DESIGN ISSUES OF TeV LINEAR COLLIDERS

Jean-Pierre Delahaye, CERN, Geneva, Switzerland

ABSTRACT

Within the frame work of a world-wide collaboration, various possible approaches for Linear Colliders in the TeV energy range (TLC) and high luminosity (~ 10^{34} cm^{-2} sec^{-1}) are explored in different laboratories and periodically compared in international workshops. The main accelerator physics issues required to meet the requested performance improvement by three orders of magnitude in luminosity and by a factor 10 in beam energy with respect to the unique linear collider presently operational, the SLC at SLAC, are reviewed, pointing out the main challenges common to all designs as well as the possible technological choices. Corresponding designs based on the improvement of present standard or the development of new technologies are presented, emphasizing their main issues and specific challenges. The main goals of ambitious test facilities presently set-up to study the feasibility and cost of the various schemes in the next few years are introduced.

1 INTRODUCTION

In the quest for higher energies, hadron and lepton colliders with a regular and parallel evolution in the past have shown to be very complementary for the discoveries and studies of elementary particles. This is why, now that the construction of a 14 TeV Large Hadron Collider (LHC) has been launched, the study for a Lepton Collider in the TeV range, complementary to LHC with possibly an option for γ-γ collisions, is strongly supported by the physics community.

The usual technology of lepton colliding beams in storage rings reaches its natural economical limit with LEP2 at ~ 200 GeV c.m. Synchrotron losses scaling with the 4^{th} power of the beam energy makes it prohibitively expensive in the TeV range. Instead the Linear Collider technology with a cost increasing linearly with the beam energy is well adapted to extend the lepton energy frontier. The first and only linear collider built so far, the SLC [1] at SLAC successfully demonstrated their feasibility and operation at a remarkable level of performance. Nevertheless, their cost has to be significantly reduced with respect to present standards which corresponds to about 10 MCHF/GeV.

Because of the size of the complex and the large extrapolation in performance with respect to the SLC, a wide range of technical options is being explored before technology and design parameters are chosen. In the last few years new concepts of beam acceleration based on lasers, plasmas or wakefields have been envisaged but it does not look as if any of these exotic schemes would present the required performance and energy conversion efficiency for such a collider. Finally, all the schemes presently studied are based on conventional RF structures with either improved or advanced power sources. A schematic layout of a TLC is presented on fig. 1 which illustrates all the subsystems common to the various designs as well as the areas requesting developments.

An international collaboration for R & D on **T**eV **L**inear **C**olliders (**TLC**), joining the efforts of 24 laboratories from all over the world was created at EPAC94. A Technical Review Committee (TRC) was nominated with a precise mandate, i.e. “examine accelerator designs and technologies suitable for a collider that will initially have centre of mass energy of 500 GeV and luminosity in excess of 10^{33} cm^{-2} sec^{-1} and be built so that it can be expanded in energy and luminosity to reach 1 TeV centre of mass energy with luminosity of 10^{34} cm^{-2} sec^{-1} “. International workshops are regularly organised to monitor the progress of the studies, compare possible performances with physics requests and favour exchanges between experts in the field. The TRC recently described [2] the status of the

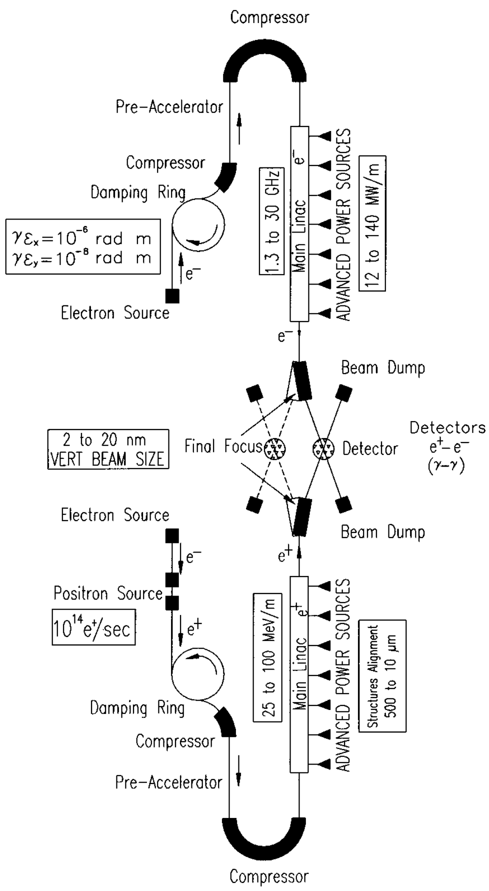

Fig. 1: Schematic layout of a TeV Linear Collider (TLC)

various options from which the updated main parameters are summarized in table 1. Four lines of R & D are intensively studied (as explained in paragraph 5) which mainly differ by the technology and the frequency of the main linac accelerating structures covering a wide range from 1.3 to 30 GHz with:

- a conventional approach in the SBLC study,
- superconducting technology (S.C.) in TESLA
- high frequency klystrons in JLC, NLC and VLEPP,
- a Two Beam Acceleration (TBA) scheme in CLIC and TBNLC.

2 LUMINOSITY

The luminosity is given by the standard formula (see table 1 for definition of parameters):

$$L = \frac{H_D N_b N_e^2 \ f_{rep}}{4\pi\sigma_x\sigma_y} \qquad (1)$$

The enhancement factor, H_D, takes into account the modification of the beam size by disruption during collision at the Interaction Point (I.P.). The so-called pinch effect helps to increase the integrated luminosity by mutual focusing of the bunches when colliding electrons and positrons. But this effect has to be limited as it generates synchrotron radiation by beamstrahlung which is responsible for average beam energy loss, δ_B [3], broadening of the luminosity spectrum and background, all detrimental for good physics conditions:

$$\delta_B \propto \frac{U_b}{\sigma_z} \frac{N_e^{\,2}}{\left(\sigma_x^2 + \sigma_y^2\right)} \propto \frac{U_b}{\sigma_z} \frac{N_e^2}{\sigma_x^2} \qquad (2)$$

A flat beam at the I.P. ($\sigma_y << \sigma_x$) makes possible at the same time a high luminosity and a reasonable δ_B. Acceptable average energy loss, typically of the order of a few %, limits the achievable enhancement factor. Adjusting the vertical focusing at the I.P. to the optimum of the "hourglass" effect, the luminosity at a given beam energy U_b and a specified δ_B only depends on the beam power and its normalized vertical emittance:

$$L \propto H_{Dy} \frac{\delta_B^{1/2}}{U_b} \frac{P_b}{\varepsilon_y^{*1/2}} \propto H_{Dy} \frac{\delta_B^{1/2}}{U_b} \frac{\eta_b^{AC} P_{AC}}{\varepsilon_y^{*1/2}} \qquad (3)$$

In order to reach the specified luminosity of $10^{34}\,cm^{-2}\,sec^{-1}$ at 1 TeV c.m., a future TLC will have to collide beams with several MW of power and extremely small emittances strongly focused to vertical sizes of a few nm at the I.P. (table 1). RMS beam dimensions down to 70 nm have already been demonstrated by an international collaboration in the F.F.T.B. experiment [4] at SLAC and feasibility of a few 10^{-8} rad-m vertical emittances will soon be studied in the Accelerator Test

			TESLA	SBLC	JLC_C	JLC_X	NLC	VLEPP	CLIC
Technology			**S.C.**	⇐	**KLYSTRONS**			⇒	**TBA**
Beam parameters at I.P.									
Centre of mass energy	[TeV]	$2U_b$	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Luminosity	$10^{33}cm^{-2}s^{-1}$	L	6.0	5.0	6.6	5.2	5.5	9.3	6.7
Beamstrahlung mom. spread	[%]	δ_B	2.9	3.1	3.9	3.5	3.2	13.3	3.5
Linac repetition rate	[Hz]	f_{rep}	5	50	100	150	180	300	700
Number of particles/bunch	$[10^{10}e^{\pm}]$	N_e	3.63	1.1	1.0	0.63	0.75	20	0.8
Number of bunches/pulse	[-]	N_b	1130	333	72	85	90	1	20
Bunch spacing	[nsec]	Δ_b	708	6	2.8	1.4	1.4	-	1.0
Transverse emittances .	10^{-8} radm	$\gamma\varepsilon_{x,y}$	1400/25	500/25	330/4.5	330/4.8	400/9	2000/7.5	487/10
RMS beam width .	[nm]	$\sigma_{x,y}$	845/19	335/15	318/4.3	260/3.0	294/6.3	2000/4	315/4.2
Bunch length	[µm]	σ_z	700	300	200	90	125	750	160
Enhancement factor	[-]	H_D	2.3	1.8	1.82	1.4	1.4	2.0	1.24
Beam power per beam	[MW]	P_b	16.5	7.25	3.2	3.2	4.8	2.4	4.49
Main Linac									
RF frequency of main linac	[GHz]	$\omega/2\pi$	1.3	3	5.7	11.4	11.4	14	30
Accelerating field (loaded)	[MV/m]	G	25	17	31.9	58	29.4	91	100
Total two linacs length	[km]	l_T	32	36	18.8	10.4	17.6	7	7.5
Length of sections	[m]	l_s	1.04	6	1.8	1.31	1.8	1.0	0.32
Klystron peak power	[MWatts]	P_k	8	150	50.3	135	50	150	159000
Klystron pulse length	[µsec]	Δ_k	1315	2.8	2.44	0.5	1.2	0.5	0.041
RF pulse compression ratio	[-]	-	-	-	5	2	3.6	3.2	-
Number of klystrons	[-]	N_k	604	2517	4184	3320	4528	140	10
AC to RF efficiency	[%]	η_{RF}^{AC}	35	37	22.6	30	28	39	35
AC to beam efficiency	[%]	η_b^{AC}	19	10.7	4.2	5.6	7.9	8.4	9.4
AC power for RF generation	[MW]	P_{AC}	88	136	153	114	121	57	96

Table 1: Main parameters of TLC designs in a first stage at 500 GeV c.m., updated from [2]