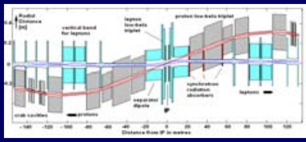

LHeC: A LEPTON-PROTON COLLIDER WITH THE LHC

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Abstract

The luminosity and collision energy of lepton proton collisions using the LHC and a LEP-size storage ring is explored assuming proton-proton collisions in parallel. A model accelerator layout demonstrates that luminosities in the order of $L=10^{33}cm^{-2}sec^{-1}$ should be possible.

PHYSICS

- new lepton-quark physics @ TeV scale
  - precision resonance spectroscopy
  - precision anomalous dynamics
- low-*x* physics
  - dense chromodynamics: *ep* and *eA*
- precision nucleon & nuclear structure
  - parton densities for LHC @ LHC
  - proton+heavy ion "structure" @ low *x*
  - precision chromodynamics
  - strong coupling constant
- precision photon structure
- heavy flavour in nucleons, nuclei,photon
- lepton structure
- quark structure
- discovery>2007: LHeC LHC LC
  ep eA *pp pA AA* e^+e^-

REQUIREMENTS

- E_{cm}=1.4TeV ➔ E_e=70GeV
- *L* =$10^{33}cm^{-2}s^{-1}$
- Use of the experience at HERA
- lepton ring, to be installed above LHC
- one interaction point.
- proton-proton collisions take place simultaneously,
- proton beam parameters for LHeC are determined by the existing LHC parameters.

Proton Beam Energy	TeV	7
Circumference	m	26658.883
Number of Protons per bunch	10^{11}	1.67
Normalized transverse emittance	μm	3.75
Bunch length	cm	7.55
Bunch spacing	ns	25

PARAMETERS

$$L=\frac{N_p\cdot N_e\cdot f_{rev}\cdot n_b}{2\cdot\pi\cdot\sqrt{\varepsilon_{xp}\beta_{xp}+\varepsilon_{xe}\beta_{xe}}\cdot\sqrt{\varepsilon_{yp}\beta_{yp}+\varepsilon_{ye}\beta_{ye}}}$$

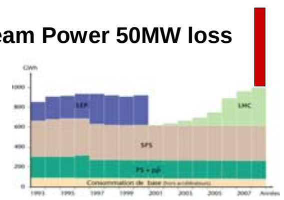
$\sigma_{xp} = \sigma_{xe}$, $\sigma_{yp} = \sigma_{ye}$

$$L=\frac{I_e\cdot N_p\cdot\gamma_p}{2\pi\cdot e\cdot\varepsilon_{Np}\cdot\sqrt{\beta_{xp}\cdot\beta_{yp}}}$$

with $L=10^{33}cm^{-2}s^{-1}$
$N_p\gamma_p / \varepsilon_{Np}=3.2\cdot10^{20}m^{-1}$

$$\frac{I_e}{\sqrt{\beta_{xp}\beta_{yp}}}=0.063\ \frac{A}{m}$$

Beam Power 50MW loss



with E_e=70GeV
I_e = 71mA N_e=1.3 10^{10}

$$\sqrt{\beta_{xp}\cdot\beta_{yp}}=1m$$

Match flat e beam ➔ β_{xp}= $4\beta_{yp}$

Main parameters

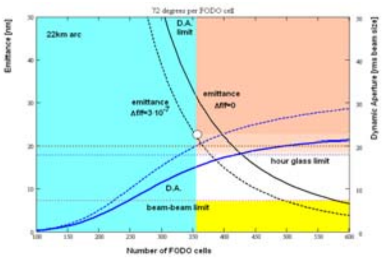
Property	Unit	Leptons	Protons
Beam Energies	GeV	70	7000
Total Beam Current	mA	74	544
Number of Particles / bunch	10^{10}	1.04	17.0
Horizontal Beam Emittance	nm	7.6	0.501
Vertical Beam Emittance	nm	3.8	0.501
Horizontal β-functions at IP	cm	12.7	180
Vertical β-function at the IP	cm	7.1	50
Energy loss per turn	GeV	0.707	$6\cdot10^{-6}$
Radiated Energy	MW	50	0.003
Bunch frequency / bunch spacing	MHz / ns	40 / 25	
Center of Mass Energy	GeV	1400	
Luminosity	$1.1\cdot10^{33}cm^{-2}s^{-1}$	1.04	

➔ Remains to design appropriate IR & appropriate e-Lattice

LEPTON LATTICE

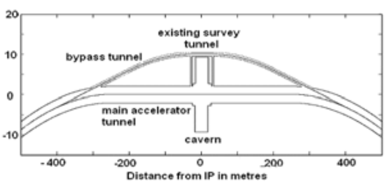
Contraints:

- $\beta_e\varepsilon_e = \beta_p\varepsilon_p$
- hourglass effect: $\beta_e < \sigma_p$
- e Physical aperture in IR quads
- e Dynamic aperture due to IR chromaticity
- e Beam-beam interaction sensitivity due to large beta



➔ Shorter cell than LEP desirable

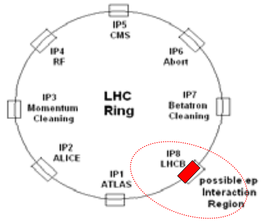
Bypass around ATLAC & CMS



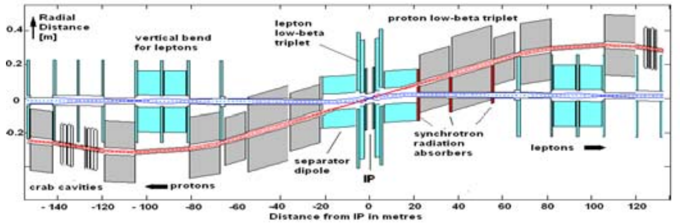
e-Ring Parameters

Electron Ring Parameters		
Parameter	Unit	Value
Circumference C	m	26658.86
Beam Energy E_e	GeV	70
Arc Focusing		FODO
Cell length L_c	m	60.3
Bending radius ρ	m	2997
Horizontal betatron Phase Adv./cell $\Delta\phi_x$	degree	72
Vertical betatron Phase Adv./cell $\Delta\phi_y$	degree	72
Number of FODO cells in the Arcs N_{cell}		376
Arc Chromaticity (hor/vert.) $\xi_{x,y}$		94/120
Beam Current I_e	mA	70.7
Bunch spacing τ_b	ns	25
Number of bunches n_b		2800
Number of particles per bunch N_e	10^{10}	1.4
Momentum compaction factor α	10^{-4}	1.34
Horizontal beam emittance ϵ_{xe}	nm	7.6
Vertical beam emittance ϵ_{ye}	nm	3.8
RMS energy spread σ_e	10^{-3}	2.4
RMS bunch length	mm	7.1
Particle Radiation energy loss per turn eU_{loss}	MeV/turn	706.8
Beam Power loss P_{loss}	MW	50
Circumferencial Voltage U	MV	1521
Synchronous Phase ϕ_{synch}	degree	27
RF frequency f_{rf}	MHz	1000
Bucket height h_b	σ_e	8.4
RF frequency shift	Hz	250
Synchrotron frequency f_s	f_{rev}	0.191

IR DESIGN

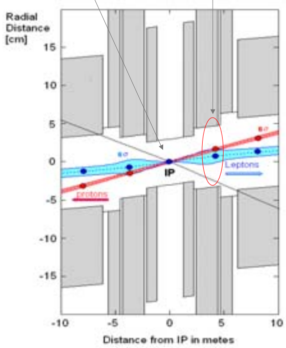


Interaction region parameters			
property	unit	leptons	protons
Horizontal Beta function at IP	cm	12.7	180
Vertical beta function at IP	cm	7.07	50
Horizontal IR Chromaticity		-7.5	-7.9
Vertical IR chromaticity		-29.7	-7.7
Maximum horizontal Beta	m	131.7	2279
Maximum vertical Beta	m	704.4	2161
Minimum of available Aperture	σ_r	16	13.5
Low beta quadrupole gradient	T/m	93.3	115
Separation dipole field	T	0.033	-
Sychrotron Radiation Power	kW	9.1	-
Low beta quadrupole length	m	.96/2.43/1.14	16.5/18.6/11
Low beta quadrupole apertures	mm	30/40/50	12/15/15
Distance of first quadruple from IP	m	1.2	13.74
Detector Acceptance Polar Angle	degree	9.4	
Crossing Angle	mrad	2	



BEAM-BEAM INTERACTION

θ_c=2mr $8\sigma_e$ separation



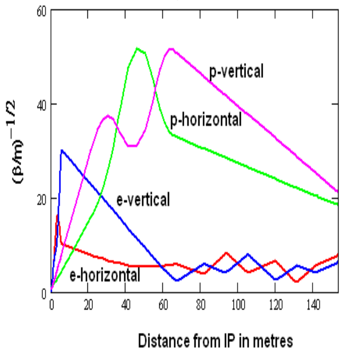
Central Beam-Beam Tune shifts

$$\Delta\nu_x^p=\frac{r_pN_e\beta_{xp}}{2\pi\gamma_p\sigma_{xe}(\sigma_{xe}+\sigma_{xe})}=0.83\cdot10^{-3}$$
$$\Delta\nu_y^p=\frac{r_pN_e\beta_{yp}}{2\pi\gamma_p\sigma_{ye}(\sigma_{xe}+\sigma_{xe})}=0.32\cdot10^{-3}$$
$$\Delta\nu_x^e=\frac{r_0N_p\beta_{ye}}{2\pi\gamma_e\sigma_{xp}(\sigma_{xp}+\sigma_{xp})}=48\cdot10^{-3}$$
$$\Delta\nu_y^e=\frac{r_0N_p\beta_{ye}}{2\pi\gamma_e\sigma_{xp}(\sigma_{xp}+\sigma_{xp})}=51\cdot10^{-3}.$$

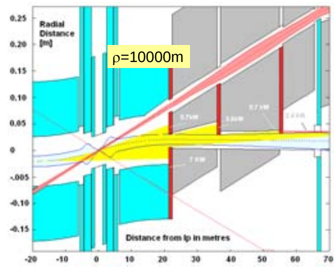
Parasitic BBI with $8\sigma_e$ separation may be critical

➔ needs further study

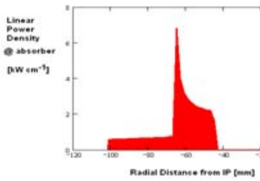
IR Lattice functions

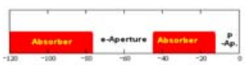


SYNCHROTRON RADIATION

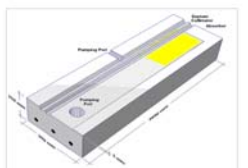


Power density at collimator

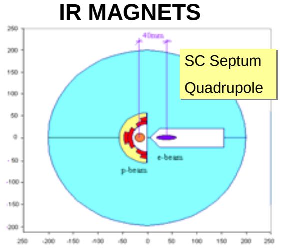


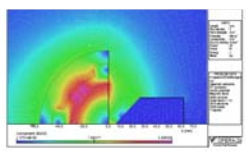


1m long absorber



IR MAGNETS





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DESY