Status of the LHeC Facility Plans

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for the LHeC study group IRF

Accelerator Design [RR and LR]

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Interaction Region and Fwd/Bwd

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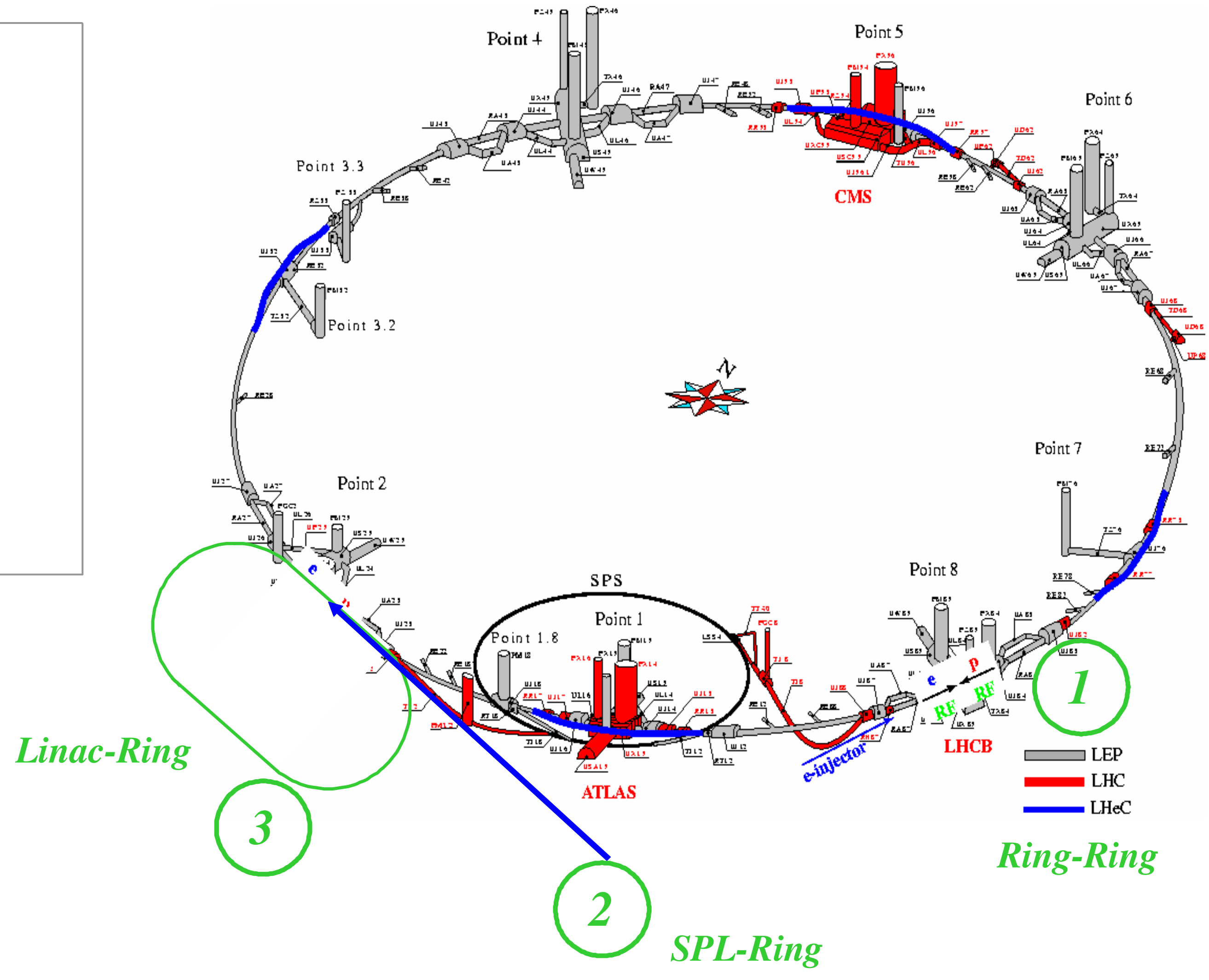
Pierre van Mechelen (Antwerpen)

Detector Design

Peter Kostka (DESY),

Rainer Wallny (UCLA),

Alessandro Polini (Bologna)



Goal of the Workshop:

identify topics & problems related to the layout of the LHeC
& the design of its critical components

with special emphasis on the layout of the interaction region
and the RR design

- *beam optics,*
- *beam separation,*
- *crossing angle required*
- *detector opening angle ... 1° / 10°*

discuss present status of the required technical components

- *crab cavities*
- *exotic magnets (sc half magnets, open magnets etc)*
- *double magnets for fast beam separation*
- *the electron-ring & its bypass system*

and identify names ... in view of the CDR

Goal: Technical Design of the two LHeC Alternatives
RR / RL for a CDR within a Year

Status Divonne 2008:

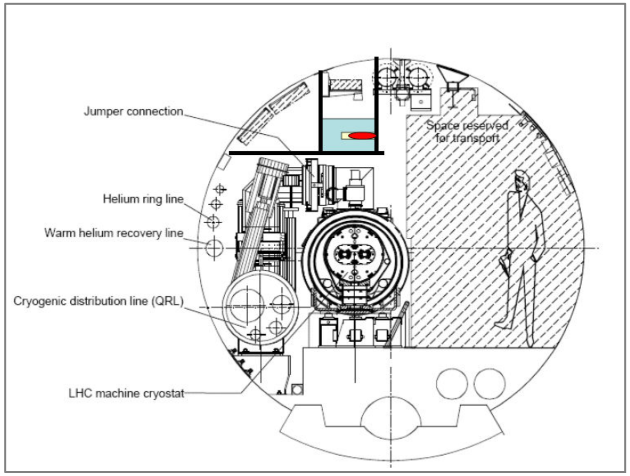
General Statement: Whatever we do ... the fundamental layout of the LHC delivers an enormous potential for e/p Luminosity

2808 bunches
7 TeV
$\rightarrow \varepsilon_n = 3.75\ \mu m$

} *RR Option / RL Option*

LHeC Ring-Ring: basic parameters

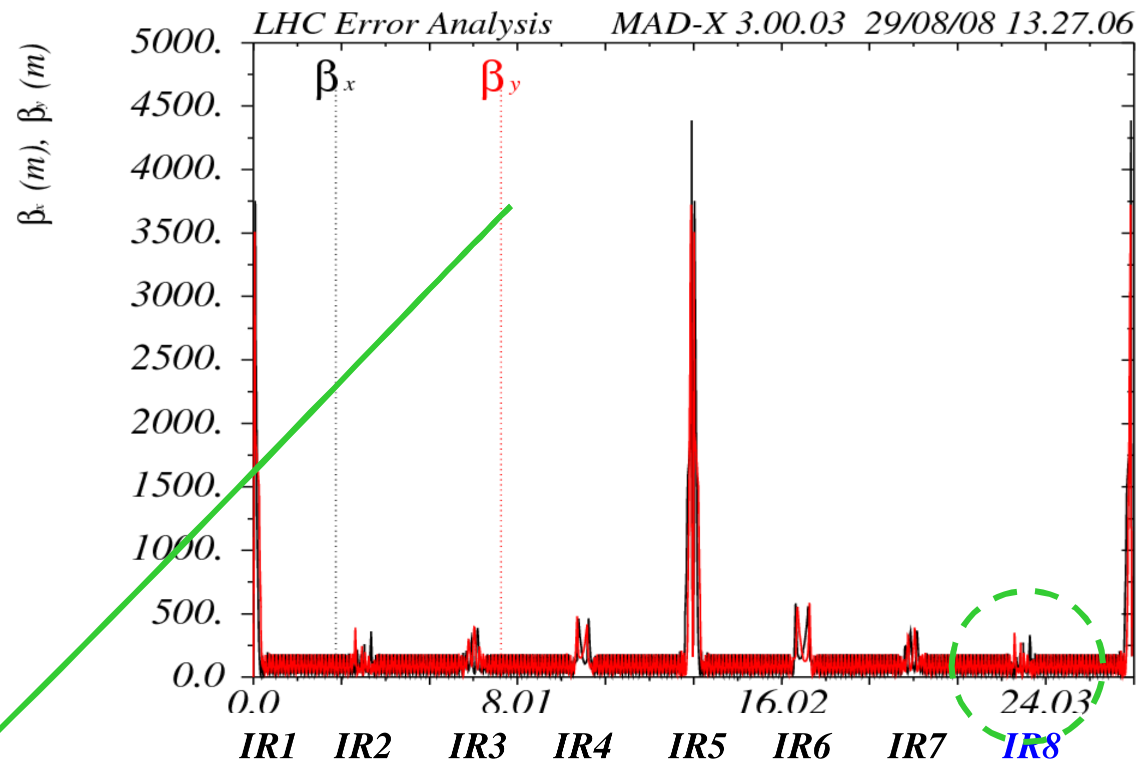
Standard Parameters	Protons	Electrons
	$Np=1.15*10^{11}$	$Ne=1.4*10^{10}$
	$Ep=7$ TeV	$Ee=70$ GeV
	nb=2808	nb=2808
	Ip=582mA	Ie=71mA
Optics	$\beta_{xp}=180cm$	$\beta_{xe}=12.7cm$
	$\beta_{yp}=50cm$	$\beta_{ye}=7.1cm$
	$\varepsilon_{xp}=0.5nm\ rad$	$\varepsilon_{xe}=7.6nm\ rad$
	$\varepsilon_{yp}=0.5nm\ rad$	$\varepsilon_{ye}=3.8nm\ rad$
Beam size	$\sigma_{xp}=30\ \mu m$	$\sigma_{xe}=30\mu m$
	$\sigma_{yp}=15.8\ \mu m$	$\sigma_{ye}=15.8\mu m$
Luminosity	$8.2*10^{32}\ cm^{-2}\ s^{-1}$	

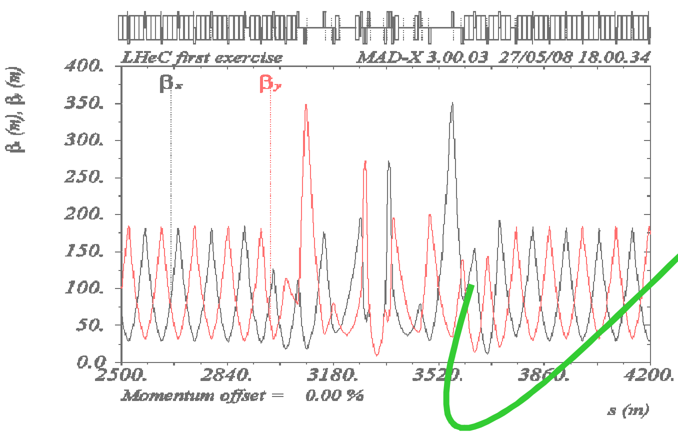


e storage ring on top of LHC

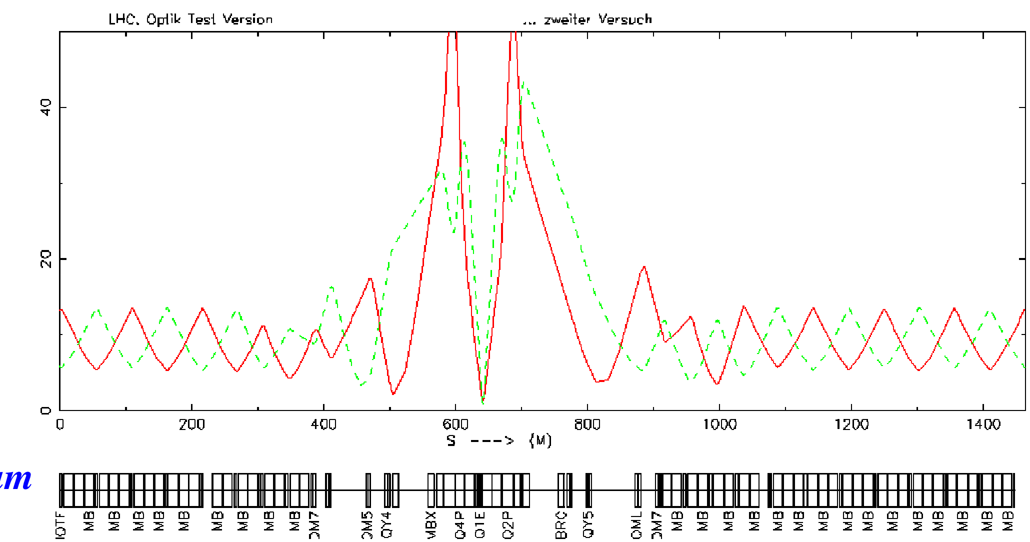
Optics Design: Proton Ring *(Status 2008)*

LHC Standard Luminosity Optics





Standard LHC IR8 Optics



new p Optics

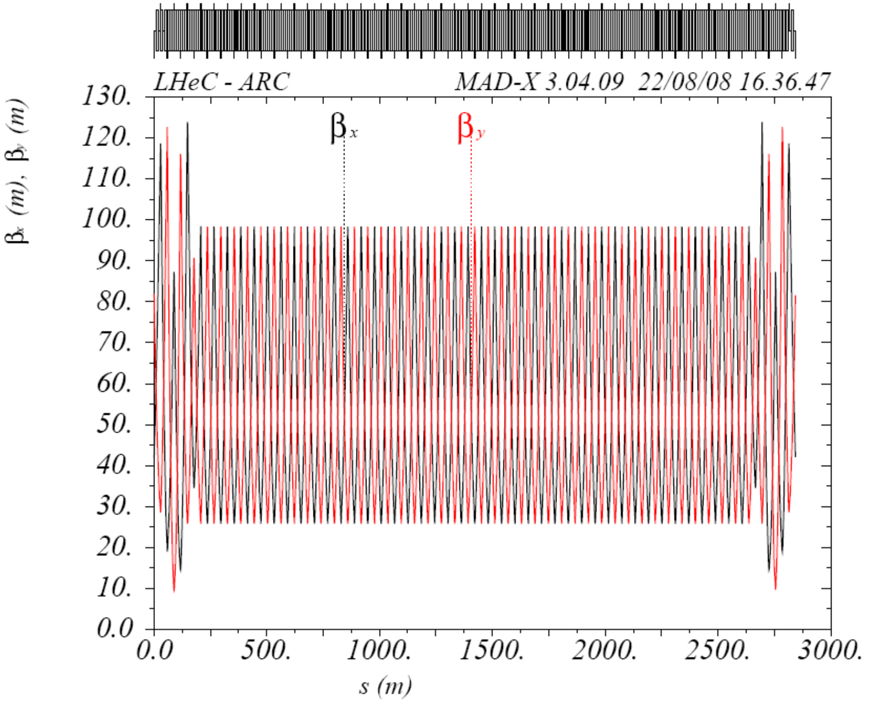
including triplett for the e-beam

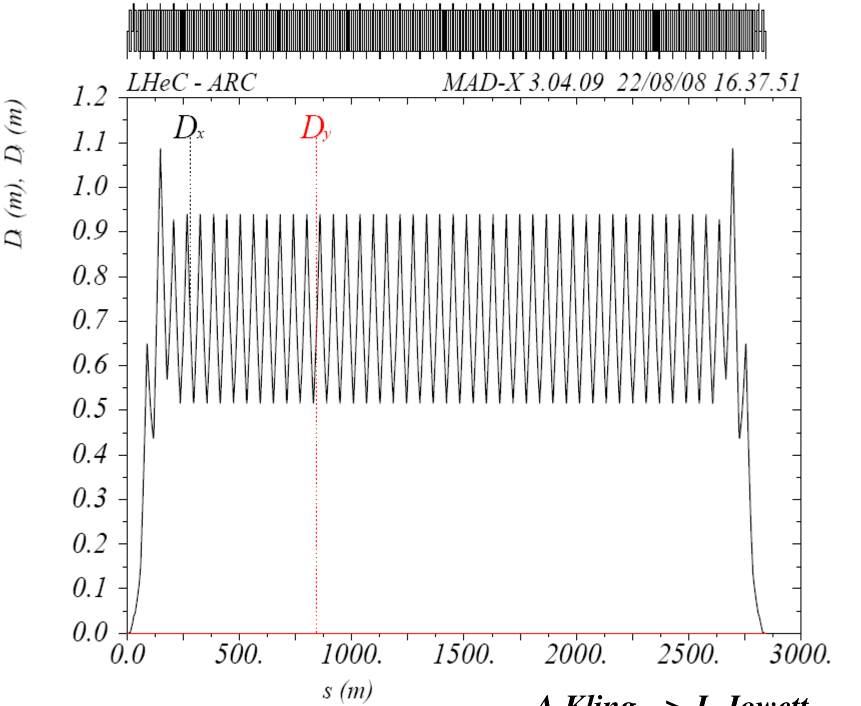
Optics Design: Electron Ring (Status 2008)

Design Constraints

- **Matched beam sizes at the IP required for stable operation.**
- **Tolerable beam-beam tune shift parameters ... for both beams**
- **Choose parameters close to LEP design and optimise the lattice for one ep Interaction region**

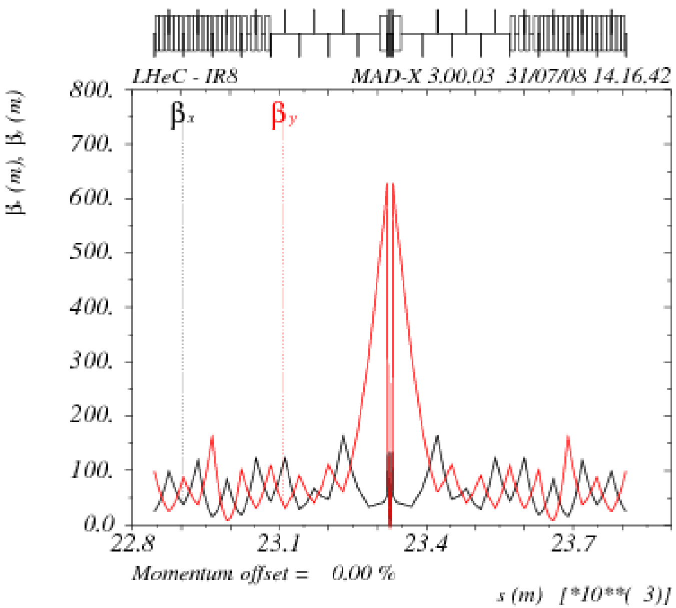
	LEP	LHeC
cell length	79m	59.25m
phase advance	60/90/108°	72°
number of cells	290	384

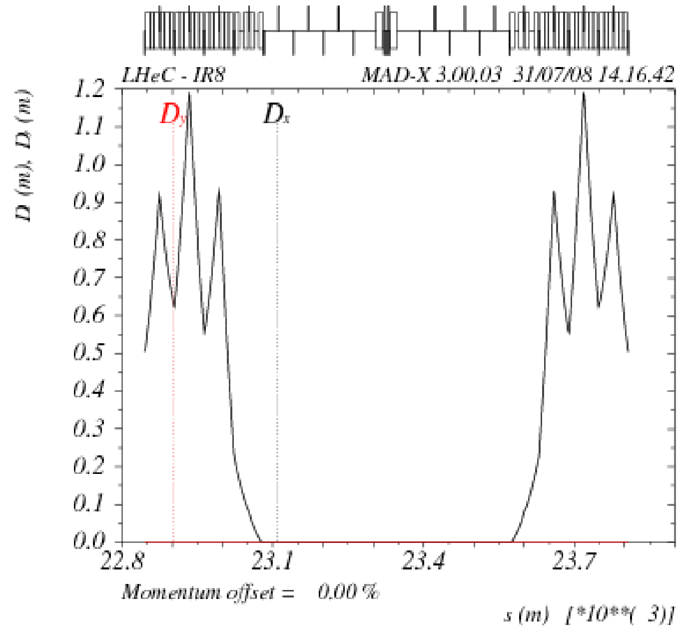




A.Kling --> J. Jowett

Electron Ring: Optical functions in IR 8





Alexander Kling

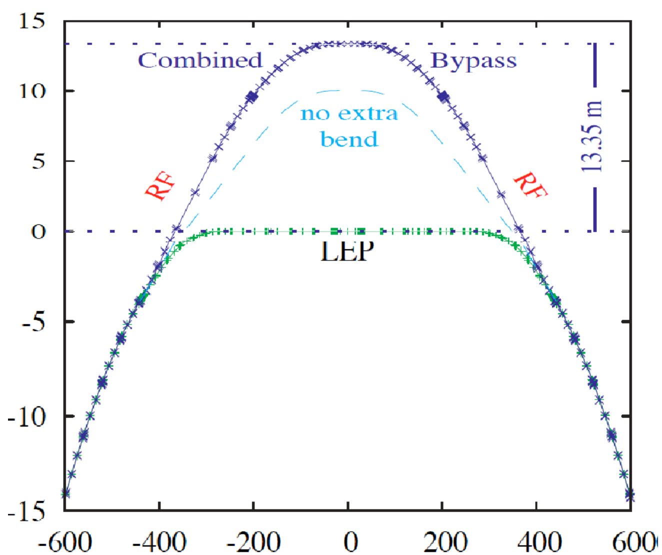
- ***Use a triplet focusing** (βx = 7.1 cm, βy =12.7cm)*
- ***Triplet is displaced** to allow for a quick beam separation*
  --> additional dispersion created close to IP

Overview of Parameters (2008)

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	*MeV/Turn*	*686*
Hor. / vert. Beta Function at IP	*m*	*12.7 cm / 7.1 cm*

A.Kling --> J. Jowett

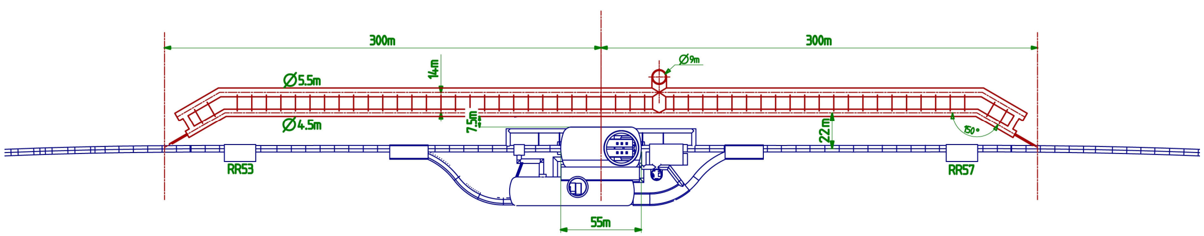
Layout IR 1 & 5



Guide the electron beam in "Bypass Beam Lines" around Atlas & CMS

geometrical layout of the bypass sections

Helmut Burkhardt

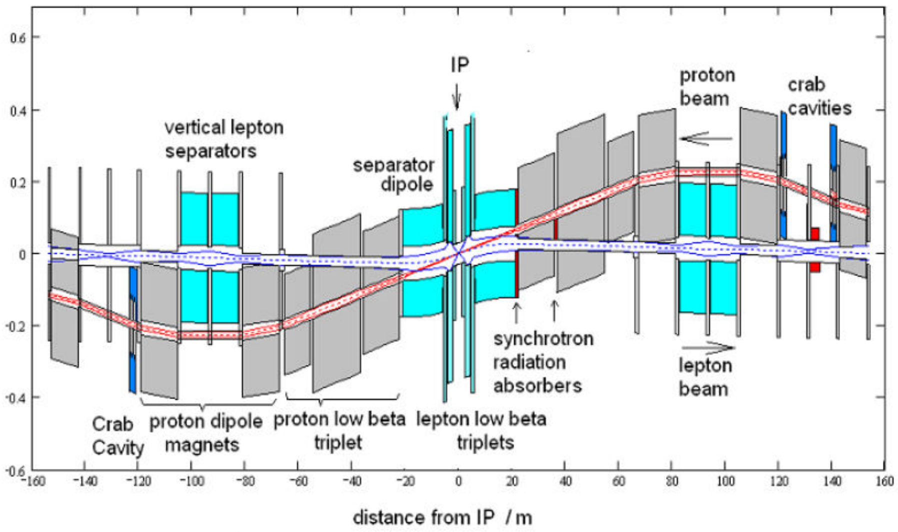


Bypass independent of IR
~30m distance, 1 shaft

to do list: establish optics for the bypass lines & include them into the overall e-ring lattice
--> H. Burkhardt, M. Fitterer (PhD)

Interaction Region Design IR 8:

layout dominated by the separation scheme



spectrometer effect: use dipole fields to separate the beams according to their momentum.

... don't loose too much space:

→ quadrupole triplett of centre

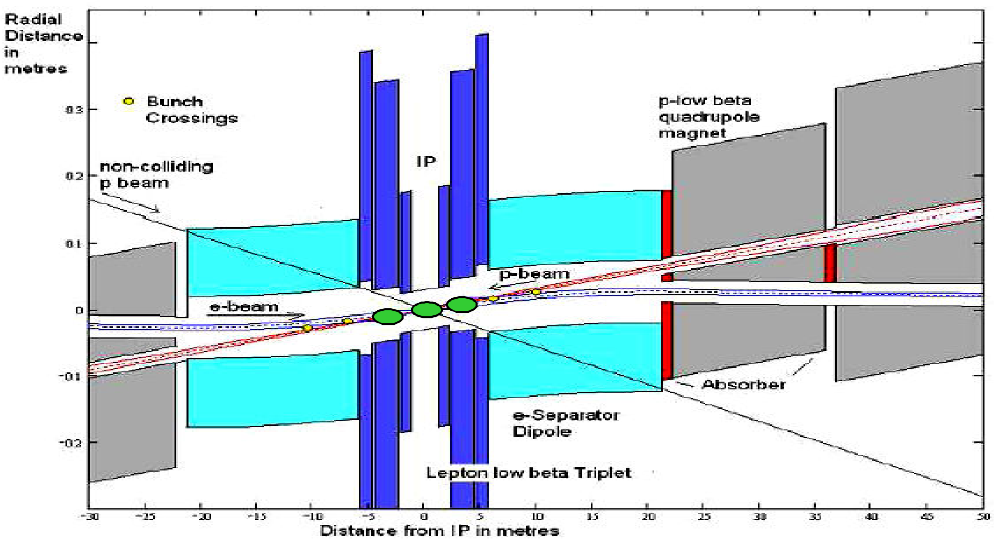
LHC bunch distance:	*25 ns*
1st parasitic crossing:	*3.75m*
first e-quad positioned at	*1.2m*

... too far for sufficient beam separation

separation has "to start at the IP"

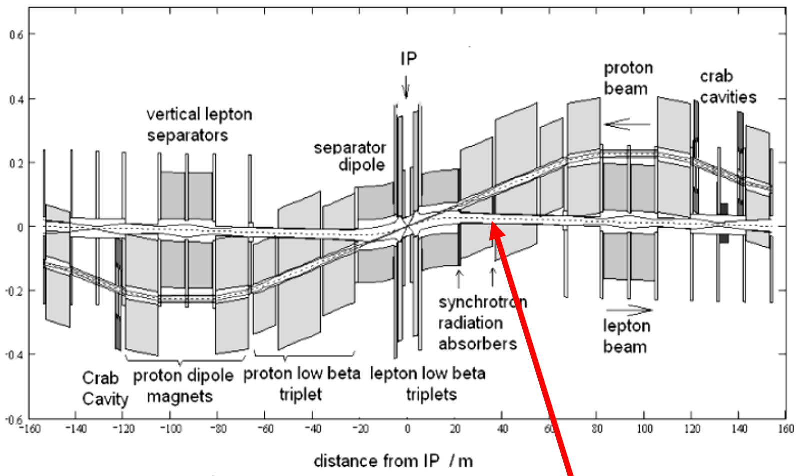
--> support the off-centre-quadrupole separation scheme by crossing angle (≈1.5 mrad) at the IP.

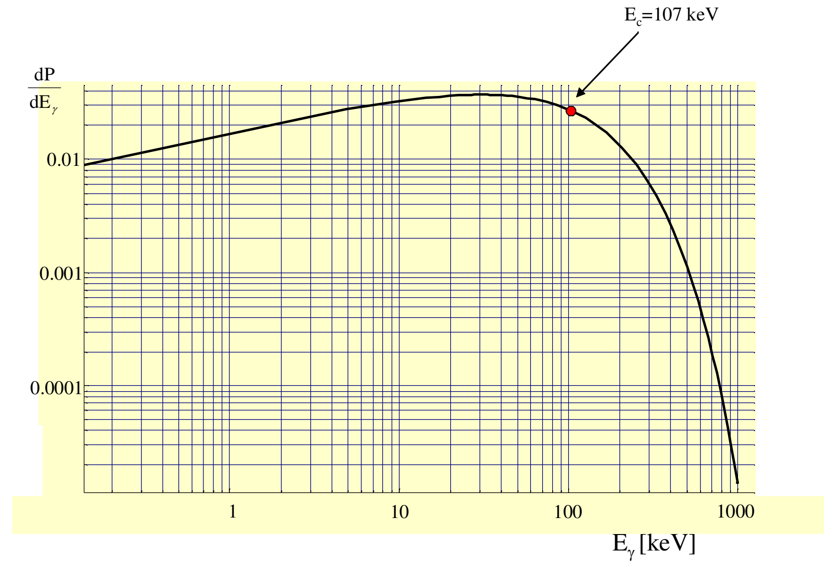
--> ... and the Luminosity Calorimeter ??



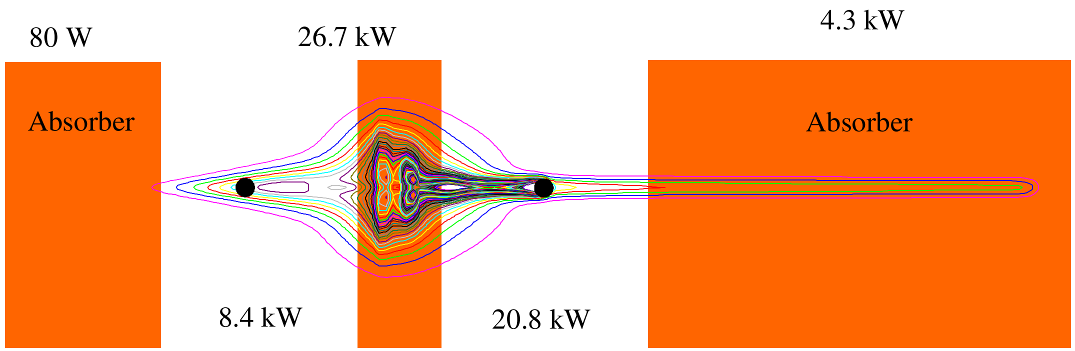
F. Willeke

IR Design: Synchrotron Radiation





large contribution from quadrupole magnets



Boris Nagorny

overall radiation power in IR: 60 kW (HERA II: 30 kW)

geometry of detector beam pipe and synchrotron radiation masks ?

Performance Limitations Ring-Ring

Tuneshift Limit

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

LHC upgrade: N_p increased.
Need to keep e tune shift low:
by optimising β & ε (but keep e and p matched).

LHeC profits from LHC upgrade
but not proportional to N_p

Tuneshift Limit:

$$\Delta \nu_{xe} = \frac{\beta_{xe} r_e}{2\pi \gamma_e} * \frac{N_p}{\sigma_{xp}(\sigma_{xp} + \sigma_{yp})}$$

Experience:

LEP	$\Delta v_e = 0.048$
LHC-B	$\Delta v_p = 0.0037$
HERA	$\Delta v_e = 0.051$
	$\Delta v_p = 0.0022$

Standard Parameter	Protons	Electrons	
	$Np=1.15*10^{11}$	$Ne=1.4*10^{10}$	nb=2808
	Ip=582 mA	Ie=71mA	
Optics	βxp=180 cm	βxe=12.7 cm	
	βyp= 50 cm	βye= 7.1 cm	
	εxp=0.5 nm rad	εxe=7.6 nm rad	
	εyp=0.5 nm rad	εye=3.8 nm rad	
Beamsize	σx=30 µm	σx=30 µm	
	σy=15.8 µm	σy=15.8 µm	
Tuneshift	Δvx=0.00055	Δvx=0.0484	
	Δvy=0.00029	Δvy=0.0510	
Luminosity	$L=8.5*10^{32}$		

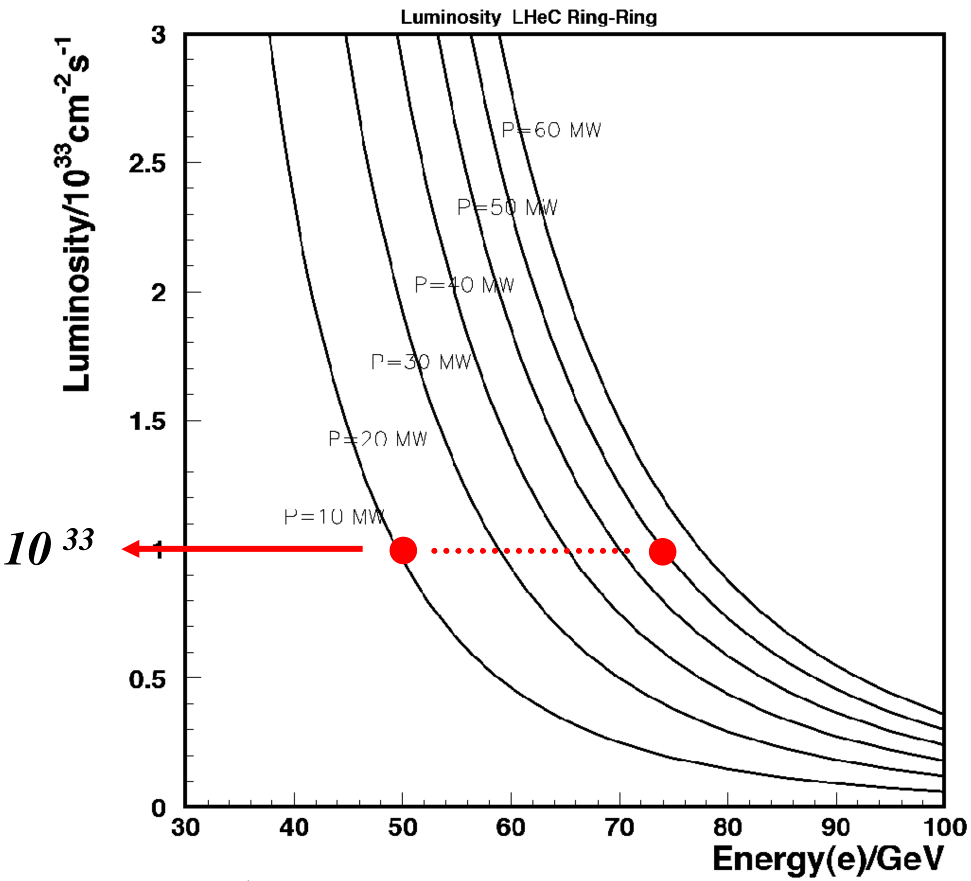
Ultimate Parameter	Protons	Electrons	
	$Np=1.7*10^{11}$	$Ne=1.4*10^{10}$	nb=2808
	Ip=860mA	Ie=71mA	
Optics	βxp=230 cm	βxe=12.7 cm	
	βyp= 60 cm	βye= 7.1 cm	
	εxp=0.5 nm rad	εxe=9 nm rad	
	εyp=0.5 nm rad	εye=4 nm rad	
Beamsize	σx=34 µm		
	σy=17 µm		
Tuneshift	Δvx=0.00061	Δvx=0.056	
	Δvy=0.00032	Δvy=0.062	
Luminosity	$L=1.03*10^{33}$		

Upgrade Parameter	Protons	Electrons	
	$Np=5*10^{11}$	$Ne=1.4*10^{10}$	nb=1404
	Ip=1265mA	Ie=71mA	
Optik	βxp=400 cm	βxe= 8 cm	
	βyp=150 cm	βye= 5 cm	
	εxp=0.5 nm rad	εxe=25 nm rad	
	εyp=0.5 nm rad	εye=15 nm rad	
Beamsize	σx=44 µm		
	σy=27 µm		
Tuneshift	Δvx=0.0011	Δvx=0.057	
	Δvy=0.00069	Δvy=0.058	
Luminosity	$L=1.5*10^{33}$		

Luminosity Ring Ring & Performance Limit

Design values limited by 50 MW available rf power
--> $E_e \approx 70$ GeV.

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



Max Klein

Luminosity Performance Limit: E_e, I_e due to Synchrotron Radiation

$$P_\gamma = \frac{e^2 c}{6\pi \varepsilon_0} * \gamma^4 * r^2 * N_e$$

10^{33} can be reached in RR

E_e = 50 GeV ↔ P_{syn} = 10MW
E_e = 75 GeV ↔ P_{syn} = 50MW * 2

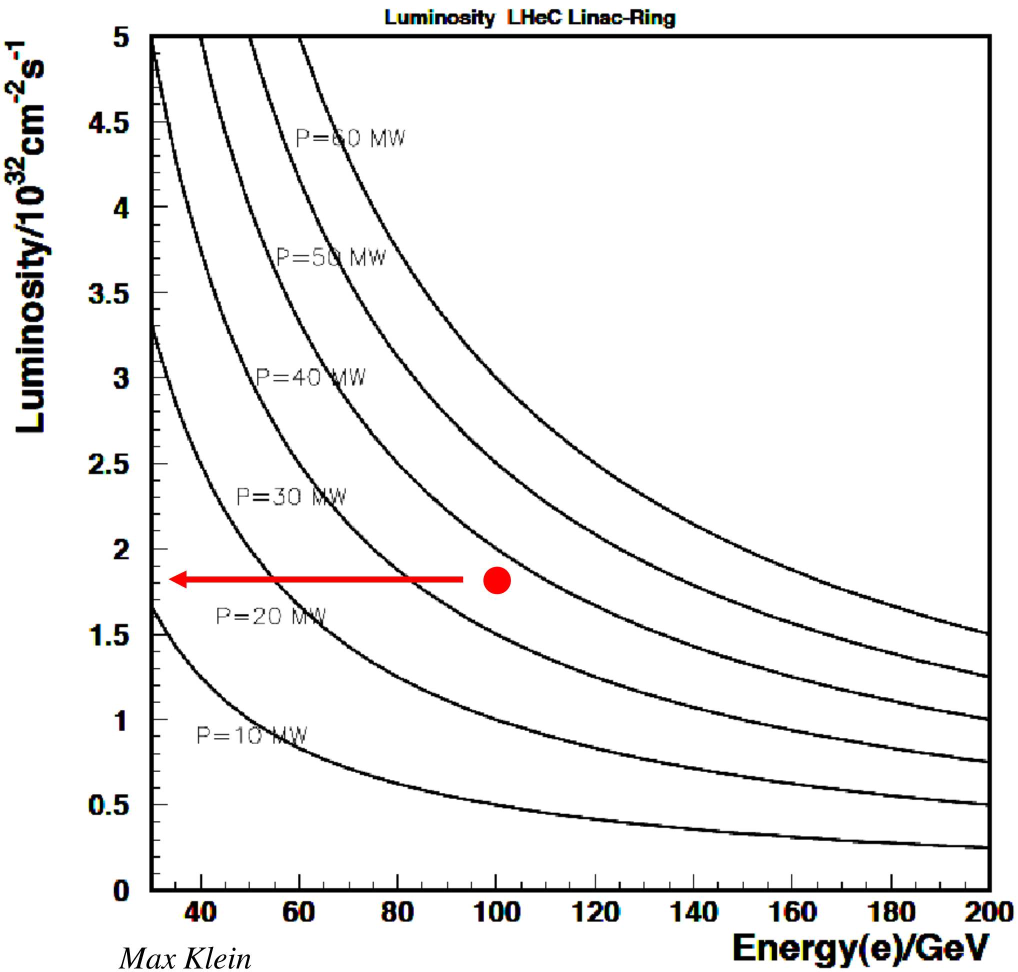
klystron efficiency: 50%

Overall power consumption: limited to 100MW

Luminosity Linac Ring: Performance Limit

$$L = \frac{N_p \gamma}{4\pi\, \varepsilon_{pn} \beta^*} * \frac{P_{total}}{E_e}$$

M.Tigner, B.Wiik, F.Willeke, Acc.Conf, SanFr.(1991) 2910



Max Klein

Luminosity Performance Limit: beam power

adequate for high beam energy

--> see talk by Frank

Performance Limits: the 1° problem

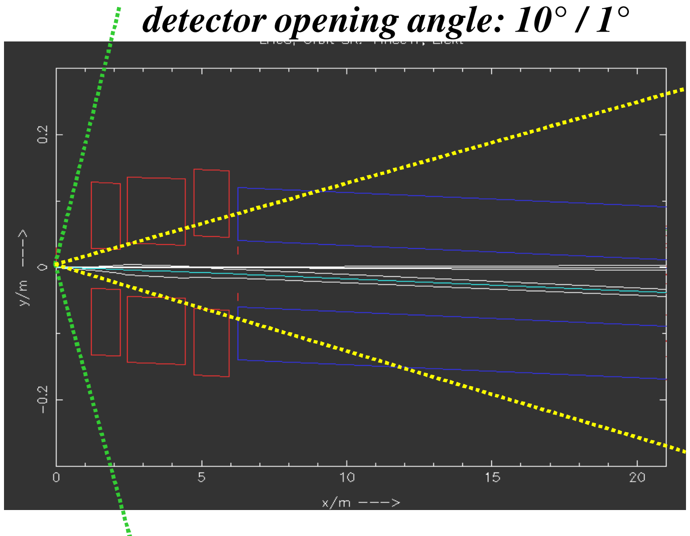
Luminosity vs. Acceptance

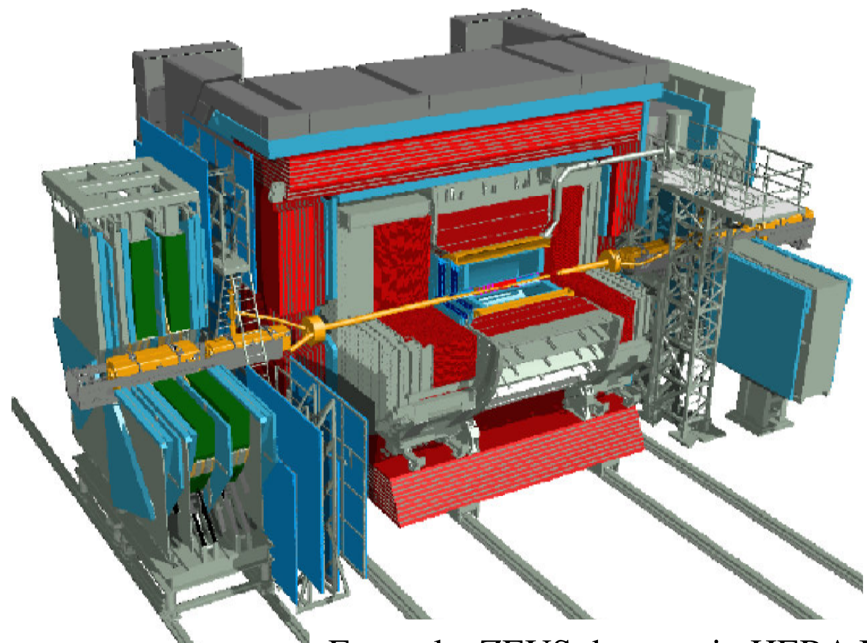
- Luminosity and acceptance very much depend on physics program (to be defined during this workshop)

=> Possible scenario two different interaction region setups

- $L = 10^{33}\ cm^{-2}\ s^{-1}$, $10° < \theta < 170°$ (prefer magnets not in front of calorimeter)
- $L = 10^{31}\ cm^{-2}\ s^{-1}$, $1° < \theta < 179°$

detector opening angle: 10° / 1°





Example: ZEUS detector in HERA II with integrated mini beta quads

the good news:
Cockcroft will contribute to that workpackage
(Rob Appleby et al)

Electron-nucleus (e-A) collisions

- The LHC will operate as a nucleus-nucleus (initially Pb-Pb) collider
  - Physics programme is expected to include:
    - Pb-Pb at $\sqrt{s_{NN}} = 5.5\,\mathrm{TeV}$
    - p-Pb
    - A-A where A may be Ca, O, …
- Natural possibility of colliding electrons with $^{208}Pb^{82+}$ nuclei
  - Requires maintenance of LHC ion injector complex (source-LINAC3-LEIR) through to the time of operation of LHeC
  - Also requires inclusion of ion capability in new generation of injector synchrotrons (PS → PS2, SPS → SPS2 ??)
- Electron-deuteron e-d collisions would require a completely new source (at least!)
  - Present CERN complex does not foresee deuterons

SUMMARY: To Do List (Status Divonne 2008)

✓ • e-Ring: Design straight sections 1-7 : replace dummy straight sections by bypass regions (H. Burkhardt / M. Fitterer)

✓ • Include Rf sections ... can be done in the by pass regions

• Include sextupoles for correction of chromatic lattice functions.

✓ • Optimise damping partition numbers ... not needed anymore (?)

✓ • Optimise Phase Advance in the FoDo to reduce beam emittance . (goal = 7.6 nm !) (J. Jowett)

✓ • compare the two schemes: linac-ring / ring-ring ... for a given overall wall plug power: 100MW (M. Klein)

✓ • calculate the linear beam beam tune shift for both beams (B. Holzer)

✓ • calculate the (long range) beam beam effect (W. Herr, T. Pieloni -EPFL-)

→ • design for a 1° / 179° option --> Cockcroft (R. Appleby)

→ • synchrotron radiation & Luminosity Counter
→ close collaboration with detector people

→ • R & D on technical components ... exotic quads, crab cavities