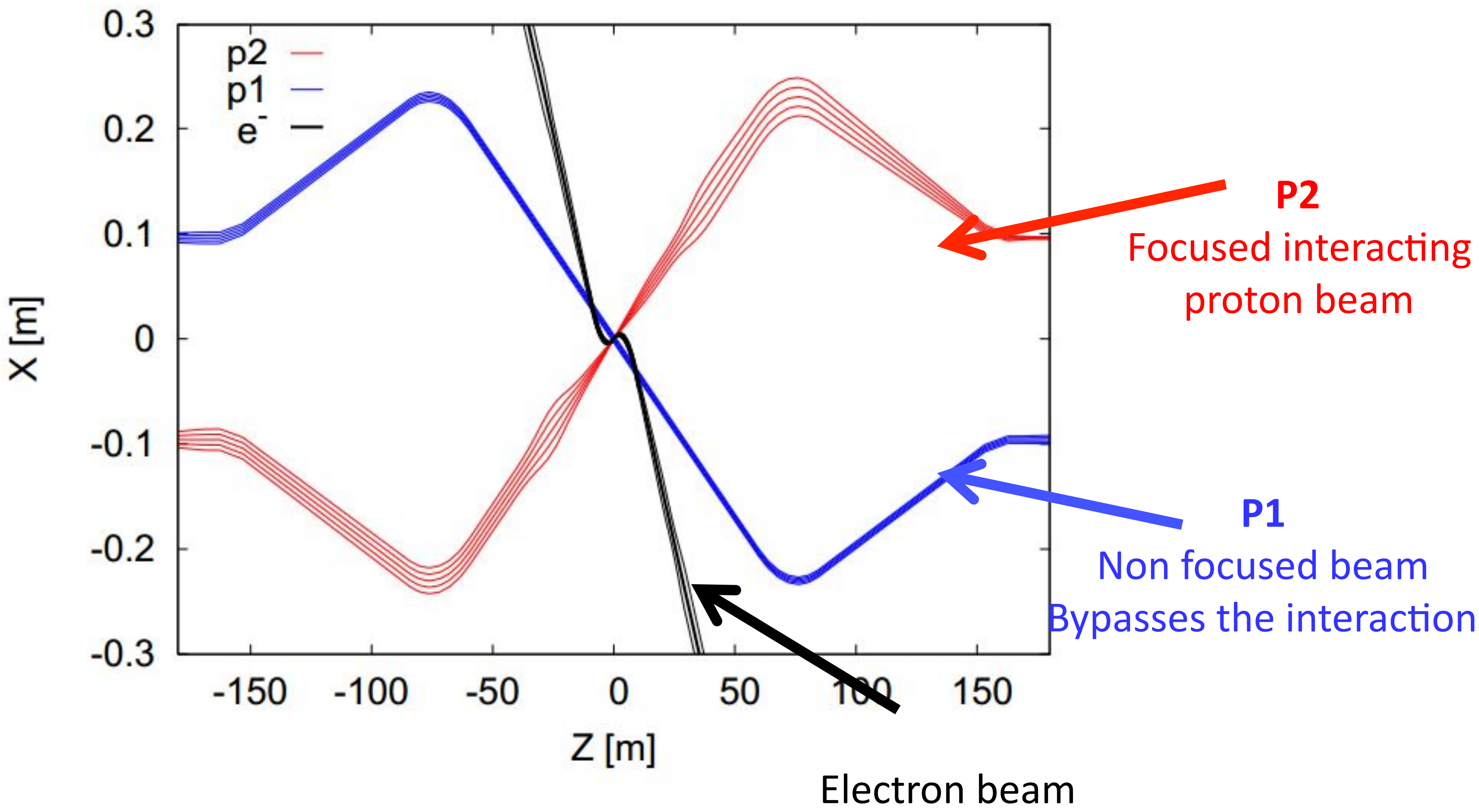
E. Cruz-Alaniz
R. Tomas

LHeC Workshop
24-26 June, 2015

Linac-Ring LHeC IR

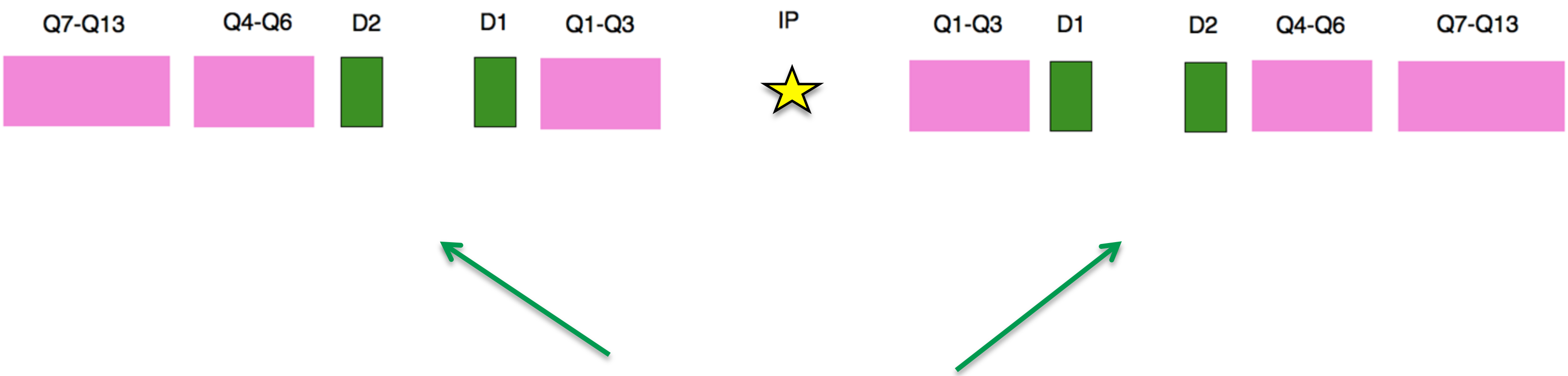


Interaction Region Conceptual Design



Interaction Region Lattice

Interaction Region Lattice

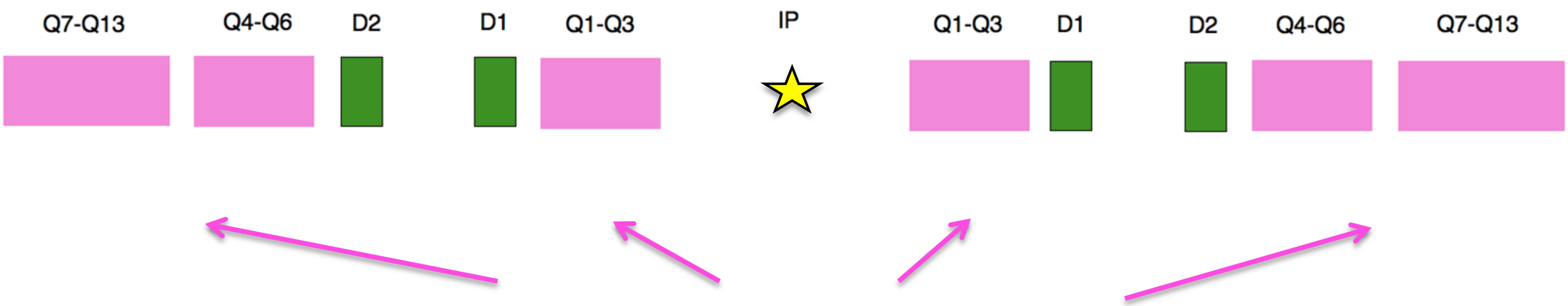


2 Recombination Dipoles

Change trajectory of proton beams

```
kd1.l2          :=  ad1.l2/l.mbx  ;
kd1.r2          :=  ad1.r2/l.mbx  ;
kd2.l2          :=  ad2.l2/l.mbrc ;
kd2.r2          :=  ad2.r2/l.mbrc ;
```

Interaction Region Lattice



26 Quadrupoles for each beam.
13 each side. 23 independent.
Focus proton beams

IT antisymmetric

```
KQX.L2      :=   0.877985714100E-02 ;
KTQX1.L2    :=   0.000000000000E+00 ;
KTQX2.L2    :=   0.000000000000E+00 ;
KQX.R2      :=              -KQX.L2   ;
KTQX1.R2    :=              -KTQX1.L2 ;
KTQX2.R2    :=              -KTQX2.L2 ;
```

```
 !Beam1
KQ4.L2B1     :=  -0.258592456320E-02 ;
KQ4.R2B1     :=   0.371540198462E-02 ;
KQ5.L2B1     :=   0.289870812115E-02 ;
KQ5.R2B1     :=  -0.364729424407E-02 ;
KQ6.L2B1     :=  -0.469531641707E-02 ;
KQ6.R2B1     :=   0.432365742510E-02 ;
KQ7.L2B1     :=   0.745357182830E-02 ;
KQ7.R2B1     :=  -0.640978067866E-02 ;
KQ8.L2B1     :=  -0.529525684936E-02 ;
KQ8.R2B1     :=   0.671971927152E-02 ;
KQ9.L2B1     :=   0.703623363164E-02 ;
KQ9.R2B1     :=  -0.651667220851E-02 ;
KQ10.L2B1    :=  -0.644030443578E-02 ;
KQ10.R2B1    :=   0.730142490022E-02 ;
KQTL11.L2B1 :=   0.294599974395E-03 ;
KQTL11.R2B1 :=  -0.711502410599E-04 ;
KQT12.L2B1  :=   0.208264468927E-02 ;
KQT12.R2B1  :=  -0.237270956314E-02 ;
KQT13.L2B1  :=   0.296816023135E-02 ;
KQT13.R2B1  :=  -0.206932585417E-02 ;
```

```
 !Beam2
KQ4.L2B2     :=   0.185133533486E-02 ;
KQ4.R2B2     :=  -0.309985129373E-02 ;
KQ5.L2B2     :=  -0.349664775637E-02 ;
KQ5.R2B2     :=   0.469937679927E-02 ;
KQ6.L2B2     :=   0.442385030629E-02 ;
KQ6.R2B2     :=  -0.370019633193E-02 ;
KQ7.L2B2     :=  -0.813254954261E-02 ;
KQ7.R2B2     :=   0.733992956089E-02 ;
KQ8.L2B2     :=   0.700517746627E-02 ;
KQ8.R2B2     :=  -0.560890926907E-02 ;
KQ9.L2B2     :=  -0.701852180932E-02 ;
KQ9.R2B2     :=   0.681308273586E-02 ;
KQ10.L2B2    :=   0.702844127608E-02 ;
KQ10.R2B2    :=  -0.525944973661E-02 ;
KQTL11.L2B2 :=   0.381920898127E-02 ;
KQTL11.R2B2 :=   0.399409216637E-03 ;
KQT12.L2B2  :=  -0.333493643883E-02 ;
KQT12.R2B2  :=  -0.194961708850E-02 ;
KQT13.L2B2  :=   0.278690239431E-03 ;
KQT13.R2B2  :=   0.482280250116E-02 ;
```

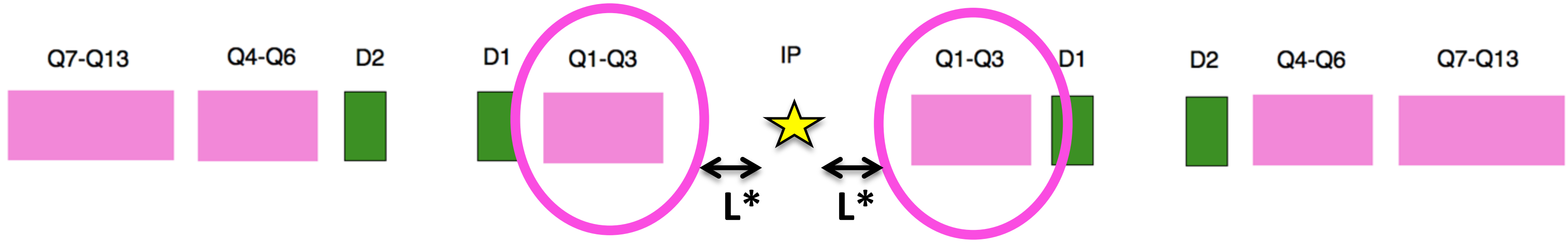
Interaction Region Lattice

$$L = \frac{1}{4\pi e} \frac{N_{b,p}}{\varepsilon_p} \frac{1}{\beta_p^*} I_e H_{hg} H_D$$

Minimize β* = More Luminosity!

$$\sigma_x = \sqrt{\epsilon \beta(s)}$$

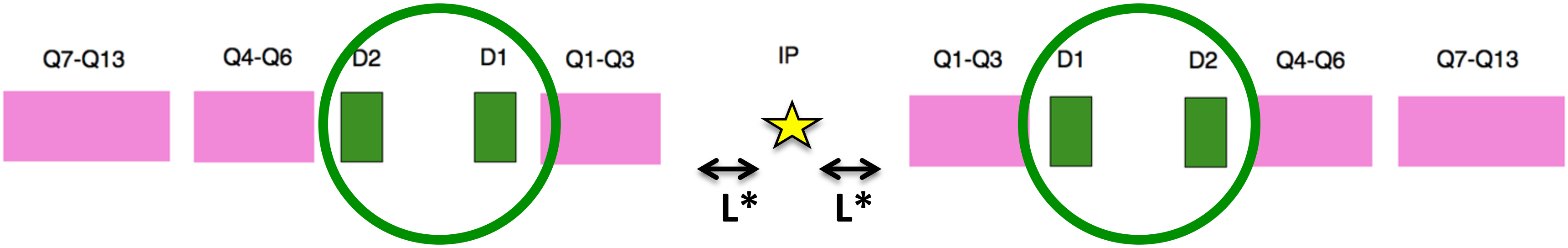
Changes to the IR lattice



$$L = \frac{1}{4\pi e} \frac{N_{b,p}}{\varepsilon_p} \frac{1}{\beta_p^*} I_e H_{hg} H_D$$

FOCUSING. QUADRUPOLES. Implementation of new inner triplet Q1-Q3 (L*=10 m) with normal (for P2) and field free holes (P1).

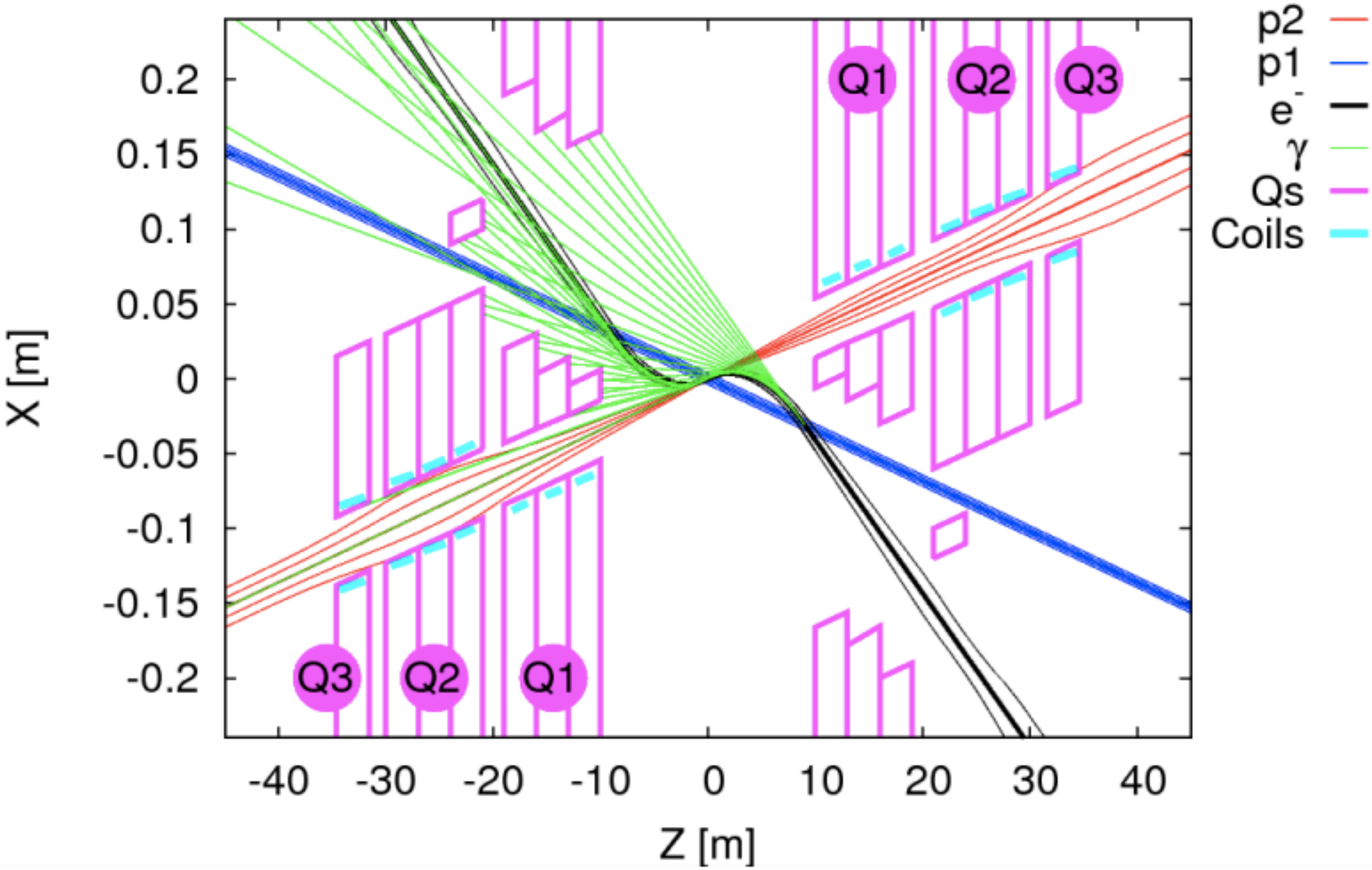
Changes to the IR lattice



$$L = \frac{1}{4\pi e}\frac{N_{b,p}}{\varepsilon_p}\frac{1}{\beta_p^*} I_e H_{hg} H_D$$

TRAJECTORY. DIPOLES. Inverse polarity of D1 and D2. D2 1.21 stronger, D1 3.43 Stronger give 68 mrad of aperture between proton beams in the entrance of Q1

Conceptual Design LHeC IR



Challenges Post CDR

- Integrate LHeC IR into the HL-LHC lattice. Achieve low beta* leaving HL undisturbed and while controlling the chromaticity.
- Explore flexibility of the design, limits on L*, beta* in terms of quadrupoles strengths, chromaticity correction and DA.
- SR in the IR to be absorbed and masked to the detector.

β* Minimization

Problem of minimization of β*:

We reach a limit on quadrupoles strengths and, most importantly the IT causes huge chromatic aberrations.

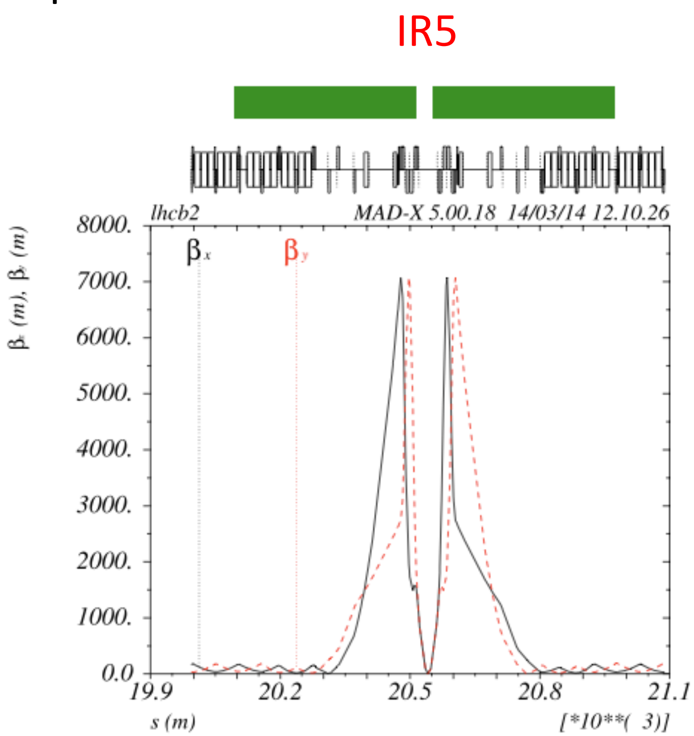
We need:

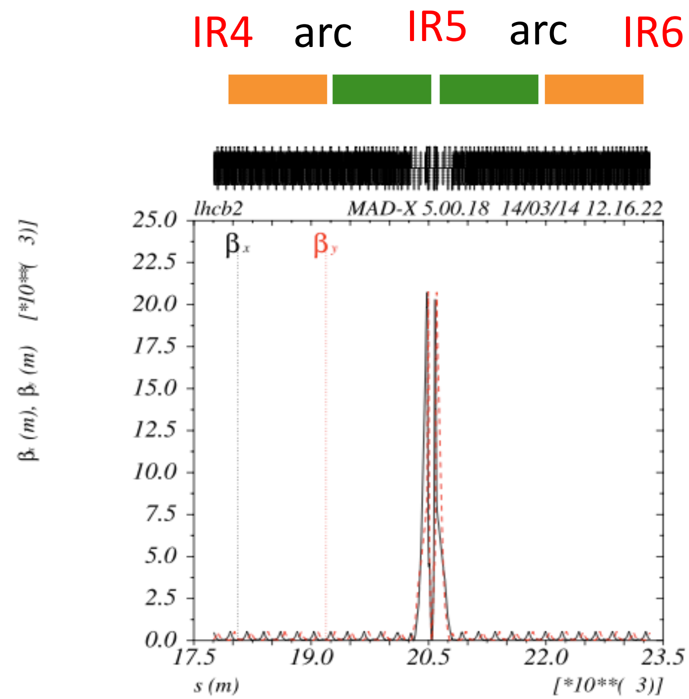
β^*= 10 cm for the Luminosity=10^{33} cm^2s^{-1}

β^*= 5 cm for the Luminosity=10^{34} cm^2s^{-1}

Achromatic Telescopic Squeezing (ATS) Scheme. HL-LHC

Take example of the ATS implemented in HL. This makes use of the adjacent arcs to the IR whose β we want to minimize (IR1, IR5 in this case) to create a β wave that will increase the β function in the location of the sextupoles at the same rate than minimizing the β*





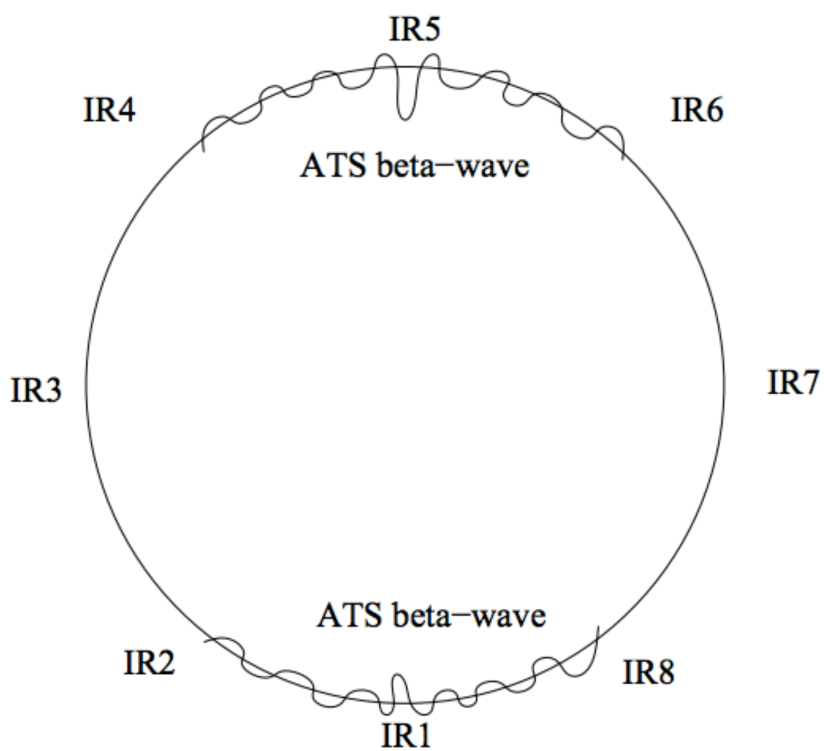
$\beta^*_{IR1,IR5}$=0.15 m

Increases Beta function in location of sextupoles in arc

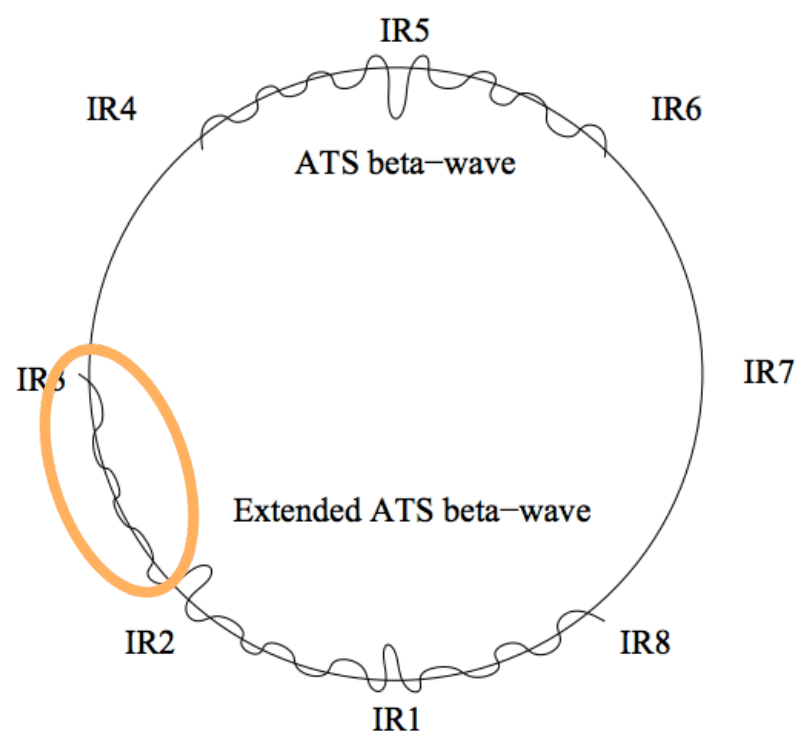
$$\xi^S_{x,y} = -\frac{1}{4\pi}\oint \mp\beta_{x,y}(s)S(s)D_x(s)ds$$

Achromatic Telescopic Squeezing (ATS) Scheme. HL+LHeC

HL-LHC



HL-LHC + LHeC



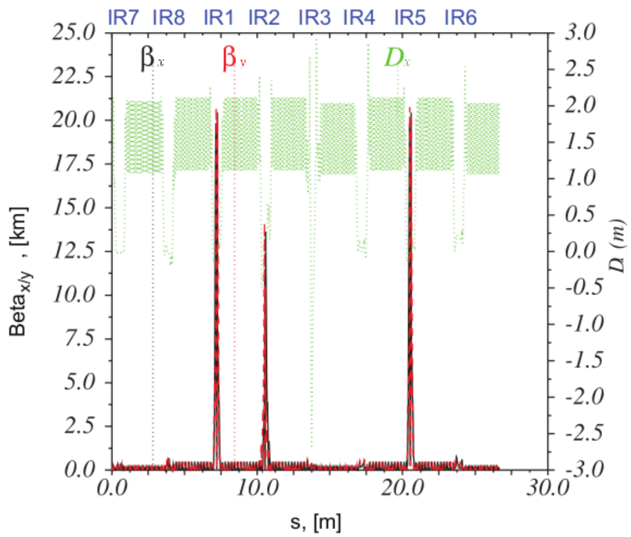
HL+LHeC ATS Optics. Beam 2

The first integration of the LHeC IR into the HL-LHC lattice using the ATS optics was done by M. Korostelev. This integration achieved a minimization of β* values simultaneously in IP1, IP2 and IP5.

New triplet
Q1=187 T/m
Q2=310 T/m
Q3=182 T/m
Length=9 m

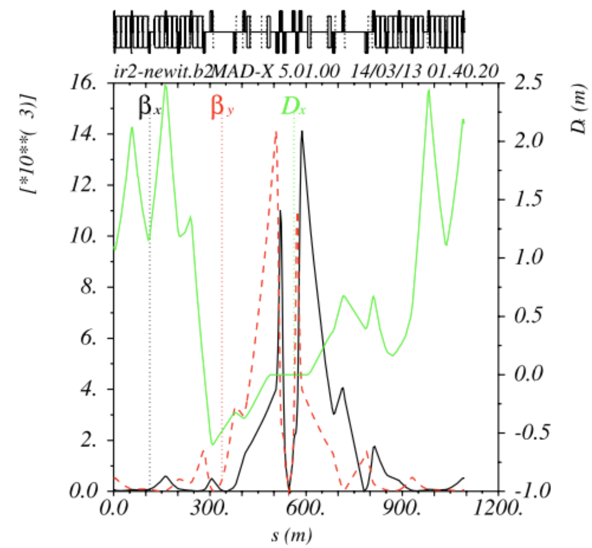
IP1/IP5

β*=15 cm



IP2

β*=10 cm



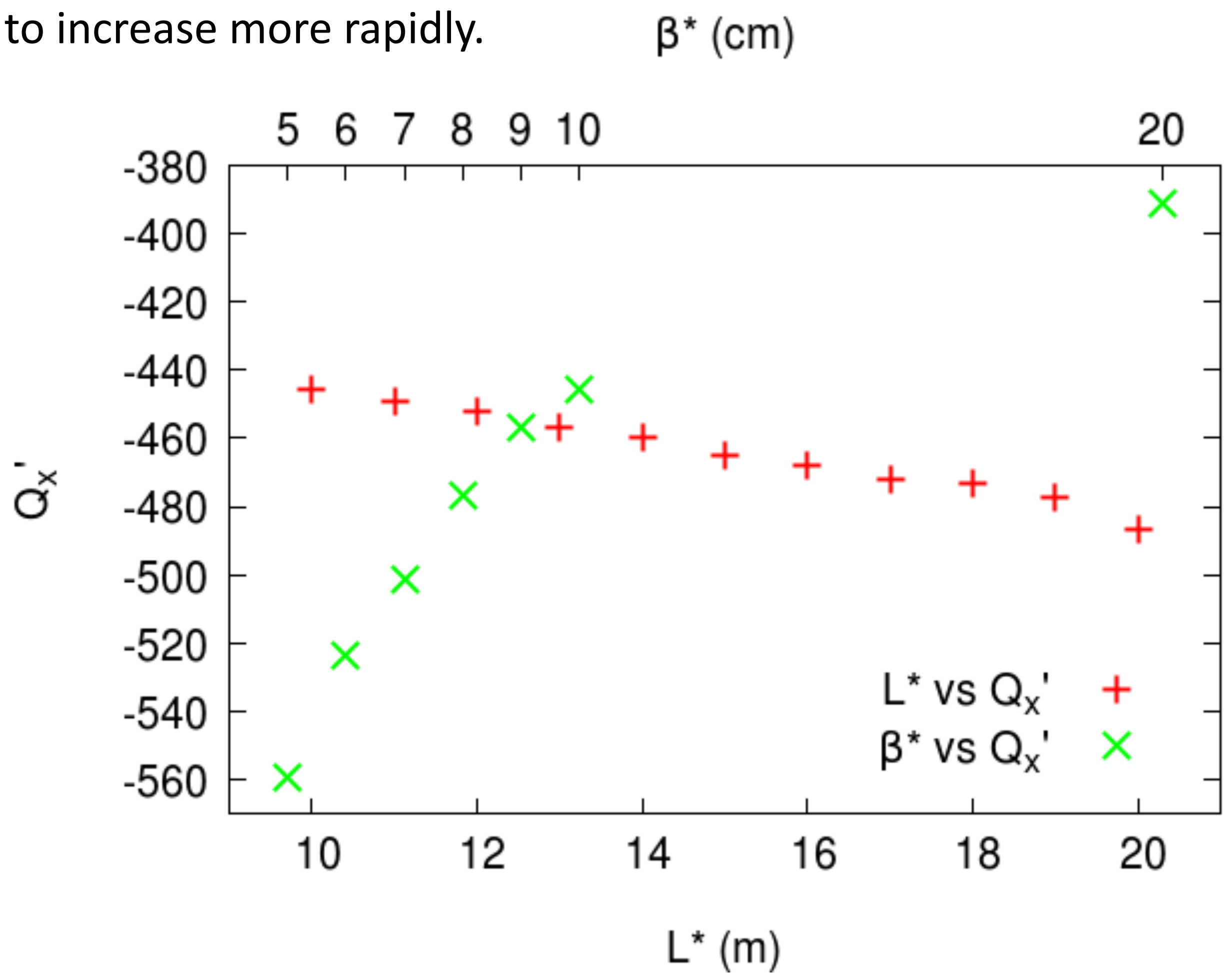
Qxb2/Qyb2 = 62.31/ 60.32

Design Flexibility

	Disadvantages	Advantages	Cases found
Minimize β*	Increase **Chromatic Aberrations**	Increase **Luminosity**	**β*=5-10, 20 cm With L* fixed at 10 m**
Increase L*	Increase **Chromatic Aberrations**	Reduction **Synchrotron Radiation** **Shorter cantilever**	**L*=10-20 m With β* fixed at 10 cm**

Chromaticity

Figure shows the natural chromaticity for different L* and β*. The absolute value of the natural chromaticity increases linearly as we increase L* while minimizing β* causes the chromaticity to increase more rapidly.



Chromatic Correction

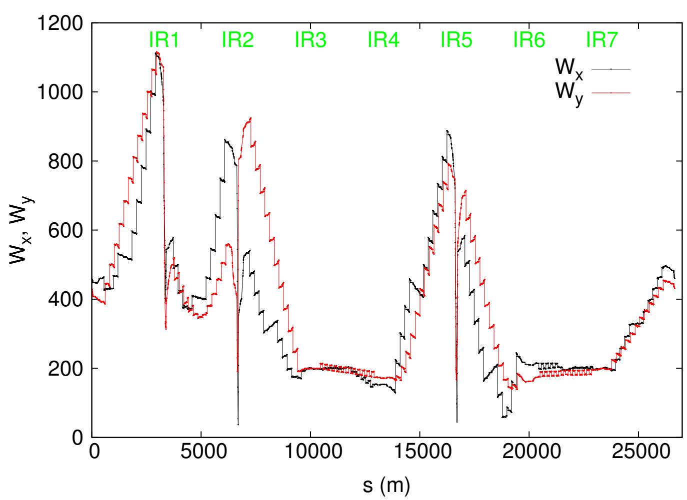
The chromatic correction was done in two different ways, LHC-like adjusting only the chromaticity to a value of 2 and LHeC-like, adjusting also the Wx, Wy below a value of 200 in the collimation insertions IR3 and IR7. The benefits of the second correction are clear in terms of the peak W functions. DA studies also confirm this in terms of stability of the beam.

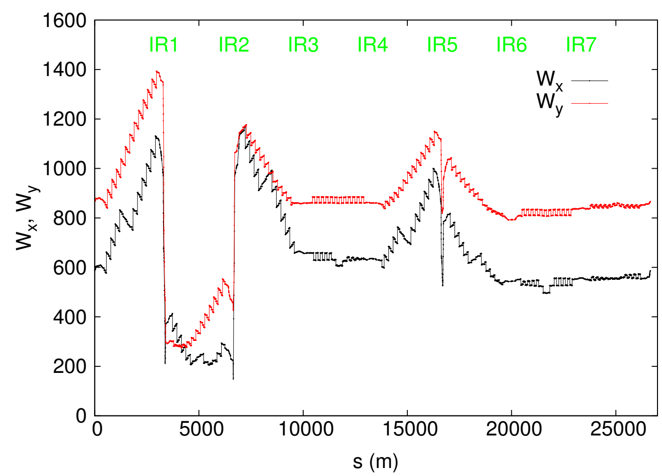
LHC-like correction

Vary	Constraints
KSF1, KSF2, KSD1, KSD2 all arcs varying at the same rate	dq1=2, dq2=2

LHeC-like correction

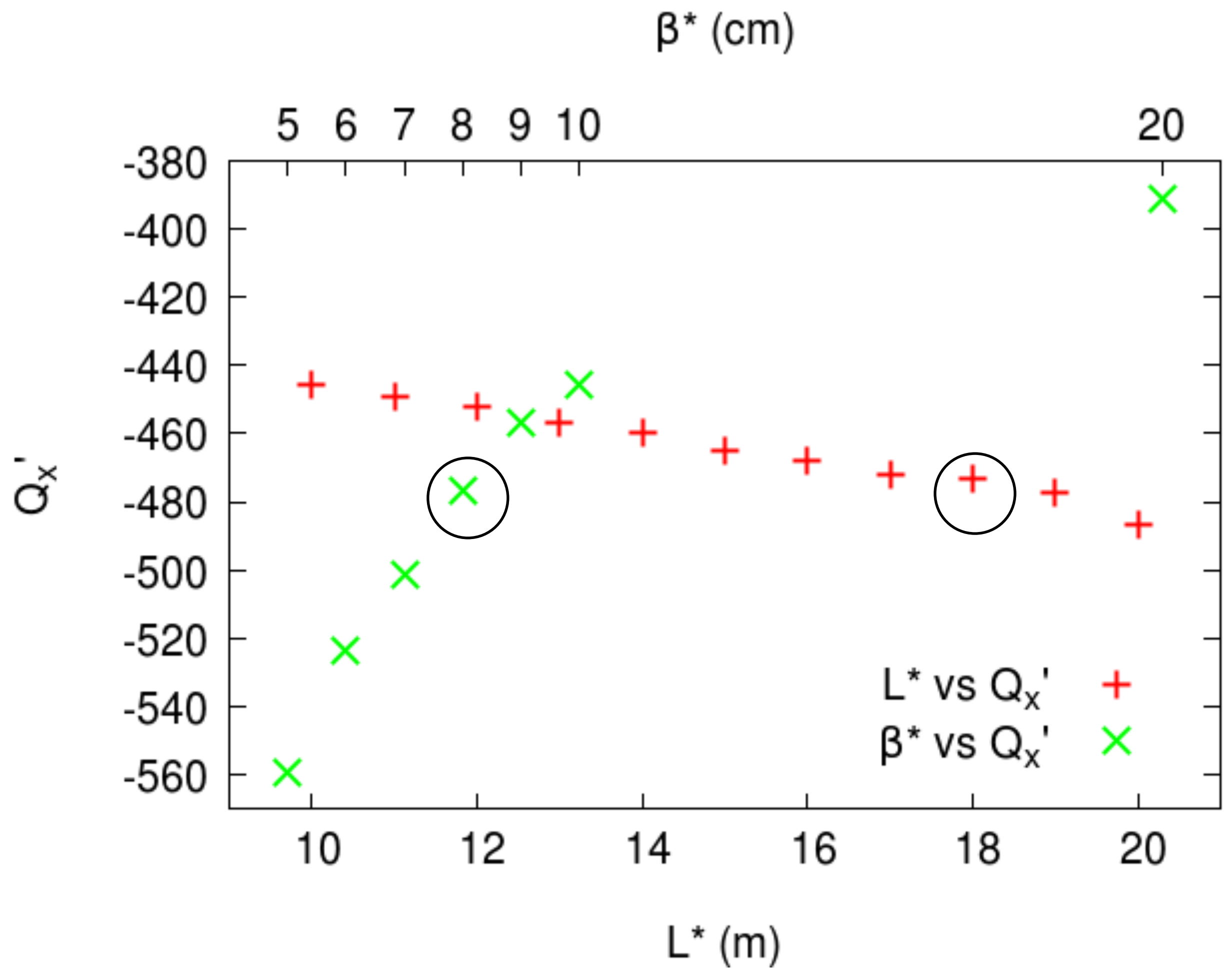
Vary	Constraints
KSF1, KSF2, KSD1, KSD2 all arcs varying independently	dq1=2, dq2=2 Wx, Wy<200 in IR3 and IR7





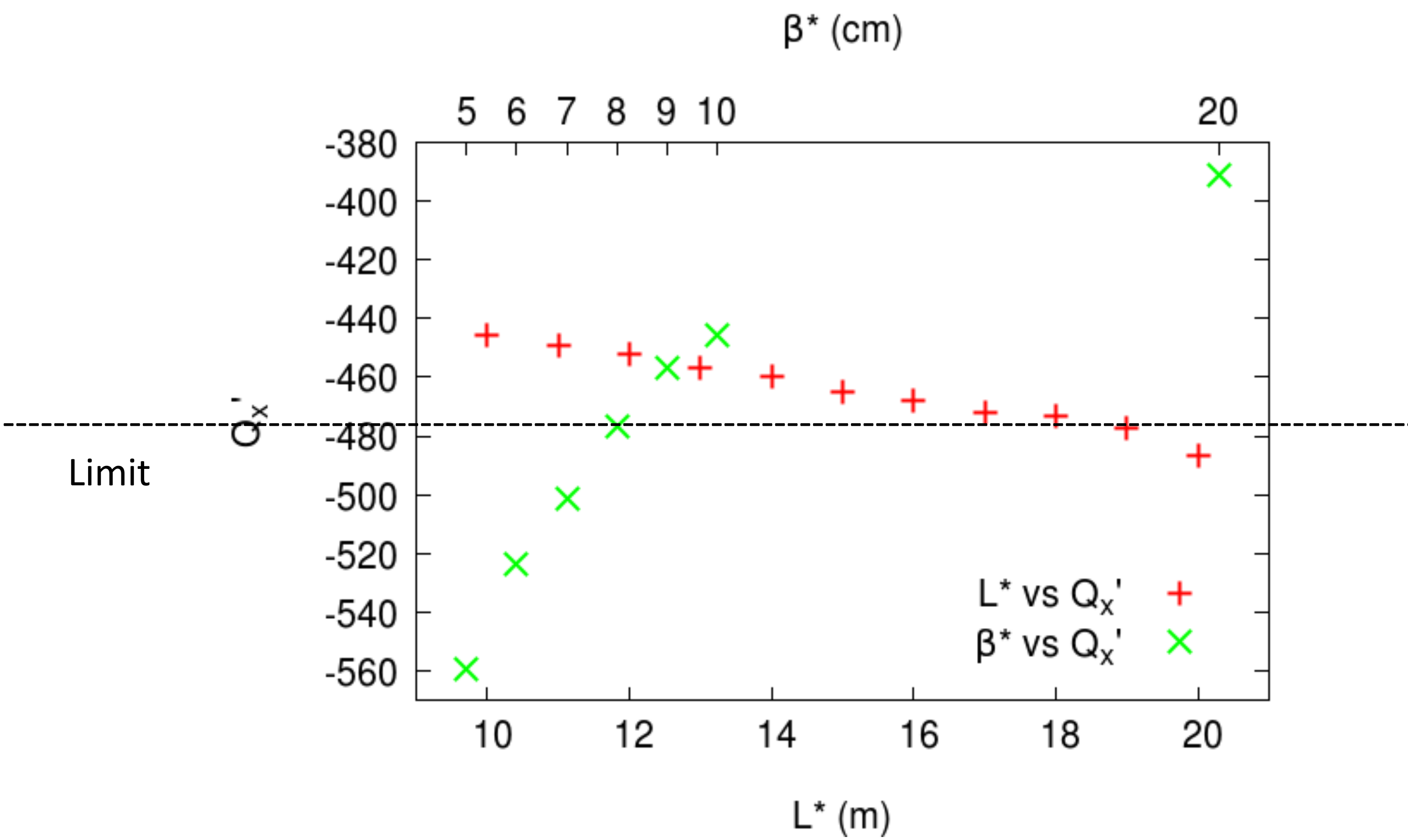
Chromatic Correction

This chromatic correction matching was successfully achieved for a maximum L* of 18 m and a minimum β*=8 cm.



Chromatic Correction

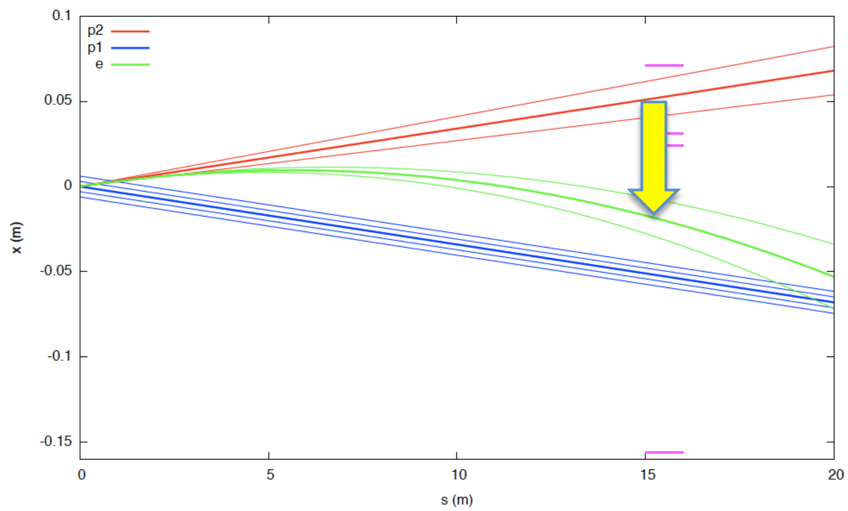
The limit of this chromatic correction matching is then found for a natural chromaticity of around -480

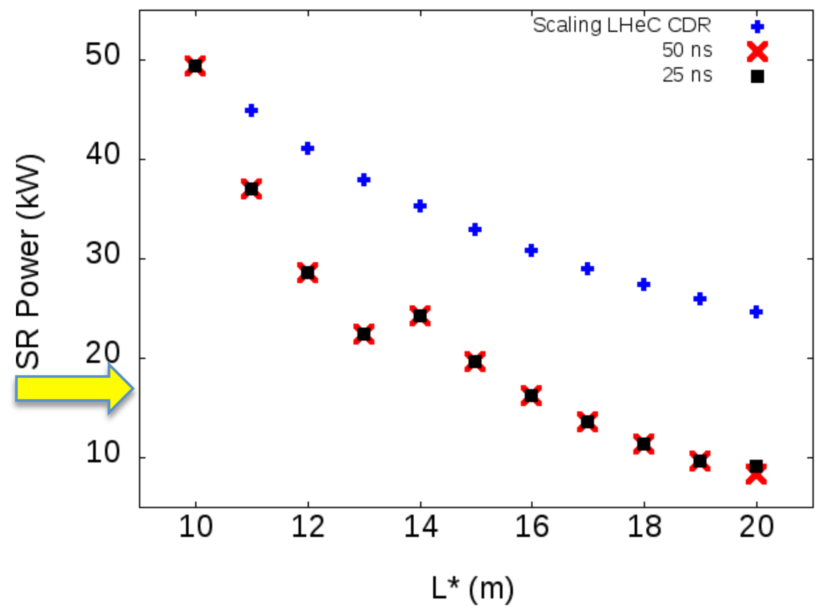


Synchrotron Radiation

Find minimum separation

1. d(L) > 65 mm for L*<14 m, d(L) > 87 mm for L*>14 m.
2. Separation at first long range encounter has to be at least 12 σ.
3. Electron beam must physically fit inside free field hole.

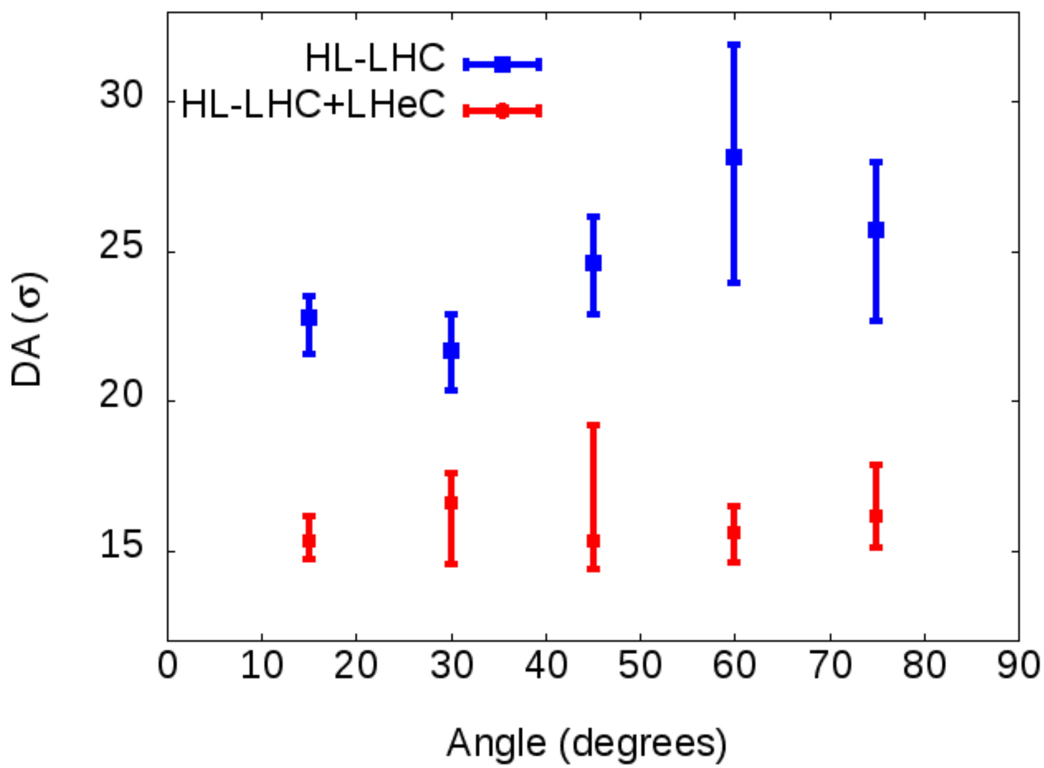




Dynamic Aperture

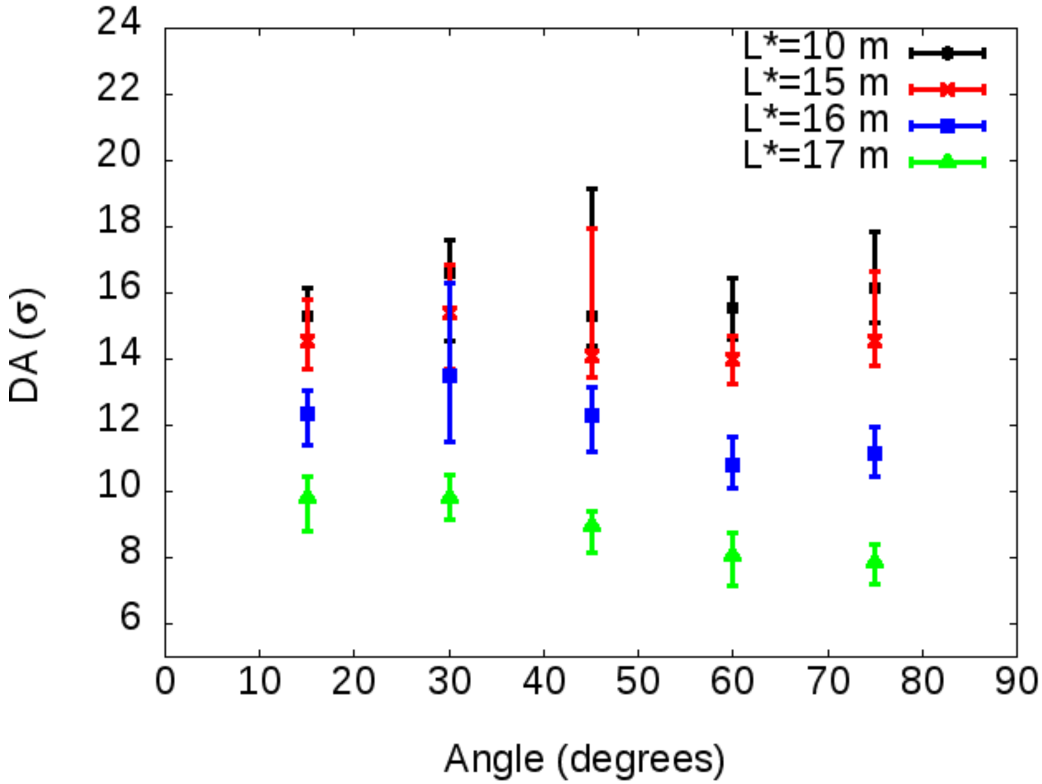
The DA was computed for the beam 4 (beam 2 backwards) of the HLLHCV1.0 version of the HL lattice. The figure compares it with the inclusion of the LHeC IR for the lattice with L*=10 m and β*=10 cm. A clear reduction of the DA is observed but further studies are to be done including the errors missing.

SixTrack
60 Seeds
100,000 turns
Errors in LHC Magnets
No errors in IT, D1, D2
In IR1,IR2 and IR5, and Q4
and Q5, in IR1 and IR5



Dynamic Aperture. Different L*

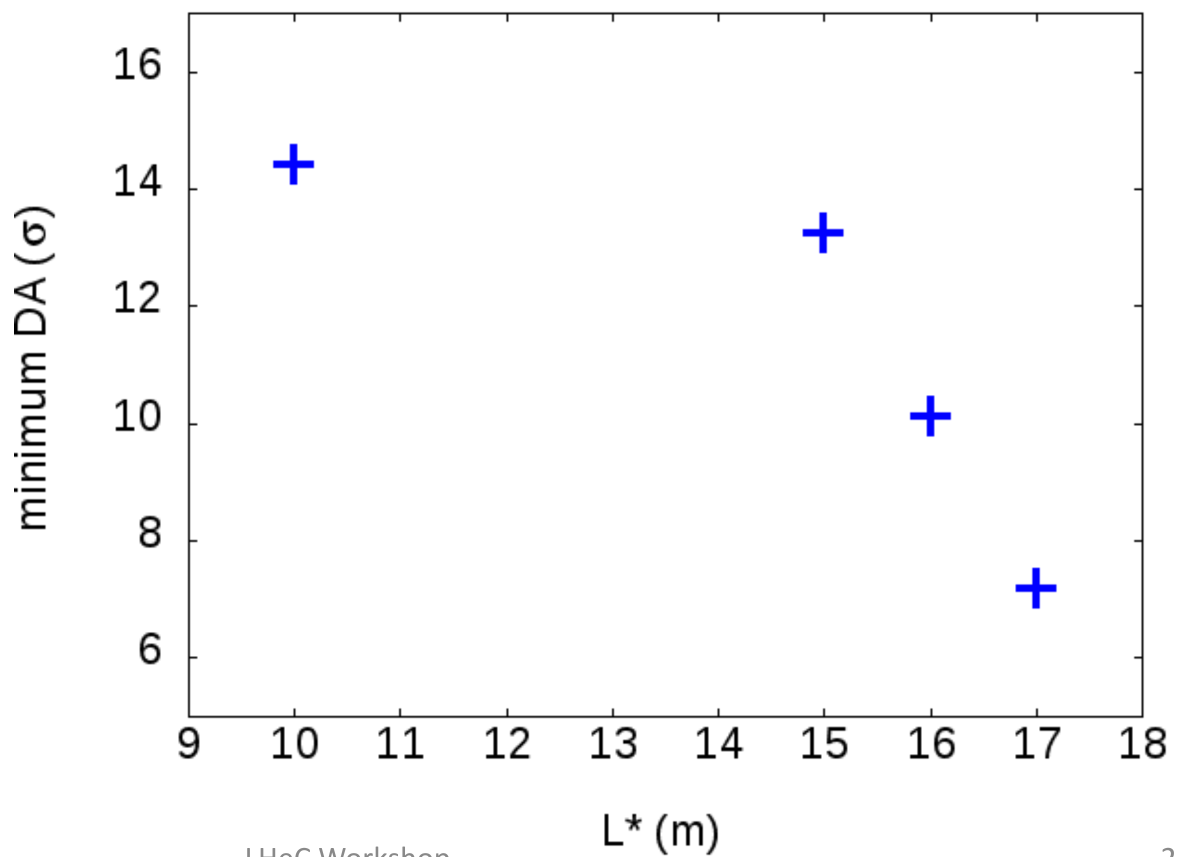
The DA was computed also for different versions of the lattice with different L* and β* fixed at 10 cm. It is shown that up to L*=15 m the DA is similar to the nominal case with L*=10 m. However for the cases L*=16 m and 17 m the DA reduces considerably.



Dynamic Aperture. Different L*

The DA was computed also for different versions of the lattice with different L* and β* fixed at 10 cm. It is shown that up to L*=15 m the DA is similar to the nominal case with L*=10 m. However for the cases L*=16 m and 17 m the DA reduces considerably.

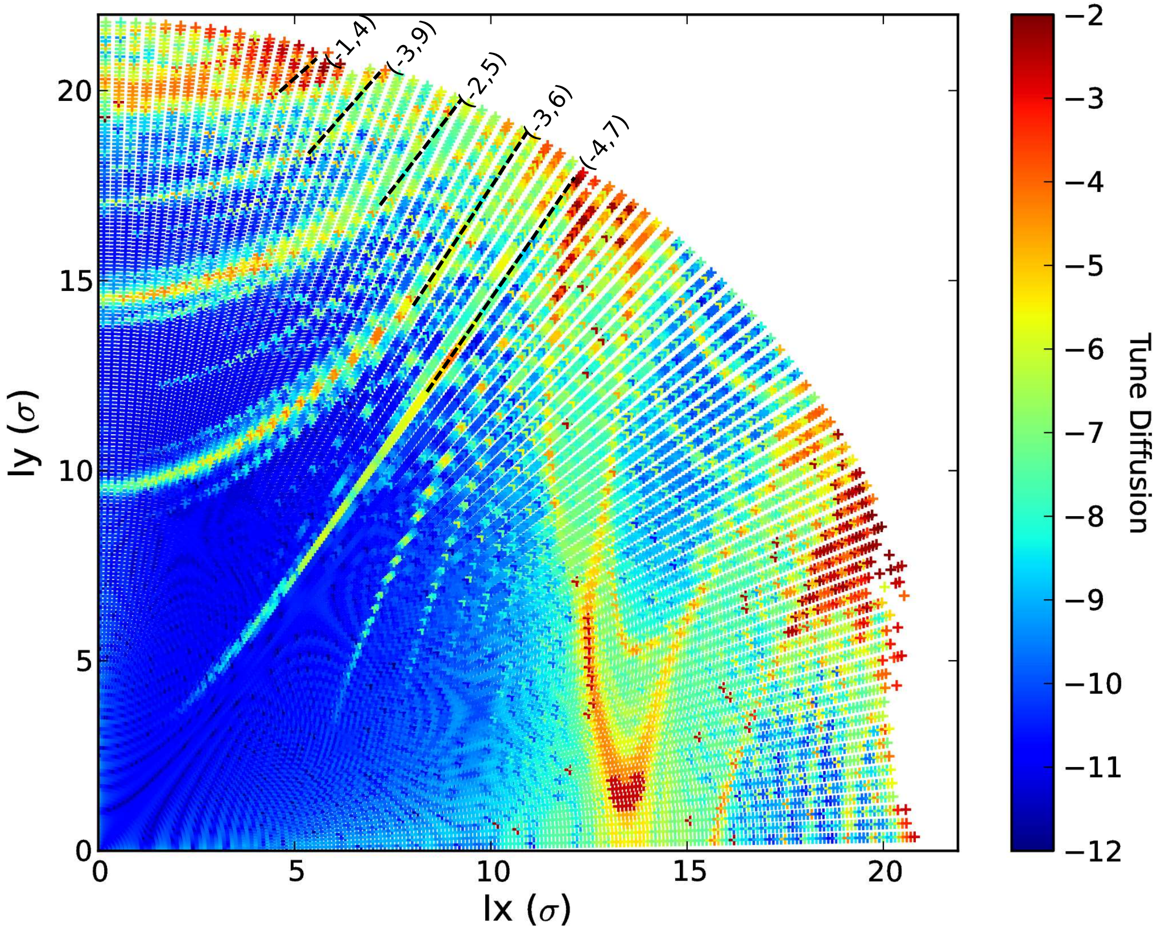
SixTrack
60 Seeds
100,000 turns
Errors in LHC Magnets
No errors in IT, D1, D2
In IR1,IR2 and IR5, and Q4 and Q5, in IR1 and IR5



Frequency Map Analysis

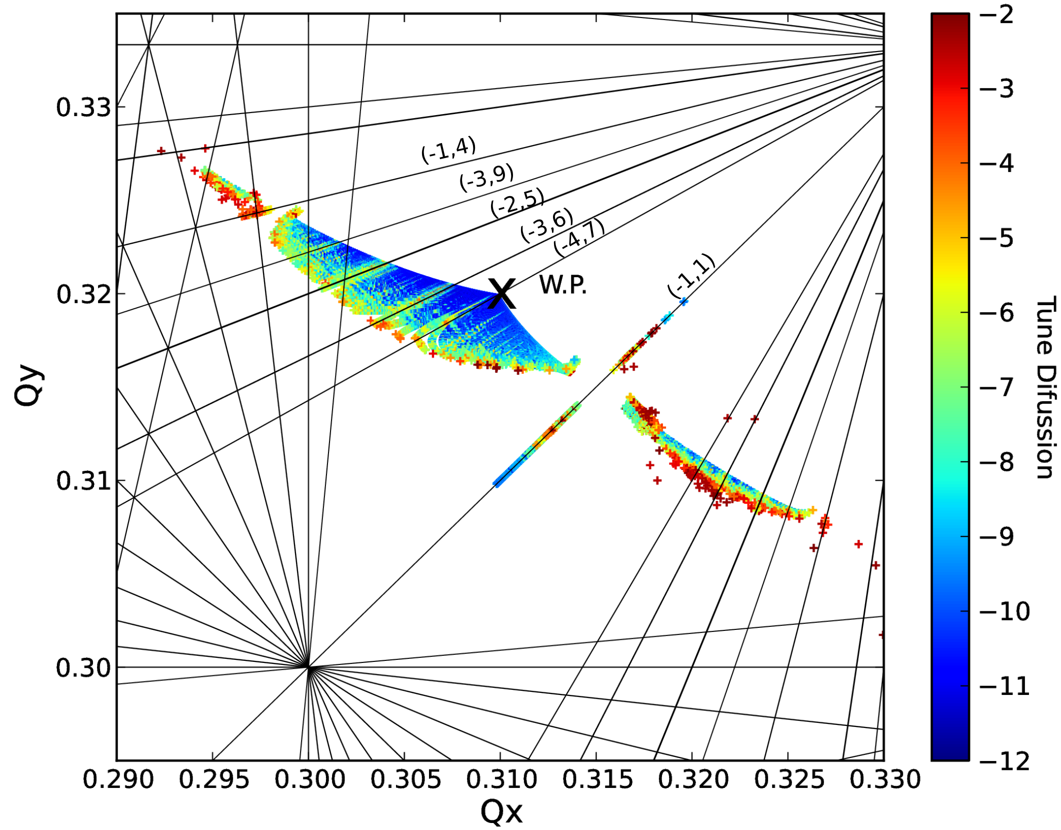
Diffusion factor **$D=\log_{10}=\sqrt{((\Delta\nu_x)^2+(\Delta\nu_y)^2)}$**

Difference of tune after 5000 and 10,000 turns



Tune Diagram

Tune diffusion between 5,000 and 10,000 turns in a resonance diagram

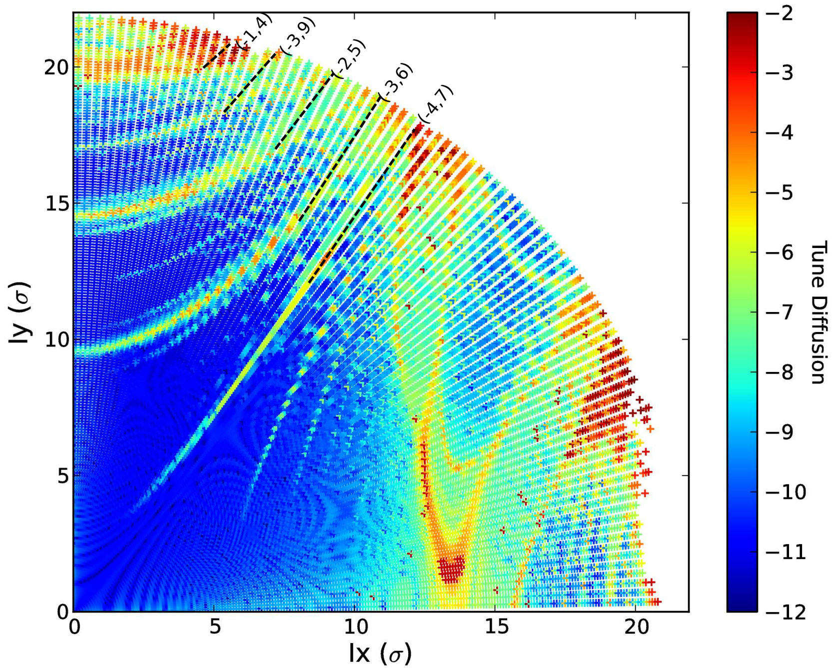


L*=10 m, β*=10 cm

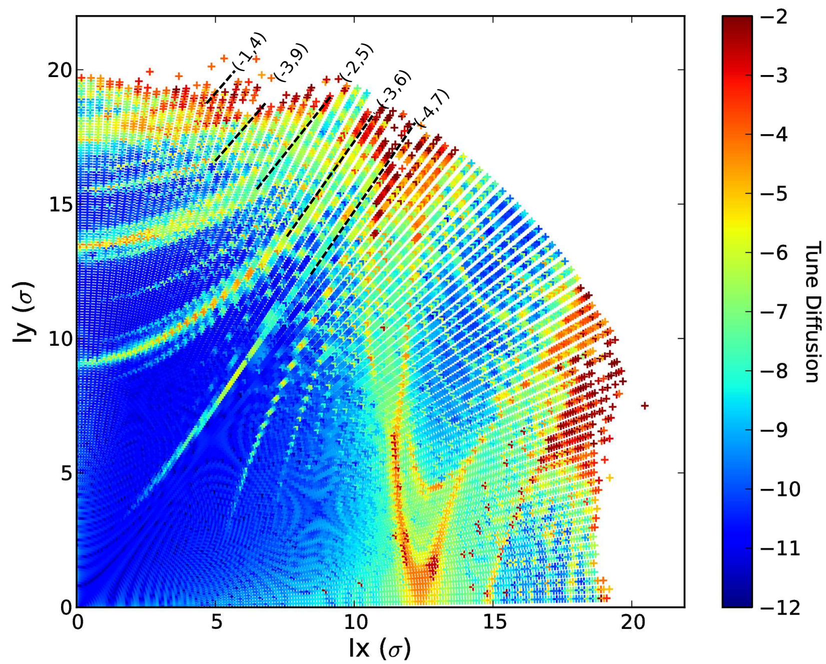
FMA. Different L*

Similar amplitude maps are found between the cases L*=10 m beta*=10 cm and L*=15 m, beta*=10 cm.

L*=10 m, β*=10 cm



L*=15 m, β*=10 cm

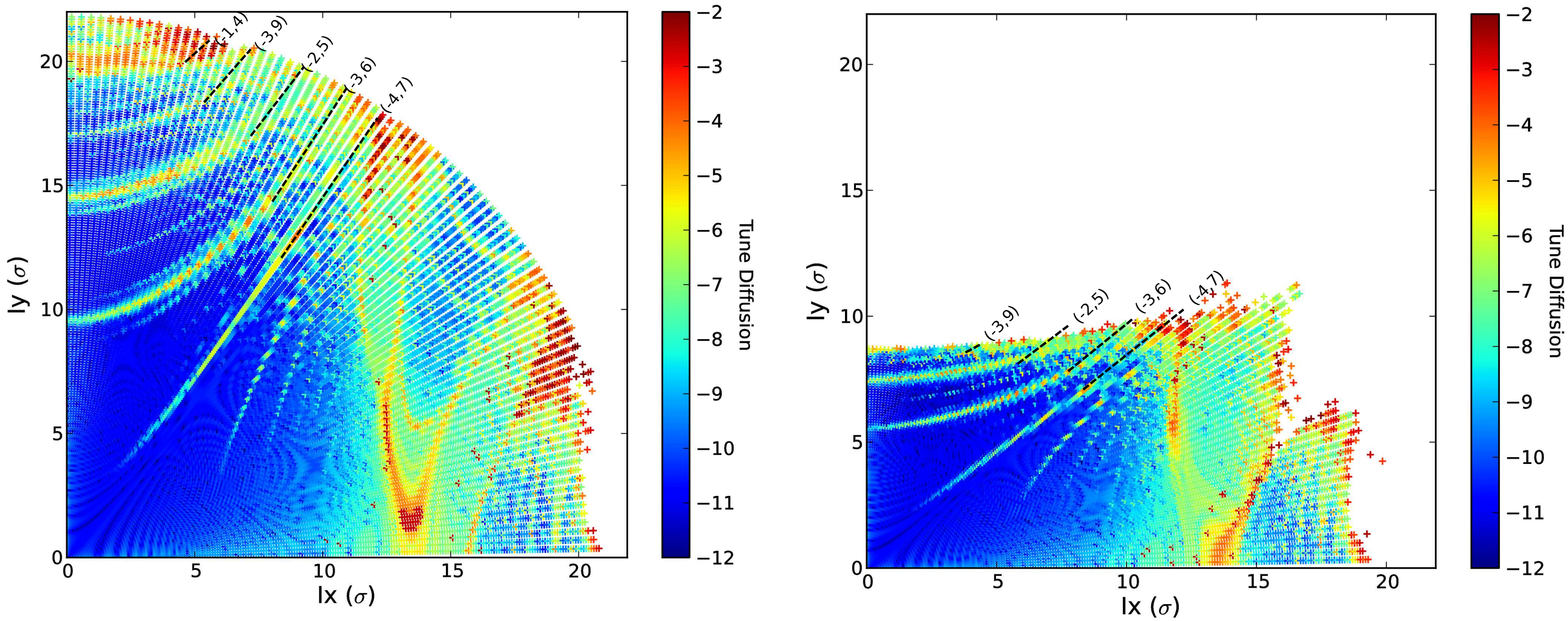


FMA. Different L*

Clear differences are found between the cases L*=10 m β*=10 cm and L*=17 m, β*=10 cm.

L*=10 m, β*=10 cm

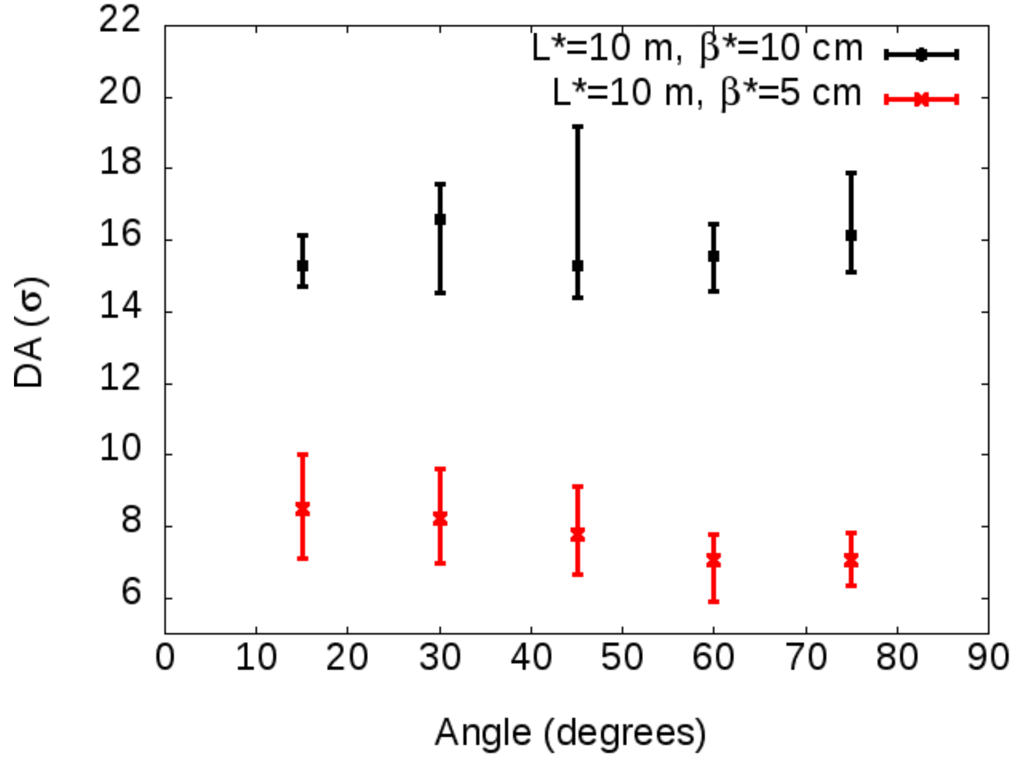
L*=17 m, β*=10 cm



The upgraded case β*=5 cm

Towards Luminosity **≥10^{34} $cm^{-2}s^{-1}$**

The most challenging case with β*=5 cm was found in terms of the quadrupoles but the chromaticity correction was only achievable without controlling the Wx, Wy functions in IR3 and IR7 which is reflected in the DA results:



Conclusions
Case 10^{33} $cm^{-2}s^{-1}$ (β^*=10 cm):

- First order optical designs have been found for up to L*=20 m.
- LHeC-like chromatic correction was only achieved up to L*=18 m and for a minimum β* of 8 cm.
- DA and FMA studies were done for up to L*=17 m.
- From DA studies largest L* is 15 m. A steep reduction of DA is observed for larger values.
- L* of 15 m could also reduced the SR by a factor of 2.

Conclusions
Case 10^{34} $cm^{-2}s^{-1}$ (β^*=5 cm):

- Control of chromatic aberrations (LHeC-like correction) is not possible.
- Too low DA (6 σ without triplet errors!).
- Not longer possible to increase L* to 15 m to mitigate SR.