A NEW CONFIGURATION FOR TWO-BEAM LINEAR COLLIDERS

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Abstract

A promising approach to multi-TeV linear colliders is the Two-Beam approach being pursued at CERN[1,2]. In this technique the energy for acceleration is provided by a drive beam that is accelerated efficiently by a fully loaded, low frequency linac. To achieve the correct pulse structure, the beam is compressed in delay rings before delivery to the linac where it is decelerated. The resulting high-frequency RF power is transferred to the main linac accelerator structures to accelerate the primary beams. In this paper we discuss the application of this technique to lower frequency, X-band, and we discuss a new configuration for the generation of the drive beam. We show how the RF power pulse for the drive beam can be extended to be used to accelerate the main beam up to the injection energy of 8 GeV. We also show a recirculating configuration for the drive beam that can substantially reduce the number of RF sources necessary for the Linear Collider.

1 TWO-BEAM ACCELERATION

The basic concept of two-beam acceleration is rather simple. In Figure 1 you see it illustrated with parameters relevant to this paper. A high-current beam, tightly bunched at the operating frequency or a sub harmonic, is decelerated by a low-impedance decelerator structure. The resulting output RF is transferred in a waveguide to a high-gradient accelerating structure where it is used to accelerate the low-current, high-energy beam. In the example shown the drive beam is decelerated by 1.5 MeV each meter while the main beam is accelerated by 93 MeV each meter. The combination of decelerating and accelerating structures acts like a transformer moving the energy stored in the drive beam to the main beam. Depending on the final desired energy, the drive beam must be replaced after it loses about 90% of its energy to maintain its stability during deceleration[2].

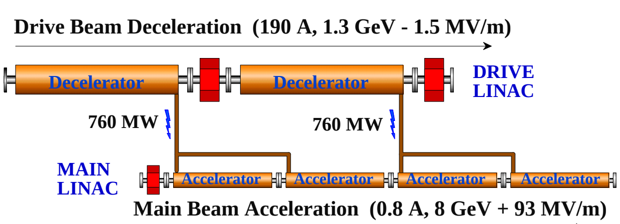


Figure 1: The Basic Concept of Two-Beam Acceleration

The creation of the drive beam is a key problem for two-beam schemes because it must be done efficiently with reliable technology. Recently, a new technique was introduced which uses a low frequency normal conducting linac to accelerate the drive beam. After acceleration the drive beam pulse structure is modified using rings that serve to compress the energy into pulses appropriate for RF production at high frequency. This technique is described in Refs. 1 and 2.

Table 1 An 11.4 GHz Two-Beam Linear Collider

Parameter	Units		½ TeV	1 TeV
Energy	TeV	2 E_b	0.5	1.0
Luminosity	$10^{34}cm^{-2}s^{-1}$	L	1.4	1.4
Beamstrahlung	%	δ_b	3.2	8.3
Beamstrahlung		Y	0.11	0.32
Photons/electron		n_γ	0.86	1.12
Linac rate	Hz	f_r	120	60
Particles/bunch	$10^9 e^\pm$	N_e	7	7
Bunches/pulse		n_b	248	248
Bunch spacing	nsec	Δ_b	1.4	1.4
Emittances	10^{-8}m-r	$\gamma\varepsilon_{x/y}$	400/6.4	400/6.5
Beta functions	mm	$\beta_{x/y}$	12/.12	12/.12
RMS size	nm	$\sigma^*_{x/y}$	310/4.0	220/2.8
Bunch length	µm	σ_z	90	90
Enhancement		H_D	1.46	1.46
Beam power	MW	P_b	8	8
<u>Main Linac:</u>				
RF frequency	GHz	f	11.4	11.4
Loaded Grad.	MV/m	G	93	93
Two linac length	km	l_T	6.5	13
RF power/Acc.	Mwatts	P_s	380	380
RF pulse length	µsec	Δ_K	0.46	0.46
# Drive Beams		N_D	3	6
Frequency Mult.		1	8	8
Compression			16	16
Drive Beam Freq.	MHz		1428	1428
# of klystrons		N_K	80	80
Klystron power	Mwatts	P_K	50	50
Klystron Pulse	µsec	T_K	185	360
AC to RF eff.	%	η_{RF}	40	40
RF to beam eff.	%	$\eta_{RF\text{-}B}$	28	28
AC to beam eff.	%	$\eta_{AC\text{-}B}$	10	10
Wall AC for RF	MW	P_{AC}	160	160

In this paper we introduce two new aspects to the drive beam creation process and the concept of a two-beam linear collider. First, the drive beam is accelerated in <u>multiple passes</u> through the drive beam linac.

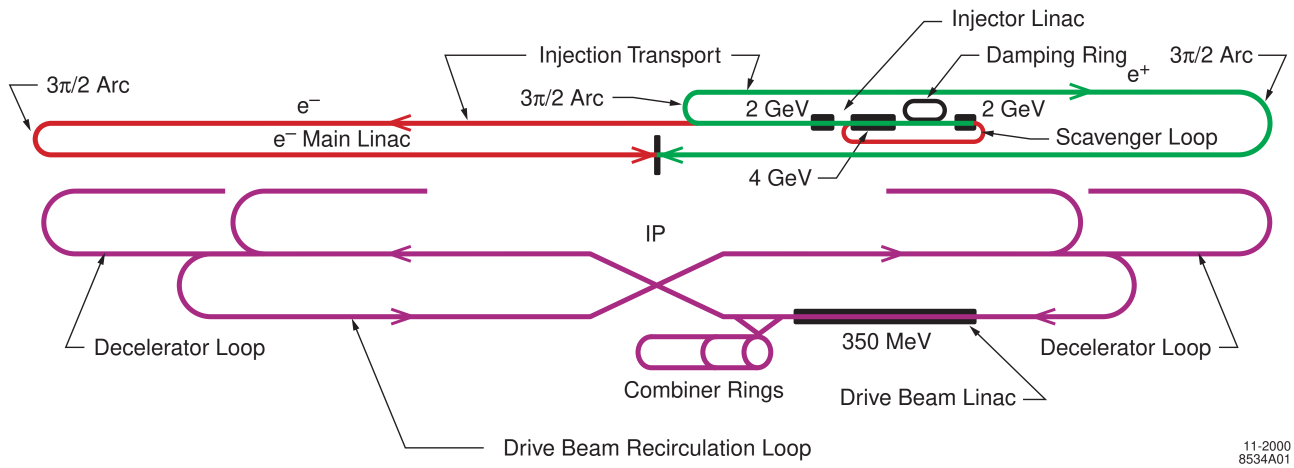


Figure 2: Schematic Layout of a Two-Beam Linear Collider with Recirculation and Central injector. The upper beam lines are for the main beam while the lower ones are for the drive beam. All long beam lines are in the same tunnel. The vertical scale is expanded for clarity. The injector linac sits beside the drive beam linac. View animation here.

This recirculation reduces the number of klystrons but increases the pulse length of each. Second, these same power sources are used to power a higher gradient main beam injector accelerator after they have finished accelerating the drive beam. Parameters for the design are shown in Table 1 while the overall layout is given in Figure 2.

To understand Figure 2 it is useful to trace a complete two-beam cycle as follows (see also animation):

1. First accelerate a long-pulse drive beam in a fully loaded L-band linac. The drive beam pulse length is twice the length of the high gradient linac.
2. Recirculate the beam to accelerate in four passes trading off the number of klystrons with pulse length.
3. After final acceleration use combiner rings and RF deflection to interleave bunches (2x4x4 = 16).
4. This compresses the long pulse beam into six shorter pulses and increases the bunch frequency by 16.
5. Distribute pulses to decelerator. After compression, the pulses are separated by twice the length of the section that they will power.
6. Transfer power to the high gradient accelerator to accelerate the high-energy beam. As in Fig 1 the drive beam decelerates while the main beam is accelerated. After each section the depleted drive beam is dumped while another arrives at the correct time and phase to take over the acceleration.
7. While compressing the long-pulse beam:
   7.1. Accelerate the main beams up to 8 GeV,
   7.2. Accelerate positron production beam to 6 GeV,
   7.3. Refill damping rings and distribute main beams.

2 DRIVE BEAM ACCELERATOR

The Drive Beam Accelerator accelerates a long pulse high current beam in order to store all the energy necessary to accelerate the main beam. The parameters for the accelerator are shown in Table 2. The accelerator is powered by an L-band RF system. This frequency is low enough to provide large stored energy for a high current beam, while being high enough to be used to power the main beam injector at the end of the drive beam cycle.

Table 2 L-Band Drive Beam Accelerator Parameters (11.4 GHz Main Beam)

Frequency:	1428 MHz
Acc. Gradient	6 MV/m
Structure length	1.4 m
Number of Structures	40
RF Power/structure	100 MW
Klystron Power	50 MW
Klystron pulse length	185 μsec
Number of klystrons	80
Drive beam current	11.8 A
Drive beam energy	1.32 GeV
Drive beam pulse length	44 μsec
Energy/pass	330 MeV
Recirculation	4 Times
Efficiency	97%
Energy/pulse	660 KJ
Ave. Dissipated power	50 KW/m

Each 1.4 m long structure is powered by two long-pulse 50 MW klystrons. Each structure is fully loaded so the transfer of energy from RF to beam is nearly 100% efficient. The structures are separated by 15m to allow the alignment of the RF input of the drive beam accelerator structures with the input to the RF pulse compression system for the injector for the main beam (see below). After each acceleration pass, the drive beam is circulated in the 'figure 8' loop shown in Fig. 2. Almost all of this beam line is just that which will be used to distribute the beam after it has been compressed in the combiner rings. The arcs consist of four vertically stacked independent arcs on the left and the right which each transport a

different pass of the beam with the appropriate bending field for the energy on that pass. On the final pass when the beam has been compressed, the vertical deflection into the return arcs is turned off to allow three of the pulses to be distributed to the right while three are distributed to left in a symmetric fashion. The drive beams arrive just ahead of the main beam to begin filling the high gradient linac with RF energy from the decelerator. The time spent by the drive beam in the combiner ring complex allows time for the drive beam klystron to be switched to power the injector.

3 THE MAIN BEAM INJECTOR

The main beam injector follows the design ideas used in the SLC to accelerate electrons, positrons and electrons-to-generate-positrons on the same RF pulse. The injector linac parameters are shown in Table 3.

Table 3 Main Beam Injector Parameters

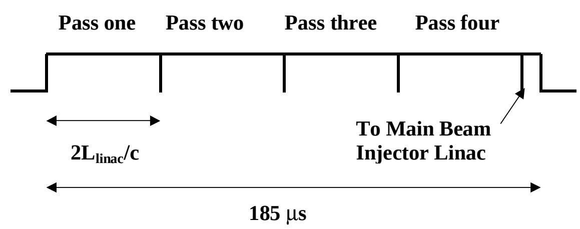
Frequency:	1428 MHz
Acc. Gradient	13.5 MV/m
Structure length	5.0 m
Number of Structures	120
RF Power/structure	100 MW
Klystron Power	50 MW
RF Pulse Compression	Times 3
Number of Klystrons	80
Main Beam Current	0.8 A
Main Beam Inj. Energy	8 GeV
Main Beam Pulse Length	3x0.45 μsec
RF to Beam Efficiency	34%

The purpose of the 8 GeV injector is to prepare a beam with the correct phase space to be accepted by the high gradient X-band accelerator. The beams are first accelerated to about 2 GeV prior to injection into damping rings. The bunches from the damping rings are compressed to sub millimeter length, accelerated another 6 GeV and then transported to the beginning of the high gradient linac.

In the design shown here two trains of electrons each with 248 bunches are accelerated with a gap in between up to 2 GeV. The initial train is injected into the damping rings while both electrons and positrons are extracted from the damping rings. This creates a train of electrons, positrons, and electrons each with 248 bunches. This triple train is accelerated another 4 GeV after which the last train is extracted and transported back to the beginning of the injector where it is used to produce positrons. The positrons are accelerated up to 2 GeV and injected into the positron predamping ring. The first two trains of electrons and positrons continue acceleration up to 8 GeV where they are separated and transported to the beginning of the high gradient linacs.

The RF power to accelerate the main beam in the injector comes from the drive beam klystrons. In Figure 3 you see a diagram of the RF pulse for the drive beam klystron. The drive beam klystron pulse is used for four passes of the drive beam. After this a phase switch is applied at the low level drive of each klystron. This phase switch, combined with a 3-db hybrid, switches the power from the drive beam accelerator to the main beam injector accelerator.

Figure 3 Drive Beam Klystron Pulse



Each pair of drive beam klystrons produces 100 MW of power that is compressed in a SLED compression system to yield a factor of 3 in power and a pulse length appropriate for the full bunch train. The resulting 300 MW pulse is distributed to three 5 m long accelerator structures. The timing of the drive beam and main beam happens naturally, but can be adjusted by the location of turnarounds for the main and drive beam.

4 ENERGY UPGRADES

Probably the most important application of a Two-Beam linear collider is as an upgrade to a collider based on conventional power sources. This study has shown that the parameters for a Two-Beam linear collider are quite similar to those for the NLC design.[3]

Upgrades in energy can happen naturally in a two-beam system. The gradient can be upgraded by increasing the gradient and current in the drive beam. The system behaves like a transformer resulting in a corresponding increase in the gradient of the main linac. The overall energy can also be upgraded by increasing the length. In this case, as shown in the 1 TeV example in Table 1, the pulse length of the drive beam klystrons increases, but the linac and combiner rings remain the same while the linac length and drive beam delivery system increase. The design shown above should be upgradeable to at least 2 TeV and perhaps beyond.

REFERENCES

[1] H.H. Braun, et al., “A New Method of RF Power Generation for Two-Beam Linear Colliders”, Proc. Of EPAC98, Stockholm, Sweden, June 1998.

[2] H.H. Braun, et al., “The CLIC RF Power Source, A Novel Scheme of Two-Beam Acceleration for $e^{\pm}$ Linear Colliders”, CERN 99-06.

[3] Tor. Raubenheimer, Proc. of Linac2000, Monterey, CA.