LHeC Ring-Ring

early stage : all rather preliminary !

- **LHeC : LHC Proton-Ion Ring + Electron Ring** (or Linac, see next talk)
- **Introduction - baseline assumptions**
- **Layout Bypass Tunnels**
- **Power considerations**
- **Injectors**
  - **re-using LEP injectors ?**
  - **alternatives - LINAC and scaled ELFE @ CERN**

based on

original plans : E. Keil, "LHC ep option," LHC-Project-Report-093 March 1997

more recently : J. B. Dainton, M.Klein, P. Newman, E.Perez, and F. Willeke, hep-ex/0603016

here mostly : discussions and material from my CERN colleagues and in particular Oliver Brüning, John Jowett, Kurt Hübner, John Andrew Osborne, Brennan Goddard, Volker Mertens, Trevor Linnecar, Hans Braun, Werner Herr

Introduction

LHeC : existing LHC 7 TeV Proton and Ion Ring

+ new ~ 50 - 70 GeV Electron Ring or Linac - see next talk

for ~ TeV collisions in c.m.s

Ring-Ring : starting point and baseline

Original plan : electron storage ring - could become an energy recovery ring

Here mostly : looking at layout, integration, simple estimates and scaling

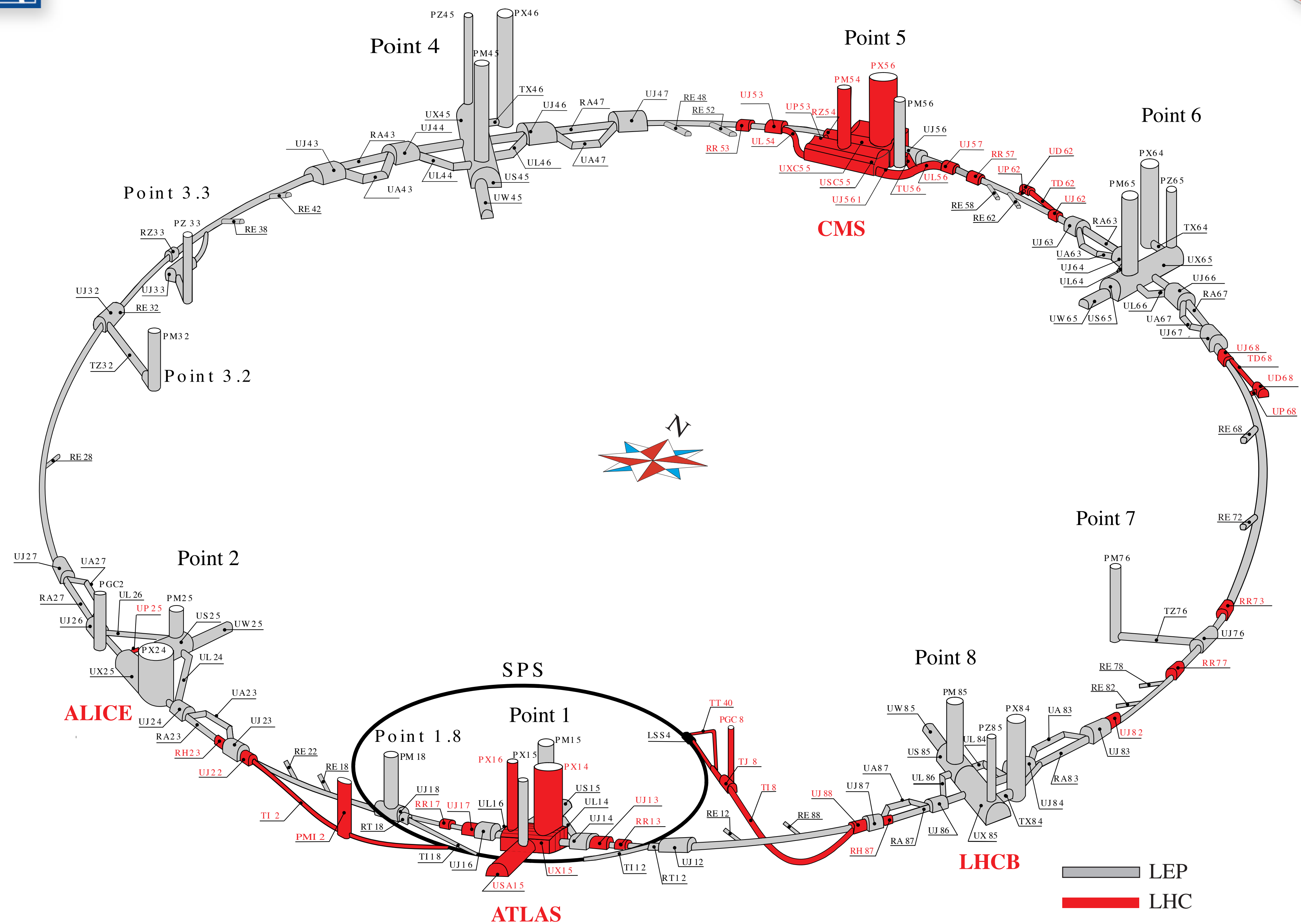
with in particular bypasses around ATLAS / CMS

idea : allow to run the LHC and LHeC as much as possible in parallel

install LHeC without need for very long LHC shutdown

tunneling speed about 10 m / week : 250 m tunnel pieces in 1/2 y shutdown

Layout LHC



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RE 52
Point 5
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TI 2
PMI 2
SPS
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Point 1.8
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PX16
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LSS4
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PGC 8
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UL16
US15
UL14
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UJ 12
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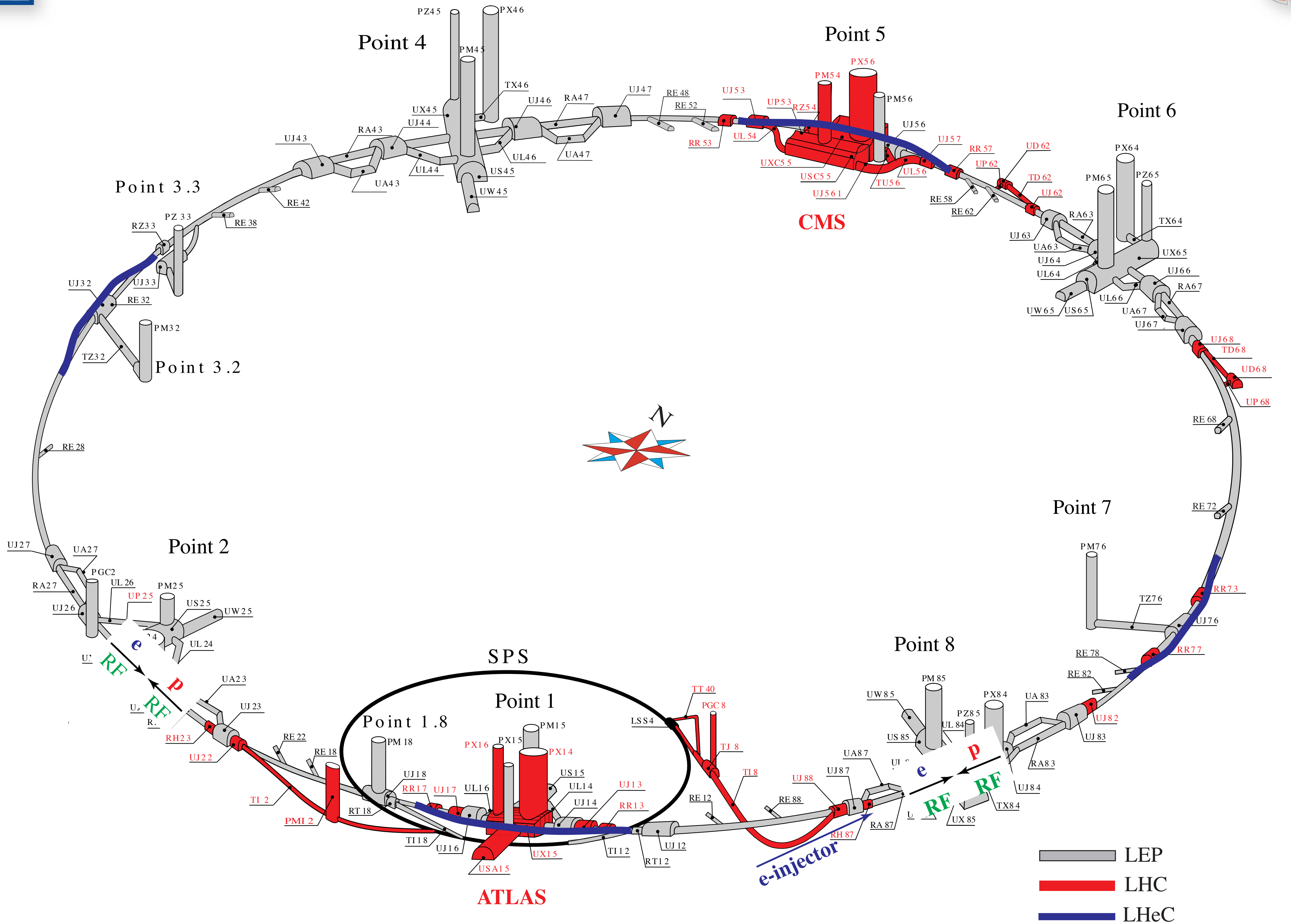
RE 12
ATLAS
N
LEP
LHC

Layout LHeC



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UJ43
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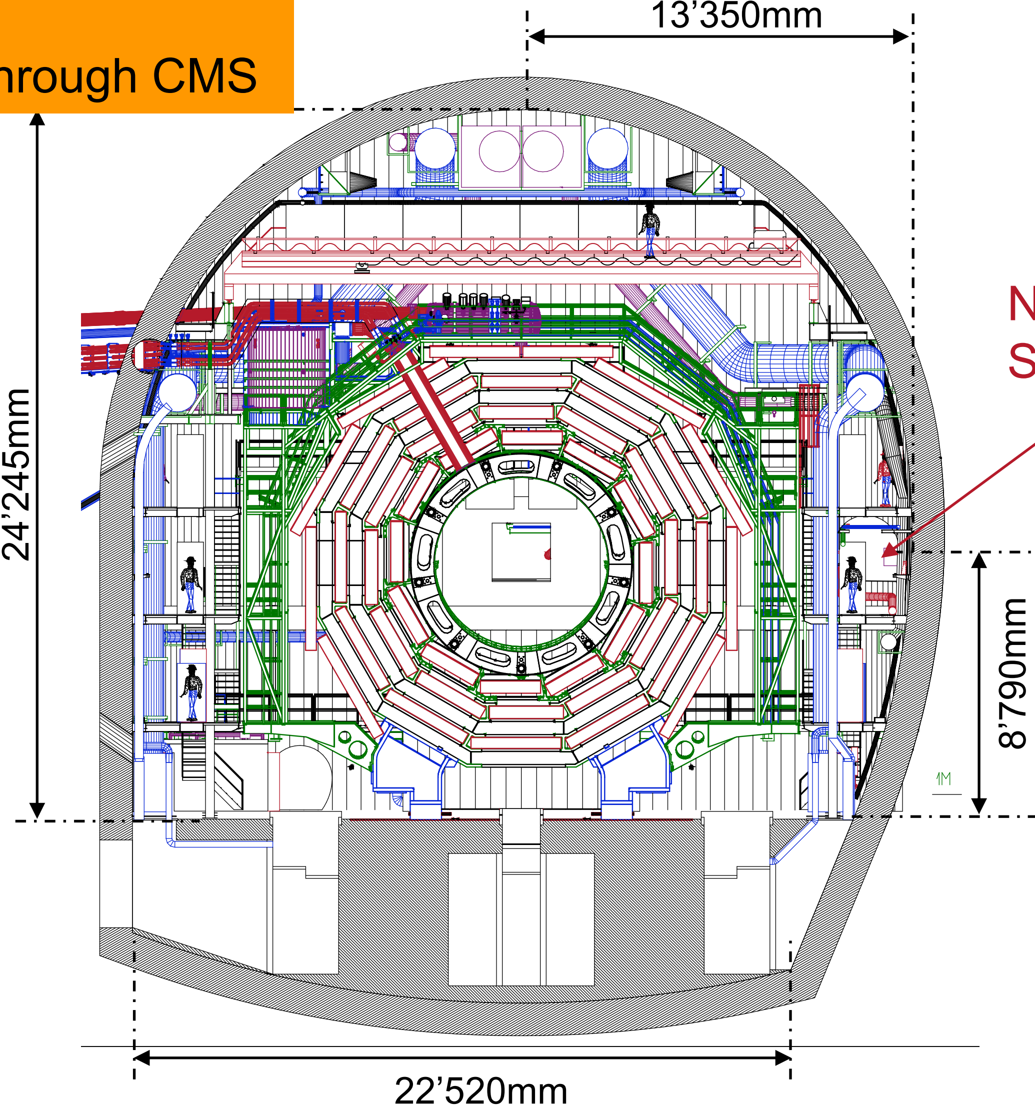
UL46
UA47
UL 54
RR 53
UXC55
USC55
UJ561
TU56
UL56

LHeC Ring-Ring : Summary Table for Extra Tunnels

	Point 1 ATLAS	Point 5 CMS	Point 2 and/or 8 RF	Point 3 Collimators	Point 7 Collimators	
Type	Bypass Experiment	Bypass Experiment	Bypass ; allow for space for e - ring RF	Bypass Collimation	Bypass Collimation	
Approximate Tunnel length	500 m	500 m	500 m	500 m	500 m	2500 m - 3000 m
Diameter	4.40 m	3.80 m	5.50 m	4.20 m	3.80 m	
Distance to p-Ring axis	10 - 13 m	10 - 13 m				

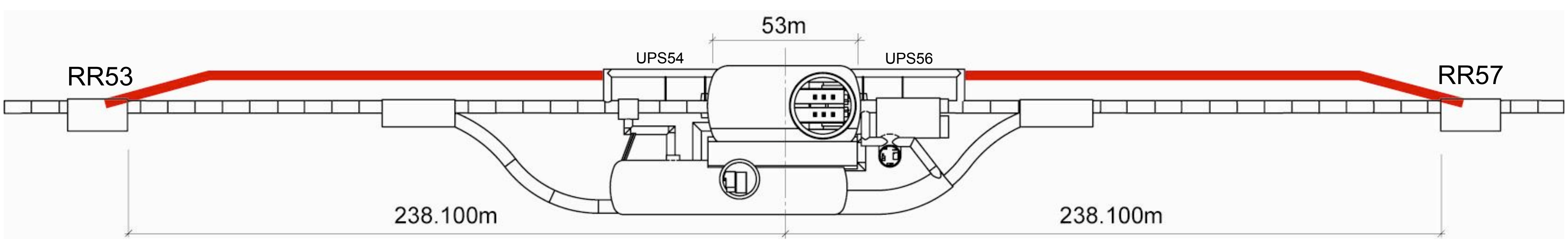
based on layout and integration considerations, very prelim.

LHeC
Typical Cross Section through CMS



New beam in Survey Gallery

(UPS54)



from J.A. Osborne CERN/TS

LHeC
UPS 54 Survey Gallery

from J.A. Osborne CERN/TS

LHeC

View from UPS54 Survey Gallery into CMS Cavern on Walkways

from J.A. Osborne CERN/TS

Ring Layout and Optics Considerations

well known starting point :

LEP with its FODO lattice, matching the tunnel and LHC layout.

basic LEP numbers :

73 % of circumference in arcs, 88 % of arcs with dipoles

79 m long cells ; bending angle of half cell 11.30640 mrad

from 3 × 11.55 m long dipoles

dipole bending radius ϱ = 3096.175 m

31 cells per octant; in total 8 × 31 = 244 cells

Equal Circumference of p and e Rings ?

Needed ?

- **Maybe** : for abort or rather ion-instability cleaning gap
  - same C allows synchronisation with p-abort gap and fixed bunch pairing for collisions
  - otherwise : packman bunch effects, mixed pairing with increased heating of p-beam, ---> beam-beam simulations to be more quantitative

Possible ?

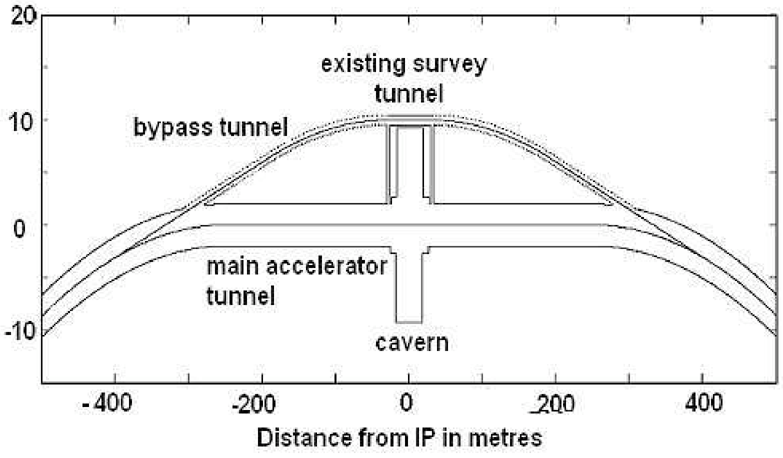
- **Yes** : a bypass adds little in circumference

the 10 m bypass shown later adds only $\Delta = 0.42$ m in C, can be compensated

by decrease in e-ring radius of $\Delta/4\pi = 6.7$ cm

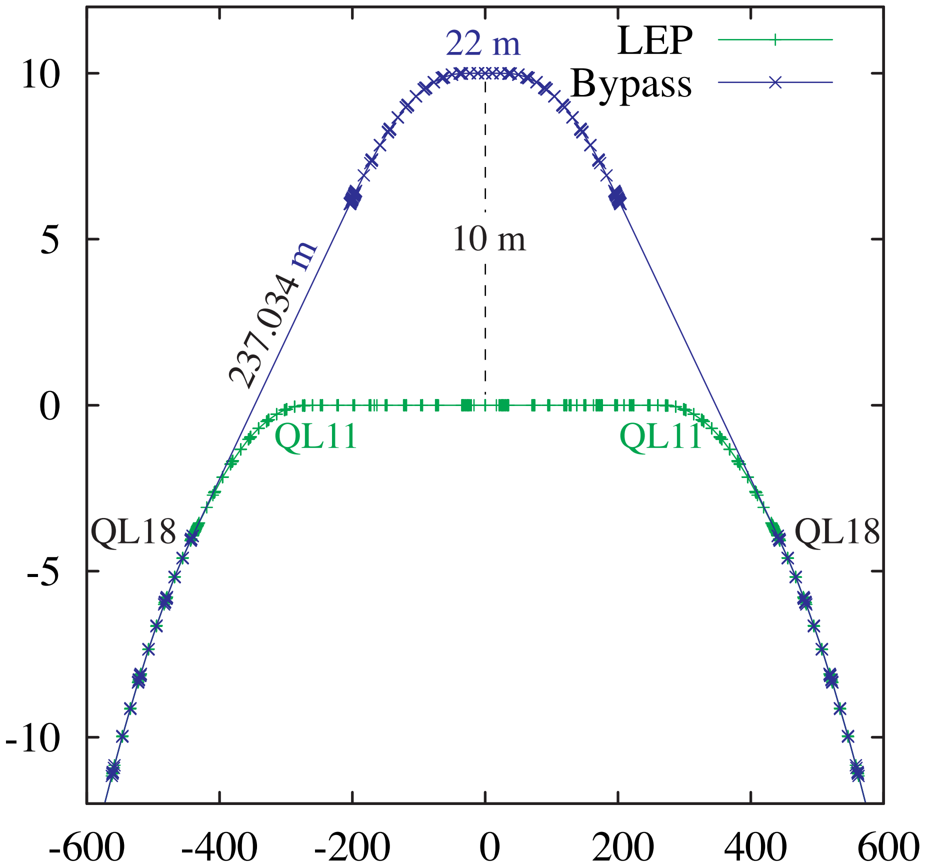
Bypass Layout Study - based on LEP lattice - no extra bends

schematic layout
Dainton / Willeke et al.

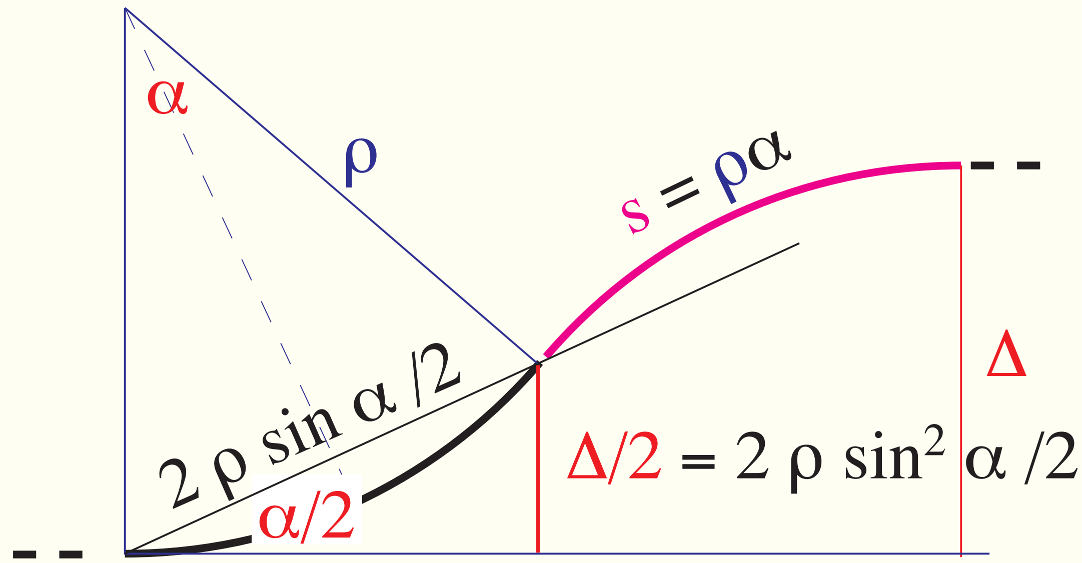


LEP lattice

Point	θ	$\Delta\theta$	Δs IP5, m
QD24.L5	0.1100390391	0.0113064017	677.879431
QF23.L5	0.09873263743	0.0113064017	638.379431
QD22.L5	0.08742623577	0.0113064017	598.879431
QF21.L5	0.07611983411	0.0113064017	559.379431
QD20.L5	0.06481343245	0.0113064017	519.879431
QF19.L5	0.0535070308	0.0113064017	480.379431
QL18.L5	0.04220062914	0.0113064017	440.479431
QL17.L5	0.03843462774	0.0037660014	408.049431
QL16.L5	0.03089842621	0.0075362015	380.979431
QL15.L5	0.02336222468	0.0075362015	353.909431
QL14.L5	0.01582602315	0.0075362015	326.839431
QL13.L5	0.008289821623	0.0075362015	299.769431
QL12.L5	0.0007536200942	0.0075362015	272.699431
QL11.L5	0.0	0.0007536201	245.629431



Compact **Bypass with extra bends**



lateral separation $\Delta = 4\,\rho\,\sin^2\frac{\alpha}{2}$

total length in bends in bypass $s = 4\,\rho\,\alpha$

using standard LEP bends, ϱ = 3026 m, we would need α = 57 mrad to get Δ = 10 m separation by 4 x 176 m of bends. This would add 3.6% in the total energy loss.

In absolute, the loss in such a bypass is 1.8 MW at 70 GeV for 70 mA beam current.

With 2x stronger bends in bypass : 4 x 124.5 m long bends, adding 5.1% in power

LHeC Electrons ; Intensity / Power considerations

f_{rev} = 11245. 5 Hz given by LHC circumference #bun = 2800

high collision frequency f = #bun × frev = 31.5 MHz and high beam current

beam current I = n e f e = 1.60218 × 10^{-19} As

Ring : loss in SynRad $U_0 = C_\gamma E^4/\rho$ ρ = 2997 m LEP had ρ_{eff} = 3026.42 m

LINAC : beam power P = V I

machine	N / bun	#bun	Ntot / beam	I beam	V [GV]	P_{acc}= V I [MW]	U_0 [GeV]	Psyn [MW]	
LEP 2	4.16E+11	4	1.67E+12	4×0.75 mA	100	300	2.923	8.77	
LHeC, ring-e	1.40E+10	2800	3.92E+13	70.63 mA	70	4944	0.7087	50.05	*ultimate*
					50	3531	0.184	13.0	LHeC 1

power needed in case of direct Linac, several GigaWatt

Max Klein - ECFA 30/11/2007

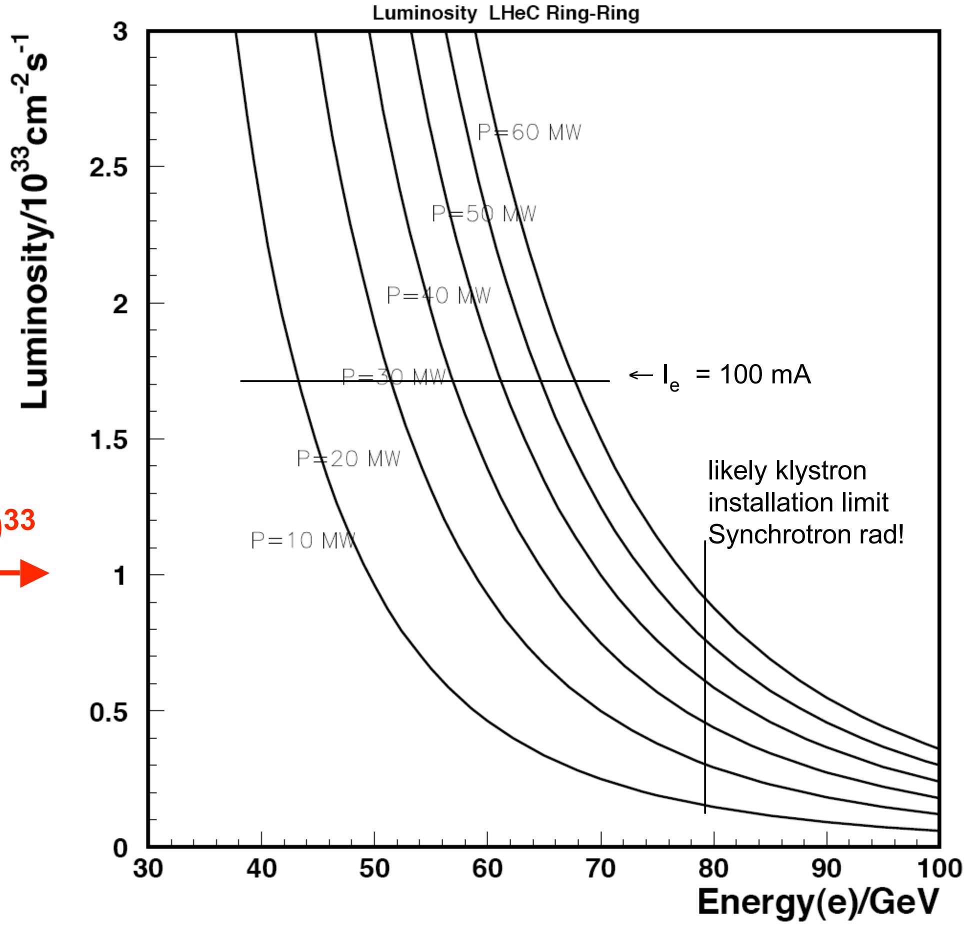
Luminosity: Ring-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.3 10^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 1.7 \cdot 10^{11}$$
$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$
$$\beta_{px} = 1.8m$$
$$\beta_{py} = 0.5m$$

$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

10^{33} →



10^{33} can be reached in RR
E_e = 40-80 GeV & P = 5-60 MW.

HERA was 1-4 10^{31} cm^{-2} s^{-1}
huge gain with SLHC p beam

F.Willeke in hep-ex/0603016:
Design of interaction region
for 10^{33} : 50 MW, 70 GeV

May reach 10^{34} with ERL in bypasses, or/and reduce power.
R&D performed at BNL/eRHIC

cf also A.Verdier 1990, E.Keil 1986

LEP injectors

what we had, with electron energy range   and what is left

- LIL 600 MeV ; gone ; replaced by CLIC
- PS 0.6 - 3.5 GeV ; nothing left for e-acceleration - old machine - not very reasonable to re-upgrade for leptons
- SPS 3.5 - 22 GeV ; 8 MV 200 MHz TW cavities not ok for leptons ; had extra cavities for leptons, removed for impedance reduction ; Impedance issue - no increase wanted ! rather needs further reduction for LHC ultimate

LEP injectors were all removed.

Rebuilding them is not really an option.

Parts and components could be re-used in new injectors

(kickers, parts and components of transfer lines)

new LHeC injectors

basic parameters :

about 20 GeV injection energy

be able to fill reasonably fast - say within 10 min

low intensity 1.4×10^{10} / bunch – could do without accumulation

many (2800) bunches, 25 ns spacing, total intensity 3.92×10^{13} electrons

injection scheduling :

analog to protons (3 - 4 batches of nominally 72 bunches)

e+ and e- : no principle problem - needs extra e+ source and possibility to change polarities

direct injection @ about 20 GeV

- **low energy Linac, e- and e+ conversion (@ 0.2 - 0.5 GeV), EPA like e+ acc. ring accelerate with synchrotron ; same principle as we had of LEP**

- **what about 20 GeV Linac based on CLIC ?** clictable2007.html

  high gradient 100 MV/m in 85% of LINAC ; L = 235 m to reach 20 GeV

  N = 3.72e9 / bun; k = 312 bun/train ; Linac repetition rate of 50 Hz : 5.83e13 Elec/sec. Significant overhead for drive beam generation - probably not very economic for a relatively short LINAC

- **20 GeV SC Linac, inspired by ILC**

  gradient 31.5 MV/m (ILC BCD) **in 85% of LINAC : L = 747 m**

  N = 2e10 / bun, k = 2820 bun /train ; repetition rate of 5 Hz : 2.82e14 Elec/secs

  modify to match LHC batch structure

- **or →**

ELFE @ CERN

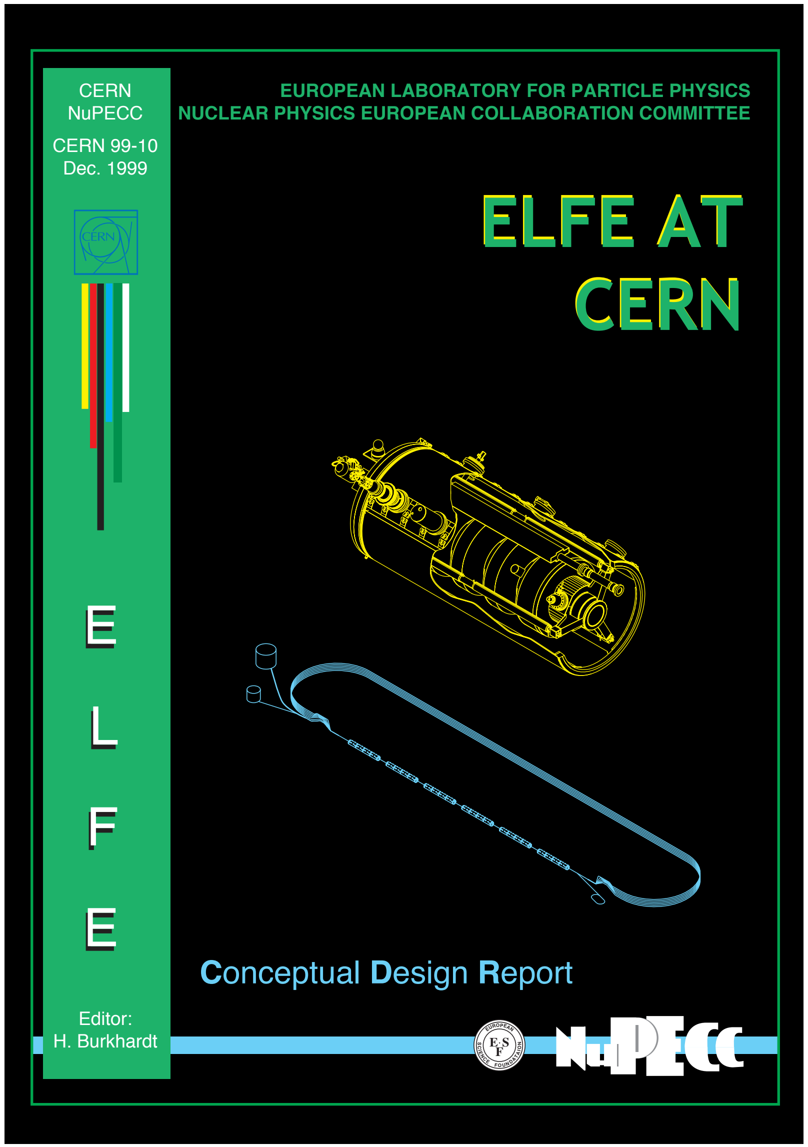


Table 1: ELFE performance parameters.

Top energy	25 GeV
Beam current on target	100 μA
Beam power on target	2.5 MW
Injection energy	0.8 GeV
Number of passes	7
Energy gain per pass	3.5 GeV
Relative r.m.s. momentum spread at top energy	$\leq 10^{-3}$
Emittance at top energy	$\leq$ 30 nm
Bunch repetition time on target	2.8 ns

Table 2: Estimated capital expenditure for the construction of ELFE at CERN.

System	MCHF	MCHF	MCHF
Injection	20.400		
RF system	10.868		
Cryogenics	63.000		
Magnets	55.209		
Vacuum	19.410		
Beam diagnostics	9.400		
Power converters	11.165		
Control system	10.000		
Accelerator components		199.452	
Electrical power distribution	29.031		
Civil engineering	109.700		
Experimental hall(s)	31.200		
Cooling, ventilation, etc.	25.773		
Access control, etc.	2.050		
Conventional construction		197.414	
Total			397.206

with LEP RF for free

modified ELFE as LHeC injector

ELFE@CERN

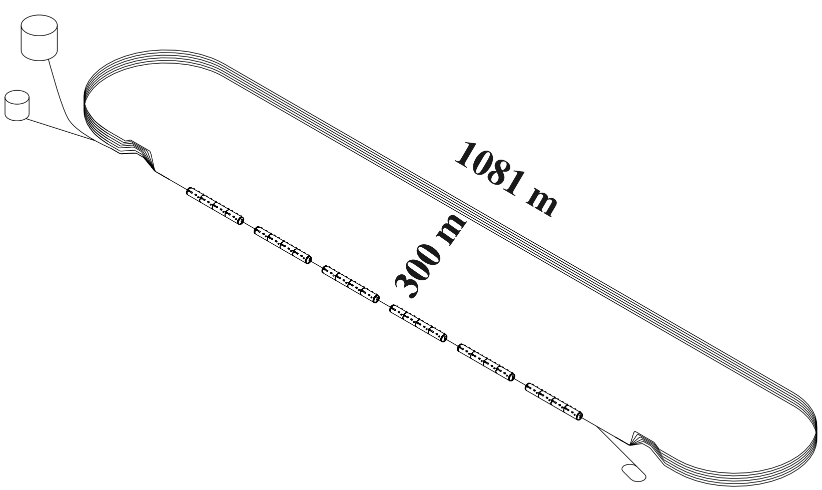
f_{rf} = 352 MHz, gradient 8 MV / m

V_{rf} = 3.5 GV, 72 rf-modules

7 passes (last at 21.5 GeV)

L = 3924 m of which Linac 1081 m

ϱ = 56.9 m



LHeC injector

f_{rf} ~ 1 GHz, gradient 31.5 MV/m

Linac L = 150 m 7× shorter

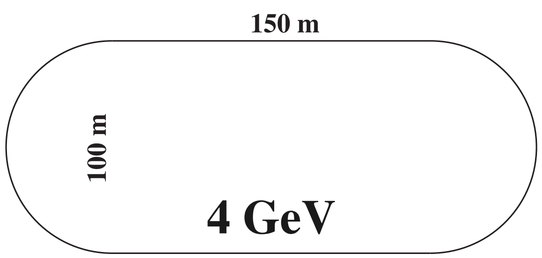
V_{rf} = 4 GV, 5 passes ; last 16 GeV

ϱ = (16/21.5)^4×56.9 m = 17.5 m

or 3.3× shorter

significantly downscaled L ≈ 600 m

and simplified (5 passes) version of ELFE@CERN



recirculating LINAC

more cost effective (?) than single LINAC

+ extra phys. potential

(my) conclusion

p-Ring - e-Ring (both storage rings) as baseline option

proven technology -- no fundamental problems expected

issues : mostly layout - integration

- **cost and time effective bypass design**

  -- with possible synergy with energy recovery rings

- **RF and injectors**

Backup Slides

RF for LEP / LEP Injectors – Notes: T.Linnecar

LEP: 352 MHz RF system

At one point:

- 10 SC modules on each side of IP.
  1 module contains 4 cavities
  Each klystron (1.3 MW) drives 8 cavities (2 modules)
- 80 cavities in 20 modules, 10 klystrons at one point.
  Nb/Cu cavities, 7.5 MV/m average finally
  ~12 MV /cavity, 960 MV total / point
- One point filled with RF, energy ~75 GeV
- Dynamic cryogenic (4.5K) losses 133 W / cavity @ 7.5 MV/m
  12 KW cryogenic plant per point (18 kW finally in LEP but other uses)
- 1 HV power convertor (100 KV / 40 A) for 2 klystrons (65% efficiency).
  ~25 MVA total

- Availability
  No klystrons left
  SC modules stored (state and quantity to be confirmed)
  HV convertors – LHC proton RF

- Space
  10 modules @ 12 m on each side
  Total tunnel length 250 m, *fully occupied*
  Module diameter ~ 80 cm (plus bits sticking out)

  Klystron galleries *fully occupied*
  5 x 1.3 MW RF power / wave-guides / control racks (50) / water cooling units / HV bunkers (3)
  Personnel access possible in LEP, not true with 7 TeV protons
  (electronics in control racks?)

SPS:

- Injection into LHC at 22 GeV (20)

Email from Oliver Brüning, April 2008, on potential collaborators:

General machine design and beam dynamics (lattice and magnets):
DESY
PSI
EPFL
BNL
FERMILAB
SLAC
John Adams Institute (Ted Wilson)
JAI Royal Holloway
Crockcroft

From Louis Rinofli I got the following list of interested collaborators for the source development:

i. Polarized electron source design
1. JLAB (M. Polker), Mainz (K. Aulenbacher)
2. LOA (V. Malka), RAL (G. Hirst)
3. LAL (R. Roux), CEA (F. Orsini)

ii. Unpolarized positron source design
1. LAL (A. Variola)
2. LNF (M. Ferrario), CEA (F. Orsini)
3. Cockcroft Institute (I. Bailey), SLAC (J. Sheppard)
4. LAL (A. Variola), IPNL (R. Chehab)

iii. Polarized positron source design
1. LAL (R. Roux), DESY (S. Schriber)
2. LOA (V. Malka), RAL (G. Hirst)
3. LNF (M. Ferrario), CEA (F. Orsini)
4. KEK (Omori) Ukraine (E. Bulyak)
5. LAL (F. Zomer), KEK (J. Urakawa)
6. Cockcroft Institute (I. Bailey), SLAC (J. Sheppard)
7. LAL (A. Variola), IN2P3 (R. Chehab)

Concerning the polarized positron, we have the POSIPOL group including CERN, LAL, KEK, Hiroshima University, BNL, ANL, SLAC, DESY, Ukraine University, Cockcroft, etc...

The POSIPOL group could be contacted and informed about such proposal.