

Interaction Region Design of the LHeC Ring / Ring Version

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Deep Inelastic Electron-Nucleon Scattering at the LHC*

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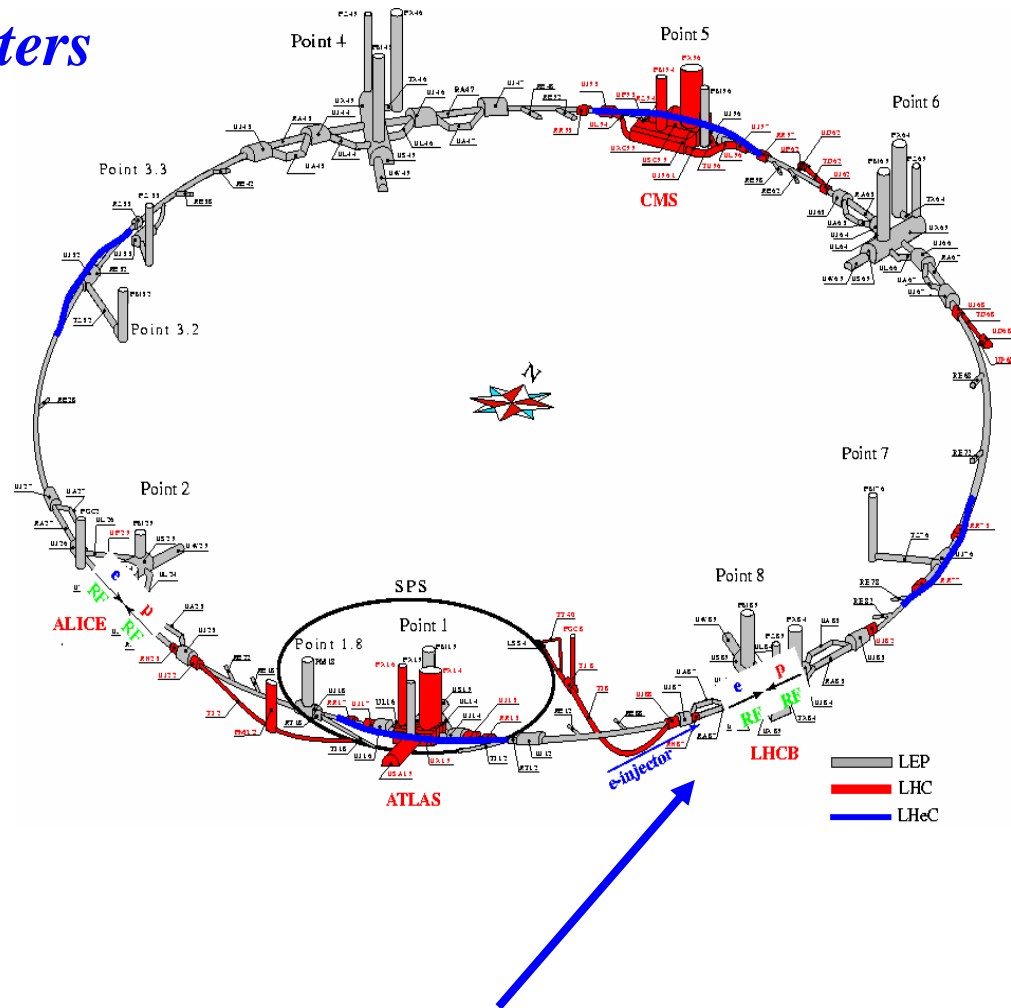
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Abstract

The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, $10^{33}\text{cm}^{-2}\text{s}^{-1}$, and high energy $\sqrt{s} = 1.4\text{TeV}$, 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 10^6GeV^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

	<i>Electrons</i>	<i>Protons</i>
<i>Beam Energy</i>	70 GeV	7 TeV
<i>total current</i>	74 mA	544 mA
<i>part. / bunch</i>	$1.4 \cdot 10^{10}$	$1.7 \cdot 10^{11}$
<i>hor. emittance</i>	7.6 nm	0.5 nm
<i>vert. emittance</i>	3.8 nm	0.5 nm
β^* hor	12.7 cm	180 cm
β^* vert	7.1 cm	50 cm
<i>bunch spacing</i>	25 ns	
<i>Luminosity</i>	$10^{33} \text{ cm}^{-2} \text{ s}^{-1}$	



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:

$$\int Gdl = 127 \frac{T}{m} * 13.5 m = \underline{1715 T}$$

--> *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.

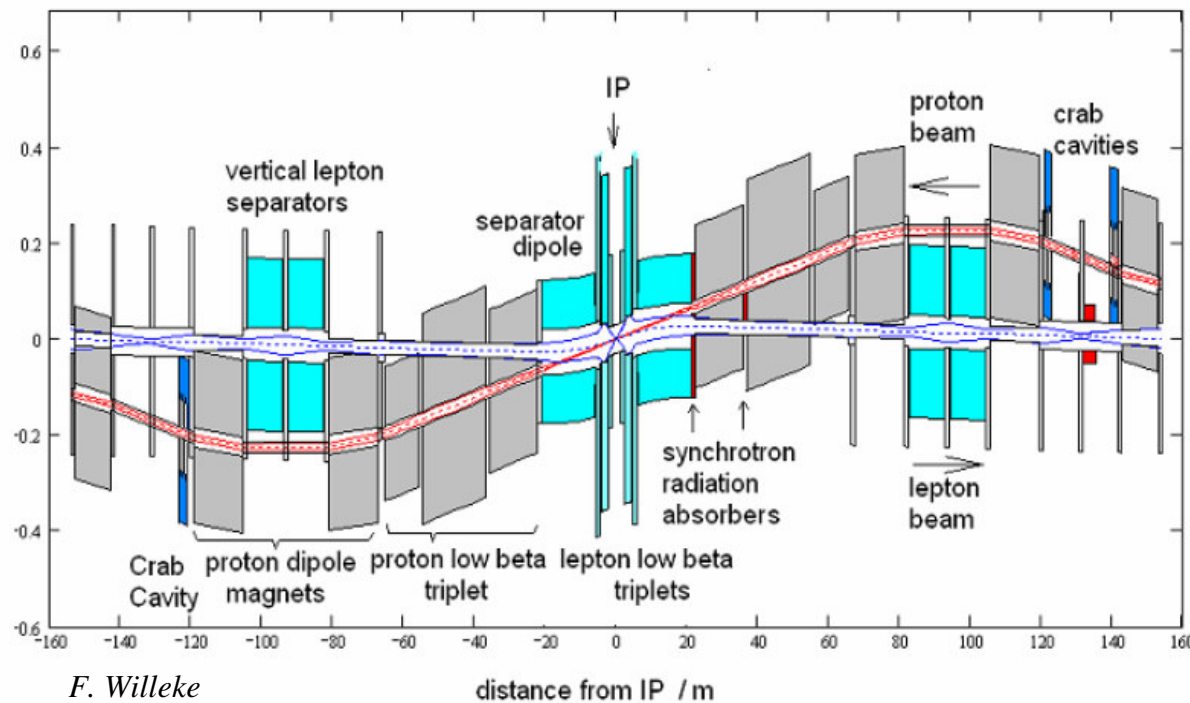
IR Design: Ingredients

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 lose too much space: → **shift the quadrupole triplett** in horizontal plane*



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

IR Design: Beam Separation Scheme

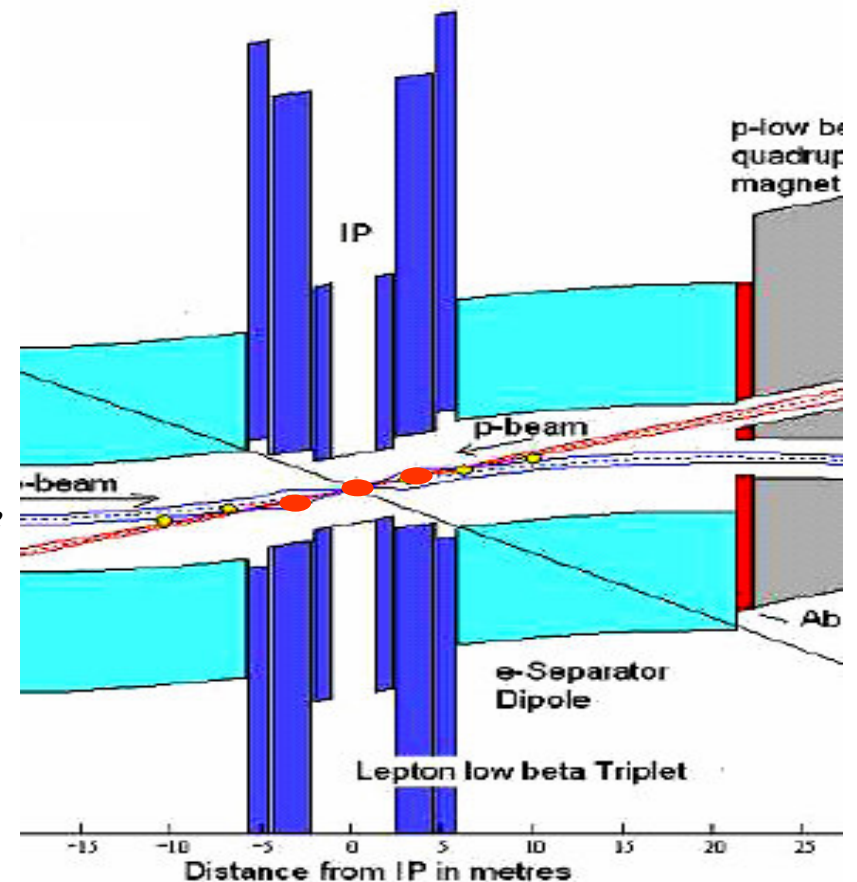
fast beam separation needed
crossing angle to support early separation

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

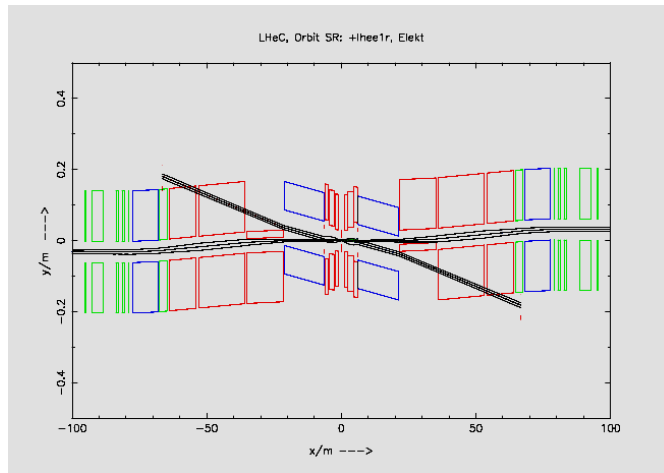
separation has "to start at the IP"

--> 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 (10σ),

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_y	
3.75m	$5 \cdot 10^{-10}$ 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

$$10\sigma + 10\sigma = 0.7\text{mm} + 10.1\text{mm} \approx 11\text{mm}$$

$$\rightarrow X - \text{angle} = 2.9\text{mrad}$$

$$5\sigma + 5\sigma = 0.35\text{mm} + 5\text{mm} \approx 5.5\text{mm}$$

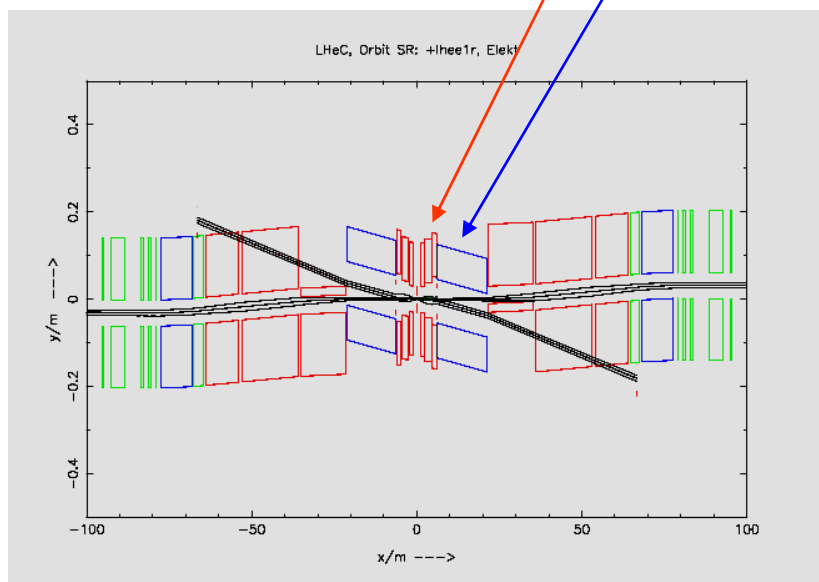
$$\rightarrow X - \text{angle} = 1.5\text{mrad}$$

IR Design: Beam Separation Scheme

preferred separation scheme: crossing angle = 1.5 mrad

*quadrupole triplett off axis
separation dipole*

*const. bending radius:
 $\rho = 26315 \text{ m}$*



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

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

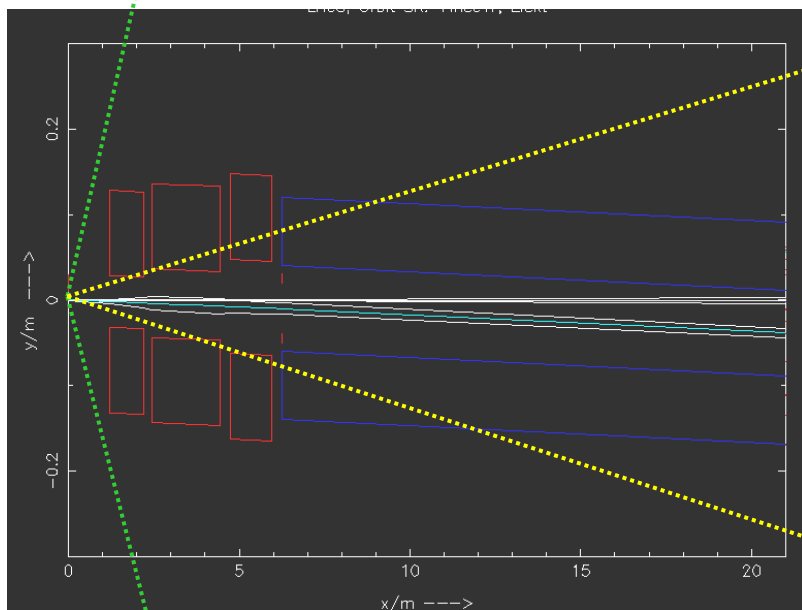
- * separation at first proton magnet (half quadrupole) 37mm*
- * synchrotron light calculations done for x-angle of 0.5mrad and 1.5 mrad keeping the overall separation constant.*
- * crab cavities needed*

IR Design: Ingredients

3.) Detector Acceptance: the opening angle ... an old story

two options discussed at the moment:

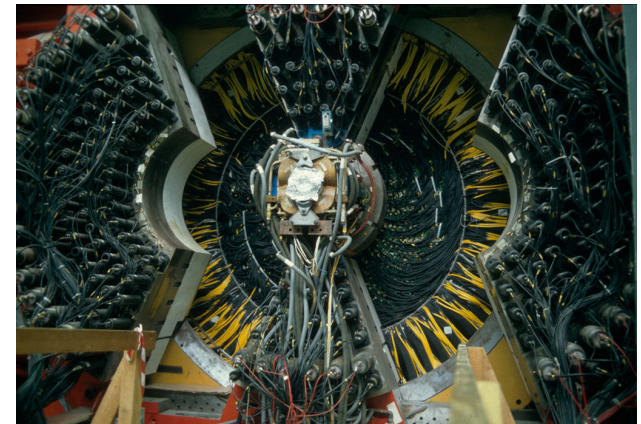
10° / 1°



compact magnet design required:

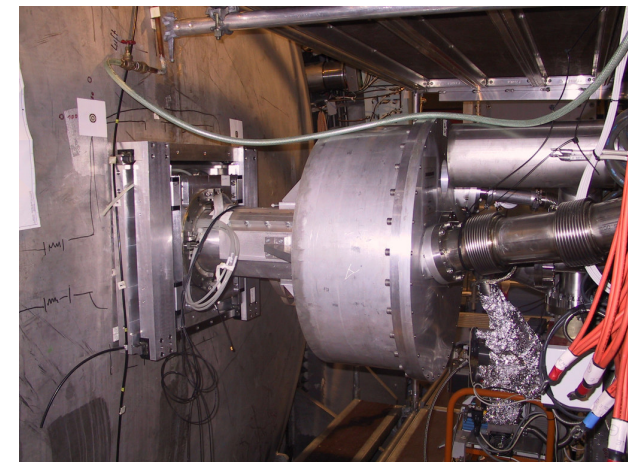
$10^\circ = 21$ cm outer radius of QIE quadrupole

$1^\circ =$ requires an alternative lattice, optics and luminosity



1985 ARGUS Detector
with low beta quadrupole

Example:
compact magnet design at HERA II



IR Design: Ingredients

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

proton lattice: embedded into LHC luminosity optics

electron optics: arc based on LEP-2 like structure

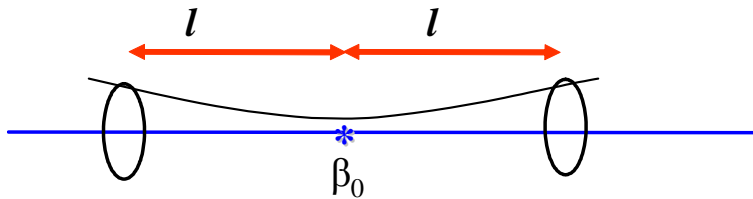
IR_8: low beta insertion using triplett focusing

special effects: flat electron beam $\epsilon_x \gg \epsilon_y$ has to match

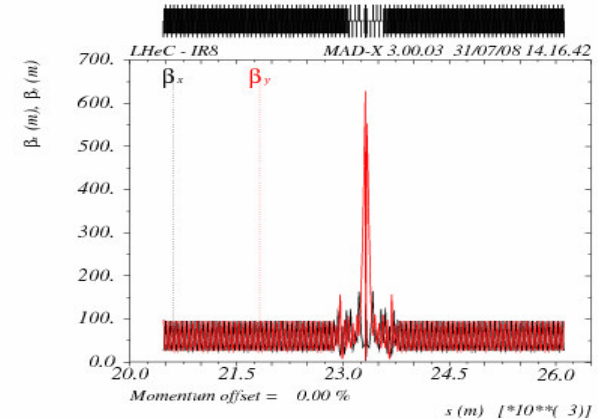
round proton beam $\epsilon_x \approx \epsilon_y$

beam separation \leftrightarrow early focusing

detector angle



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

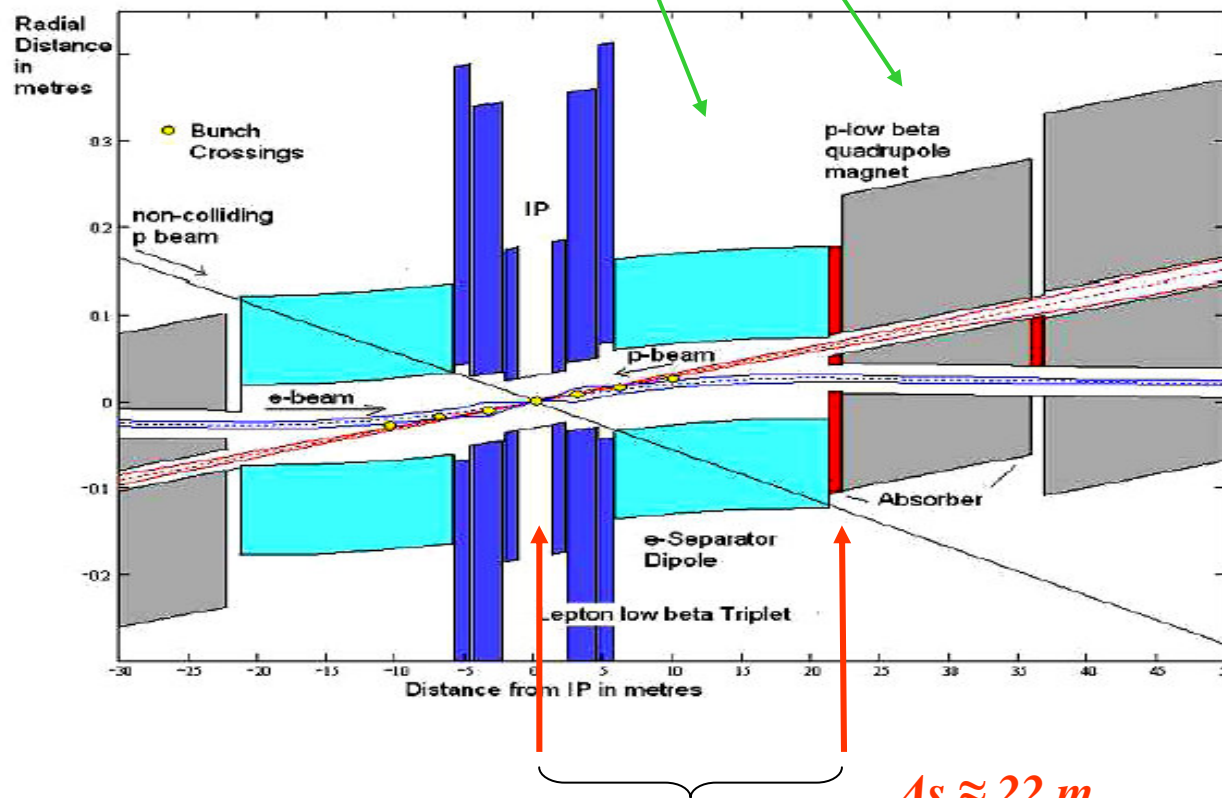


$$L = \frac{1}{2\pi e^2 f_0 n_b} * \frac{I_1 * I_2}{\sqrt{(\sigma_{xp}^2 + \sigma_{xe}^2)(\sigma_{yp}^2 + \sigma_{ye}^2)}}$$

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

IR Design: Ingredients

- 5.) technical challenges: *sc. half quadrupole*
- drilling holes into sc magnets*
- crab cavities for proton beam*
- layout of synrad collimators*

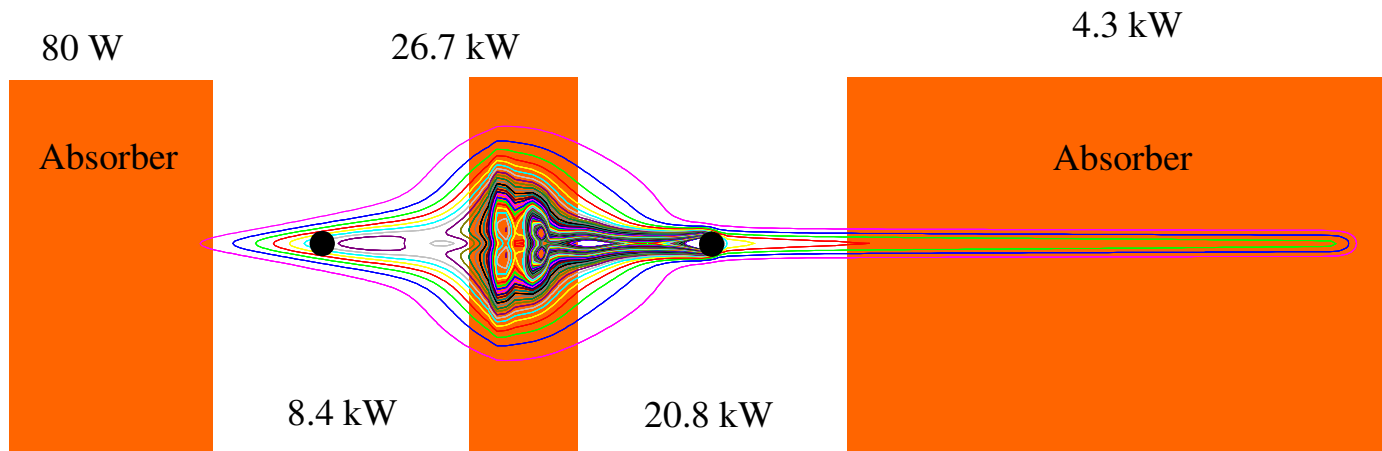


$\Delta s \approx 22 \text{ m}$

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

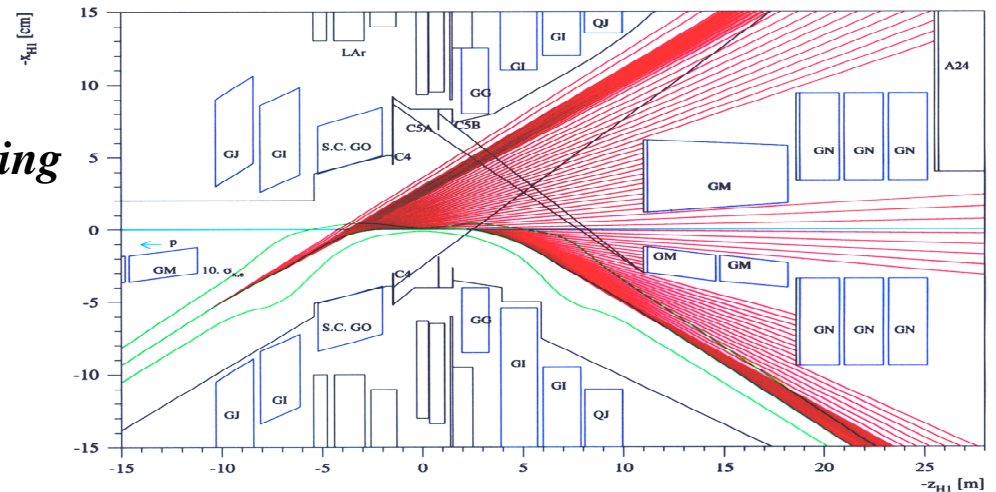
IR Design: Ingredients

6.) Synchrotron Radiation



(Boris Nagorny)

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



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)

