OPTICS DESIGN FOR THE LHEC

A DESIGN FOR THE LHEC LEPTON RING LATTICE

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OUTLINE LHeC Lepton Ring

1.) PRELIMINARIES

2.) ARC LATTICE

3.) MATCH TO IR8

4.) SUMMARY

Add a lepton ring to LHC

Energy: 70 GeV $E_{cm} = 1.4$ TeV

Luminosity: 10^{33} cm^{-2} s^{-1}

Interaction Point: IP8

DESY 06-006
Cockcroft-06-05

Deep Inelastic Electron-Nucleon Scattering at the LHC*

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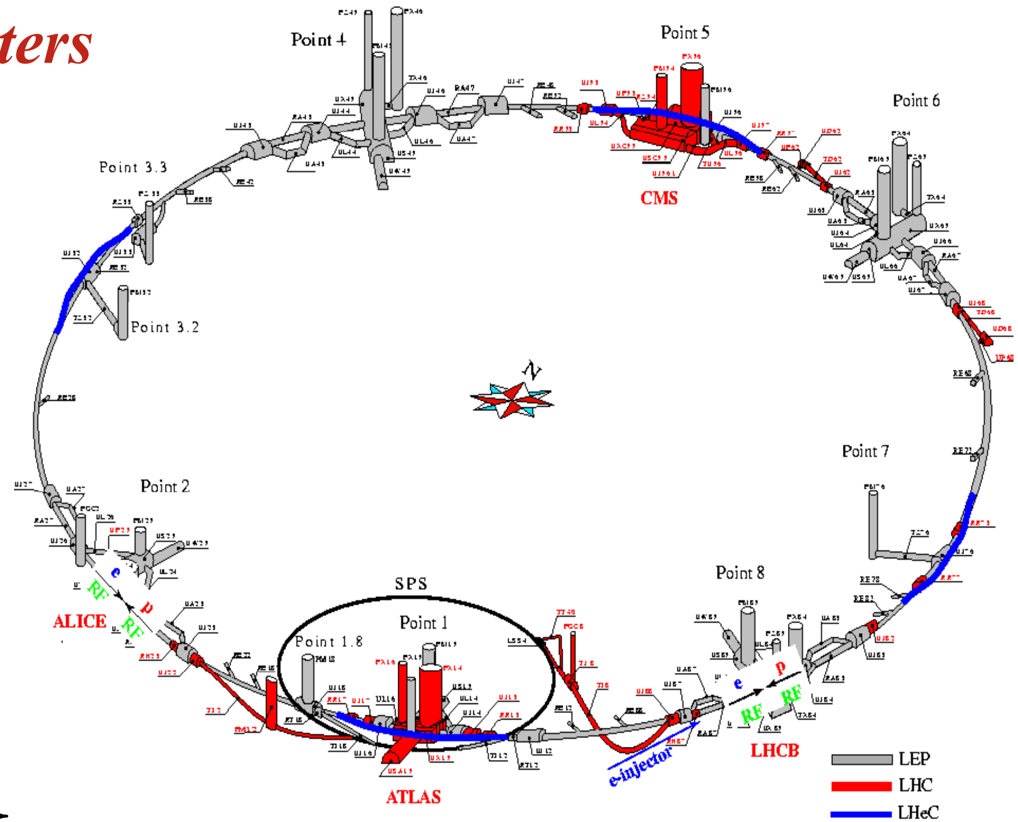
Abstract

The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, 10^{33}cm^{-2}s^{-1}, and high energy $\sqrt{s} =$ 1.4 TeV, such a collider can be built in which a 70 GeV electron (positron) beam in the LHC tunnel is in collision with one of the LHC hadron beams and which operates simultaneously with the LHC. The LHeC makes possible deep-inelastic lepton-hadron (ep, eD and eA) scattering for momentum transfers Q^2 beyond 10^6 GeV^2 and for Bjorken x down to the 10^{-6}. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense Quantum Chromodynamics, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure and of parton dynamics at the TeV energy scale. The LHeC thus complements the proton-proton and ion programmes, adds substantial new discovery potential to them, and is important for a full understanding of physics in the LHC energy range.

LHeC Ring-Ring: basic parameters



	Electrons	Protons
Beam Energy	70 GeV	7 TeV
total current	74 mA	544 mA
part. / bunch	$1.4 \cdot 10^{10}$	$1.7 \cdot 10^{11}$
hor. emittance	7.6 nm	0.5 nm
vert. emittance	3.8 nm	0.5 nm
β* hor	12.7 cm	180 cm
β* vert	7.1 cm	50 cm

main goal

bunch spacing 25 ns

Luminosity 10^{33} cm^{-2} s^{-1}

DESIGN CONSTRAINTS

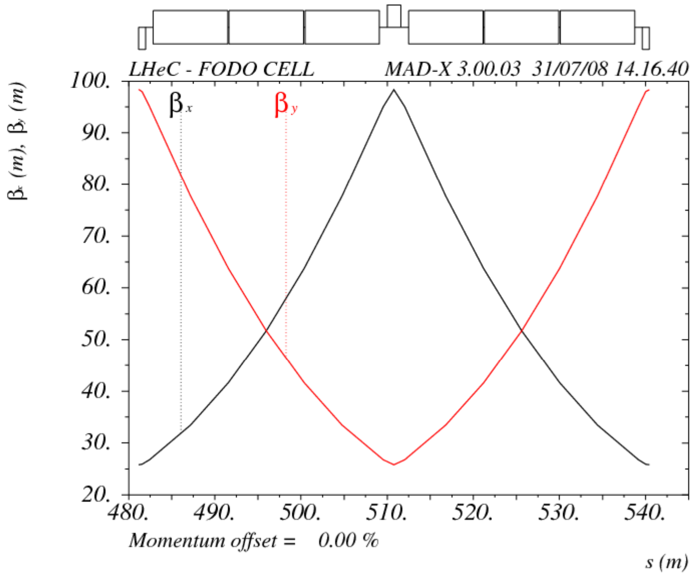
- *Matched beam sizes at the IP* *required for stable operation.*
- *Tolerable beam-beam tune shift* *parameters.*
- *Lepton* *beta function* *must respect certain limits:*
  Upper limit to *avoid excessive chromaticity contribution* *from strong focusing at the IP.*
  Lower limit from maximally *tolerable beam-beam tune shift.*
- *Choose* *parameters close to LEP design*

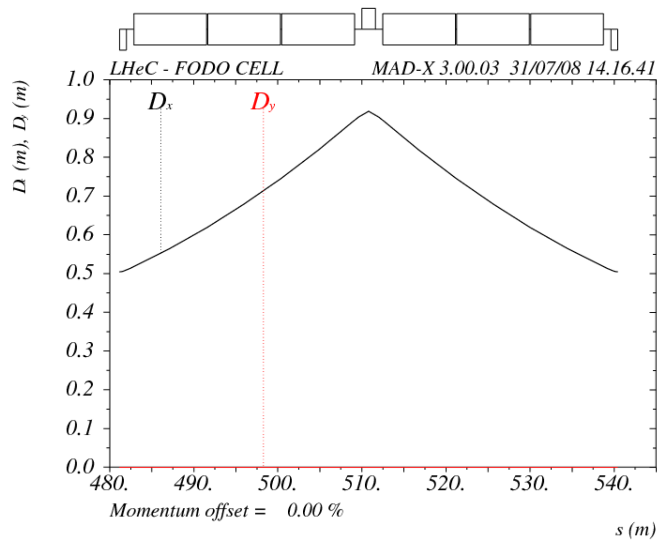
Lepton Ring Parameter	*Unit*	*LEP*	*LHeC*
Cell length	*m*	*79*	*59.25*
Phase Advance	*deg*	*60/90/108*	*72*
Number of Cells		*290*	*384*
Bending Radius	*m*	*3065.2*	*3060.2*

- *Apply an RF frequency shift to adjust the emittance to the desired value.*

2.) ARC LATTICE

Parameter	Unit	Value
Cell length	m	59.25
Phase Advance hor./ver.	deg	72/72
Bending Radius	m	3060.2
Length of Dipoles	m	8.65
Number of Dipoles/Cell		6
Length of Quadrupoles	m	1.6
Maximum Beta Function	m	98.4
Minimum Beta Function	m	25.9
Maximum Dispersion	m	0.94
Minimum Dispersion	m	0.52



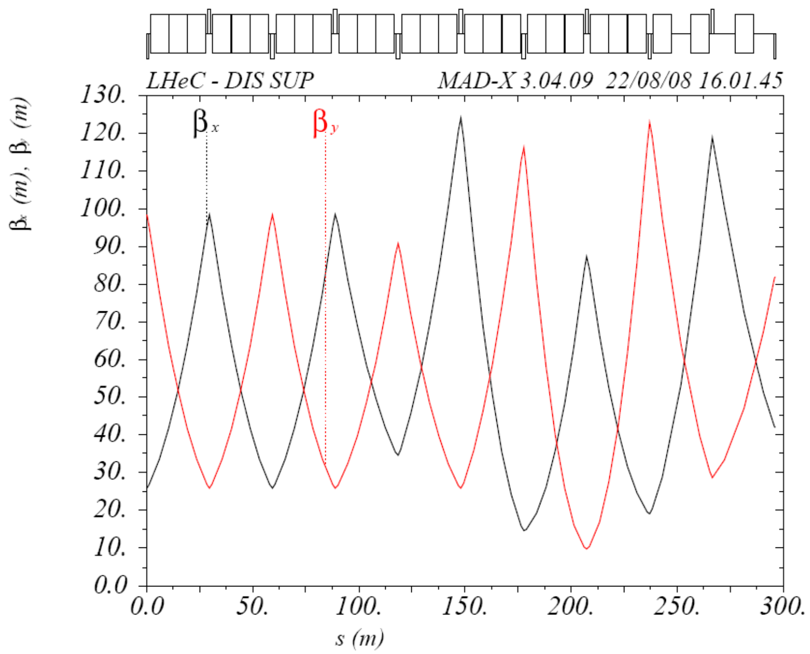


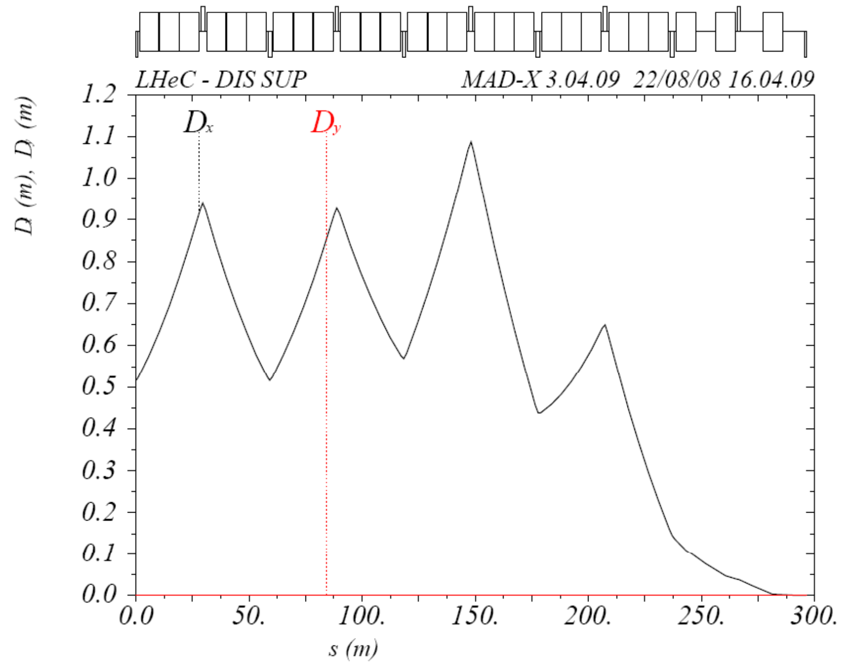
3.) DISPERSION SUPPRESSOR

Very preliminary design:

- ***Continue FODO structure from arc for 7 half cells. Length of dispersion suppressor:207.375 m***
- ***Use 8 individually powered quadrupoles.***
- ***Leaves two degrees of freedom to adjust hor./ver. phase advance over the dispersion suppressor.***
- ***Optical functions matched to reasonable values until input from straight section design is vailable.***

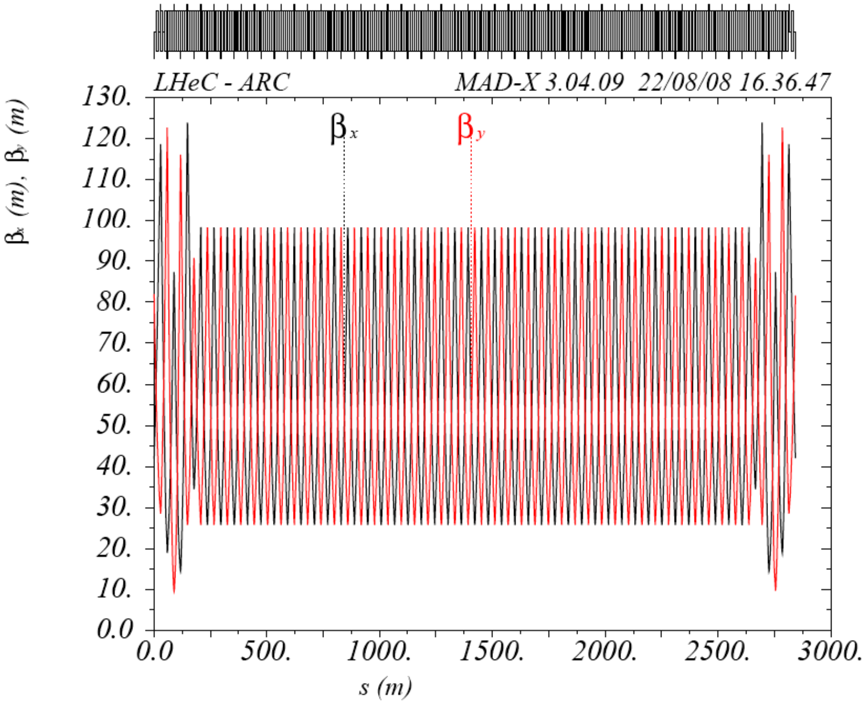
DISPERSION SUPPRESSOR - OPTICAL FUNCTIONS

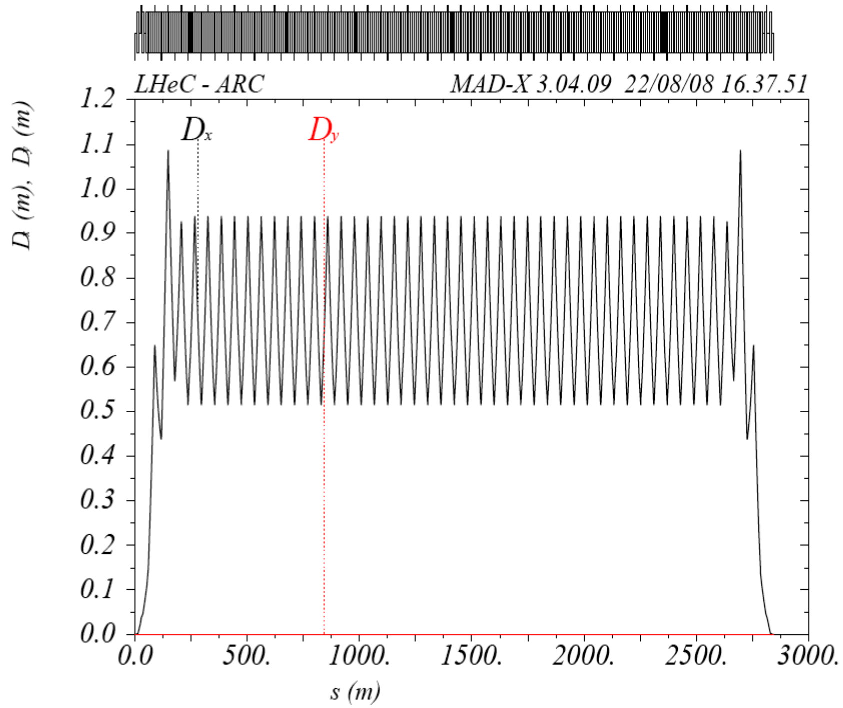




ARC PARAMETERS

Parameter	Unit	Value
Number of regular Cells		40
Length	m	2370 (as in LEP)
Length incl. Disp. Suppr.	m	2844
Bending Radius	m	3060.2
Total Phase Advance hor. / vert.	rad/2π	9.66 / 9.76
Chromaticity hor. / vert.		-11.43 / -11.67

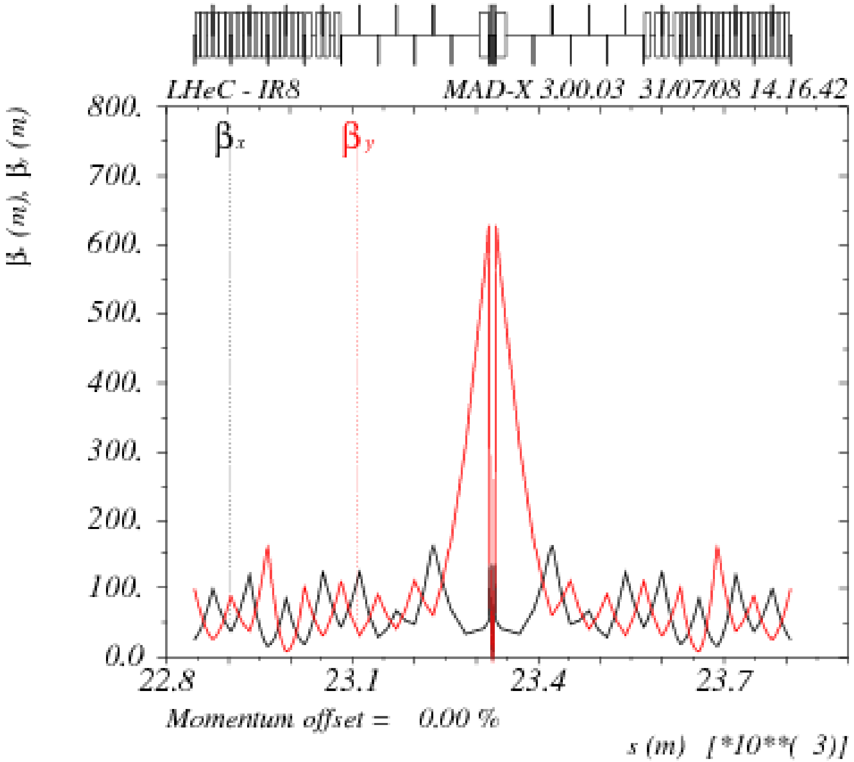


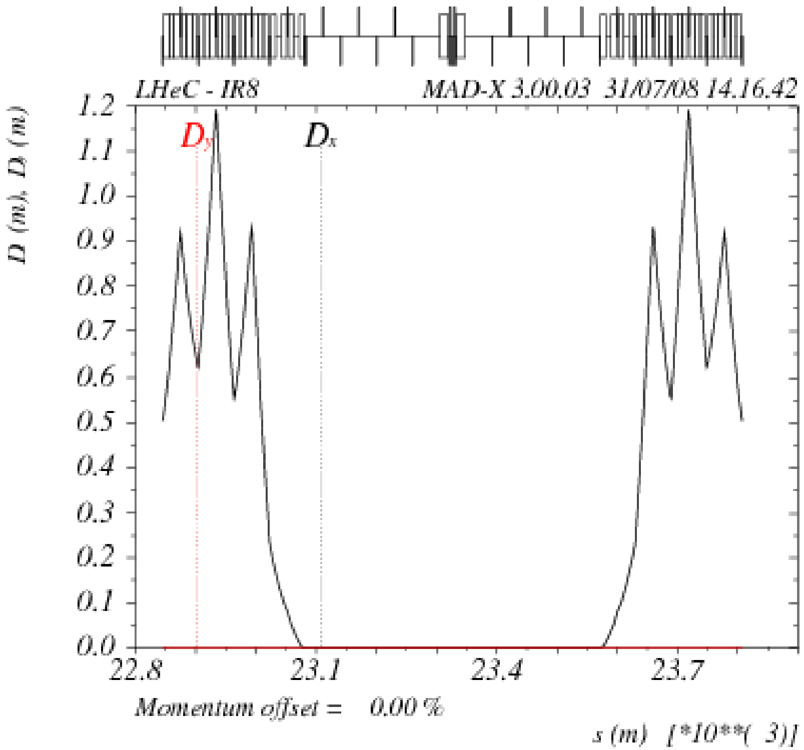


4.) LAYOUT IR8

- Use a triplet focusing (β_x = 7.1 cm, β_y =12.7cm)
- Triplet is displaced to allow for a quick beam separation
  --> additional dispersion created close to IP
- Beam separation facilitated by crossing angle (1.5 mrad).
  15 m long soft separation dipole completes the separation before the focusing elements of the proton beams.
- Interleaved magnet structure of the two rings: First matching quadrupole after the triplet: at 66.43 m to adjust optical functions --> try to avoid "large" β-functions
- Layout is asymmetric
  asymmetry compensated by asymmetrically powered dispersion suppressors.
- Optical functions matched to the values at the IP: x = 12.7cm,
  y = 7.07cm .

OPTICS FUNCTIONS: IR 8





5.) SUMMARY: Overview of Parameters

Lepton Ring Parameters		
Parameter	*Unit*	*Value*
Circumference	*m*	*26658.872*
Beam Energy E_e	*GeV*	*70*
Arc Focusing		*FODO*
Cell Length lcell	*m*	*59.25*
Bending Radius	*m*	*3060.213*
Hor. / Vert. Betatron Phase Advance per Cell	*degree*	*72 / 72*
Number of FODO Cells in the Arc Ncell		*384*
Arc Chromaticity (hor./ver.)		*-91.44/-93.36*
Momentum Compaction Factor c		*1.28 · 10−4*
Horizontal Beam Emittance x (no RF frequency shift)	*nm*	*22*
Particle Radiation Energy Loss per Turn eU0	*MeV/Turn*	*686*
Hor. / vert. Beta Function at IP	*m*	*12.7 cm / 7.1 cm*

SUMMARY: To Do List

- ***Design straight sections 1-7 :** replace dummy straight sections by bypass regions (Helmut).*
- ***Include Rf sections.***
- ***Include sextupoles for correction of chromatic lattice functions.***
- ***Include energy offset - change of damping partition numbers.***
- ***Optimise Phase Advance in the FoDo to reduce beam emittance .***
- ***Lepton emittance has to be reduced (goal = 7.6 nm !)***

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Proton Beam Optics and Separation Scheme

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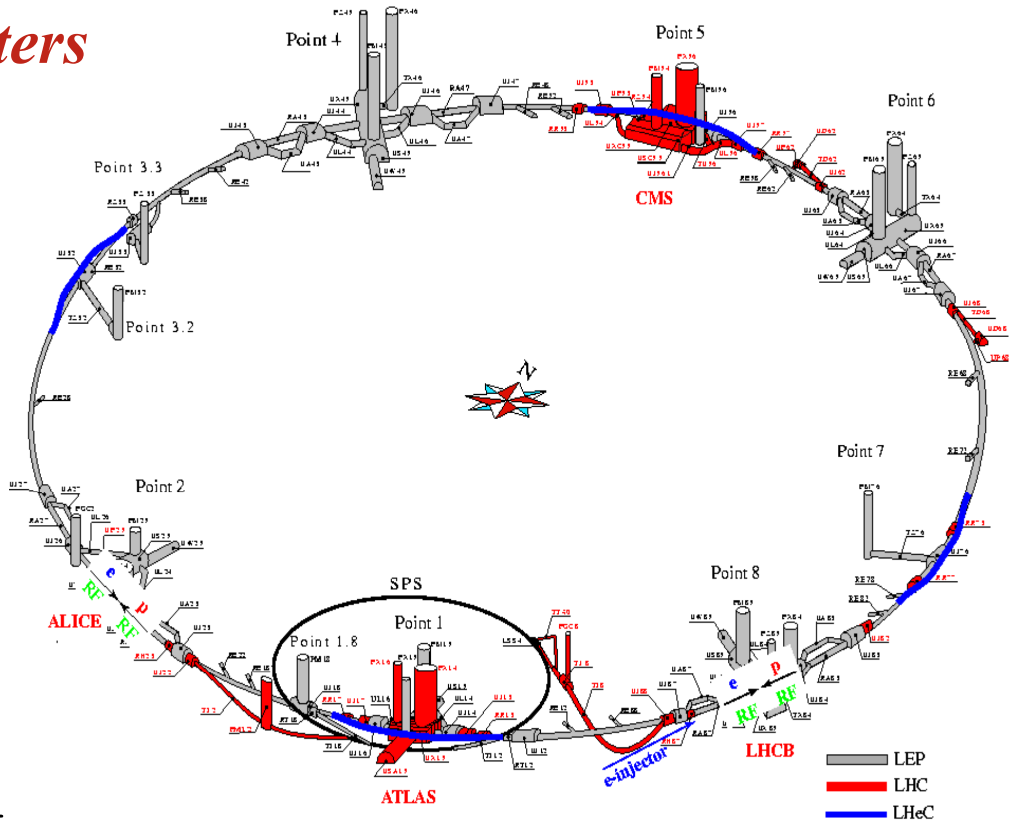
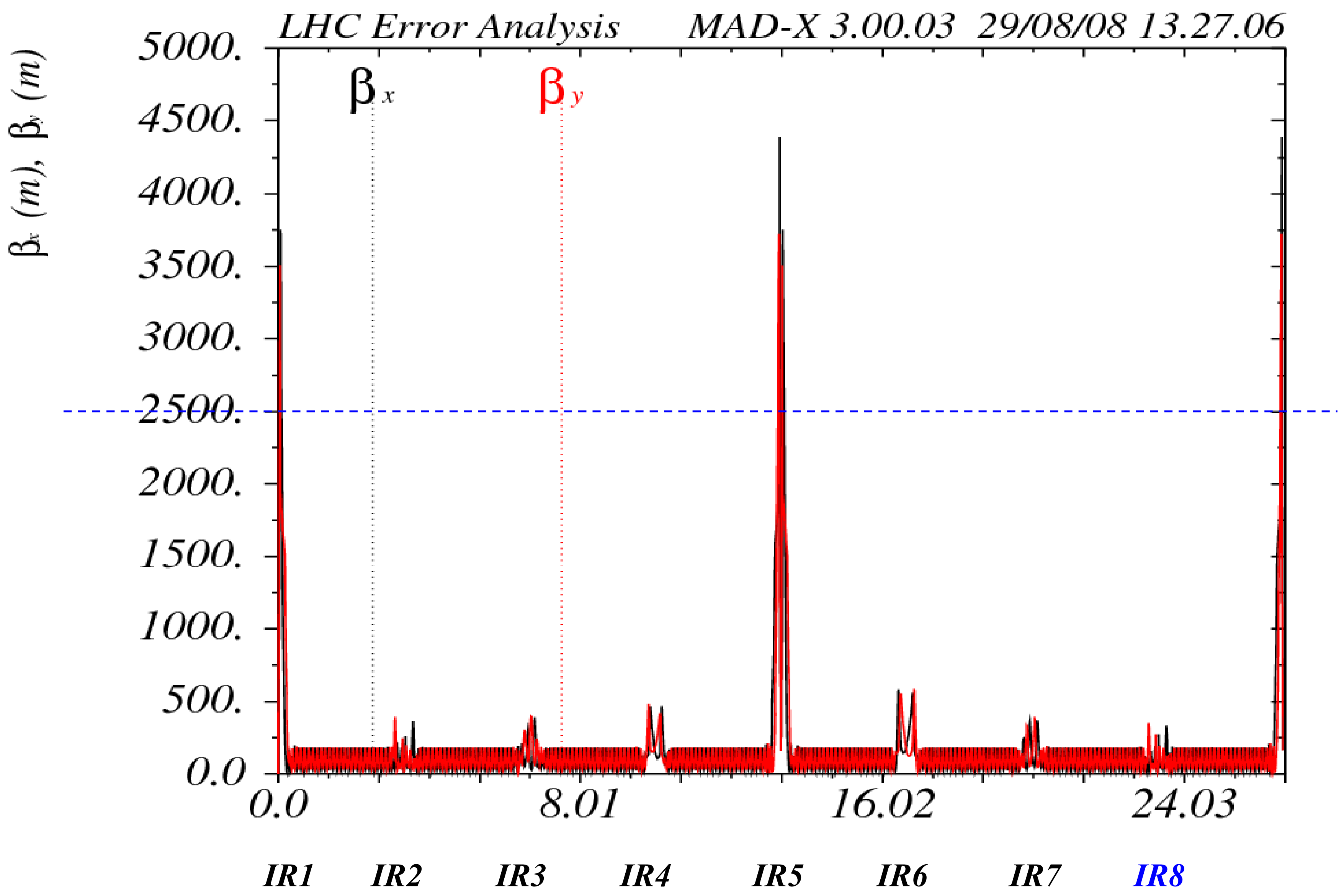


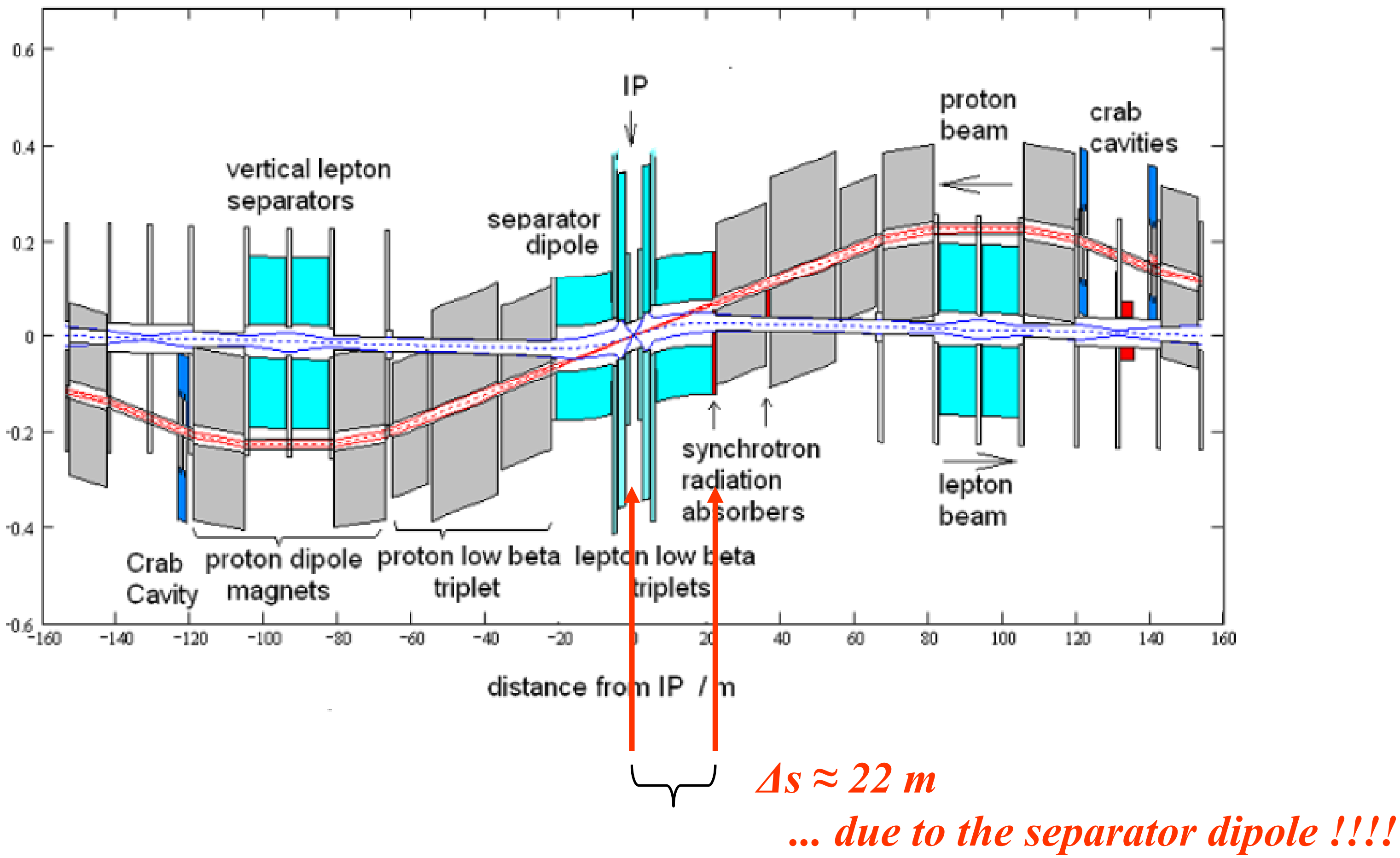
LHC Standard Luminosity Optics



Basic Layout ... and the Problem of the story

... it is forbidden to act with a 7 TeV field on 70 GeV electrons.

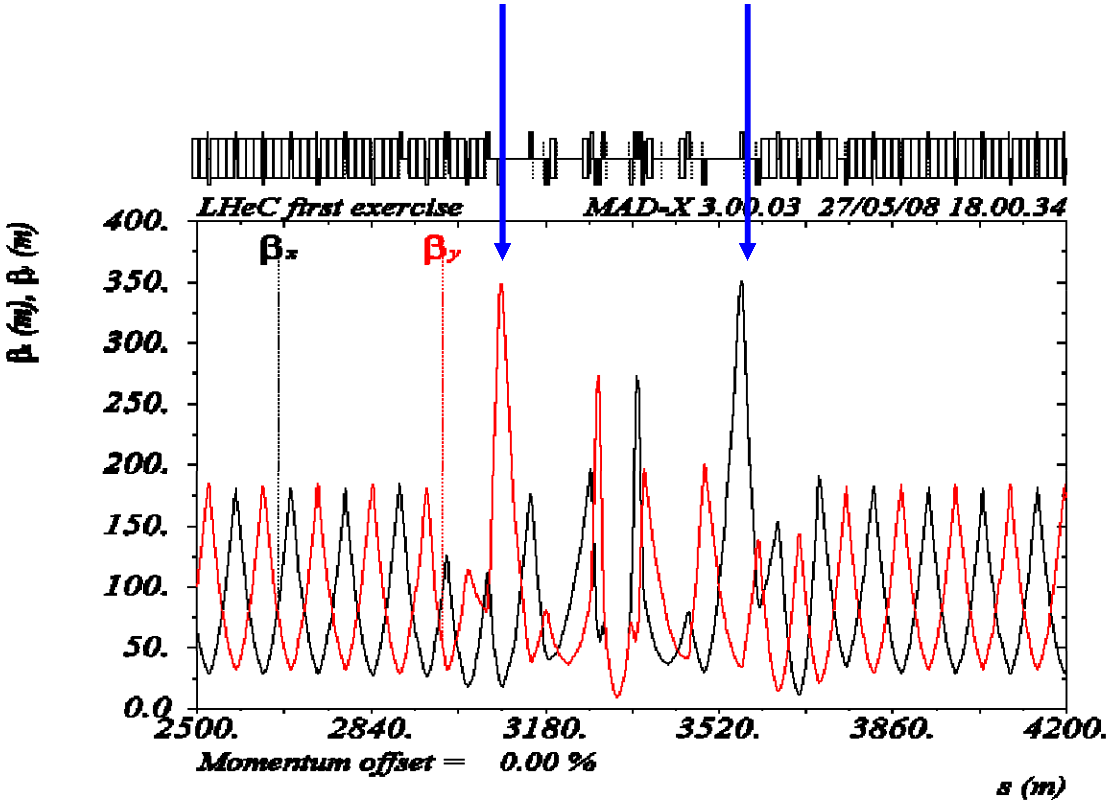
→ any IR layout is dominated by the separation scheme



Proton Optics: LHC Standard at IR 8

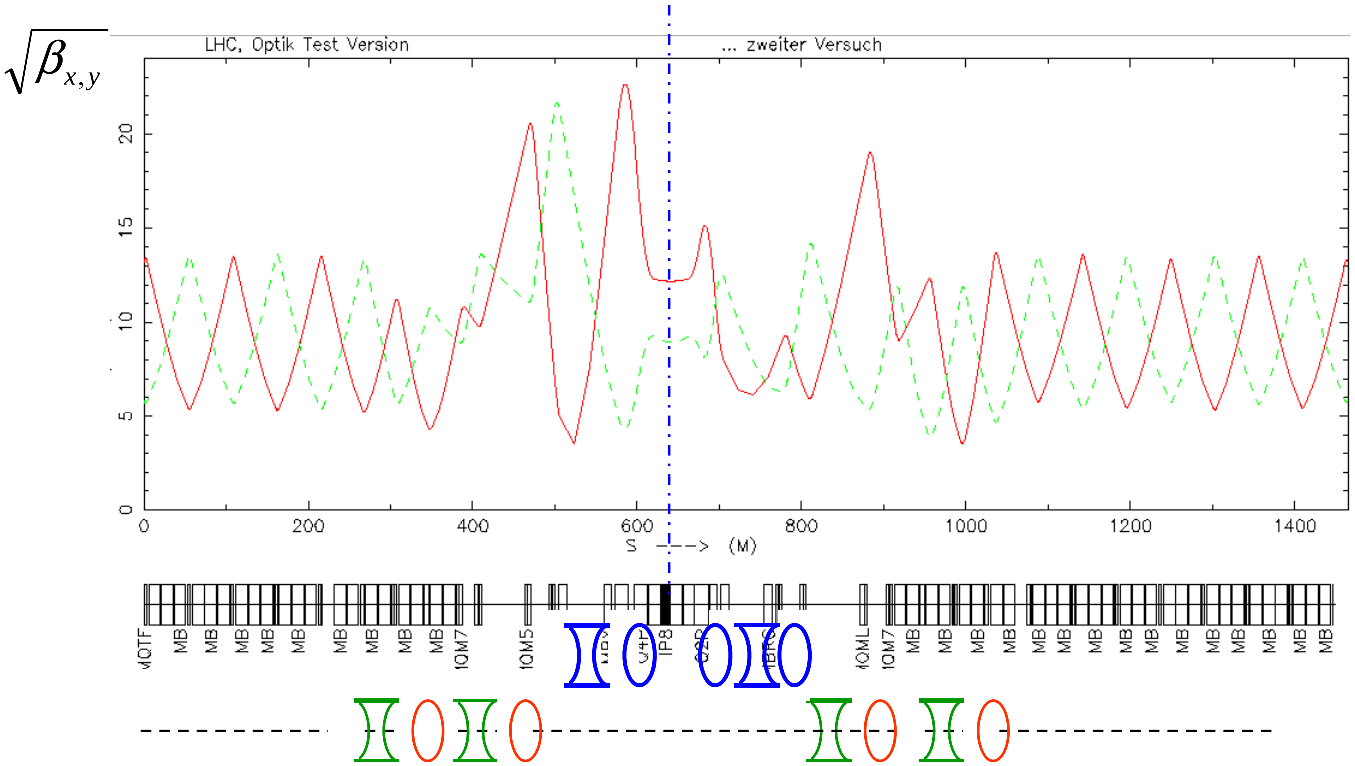
-- Basic Lattice Design: Antisymmetric Situation

requires: $\beta_x = \beta_y$ ***QF*** ***QD***



LHeC Proton Optics: "The natural choice"

lhs = doublet, rhs = triplet



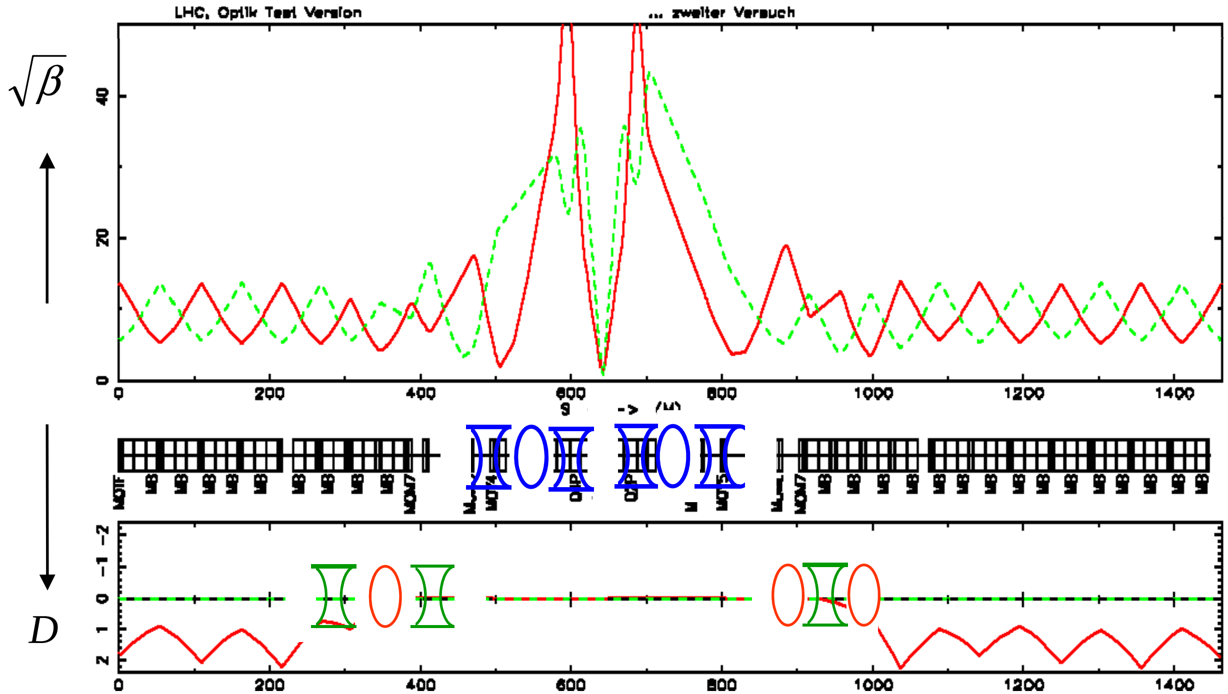
smooth behavior & match to the first arc quad

BUT only for moderate β^*

... work still in progress but not the preferred solution

LHeC Proton Optics: The most pretty one
-- again a triplet --

... but an asymmetric one



$\beta_x^* = 1.8m$

$\beta_y^* = 0.5m$

triplett magnets independently powered

!! optics scalable up to 7 TeV

!! room for optimisation $\leftrightarrow \quad \hat{\beta} \le 2500\ m$

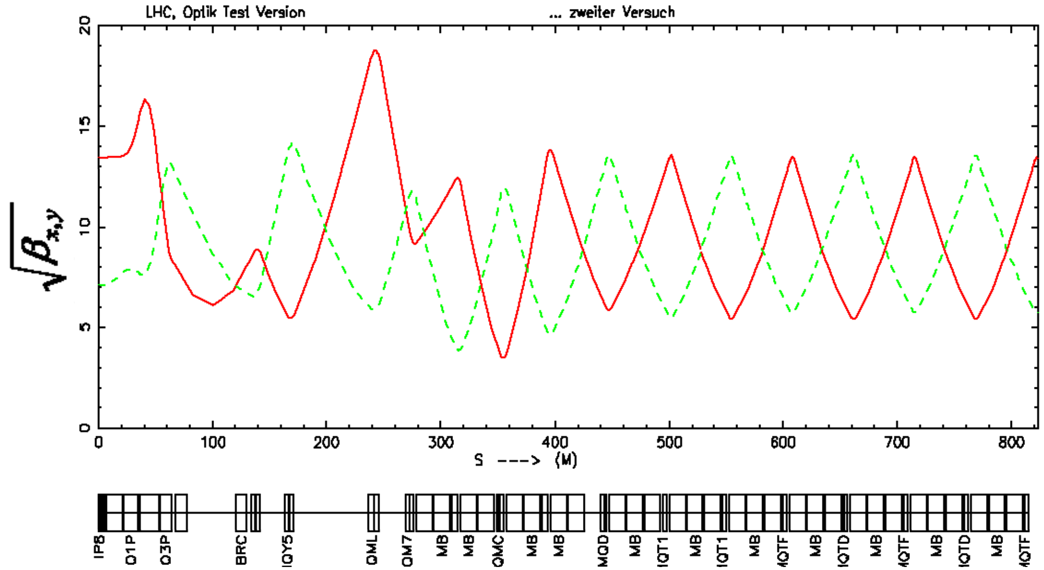
?? new quadrupole magnets ??

LHeC Proton Ring: *low energy optics*

** we have to inject the protons at a large emittance*
** we have to separate the protons during electron injection & ramp*

$$\varepsilon_{7TeV} \approx 5*10^{-10}\ m$$

$$\varepsilon_{450GeV} \approx 8*10^{-6}\ m$$



... work in progress: rhs optics scalable up to flat top.
$\beta \leq$ 400 m

The next steps to go:

* *include the electron optics & optimise*

* *proton luminosity optics: ... $\Delta\beta / \beta = 7\ \%$ local compensation trivial.*

* *e-optics during acceleration: optics & orbit affected*
  proton flat top optics required (aperture need)
  dynamic perturbation for the protons
  has to be compensated during electron ramp

  --> "null problemo ... ?" (HERA was more difficult)
  but extra corrector dipoles needed

* *optimise the separation --> !!!!!!*
  reduce the Bsep dipole length ??
  optimisation of the synchrotron light background
  reduce distance "s" of first proton quadrupole ??*

* *include the dispersive effects of the beam separation (& the half quad)*

* *... and what about the second proton beam ????*

* *Most critical: technical feasibility of Magnets, Crab Cavities etc*