REVIEW OF LINEAR COLLIDER DESIGNS AND PATH TO THE FUTURE

M. Tigner, Cornell University

Abstract

In the world of accelerator based particle physics, it is now widely agreed that, after LHC, an e+e- linear collider should be the next energy frontier accelerator. A start up energy of 0.5 TeV CM is also generally agreed on and several approaches have been under study for some time. These approaches using both normal conducting and superconducting technology are briefly described, the design issues enumerated and some thoughts about the future beyond the next generation of linear collider reviewed.

1 INTRODUCTION

High level panels in Asia, Europe and America have all recommended that an e+e- linear collider be the next frontier accelerator after LHC. It is generally agreed that the focus of such a machine should be on electro-weak symmetry breaking, in the beginning, as a complement to LHC. That being the case, a starting energy of 0.5 TeV CM with capability of extension to about 1 TeV or more is indicated as is a luminosity of the order of 10^{34} cm^{-2}s^{-1}. In terms of first linear collider, the SLC at SLAC, the energy needed will be 5 to 10 (or more) times greater, the luminosity 10^4 greater and the beam size at the collision point 100 times smaller. Challenges indeed. Perhaps the most daunting is the luminosity requirement.

Several approaches to meeting these requirements have been identified over the years. Currently there are three distinct technologies being pursued actively. Japan and America are jointly pursuing a machine based on X-band linacs, the Japanese are also pursuing a C-band approach. The TESLA collaboration, centered at DESY, has developed an L-band superconducting approach. For the next generation beyond that may seek E cm above 3 TeV a collaboration centered at CERN is pursuing a Ka-band (30 GHz) approach with novel power sources.

The cost of such a facility is likely to be such that no one region will feel able to support it alone so that global collaboration seems to be a must. Proper selection of the technology with which to go forward is thus of paramount importance. As an aid in that effort, ICFA, in 2001, commissioned a Technical Review Committee (Loew panel) to make a detailed technical comparison of the various designs and report back this year. The report will be delivered at the ICFA Seminar this October. A preliminary report will be delivered at this conference.

Table 1 shows some of the important parameters for the various machines.

2 COLLIDER DESCRIPTIONS

2.1 TESLA

The TESLA collaboration has developed an L-band superconducting version with layout shown in Fig. 1.

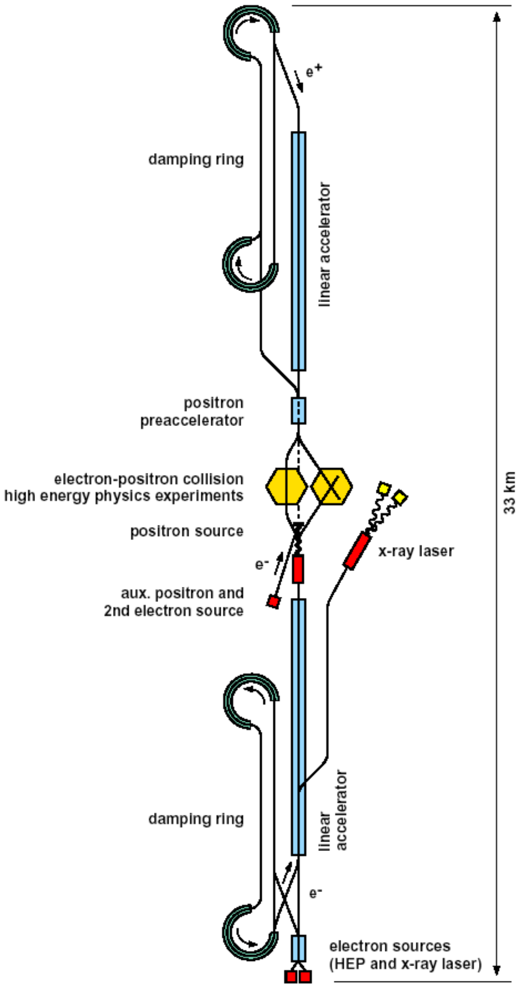

Figure 1. the TESLA layout

An artist's view of the tunnel assembly is shown in Fig. 2. A distinguishing feature of this particular design is the very long damping rings needed to accommodate the ~ 1 ms pulse length afforded by the SC technology.

Table 1 Overall Specifications

	TESLA		JLC (C)		JLC/NLC* (X)		CLIC	
Center of mass energy	500 GeV	800 GeV	500 GeV	1000 GeV	500 GeV	1000 GeV	500 GeV	3000 GeV
RF frequency of main linac (GHz)	1.3		5.7	5.7/11.4¶	11.4		30	
Peak luminosity (10^{33}cm^{-2}s^{-1})	34	58	12.6	25.0	25.0 (20.0)	25.0 (30.0)	14.2	103
Linac repetition rate (Hz)	5	4	100		150 (120)	100 (120)	200	100
No. of particles/bunch at IP (10^{10})	2	1.4	0.75		0.75		0.4	
No. of bunches/pulse	2820	4886	192		192		154	
Bunch separation (nsec)	337	176	1.4		1.4		0.67	
Bunch train length (μsec)	950	860	0.267		0.267		0.102	
Beam power/beam (MW)	11.3	17	5.7	11.5	8.6 (6.9)	11.5 (13.8)	4.9	14.8
Unloaded/loaded gradient† (MV/m)	23.4 / 23.4	35 / 35	41.8/31.5	41.8/31.5 / 70/54	70 / 54		172 / 150	
Total two-linac length (km)	30	30	17.1	30.3	12.6	25.8	5.0	27.5
Total beam delivery length (km)	3		3.7		3.7		5	
Proposed site length (km)	33		33		32		40	
Tunnel configuration♯	Single		Separate		Separate		Two-Beam	

∗ Numbers in ( ) for the JLC/NLC correspond to US site with 120 Hz repetition rate.

¶ The 1 TeV JLC-C collider uses a C-band rf system for the first half of each linac followed by an X-band rf system for the second 250 GeV of acceleration – the X-band rf system would be identical to that described for the JLC-X band collider.

† The main linac loaded gradient includes the effect of single-bunch (all modes) and multibunch beam loading, assuming that the bunches ride on crest. Beam loading is based on bunch charges in the linacs, which are slightly higher than at the IP.

♯ The single tunnel layout has both the klystrons and accelerator structures in the main linac tunnel while the separate tunnel layout places the klystrons and modulators in a separate enclosure. The Two-Beam scheme uses the separate tunnel layout for the drive linac–there are no klystrons and modulators associated with the main linac.

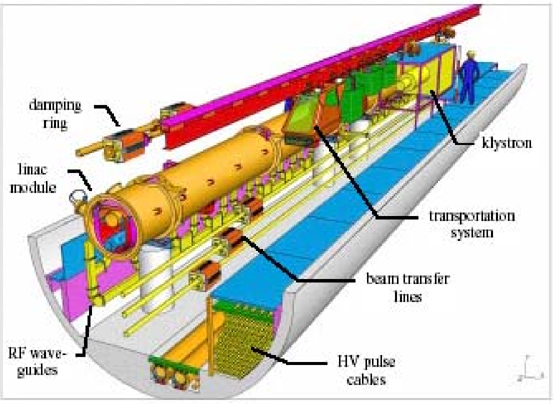

Figure 2 Tunnel layout for TESLA

2.2 *NLC/JLC X-band*

This normal conducting approach looks to the higher frequency to permit gradients considerably higher than those employed in the successful SLC, thereby economizing on the overall length of the facility. Both SLAC and KEK have worked out designs in collaboration, the result being rather similar. A schematic layout for the X-band machine is displayed in Fig. 3. Fig. 4 shows an artist's view of the JLC tunnel layout. Notice the power distribution system which provides the pulse compression needed to provided the required peak power at the accelerator input.

2.3 *JLC C-band*

At KEK a C-band design version has also been developed as offering a somewhat more conservative possibility, C-band technology being considerably closer to the world standard S-band frequency that has been in use for many years. Fig. 5 shows an artist's view in the of the C-band design in the tunnel.

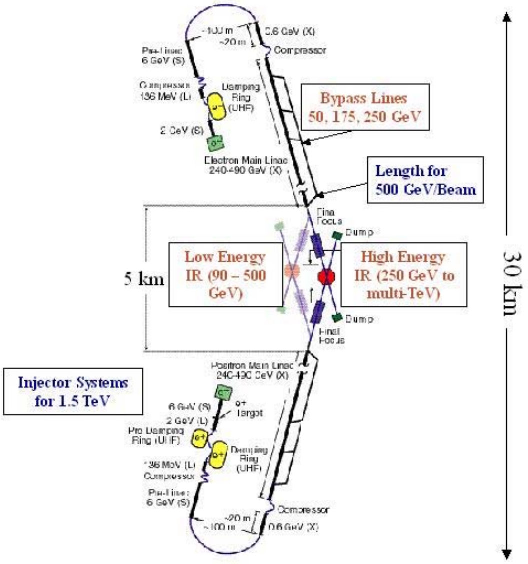

Figure 3 NLC/JLC layout

2.4 *CLIC (3 TeV)*

Aimed at the next generation of linear collider when energies well above 1 TeV will be needed, the CLIC machine utilizes 30 GHz generated in a novel manner. A relatively low energy beam carrying the power needed to accelerate the high energy beams is formed in an L-band normal conducting linac. A vernier

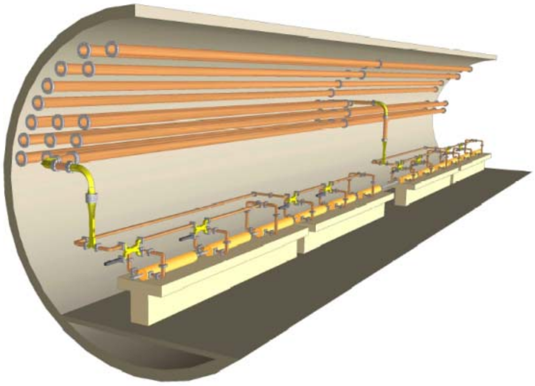

Figure 4 JLC X-band layout in tunnel

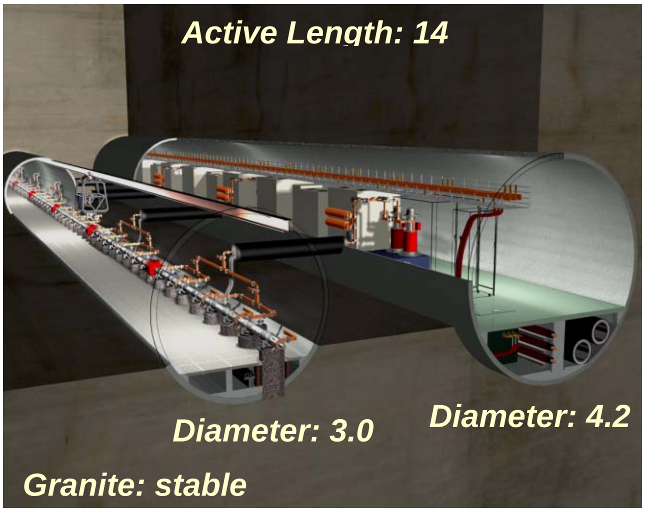

Figure 5 JLC C-band tunnel view

technique using a bypass and two rings is employed to adjust the bunch spacing so that the Fourier component at Ka band is strong. The rebunched beam train is then directed through decelerating structures adjacent the accelerating structures carrying the beams to be collided. In this way the number of klystrons is vastly reduced. The layout of the complex is shown in Fig's. 6 and 7.

3 R&D PROGRAMS AND RESULTS

Extensive test facilities for each of the versions have been constructed and exercised. The proponents are keenly aware of the technical challenges presented by the needed parameters and are actively seeking means for surmounting them. Of course each particular technology has its own challenges. Collectively it is generally agreed that the list of challenges includes, among other things: achievable gradients; pulse compression; klystrons; damping rings; background and collimation; e+ source; reliability/maintainability and positional stability against ground motion. The achievable gradients appear to be a function of cavity design and material and will influence the achievable energy and cost. Pulse compression challenges tolerances and field standoff capability and will also influence achievable energy and cost as will the ability to achieve both peak and average power with the klystrons. The damping rings must achieve two orders of magnitude lower emittance than employed in the SLC. Challenging are the short damping times needed and the high space charge density and vulnerability to electron cloud and ion instabilities. Success here is needed to assure good luminosity. With the extraordinary beam power involved background and collimation are a concern, particularly since background prediction has been shown in the past to be difficult. Conservative designs are thus called for. Again, crucial for integrated luminosity will be reliability and maintainability with the enormous number of active components. Finally, the question of control of vibration due to ground motion will primarily affect the luminosity.

Much has been achieved in all of these areas and the test facilities have served well for exposing and elucidating the issues. Solutions are envisioned for all the issues but demonstration of their effectiveness will require more time. A detailed evaluation will be available in October with the publication of the Technical Review Committee report.

4 PATHS TO THE FUTURE

For future machines, cost will be a primary driver even more than now and may make radically new designs mandatory. The CLIC concept may be the forerunner here. Use of plasmas and lasers as well as shifting to other particles have been mentioned among other possibilities.

4.1 Plasmas

Plasmas have been explored as media for high gradient acceleration now for many years. Recent results and ideas [1,2,3] may breathe new life into this concept. Gradients of ~ 100 MV/m have been measured in beam wakes and experiments to determine of the predicted wake field dependence on the inverse square of the bunch length are planned for 2003. Should this be the case then one can imagine the possibility of energy doubling a linear collider using a self generated wake. Of course there are important developments that must take place before such a thing could be implemented.

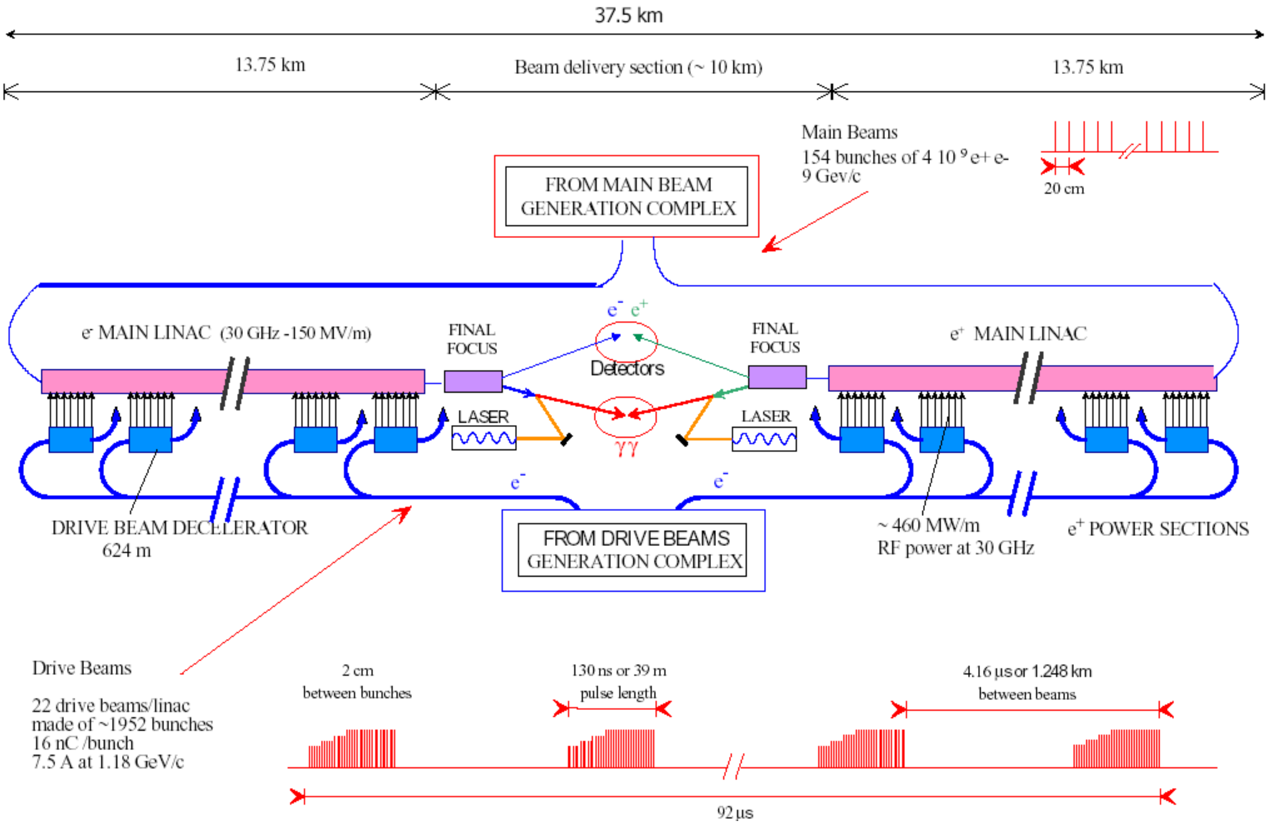

Figure 5 The CLIC overall layout for 3 TeV cm

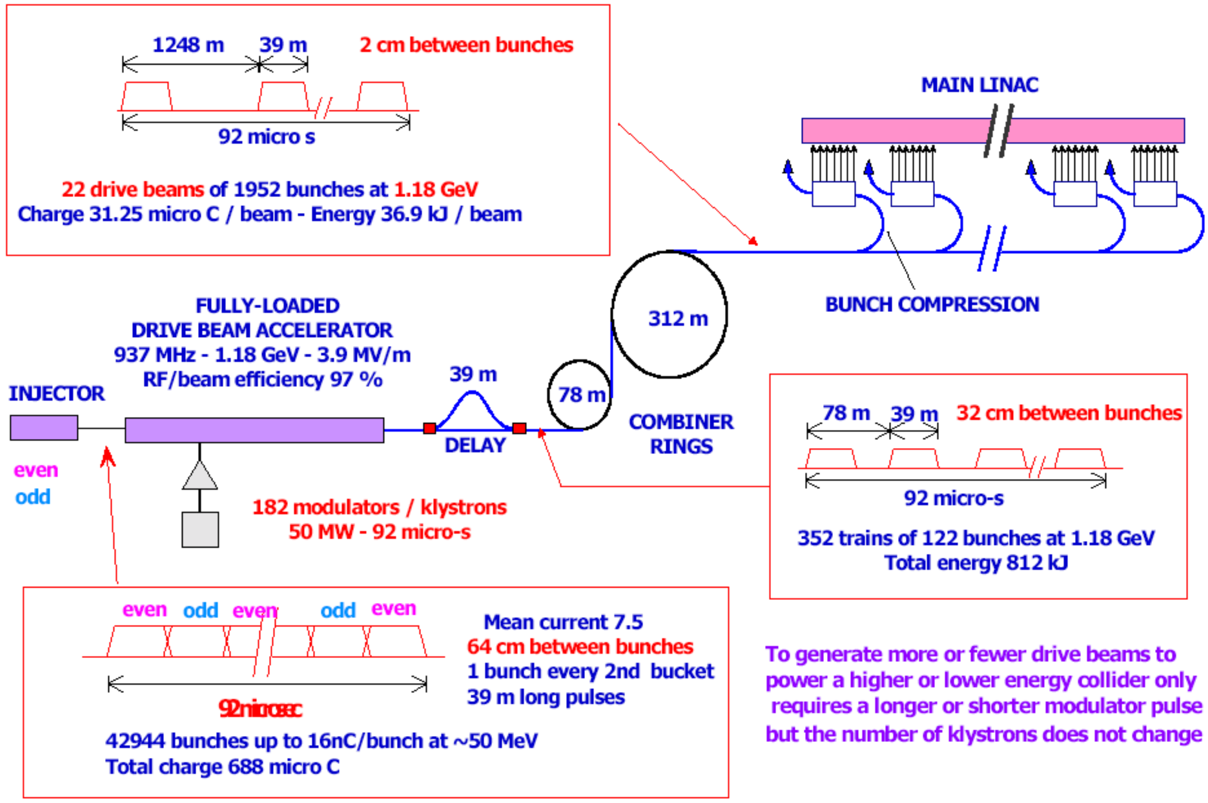

Figure 6 The CLIC power source concept

4.2 Direct Acceleration by Laser

This idea has also been pressed for many years [4,5,6,7]. Here one extends the concept of the microwave linac to light wavelengths, hoping to capitalize of the very high fields at the focus of a laser beam. Poor efficiency of power conversion of lasers and the difficulty of finding suitable mode converting structures has been an impediment. With the rapidly improving laser technology now supported by industry and the burgeoning of nano-fabrication technology this idea may be ready for reexamination.

4.3 Muon Collider

While not strictly a linear collider, a collider for muon beams could take that form provided sufficient cooling could be achieved. e+e- colliders suffer from the enormous beamstrahlung engendered in the collisions. With the inverse fourth power dependence on the mass of the radiating particles, muons offer significant advantage. Indeed the advantage may be enough to permit the storage ring collider configuration to be used again. Recent studies [8] have made great strides in showing what needs to be demonstrated to test the viability of the muon approach and R&D for component development is underway. Recently the ideal of a ring cooler which combines transverse and longitudinal cooling has gained attention. If it can be implemented it will be a key step forward.

5 ACKNOWLEDGMENTS

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