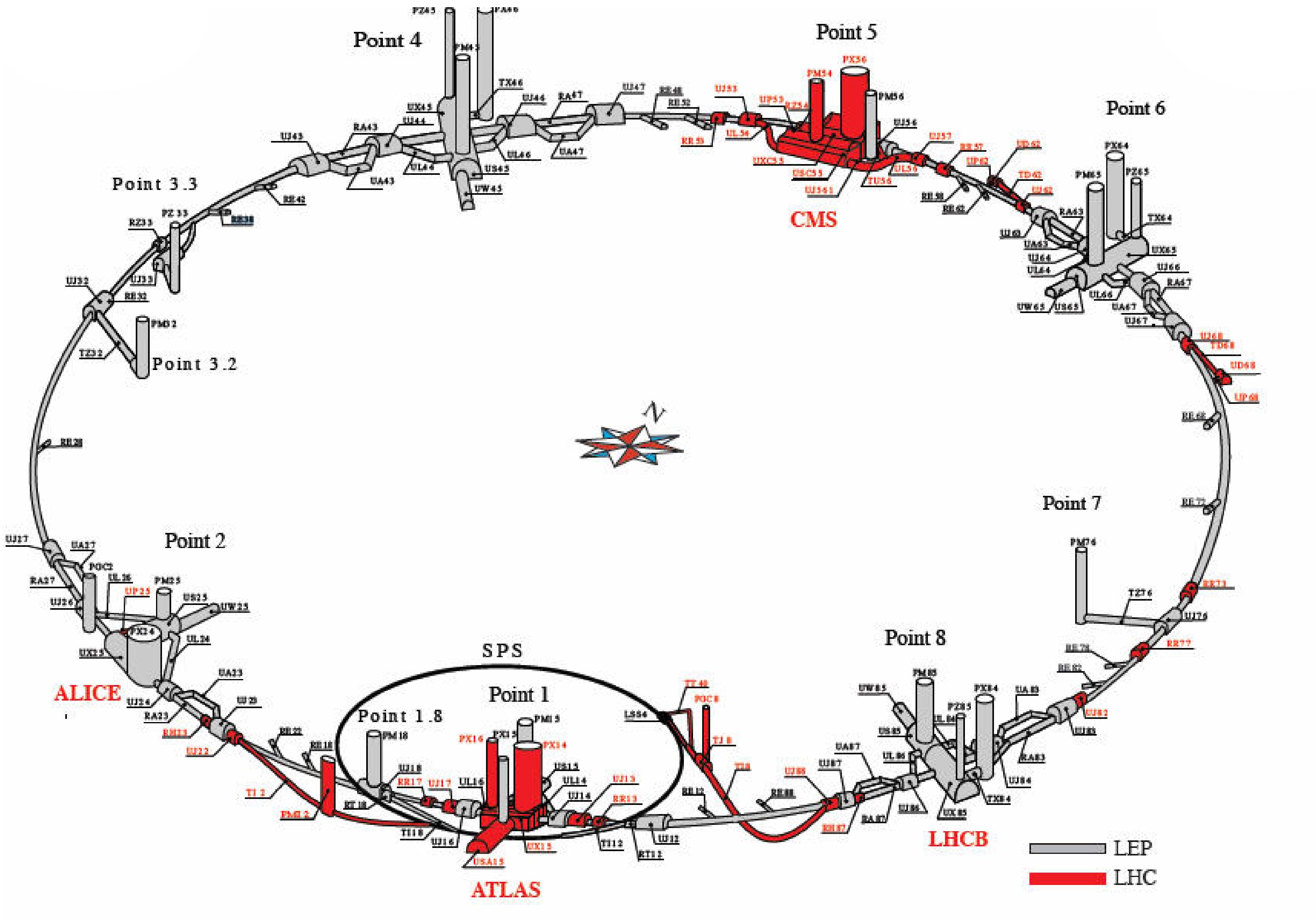
LHeC Facility Plans

Bernhard Holzer, CERN
for the LHeC study group



The LHeC Study Group: Three Alternatives

Accelerator Design [RR and LR]

Oliver Bruening (CERN),

John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd

Bernhard Holzer (CERN),

Uwe Schneeekloth (DESY),

Pierre van Mechelen (Antwerpen)

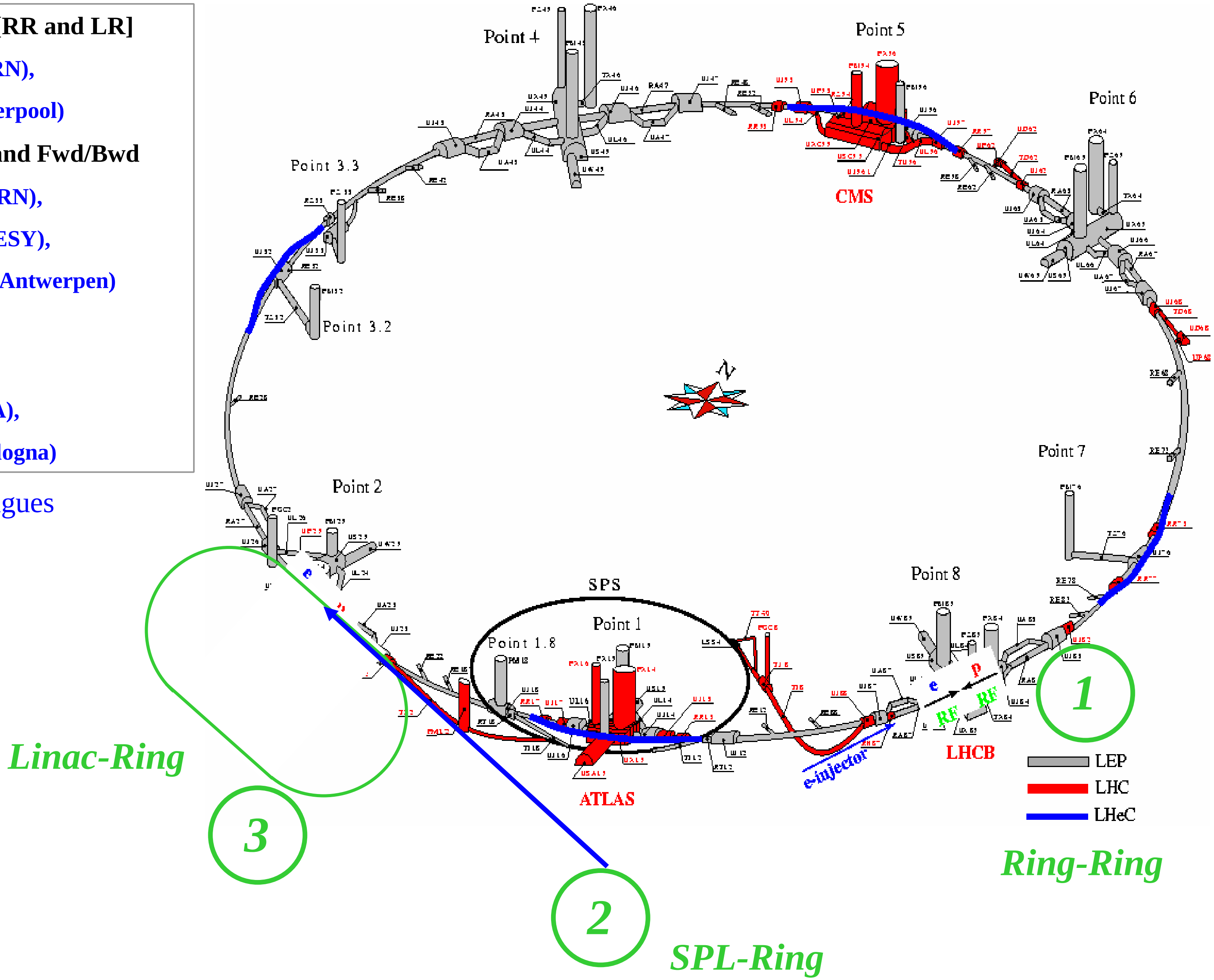
Detector Design

Peter Kostka (DESY),

Rainer Wallny (UCLA),

Alessandro Polini (Bologna)

... and many colleagues



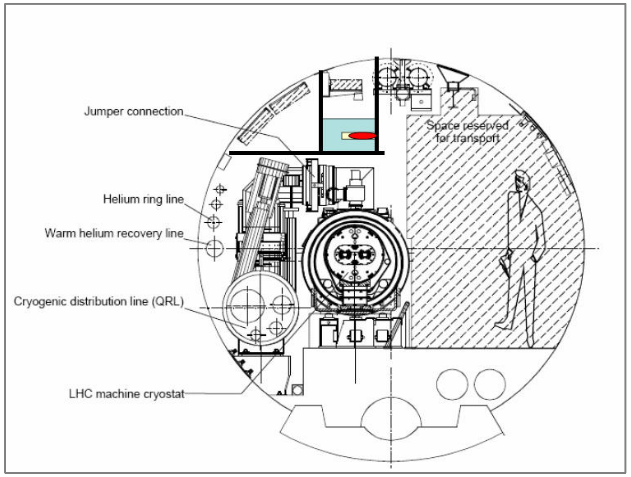
Goal: Technical Design of the three Alternatives
CDR within a Year

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

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

Example: LHeC Ring-Ring: basic parameters

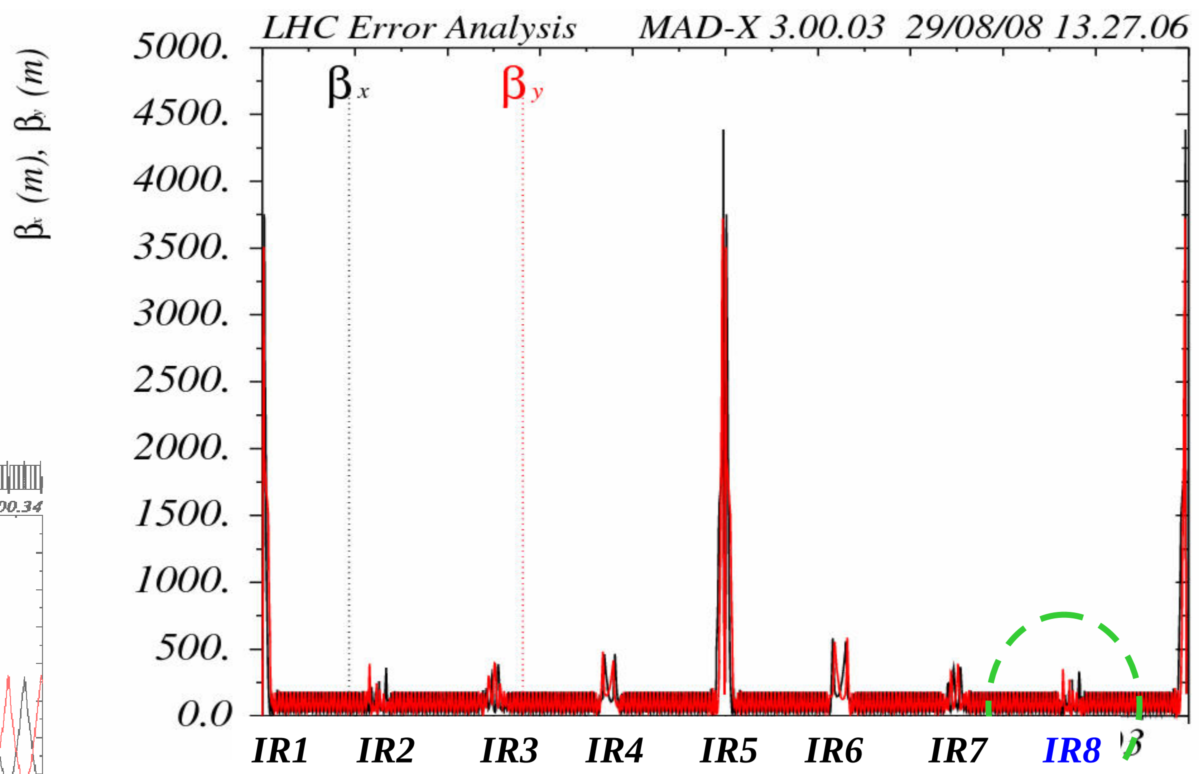
Standard	***Protons***	***Electrons***
Parameters	$Np=1.15*10^{11}$	$Ne=1.4*10^{10}$
	nb=2808	*nb=2808*
	Ip=582mA	*Ie=71mA*
Optics	$\beta_{xp}=180cm$	$\beta_{xe}=12.7cm$
	$\beta_{yp}=50cm$	$\beta_{ye}=7.1cm$
	$\varepsilon_{xp}=0.5nm\ rad$	$\varepsilon_{xe}=7.6nm\ rad$
	$\varepsilon_{yp}=0.5nm\ rad$	$\varepsilon_{ye}=3.8nm\ rad$
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	$8.2*10^{32}\ cm^{-2}\ s^{-1}$	



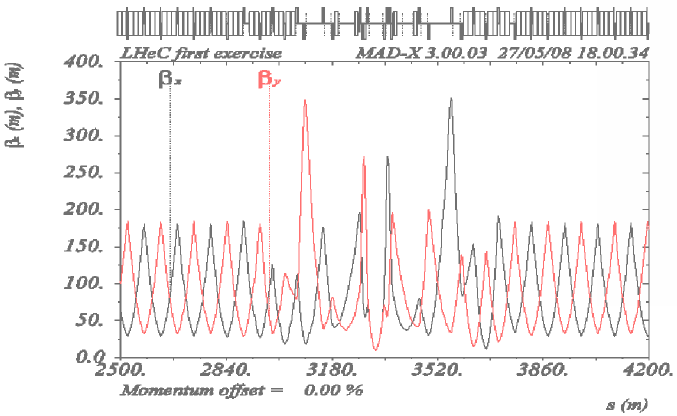
e storage ring on top of LHC

Optics Design: Proton Ring

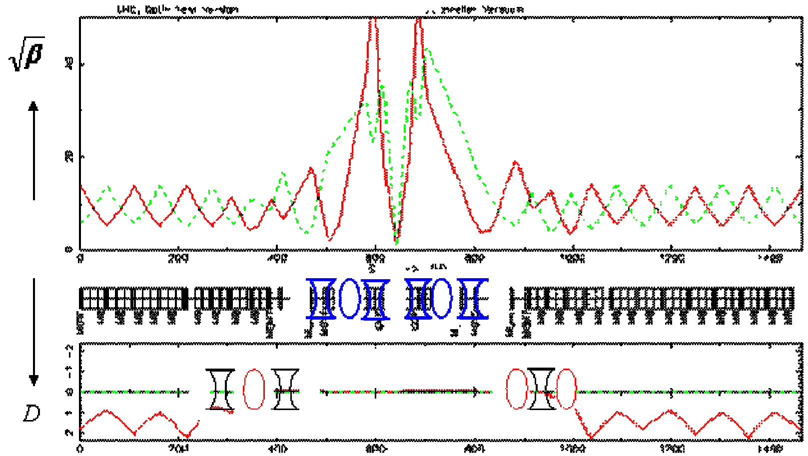
LHC Standard Luminosity Optics



... but an asymmetric one



Standard LHC IR8 Optics



$\beta_x^* = 1.8m$

$\beta_y^* = 0.5m$

new p Optics

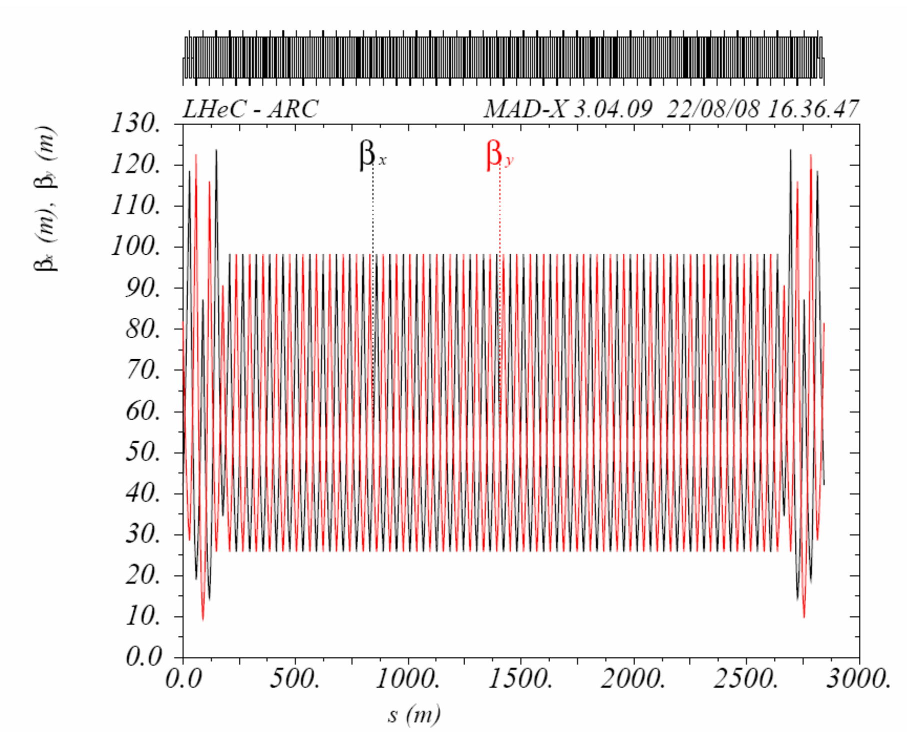
including triplett for the e-beam

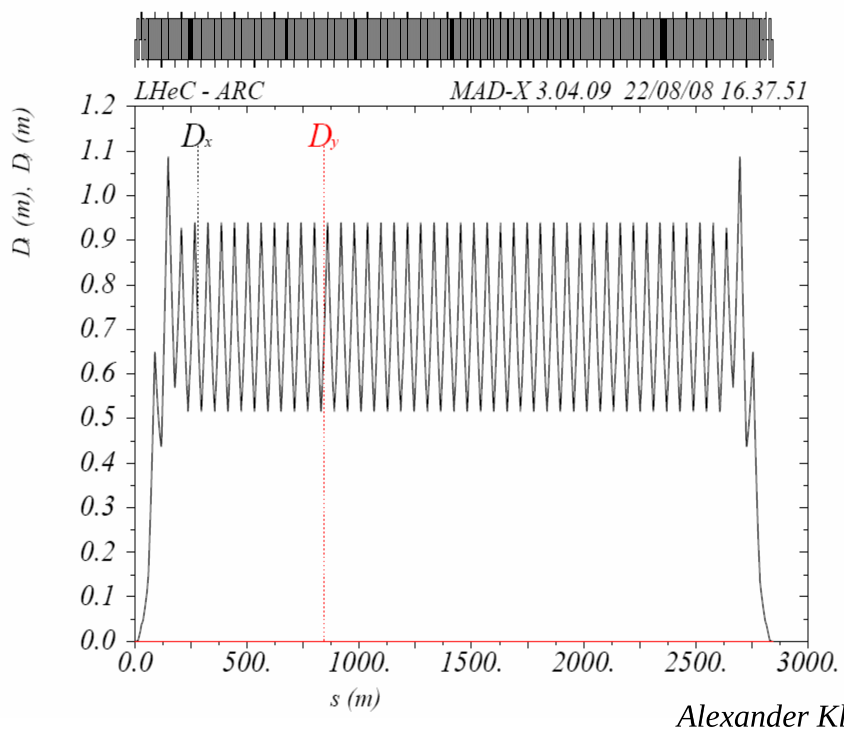
Optics Design: Electron Ring

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

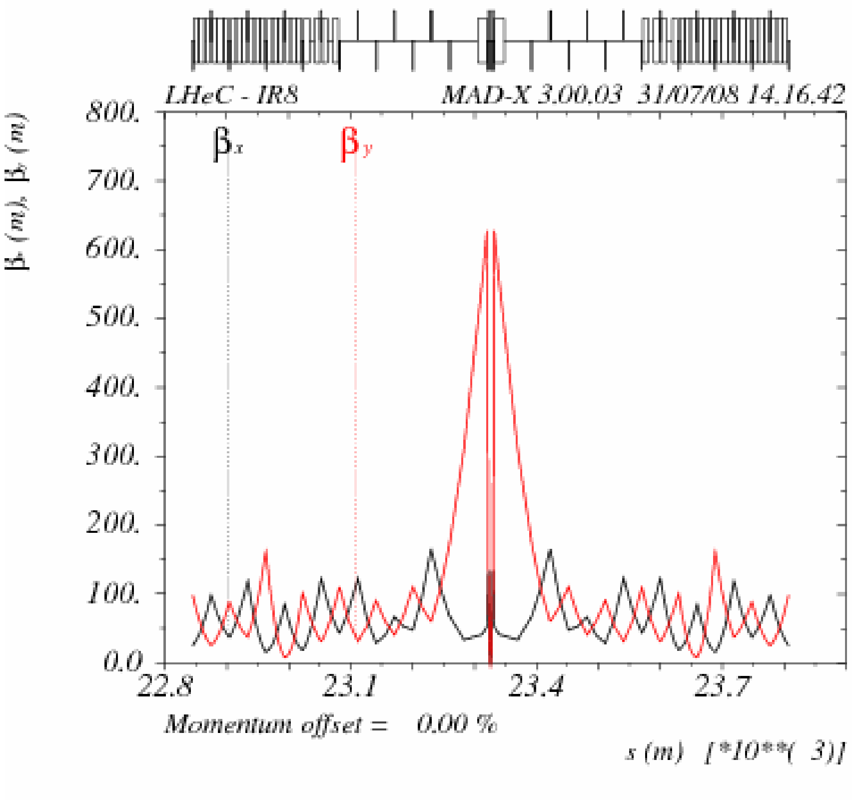
	Lep	LHeC
cell length	79m	59.25m
phase advance	60/90/108°	72°
number of cells	290	384

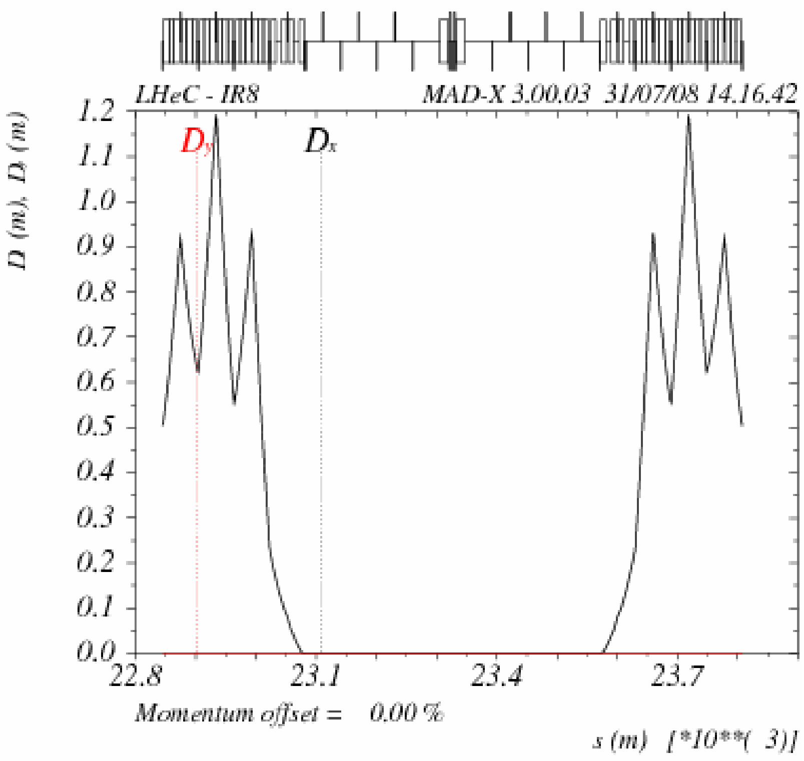




Alexander Kling

Electron Ring: Optical functions in IR 8





Alexander Kling

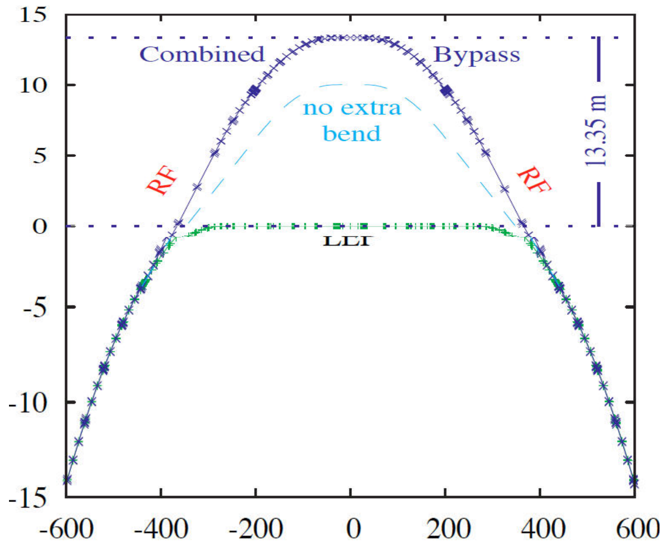
Layout IR 8

- *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 .*

Layout IR 1 & 5

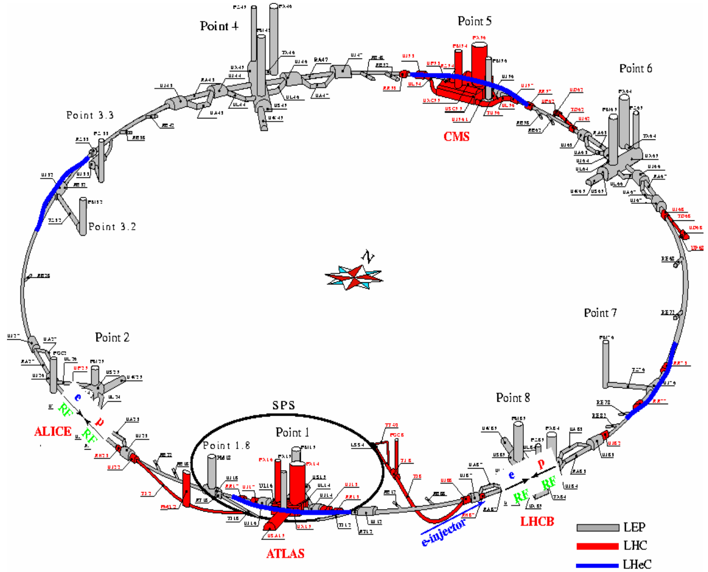
Guide the electron beam in "Bypass Beam Lines" around Atlas & CMS

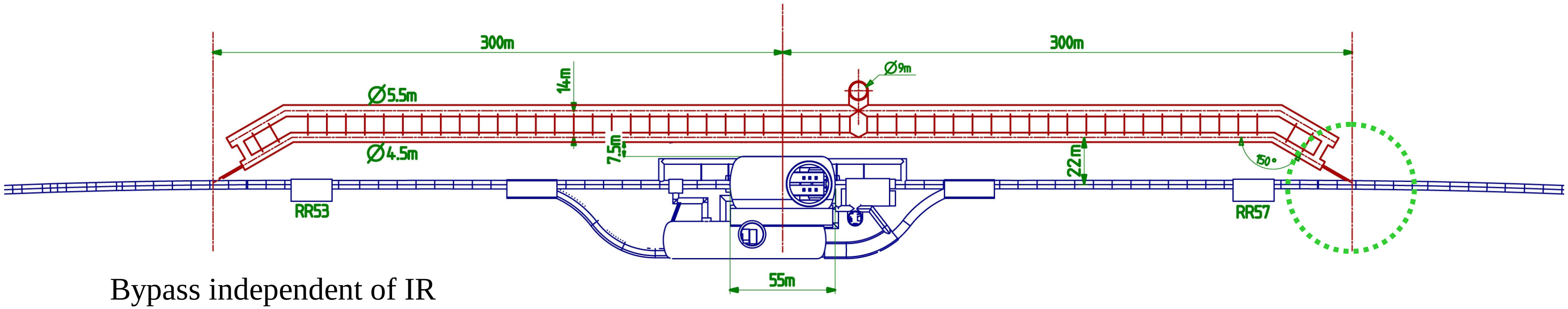
Electron Beam in IR 1 & 5



geometrical layout of the bypass sections

Helmut Burkhardt





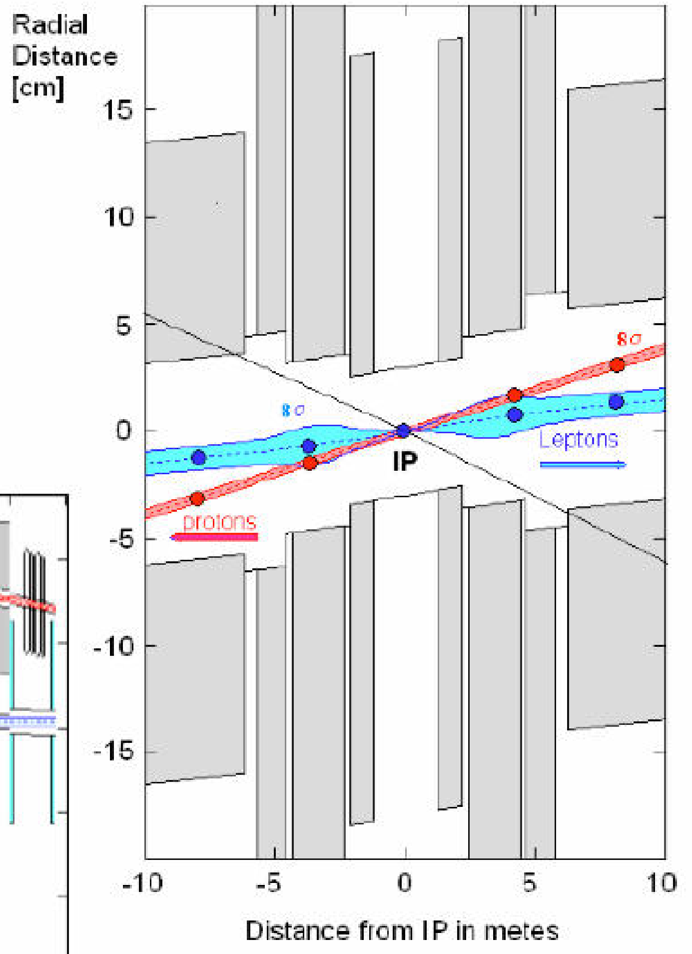
Bypass independent of IR
~30m distance, 1 shaft

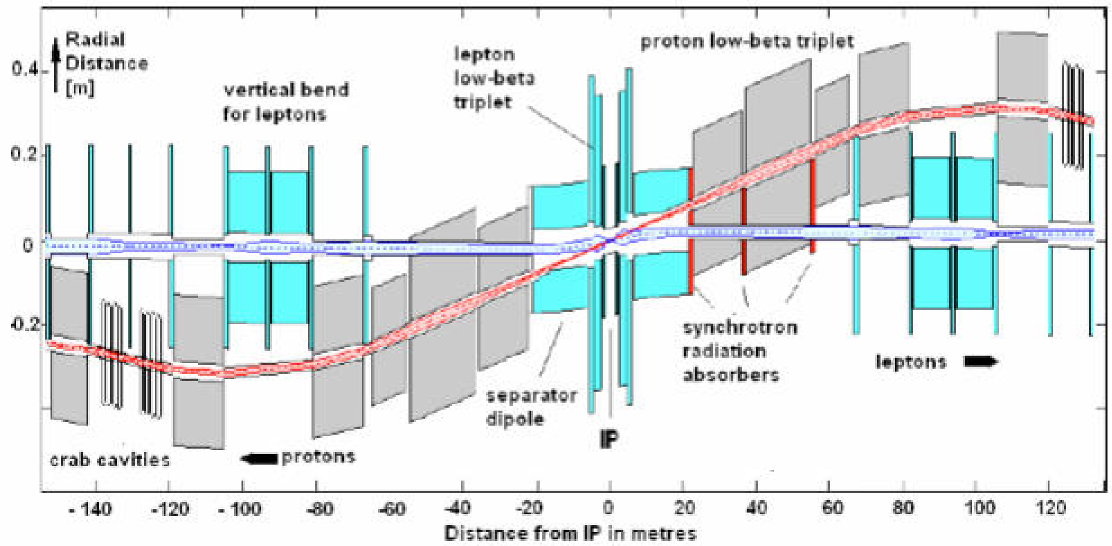
S.Myers, J.Osborne

Interaction Region Design:

A First Complete Design for 10 ^33

	Protons	Electrons
Standard Parameters	$N_p=1.15*10^{11}$	$N_e=1.4*10^{10}$
	$n_b=2808$	$n_b=2808$
	$I_p=582mA$	$I_e=71mA$
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	$8.2*10^{32}\ cm^{-2}\ s^{-1}$	





Interaction Region Design: Challenges

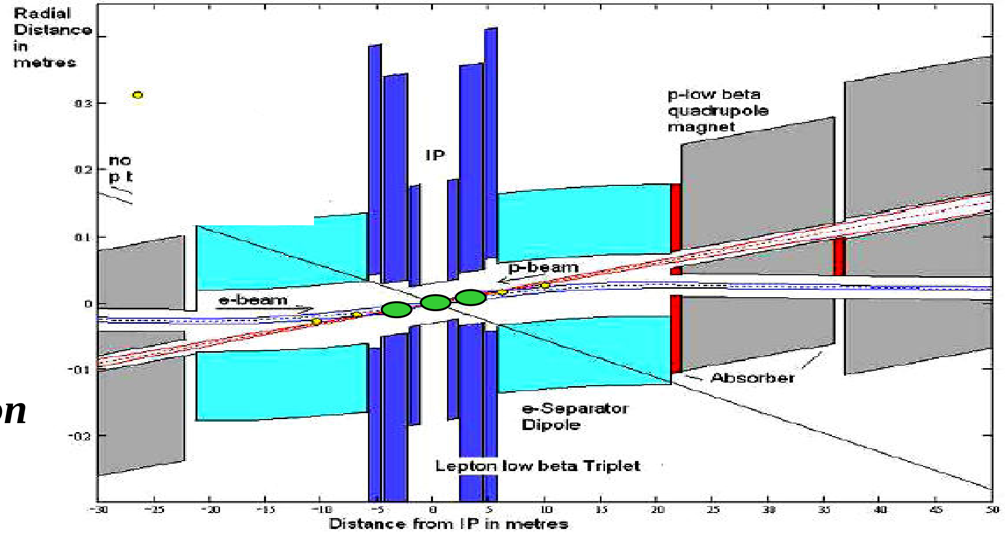
Advantage of LHC: *large number of bunches* → ***high luminosity***
Disadvantage: ***fast beam separation needed***
crossing angle to support early separation

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

... too far for sufficient beam separation

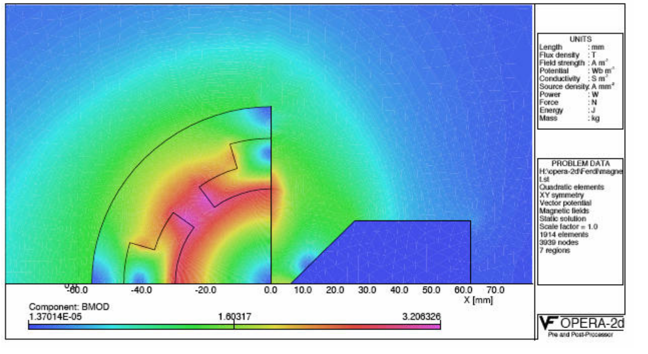
separation has "to start at the IP"

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

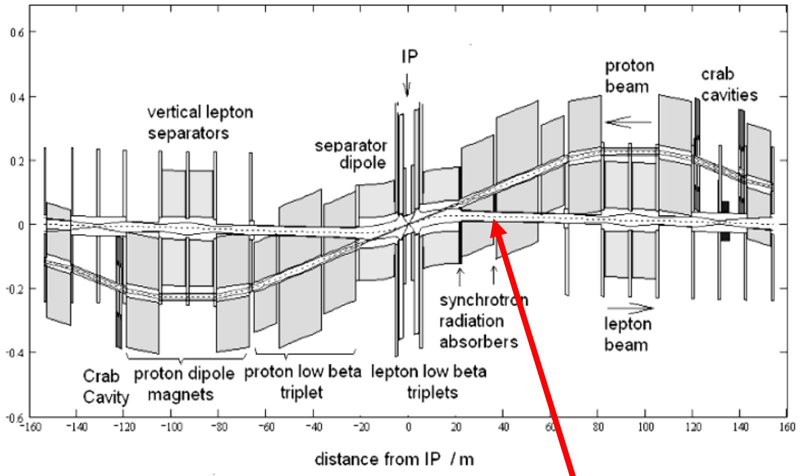


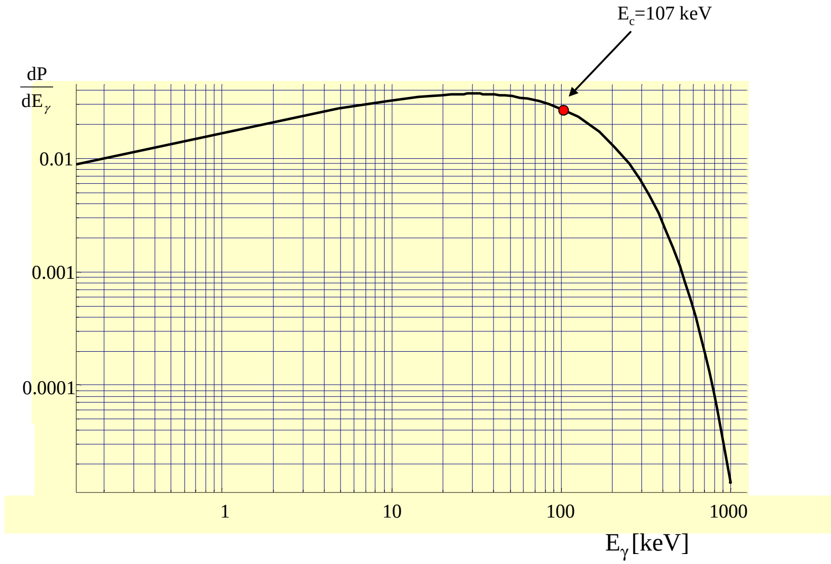
technical challenges:

sc half quadrupoles,
e beam guided through p-quad cryostat
crab cavities needed to avoid loss of luminosity

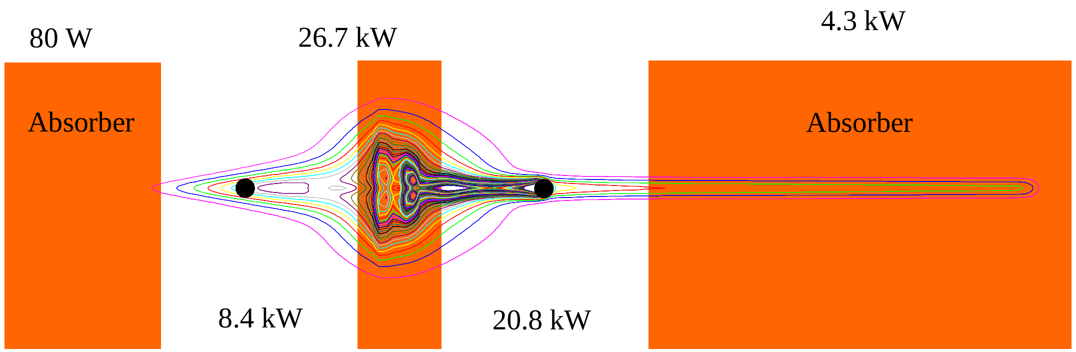


IR Design: Synchrotron Radiation





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 ?

Ring-Ring Parameters

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

LHC upgrade: N_p increased.
Need to keep e tune shift low:
by increasing β_p, decreasing β_e
but enlarging e emittance,
to 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 $\Delta\nu_e = 0.048$
LHC-B $\Delta\nu_p = 0.0037$

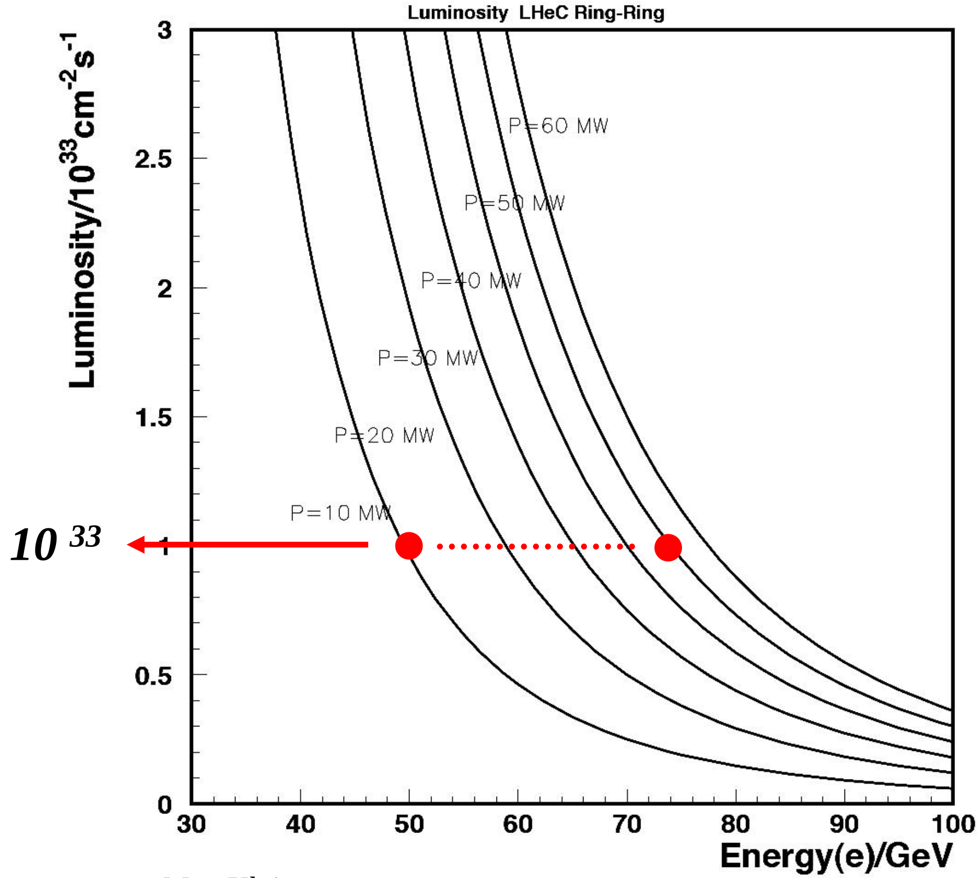
HERA $\Delta\nu_e = 0.051$
$\Delta\nu_p = 0.0016$

Standard Parameter	Protonen	Elektronen	
	$Np=1.15*10^{11}$	$Ne=1.4*10^{10}$	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	Δνx=0.00055	Δνx=0.0484	
	Δνy=0.00029	Δνy=0.0510	
Luminosity	$L=8.2*10^{32}$		
Ultimate Parameter	**Protonen**	**Elektronen**	
	$Np=1.7*10^{11}$	$Ne=1.4*10^{10}$	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	Δνx=0.00061	Δνx=0.056	
	Δνy=0.00032	Δνy=0.062	
Luminosity	$L=1.03*10^{33}$		
Upgrade Parameter	**Protonen**	**Elektronen**	
	$Np=5*10^{11}$	$Ne=1.4*10^{10}$	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	
Strahlgröße	σx=44 μm		
	σy=27 μm		
Tuneshift	Δνx=0.0011	Δνx=0.057	
	Δνy=0.00069	Δνy=0.058	
Luminosität	$L=1.44*10^{33}$		

Luminosity Ring Ring & Performance Limit

Design values are for 14 MW synrad loss (beam power) and 50 GeV on 7000 GeV. May have 50 MW and energies up to about 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

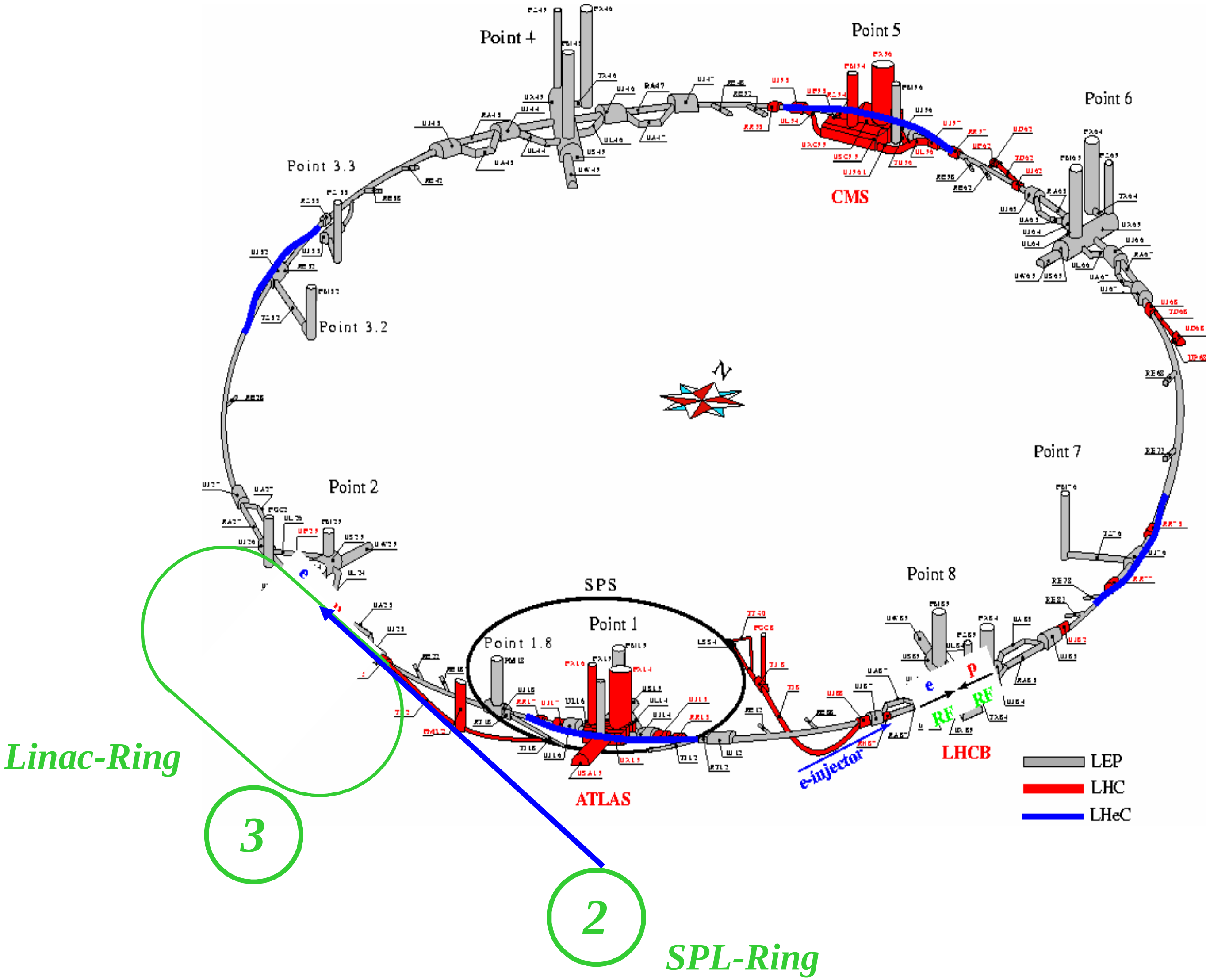
E_e = 50 GeV ↔ P_{syn} = 10MW
*E_e = 75 GeV ↔ P_{syn} = 50MW * 2*

klystron efficiency: 50%

Overall power consumption: limited to 100MW

Linac Ring Options:

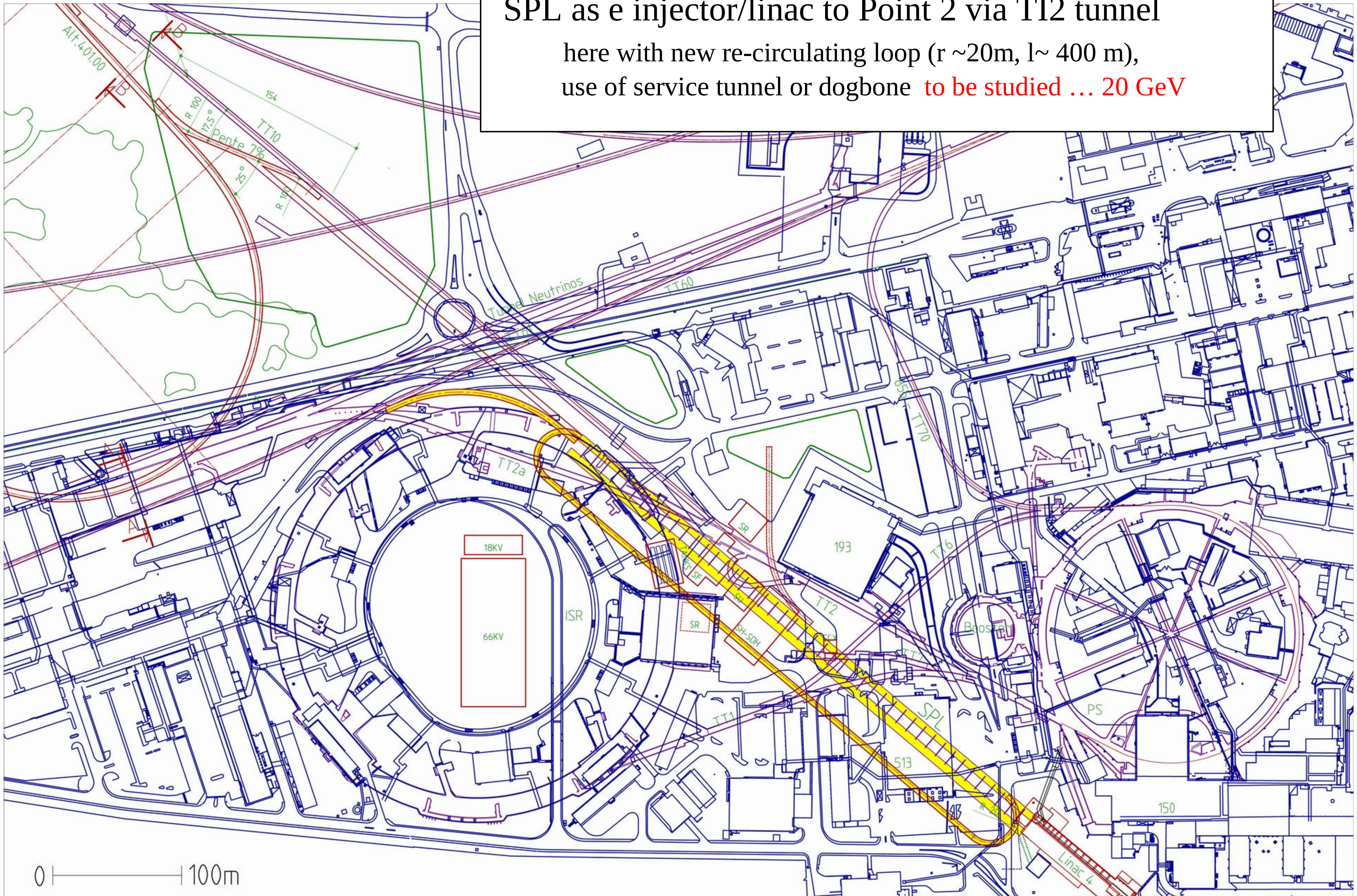
SPL ... or a recirculating Linac



SPL as e injector/linac to Point 2 via TI2 tunnel

here with new re-circulating loop (r ~20m, l~ 400 m),

use of service tunnel or dogbone to be studied … 20 GeV



for SPL see CERN-AB-2008-061 PAF. R.Garoby et al.

Drawing by TS CERN

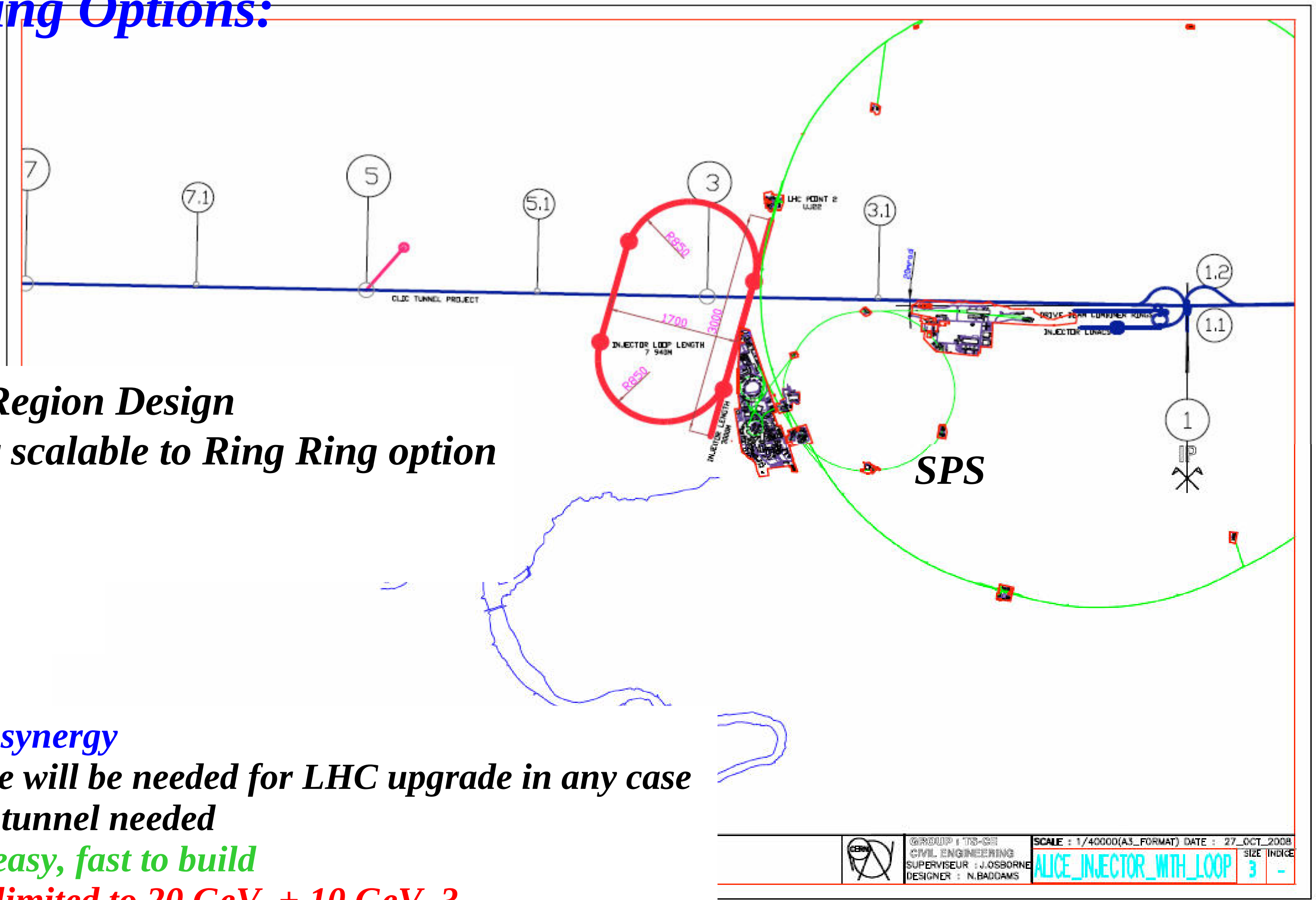
Linac Ring Options:

SPL ... or a recirculating Linac

		Pulsed	CW
e- energy [GeV]	30	100	100
comment	SPL* (20)+TI2	LINAC	LINAC
#passes	4+1	2	2
wall plug power RF+Cryo	100 (1 cr.)	100 (3 cr.)	100 (35 cr.)
bunch population [10^9]	10	3.0	0.1
duty factor [%]	5	5	100
average e- current [mA]	1.6	0.5	0.3
emittance $\gamma\varepsilon$ [μm]	50	50	50
RF gradient [MV/m]	25	25	13.9
total linac length β=1 [m]	350+333	3300	6000
minimum return arc radius [m]	240 (final bends)	1100	1100
beam power at IP [MW]	24	48	30
e- IP beta function [m]	0.06	0.2	0.2
ep hourglass reduction factor	0.62	0.86	0.86
disruption parameter D	56	17	17
luminosity [10^{32} cm^{-2} s^{-1}]	**2.5**	**2.2**	**1.3**

F.Zimmermann, S. Chattopadhyay

Linac Ring Options:



Interaction Region Design
... similar or scalable to Ring Ring option

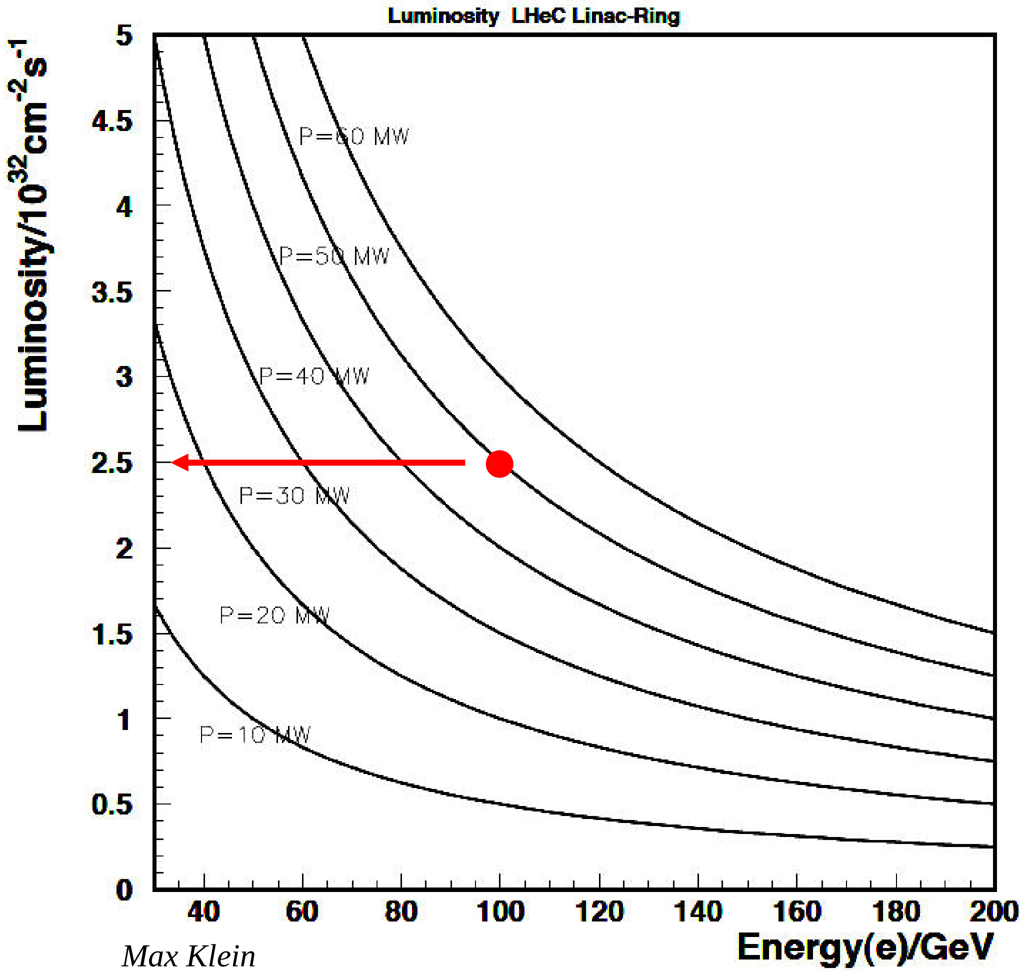
SPL: ***perfect synergy***
machine will be needed for LHC upgrade in any case
no new tunnel needed
cheap, easy, fast to build
energy limited to 20 GeV + 10 GeV ?

new e-Linac: ***100 GeV seem to be feasible***
recirculating
size ≈ SPS / HERA

Luminosity Linac Ring:

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

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



Max Klein

Luminosity Performance Limit:
beam power

adequate for high beam energy

Conclusion:

** three options studied,*

Ring-Ring
SPL - Ring ... *optimising still to be done*
Linac Ring

** Interaction Region & beam separation scheme do not differ too much,*
have to be optimised according to the beam charateristics

** Performance Limitations are quite different*
given an overall power limit of 100MW

Ring Ring:	*75 GeV /*	*7 TeV ,*	$L = 2.2*10^{33}$	*limited in energy*
SPL:	*20-30 GeV /*	*7 TeV*	$L = 2.5*10\ 32$	*fast, cheap, easy*
Linac Ring:	*100 GeV /*	*7 TeV ,*	$L = 2.2*10^{32}$	*limited in luminosity*
	140 GeV /	*7 TeV ,*	$L = 1.0*10^{33}$	*only if energy recovery woks.*

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 $\rightarrow$ PS2, SPS $\rightarrow$ SPS2 ??)
- Electron-deuteron e-d collisions would require a completely new source (at least!)
  - Present CERN complex does not foresee deuterons

e-Pb collisions

- Present nominal Pb beam for LHC
  - Same beam size as protons, fewer bunches

    $k_b = 592$ bunches of $N_b = 7\times10^7$ $^{208}Pb^{82+}$ nuclei
- Assume lepton injectors can create matching train of e^-

    $k_b = 592$ bunches of $N_b = 1.4\times10^{10}$ e^-
- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV

    $L = 1.09\times10^{29}\ \text{cm}^{-2}\text{s}^{-1} \quad \Leftrightarrow \quad L_{\text{en}} = 2.2\times10^{31}\ \text{cm}^{-2}\text{s}^{-1}$

    (gives 11 MW radiated power)
  - May be some scope to exploit additional power by increasing electron single-bunch intensity

Very(!) tentative e-d luminosity

- Rough guess for beam via Linac3
  - Same beam size as protons, fewer bunches, as for Pb

$$k_b = 592 \text{ bunches of } N_b = 1.7\times10^9 \text{ deuterons}$$

- Assume lepton injectors can create matching train of e$^-$

$$k_b = 592 \text{ bunches of } N_b = 1.4\times10^{10} \text{ e}^-$$

- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV

$$L = 2\times10^{30} \text{ cm}^{-2}\text{s}^{-1} \quad (\text{gives 11 MW radiated power})$$

  - Optimist might hope for maybe 10-50 times more if Linac4 and other systems work well.
  - A lot of further study required!!