Interaction Region Design of the LHeC Ring / Ring Version

Bernhard Holzer

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Deep Inelastic Electron-Nucleon Scattering at the LHC*

J. B. Dainton[1], M. Klein[2], P. Newman[3], E. Perez[4], F. Willeke[2]

[1] Cockcroft Institute of Accelerator Science and Technology, Daresbury International Science Park, UK
[2] DESY, Hamburg and Zeuthen, Germany
[3] School of Physics and Astronomy, University of Birmingham, UK
[4] CE Saclay, DSM/DAPNIA/Spp, Gif-sur-Yvette, France

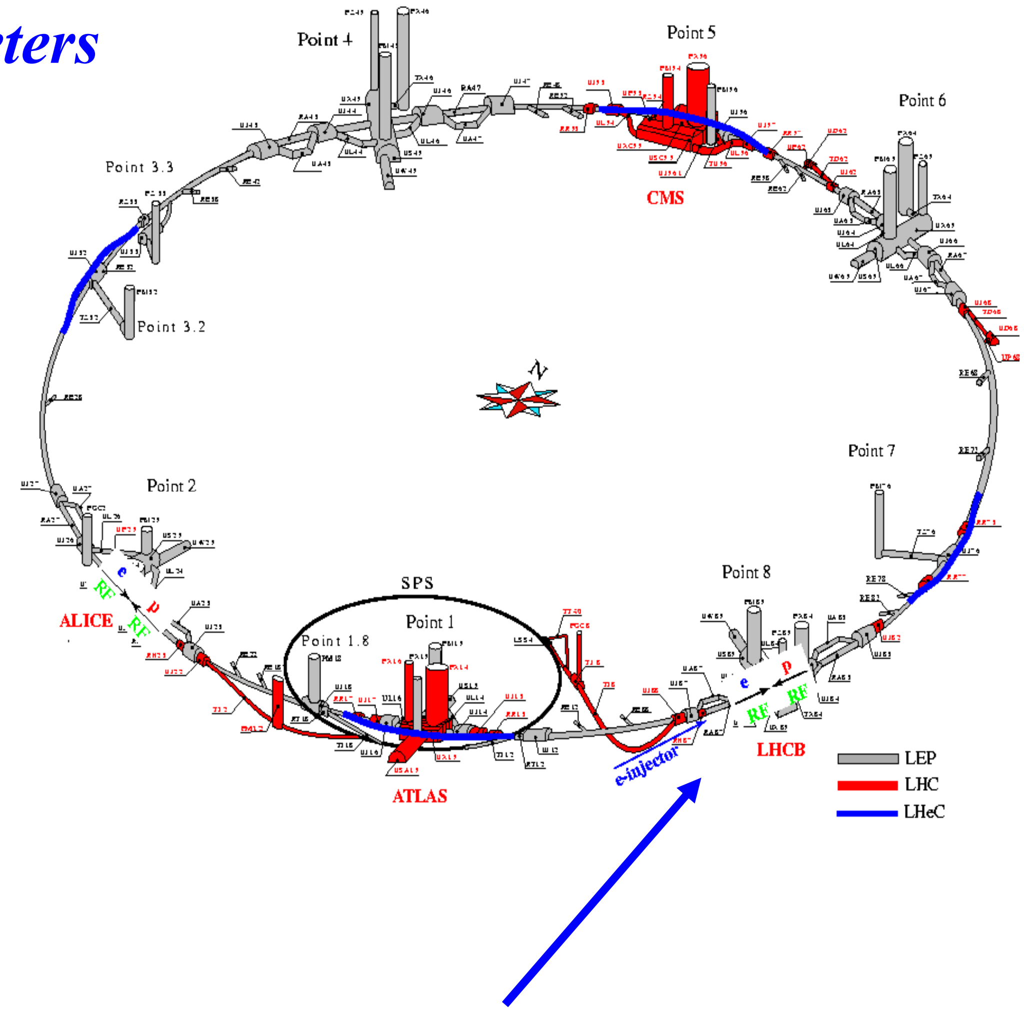
Abstract

The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 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 $10^6\,\mathrm{GeV}^2$ 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

bunch spacing	25 ns
Luminosity	10^{33} cm^{-2} s^{-1}



IR Design in Point 8

IR Design: Ingredients

1.) highly asymmetric Beam Energies

Electrons	Protons
70 GeV	7 TeV

--> separate storage rings,

--> focusing of proton beam only after complete beam separation
... but "ASAP" !!!
integrated quadrupole strength at first p-quad:

$$\int G dl = 127 \frac{T}{m} * 13.5\, m = 1715\, T$$

--> fast beam separation needed
early and compact focusing scheme required for electron beam

combine focusing of e-beam and e/p beam separation

--> and don't forget about the synchrotron radiation background

synchrotron radiation calculations
detector layout & absorber design
focusing of both beams
separation scheme

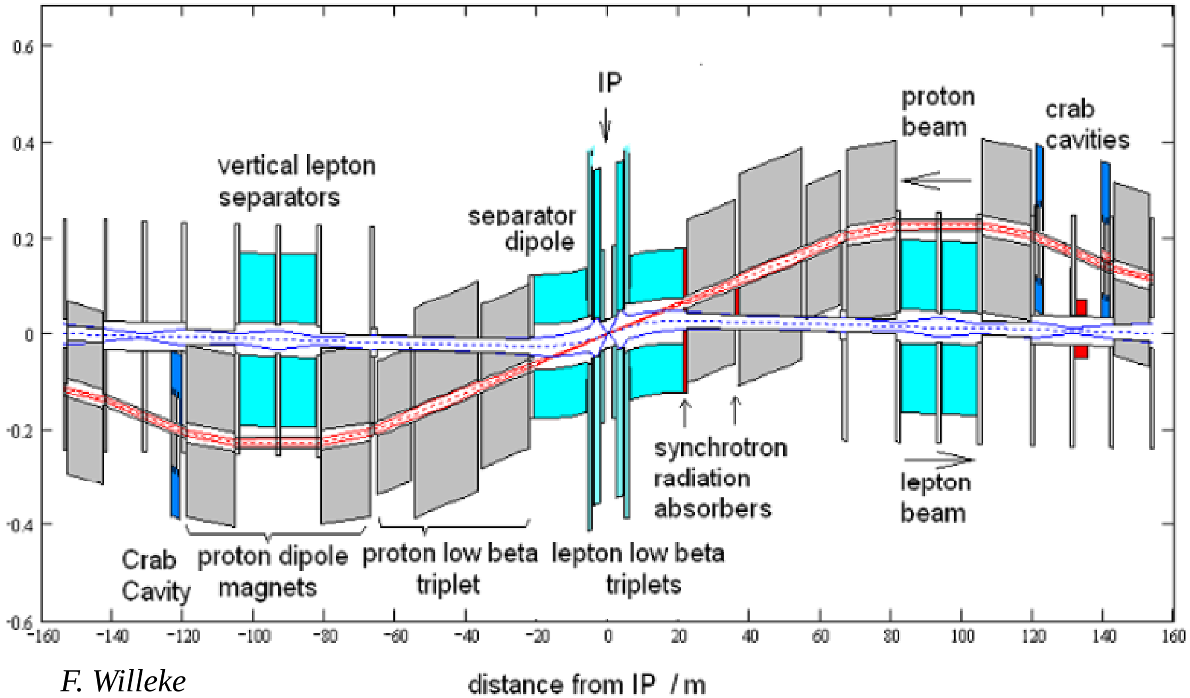
} have to be treated in an coordinated way.

IR Design: Ingredients

2.) IR layout is dominated by the separation scheme

well known ... HERA- I & II, KEK & SLAC B-factories

spectrometer effect: use dipole fields to separate the beams according to their momentum.
... don't loose too much space: → shift the quadrupole triplett in horizontal plane



F. Willeke

Implications on the e-optics:
quadrupole offsets depend on the gradient
optics & orbit are not independent.

IR Design: Beam Separation Scheme

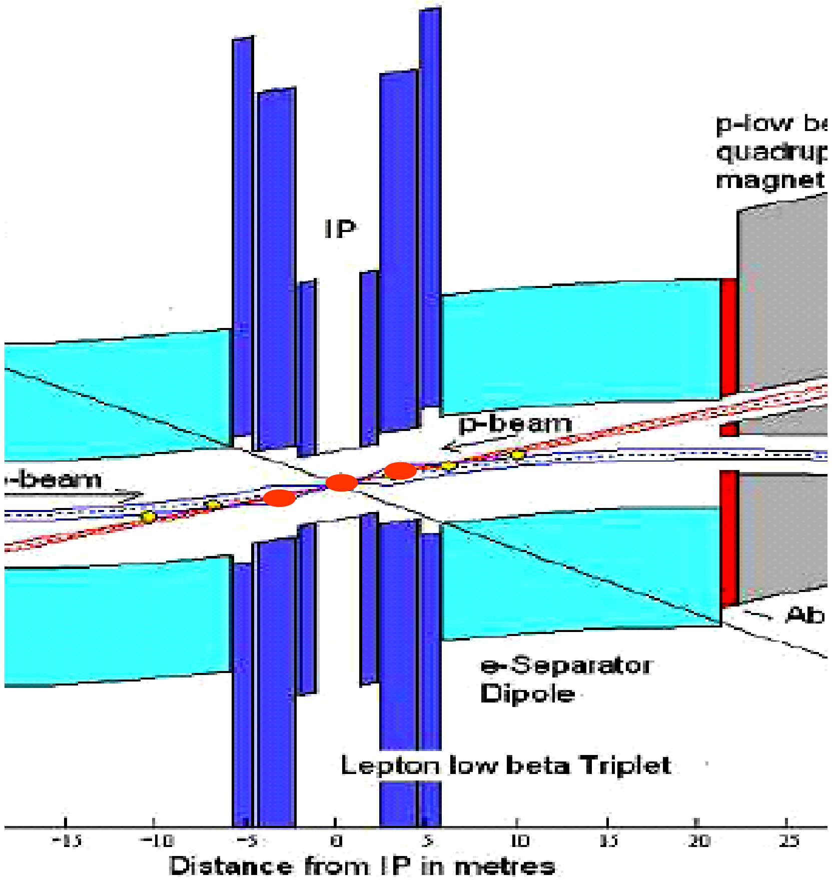
fast beam separation needed
crossing angle to support early separation

LHC bunch distance: 25 ns = 7.5 m
1st parasitic crossing: 3.75m

first e-quad: positioned at s = 1.2m
... too late for sufficient beam separation

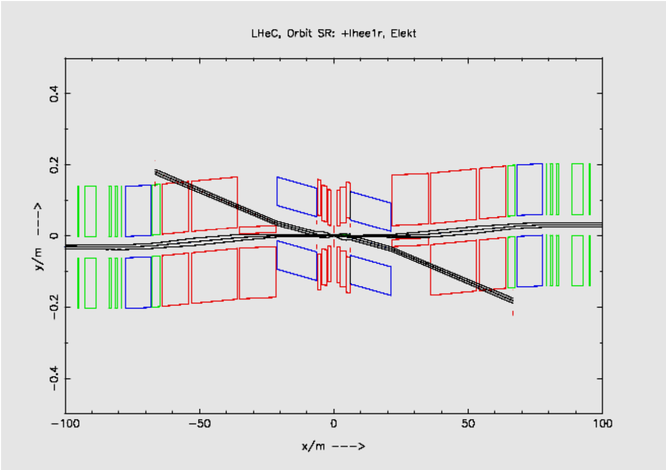
separation has "to start at the IP"

--> support the off-centre-quadrupole separation scheme
by crossing angle at the IP.



IR Design: Beam Separation Scheme

crossing angle & quadrupole separation



program to calculate the beam optics (10 σ),

calculate the electron orbit,

align the e-quads to the e-beam (min. synchrotron rad.)

track the p-beam through the e-quads

optimise the beam separation according to crossing angle and separation fields

s	ε_x / ε_y	β_x	β_y	σ_x	σ_x	
3.75m	$5*10^{-10}$ rad m	10m	24m	0.07mm	0.11mm	p
	7.6 nm / 3.8 nm	135m	98m	1.01mm	0.61mm	e

separation requirement: dominated by e-beam dimensions

$$10\sigma + 10\sigma = 0.7mm + 10.1mm \approx 11mm$$
$$\rightarrow X - angle = 2.9mrad$$

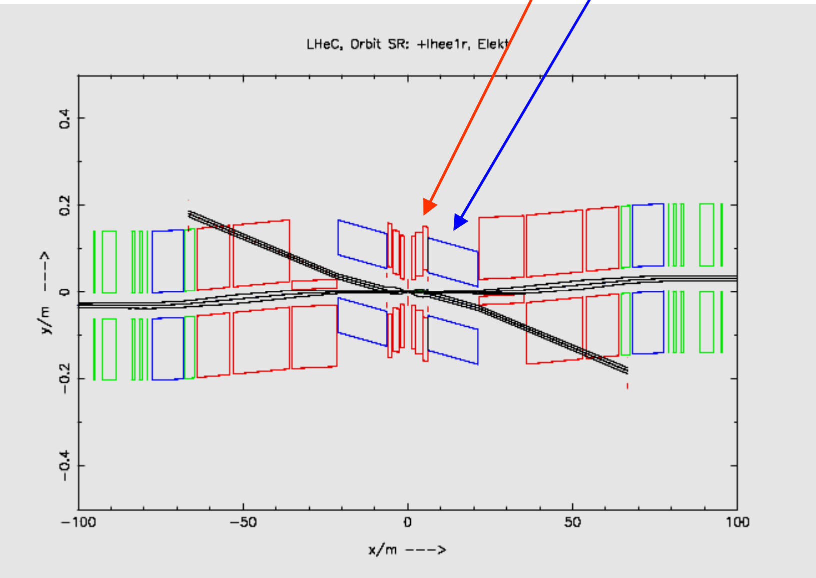
$$5\sigma + 5\sigma = 0.35\ mm + 5\ mm \approx 5.5\ mm$$
$$\rightarrow X - angle = 1.5\ mrad$$

IR Design: Beam Separation Scheme

prefered separation scheme: crossing angle = 1.5 mrad

quadrupole triplett off axis
separation dipole

const. bending radius:
ρ= 26315 m



further optimiation possible: large contribution to synchrotron radiation from focusing fields

... nota bene: ρ (arc dipoles) = 3060 m

* *separation at first proton magnet (half quadrupole) 37mm*
* *synchrotron light calculations done for x-angle of 0.5mrad and 1.5 mrad keeping the overall separation constant.*
* *crab cavities needed*

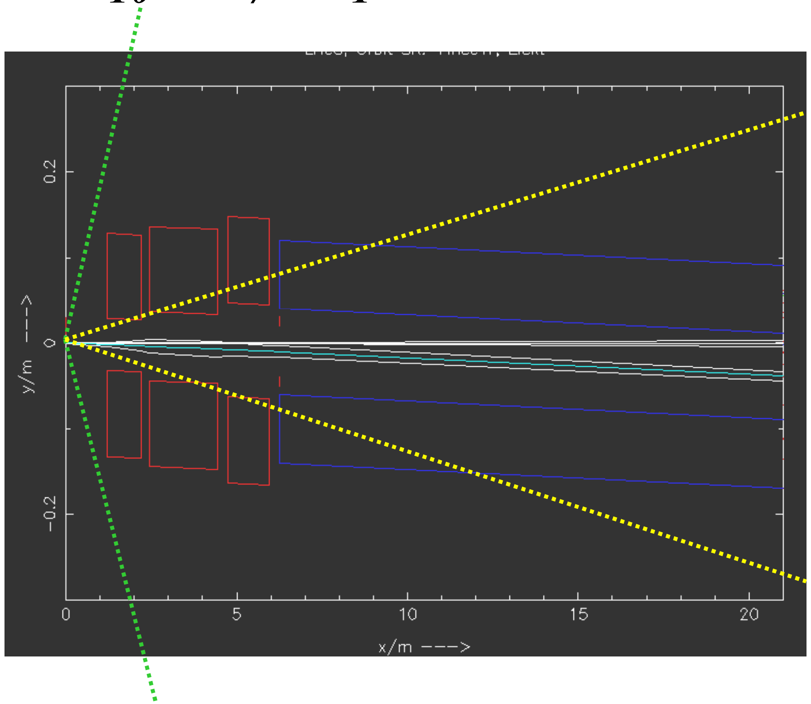
IR Design: Ingredients

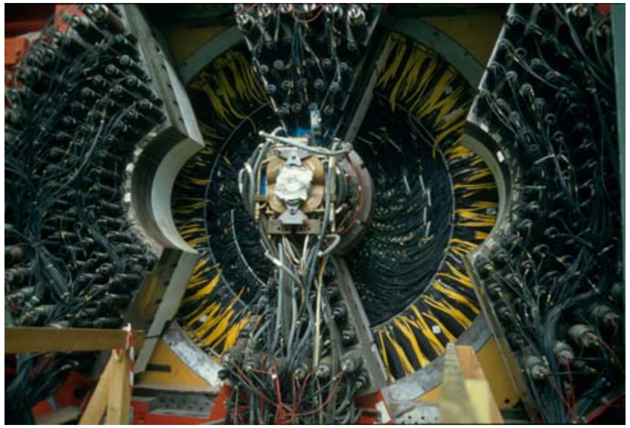
3.) Detector Acceptance: the opening angle

... an old story

two options discussed at the moment:

10°   /   1°





1985 ARGUS Detector
with low beta quadrupole

Example:
compact magnet design at HERA II

compact magnet design required:

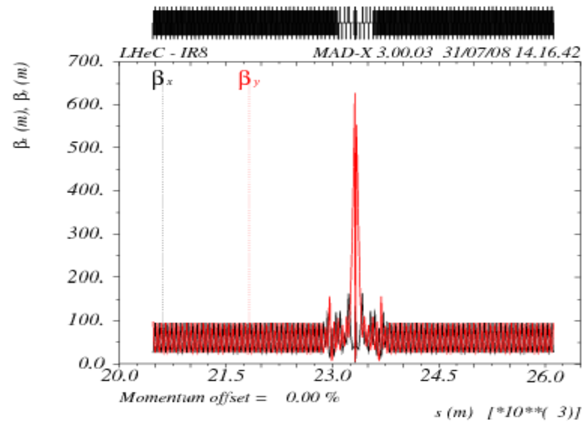
10° = 21 cm outer radius of Q1E quadrupole

1° = requires an alternative lattice , optics and luminosity

IR Design: Ingredients

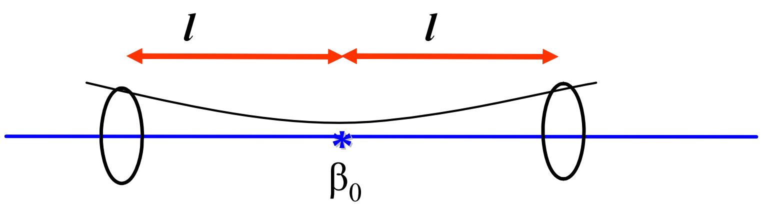
4.) Beam Optics ... & ... Detector Acceptance:

proton lattice: ***embedded into LHC luminosity optics***



electron optics: ***arc based on LEP-2 like structure***
IR_8: low beta insertion using triplett focusing

special effects: ***flat electron beam*** $\varepsilon_x >> \varepsilon_y$ ***has to match***
round proton beam $\varepsilon_x \approx \varepsilon_y$
beam separation ↔ early focusing
detector angle



$$L = \frac{1}{2\pi e^2 f_0 n_b} * \frac{I_1 * I_2}{\sqrt{(\sigma_{xp}^2 + \sigma_{xe}^2)(\sigma_{yp}^2 + \sigma_{ye}^2)}}$$

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

... keep distance "l" as small as possible

IR Design: Ingredients

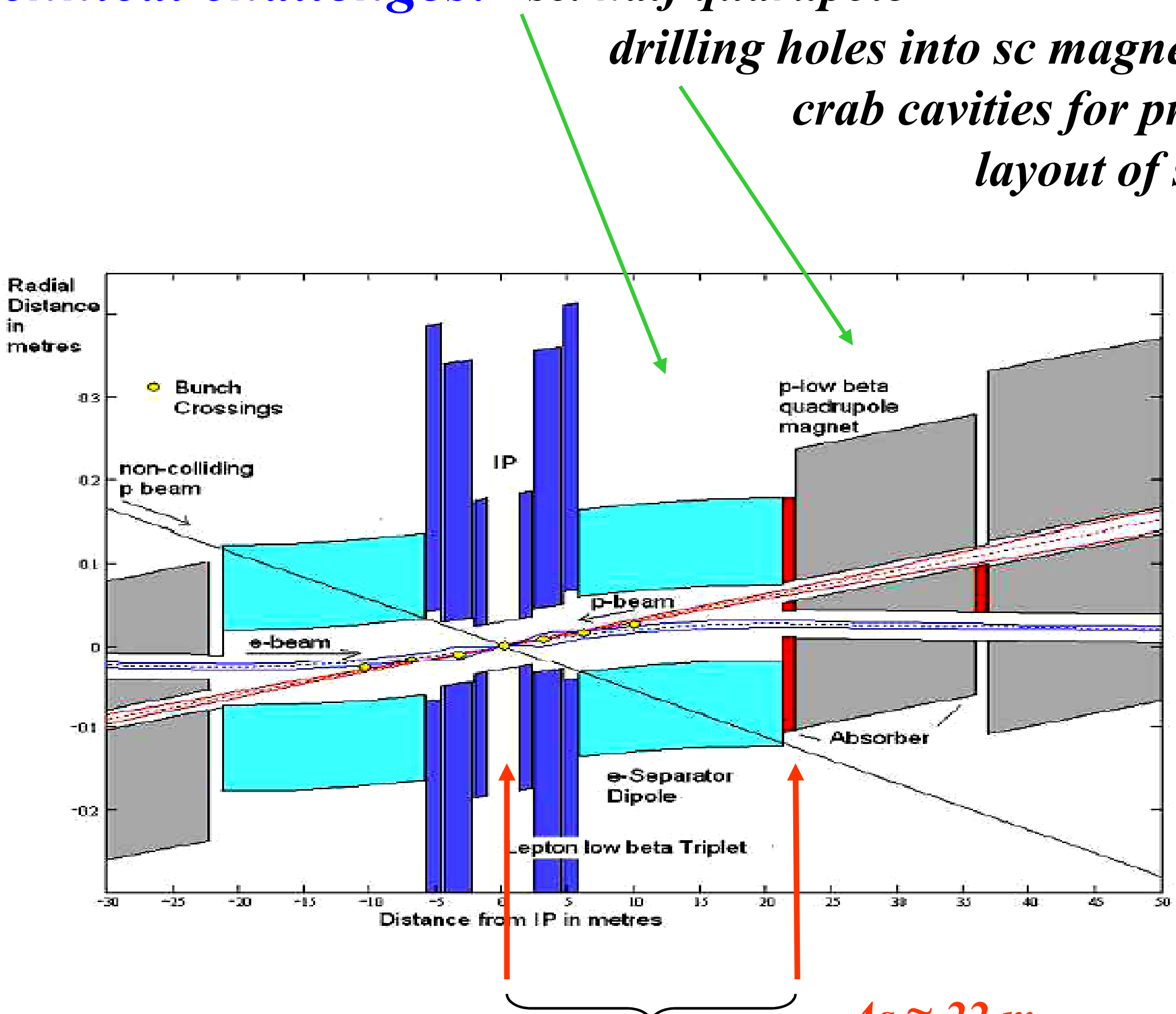
5.) technical challenges:

sc. half quarupole

drilling holes into sc magnets

crab cavities for proton beam

layout of syrad collimators

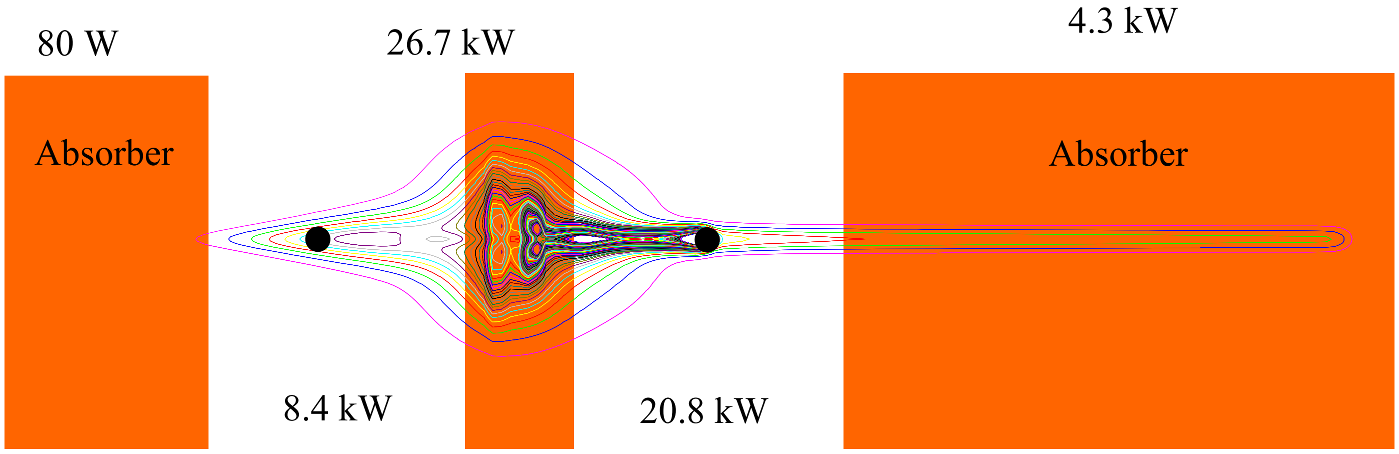


Δs ≈ 22 m

... due to the separator dipole !!!!

IR Design: Ingredients

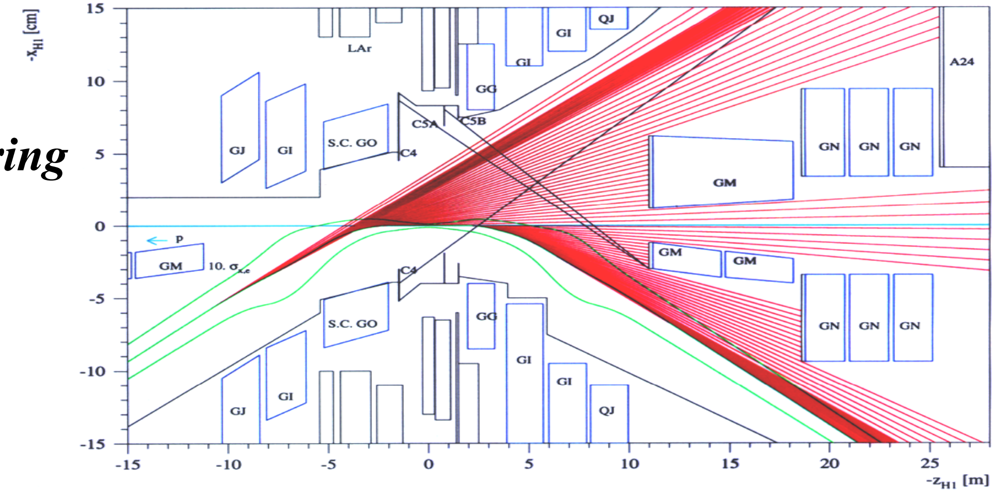
6.) Synchrotron Radiation



(Boris Nagorny)

Example: HERA:

Synchrotron Radiation produced during beam separation $P_{ges.} = 30\ kW$



Interaction Region Design:

detailed presentations about ...

* *e-optics:* ***design of a low beta insertion, embedded into a LEP-2 like arc structure*** *(Alexander Kling, B.H.)*

* *e-geometry:* ***bypass regions,*** *(Helmut Burkhardt)*

* *p-optics:* ***low beta insertion combined with the LHC luminosity lattice*** *(B.H.)*

* *sc. IR magnets*: ***first*** *exotic (?)* ***ideas about*** *(Stephan Russenschuck)*

* *sc. double magnet design, active magnets* *(Eugenio Paolomi, Simona Bettoni,Tim Greenshaw,)*

* *synchrotron radiation:* ***and beam separation*** *(Boris Nagorny)*

* *rf cavities* ***& power consumption*** *(John Jowett, Trevor Linnecar)*