Lepton on Hadron Collisions in the LHC Tunnel

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The particle and accelerator physics of lepton-hadron collisions in the LHC tunnel were studied at La Thuile [1] in 1987, at Aachen [2] in 1990, and for the CERN Scientific Policy Committee in 1995 [3]. Since then there has been little design activity for lepton-hadron collisions in the LHC tunnel. LEP is being removed from the future LHC tunnel. The LHC will be installed close to the tunnel floor, and a future lepton ring above it. In principle, a passage for the lepton ring will be left free. Exceptions from this principle must be authorized by the LHC Project Leader. There is no such exception up to now.

A generic lepton-hadron experiment and a generic lepton-hadron interaction region were designed [2]. Following [4, 5], the parameters shown in Table 1 were obtained. In the following, superscripts mark lepton ($-$) and hadron ($+$) parameters. The hadron bunch parameters E^+, N^+, $\epsilon^+_{xn} = \epsilon^+_{yn}$ are those in the LHC design. The amplitude functions at the IP $\beta^\pm_x$ and IP $\beta^\pm_y$ are arrived at be approximately scaling from LEP and LHC in proportion to the distance $\ell^\pm_{\rm Q}$ of the first quadrupole from the interaction point IP. The beam-beam tune shifts $\xi^\pm_x$ and $\xi^\pm_y$ are equal to or smaller than the values observed in LEP or assumed for LHC. The lepton bunch current N^- is smaller than in LEP.

Table 1: Parameters of Lepton-Hadron Collisions in the LHC Tunnel

	Lepton ($e^\pm$)	Hadron (p)	
Beam energy E	60	7000	GeV
Bunch population N	0.685	1	10^{11}
Norm. hor./vert. emittance ϵ_n	1120/341	3.75/3.75	μm
Free space to quads $\ell_{\rm Q}$	± 7.5	± 90	m
Hor./vert. β-function at IP β	0.85/0.26	16/1.5	m
Hor./vert. beam radius at IP σ	89.9	27.5	μm
Hor./vert. beam-beam tune shift ξ	30.8/30.8	3.4/1.0	10^{-3}
Number of bunches k	1000		
Average beam current I	180	123	mA
Luminosity L	$2.5 \cdot 10^{32}$		$\rm cm^{-2}s^{-1}$

With the assumed number of bunches k the first parasitic collisions occur at ± 13 m from the IP where the two beams can be separated by 6σ with a full crossing angle $\Phi \approx 0.635$ mr. Since the average lepton current is much higher than in LEP, the e-ring needs powerful $e^{\pm}$ injectors. The synchrotron radiation loss on a turn and power are $U_s = 370$ MeV and $P = 45.6$ MW, if the bending radius is $\rho = 3096$ m as in LEP. The critical energy is $E_c = 155$ keV. The average synchrotron radiation power density, $p = 2.1$ kW/m, is higher than in LEP. Shielding between the lepton and hadron rings by a factor much larger than 2000 limits the synchrotron radiation power absorbed in the super-conducting hadron magnets to less than 1 W/m.

The super-conducting RF system for the lepton ring will operate at the LHC frequency, 400 MHz, and consist of about 200 LHC proton ring cavities. The lattice in the arcs of the lepton ring has a shorter betatron wavelength than LEP with 0.6π phase advance in order to achieve the horizontal emittance in Tab. 1. Hence, the period length in the arcs will also be shorter than in LEP.

Although the polarization time in the lepton ring is only $\tau_p^- \approx 1.43$ h, the observed polarization in LEP at 60 GeV was only about 3%. This suggests that obtaining useful degrees of polarization in the lepton ring is unlikely. Single-beam, single-bunch phenomena are not more harmful than they were in LEP and are expected to be in LHC, since the bunch populations $N^{\pm}$ are not larger. However, single-beam, coupled-bunch phenomena in the e-ring may be more severe, since the number of bunches is much larger.

Because of the asymmetry of the lepton-hadron experiment(s) the direction of the lepton beam is fixed. Transfer tunnels for both e^+ and e^- exist. Changing the lepton polarity needs automatic polarity reversal of the power sources.

Lepton-ion collisions can also be envisaged. The e-Pb luminosity was estimated at $L \approx 10^{29}$ cm^{-2}s^{-1}per Pb nucleus [3].

References

[1] CERN 87-07, Vol. I (1987) 303.

[2] CERN 90-10, Vol. III (1990) 820.

[3] E. Keil, LHC Project Report 93 (1997)

[4] T. Nishikawa and E. Keil, Workshop on Possibilities and Limitations of Accelerators and Detectors, Fermilab, 15 to 21 October 1978.

[5] A. Verdier, CERN SL/90-105 (AP)