WF-NOTE-239
Aug.24, 2010

Paper Study of a TeV Level Linear Collider Using Short rf Pulse (~20ns) Two Beam Accelerator Concept

C. Jing and W. Gai

Abstract: In a general sense, high gradient is desirable for a TeV level linear collider design because it can reduce the length of total linacs. More importantly, the efficiency and the cost to sustain such a gradient should be considered as well in the optimization process of an overall design. We propose a high energy linear collider based on a short rf pulse (~22ns flat top), high gradient (~267MV/m of the loaded gradient), high frequency (26GHz) dielectric two beam accelerator scheme. This scheme is a modular design and its unique locally repetitive drive beam structure allows a flexible configuration to meet different needs. Major parameters of a conceptual 3-TeV linear collider are presented. Preliminary study shows an efficiently (~7% overall efficiency) short pulse collider may be achievable.

I. Introduction

Ongoing efforts toward a TeV scale electron-positron linear collider from the International Linear Collider (ILC) and Compact Linear Collider (CLIC) teams have been well established [1, 2]. Both proposed machines work at frequencies within microwave range. The ILC, which uses superconducting cavities, is designed to operate with the rf pulse length of 1.5ms and according gradient ~35MV/m. And the CLIC,

which is based on the room temperature Two-Beam Accelerator (TBA) scheme, chooses the rf pulse length of 240ns and the loaded gradient of ~100MV/m. Meanwhile, futuristic high energy machines using plasma or laser based wakefield acceleration schemes are emerging, where the accelerating gradient in GV/m level has been demonstrated in various experiments [3-5]. However, alternative designs of the high energy machine beyond the Large Hadron Collider (LHC) era still attractive and meaningful, in particular, because history has shown that a good design may not lead to a practical machine due to its cost and other factors.

Although the physics behind rf breakdown has not been fully understood yet, observations in extensive experiments reveals the rf breakdown threshold in accelerating structures increases while the rf pulse length decreases [6, 7]. In present room temperature high gradient accelerator designs, ~150 MV/m gradient with a pulse length in the range of 200-400 ns is usually the limit of normal operations [7]. In addition, rf power sources on the order of ~GW are required to power accelerating structures to tens of hundreds MV/m level, which implies a new type of power generation other than klystron is needed. Due to the simplicity of manufacture and the expected high breakdown threshold, a dielectric-based, short pulse (~20 ns), high gradient (~250 MV/m) traveling wave TBA is a good candidate to meet the requirements for future high energy machines: high efficiency, low cost and compact size, if the related technologies can be demonstrated. Table 1 presents the comparison of a few of interested points among two categories of emerged technologies and the proposed short pulse TBA toward the future TeV scale collider.

One common concern related to the short rf pulse accelerator concept is the rf overhead, which is defined by the ratio of rf transient time (i.e. filling time in a traveling wave accelerator and rise/fall time of the rf pulse) over total rf pulse length in one rf pulse. Rf overhead is directly linked to the rf-to-beam efficiency as shown in Eqn. (1),

$$\eta_{rf-beam} = \frac{I_{beam} E_{load} L_s}{P_{rf}} \times \frac{T_{beam}}{T_{rf}} . \quad (1)$$

A small rf overhead has a significant contribution to enhance the rf-to-beam efficiency which then the overall machine efficiency. For example, in the present CLIC main linac design, the filling time is 62.9ns and rf rise/fall time 22.4ns, which results in the 155ns beam time over total 240ns rf pulse length (T_{beam}/T_{rf}=64.6%), and 27.7% of the rf-to-beam efficiency [8]. In order to achieve a competitive rf-to-beam efficiency, a few strategies have been considered in a short pulse collider design: 1) using two beam acceleration scheme in the main linacs to avoid the slow rise time of klystrons; 2) using dielectric accelerator to achieve a broad bandwidth of the main linac (Note that the conventional dielectric-loaded accelerating structure has a uniform beam channel so that it is in principle a broadband device as long as it has a broadband coupling scheme, a necessity to transport a fast rise time, short period rf pulse.); 3) Design of the main linac with a relatively large group velocity and relatively short length to reduce the filling time; 4) design of the mina linac with a relatively high frequency and optimal beam loading to improve rf-to-beam efficiency. Figure 1 shows the rf pulse structure we proposed in a 26GHz short pulse TBA collider, which has a 9ns of filling time (~30cm long accelerating structure and group velocity of ~11% of speed of light) and 3ns of rf rise/fall time, resulting in the 16ns beam time over total 28ns rf pulse length (T_{beam}/T_{rf}=57.1%). It

should be pointed out that, with the release of the demanded low group velocity and long pulse length in a conventional high gradient accelerator design, metal accelerating structures may also meet requirements of the bandwidth and gradient then be used in the short pulse TBA scheme.

In the following sections, as an initial effort, we present a preliminary study of some parameters of a 3-TeV short pulse linear collider (informal name of ANL Flexible Linear Collider) including an overall layout in Section II, an efficiency estimate in Section III, details of a 3-GeV module in Section IV and drive beam accelerators in Section V. The design study of a high energy machine is far more complicated than the scope of this article. Many very important parameters, e.g. luminosity, positron generation, beam dynamics, beam injection, and final beam delivery, etc, are not touched in this article at all. Enormous theoretic and experimental efforts are needed if this concept is feasible. We hope that this article can shed the first light on the real design of a possible future high energy collider. At last, a near term plan and final remarks are presented in Section VI.

II. The Overall Layout

The proposed 3-TeV linear collider scheme uses a modular design. A simplified layout of is shown in Fig. 2 (Positron generation and final beam delivery are not discussed in the article). It consists of ten 150GeV stages in one side of machine. Each 150GeV stage is made up of fifty discrete 3GeV modules sharing with one drive beam source, which makes it look like the CLIC scheme except for a few critical differences.

Firstly, in each 150GeV stage of the proposed short pulse TBA scheme, 1000 (=50×20) short (~24ns) micro drive pulses go through 50 modules with a local beam pulse repetition rate of 20 (it represents 20 5μs-long macro bunch train as well). Each module provides 3GeV gain, which adds up to 150GeV after 50 modules. Overall, these 1000 micro drive beam pulses, which is organized by 20 repetitive macro 5μs long macro bunches, form a 100μs giant beam pulse. On top of it, machine repetition rate is 5Hz. Secondly, to match the local beam pulse repetition rate of 20, the main beam consists 20 short beam pulses in the same 100μs period of time. Another obvious difference from the CLIC scheme is that the drive beam in this short pulse scheme is generated by a 1.3GHz rf photoinjector in each 150GeV stage with a high QE cathode, which can provide 50nC/bunch with a bunch separation of 769ps (32 sequential bunches form a ~24ns micro drive pulse). At last, to achieve a high rf-to-beam efficiency in the main linacs under the short rf pulse condition, we choose a high frequency (26GHz), high group velocity (~11%c), and dielectric based structure (broadband rf coupling), which in turns provide ~270MV/m of gradient (with assumption of no breakdowns at this level in a 20ns pulse duration), ~9ns filling time, and ~3ns rise time.

Flexibility of the ANL Short Pulse TBA Concept The main purpose to introduce the local drive beam repetition is to increase the average beam current so that it can make up a comparable beam power versus the long pulse design. Figure 3 shows the generalized drive and main beam structures of the proposed short pulse TBA scheme. We can see that the drive beam is structured as a M by N matrix, where N represents the module number and M represents bunch number of the main beam in one machine repetition cycle. The larger N the higher main beam energy, while the larger M the higher average beam

current. M and N are interchangeable for the same giant drive bunch train, depending on the request of higher beam current or energy. The flexibility also comes from the choice of machine repetition rate. It notes that M also represents the local drive beam repetition rate, which governs the duration of 1 giant drive bunch train. M is interchangeable with global (machine) repetition rate, *f*, for the same average beam power, depending on the capability of the klystron (rf source of the drive beam energy booster). For example, as the 3-TeV collider presented in this article (M=20), L-band (1.3GHz) klystrons to power the drive beam accelerators are required to provide 100μs long, 30MW rf pulse with a repetition rate of 5 Hz. If klystrons with shorter pulse length are more cost-effectively available on the market, we can reduce M to 2 which shrinks the duration of a giant drive beam to 10μs, meanwhile increase the machine repetition rate *f* to 50Hz so that the average beam power (drive and main beam) remains the same.

Some preliminary design parameters Comparing with the ILC/CLIC, main features of the proposed short pulse TBA collider include the shorter rf pulse (28ns), the higher gradient (~250MV/m), the unique flexible local repetition rate, and the staging design, etc. Table 2 summarizes some preliminary design parameters. It should point out that all parameters presented in the table are subject to change for the future optimization. In addition to the gradient, among those parameters listed in the Table 2, beam power (drive and main beam) is the most meaningful parameters to compare with other schemes because that the average main beam power is directly proportional to the final luminosity and the ratio of the main beam over drive beam power is a significant factor for the efficiency estimation of a TBA scheme. It may be noticed that the average drive beam current (80mA) higher than the CLIC 3TeVdesign (~30mA). The reason is that the short

pulse scheme is a staging system. Each 150GeV stage, which contributes 8mA of the average drive beam current, is one branch of the overall machine (like a parallel circuit). But the energy of the drive beam for each stage (0.86GeV) is lower than that of the CLIC drive beam (2.4GeV) so that the overall beam power remains in a similar level.

Advantages and Challenges Through the preliminary parameter scan, a comparable main beam power and efficiency (refer to the next section) can be obtained in the short pulse TBA collider scheme. Thus a standing out advantage of the short pulse scheme is the high gradient of its main linacs if it is demonstrated. The higher gradient, the smaller is the linear collider, so is the machine cost, in particular, using a dielectric based TBA design. In general, the dielectric structure can be characterized to have: comparable impedance to metallic structures; more material choices and possible higher gradients; relatively simple geometry and thus ease of construction; and the straightforward higher order mode damping [9]. However, demonstration of the short pulse, high gradient two beam acceleration is also one of the most important challenges to proceed to this scheme. Experimental studies of dielectric-based wakefield power extractors have been conducted recently at Argonne Wakefield Accelerator (AWA) facility [10-12]. 100MV/m short pulse (<5ns) has been tested in a dielectric wakefield structure at AWA [13], and GV/m level gradient at the joint UCLA/SLAC wakefield experiment as well [5]. We understand there must be enormous challenges beyond our current expectations but it is worth to further explore this short pulse concept.

III. An Efficiency Estimate

To some extent, the wall plug efficiency has become an as important factor as the luminosity and cost while considering the next generation linear collider design. Major sub-efficiencies in the power flow chain to calculate the overall efficiency include efficiency from the wall plug to power supplies to klystrons rf output, rf-to-drive beam efficiency, efficiency of the wakefield power extraction, and rf-to-main beam efficiency. Figure 4 show the simplified efficiency and power flow chart of the proposed 3-TeV short pulse collider. In this rough estimation, we concentrate on discussion of the power flow and efficiency from the rf output of klystrons down to the final main beam delivery.

The calculation starts from the final main beam power, 31.2MW, which is from the parameter listed in Table 2. Revisiting Fig. 1, the main beam consists of twenty 16ns long micro bunches during the period of a 100μs giant drive beam pulse. Each 16ns micro-bunch has 208 individual bunches with 0.5nC charge for each one of them. These 208 bunches are distributed every two 26GHz rf cycles, which is 6.5A beam current inside a micro-bunch. The loaded gradient of main linacs is 267MV/m, calculated from the 1.264GW input rf and 6.5A beam loading (See Section IV for details). Each main accelerating structure is 0.3m. Plugging these numbers to Eqn.1, 26% of the rf `to main beam efficiency is obtained. Calculating backward, 120MW of rf input to main liancs is obtained as well. With assumption of 5% rf transportation loss, the average output power from power extractors is ~126MW. 137.6MW of average drive beam power, which is also listed in Table 2, can be obtained similarly from its beam parameters. In every 150GeV stage drive beam is boosted to 0.86GeV through series of L-band standing wave linacs before the entrance of each 3GeV module (See Fig.2). The L-band high coupling coefficient drive beam energy booster has been studied numerically. 86% of the rf to

drive beam efficiency can be reached (Details are presented in Section V). Therefore, rf power from klystrons is 160MW. For the simplicity, 55% efficiency of AC to rf output of the klystron gallery (including klystrons, modulators, and accessories) is assumed that infers 302MW power being supplied to klystrons gallery. Before inversely going back to the wall plug, we use the same power consumed in main beam injection, magnets, services, infrastructure, and detector, etc as that of the CLIC 3-TeV design [8] to complete the power flow chain. Eventually, 431MW AC power from the wall plug is estimated to generate 31.2MW beam power, which leads to 7.2% of total efficiency.

IV. Details of a 3-GeV Module

As previous mentioned, the overall short pulse collider is a modular design. 1.5TeV electron side consists of 10 150GeV stages, and each stage can be broken into 50 3GeV modules. Detailed information of one 3GeV module is shown in Fig. 5. Every 3GeV module contains 38 0.3m-long two beam accelerator pair (wakefield power extractor and main accelerator). The total length of one module is 15m, which matches the time periodicity of micro drive bunches (100ns). The drive beam pulses are evenly distributed along a common transportation line in parallel but traveling with an opposite direction to the main beam so that the distance between drive bunches has to be twice the length of one accelerating structure to ensure the arrival time at the entrance of wakefield power extractor matching with the main beam. The wakefield power extractor is one to one mapped to the accelerating structure to satisfy the GW level rf power requirement of the main accelerating structure (Since the high group velocity of main linac design, it requires more rf power (>1GW) to build up the unloaded gradient ~300MV/m).

In every 3GeV module, the drive beam is 0.86GeV at entrance of the first wakefield power extractor. It loses 20.5MeV per every wakefield power extractor and provide 1.33GW rf output. The drive beam drops to 80MeV after 38 extractors and being dumped at the end of the 3GeV module.

Dielectric-based Wakefield Power Extractor (DWPE) Due to the ease with which the RF power characteristics can be changed by manipulating the decelerator and its drive bunches, the wakefield power extractor can overcome some of the limitations of other conventional high-power RF systems at frequencies above X-band and power levels beyond a few hundred megawatts, for example, requirements of the short pulse collider, GW level 26GHz rf power, and 3ns rf rise time. A successful example of wakefield power extractor is the CLIC PETS (Power Extraction and Transfer Structure) which can provide ~240 ns, 135 MW rf power using ~100 A beam current [8]. PETS uses a metallic corrugated waveguide working as a decelerator, where the electron drive beam loses kinetic energy and generates the wakefields. In our current short pulse collider design, we choose a Dielectric-based Wakefield Power Extractor (DWPE) for a few reasons. Dielectric based accelerator/decelerator (representing circular, constant impedance dielectric loaded structure in this article unless specially mentioned) has no or very low enhancement of the electric field on inner dielectric surface over that on axis (no enhancement for the longitudinal component and normal component $Er=\pi a/\lambda$ under the synchronized condition, where a is beam aperture and λ is the wavelength) [9]. This is particularly important because of >150MV/m of gradient for the nominal rf power output, 1.33GW. Some other advantages of using dielectric based structure include the

potentially higher breakdown threshold, simple geometry (easy fabrication and low cost), and convenient parasitic mode damping [14].

The dielectric based decelerator is a constant impedance structure because of the uniformity of the dielectric constant and beam channel along the structure. The generated rf power by an ultra-relativistic bunch train in such a decelerator is given by [10]:

$$P = \frac{1}{4}\frac{\omega}{v_g}\frac{r}{Q}L^2 I^2 F^2 \left(\frac{1-e^{-\alpha L}}{\alpha L}\right)^2, \tag{2}$$

where I is the beam current (the charge per bunch over the bunch spacing), L is the active length of the decelerator, ω is the angular frequency of the RF mode, v_g is the group velocity, [r/Q] is the shunt impedance per unit length over quality factor, α is the attenuation per unit length, and F is the single bunch form factor. Major design parameters of the 26 GHz DWPE are summarized in Table 3. 1.33GW steady power is generated with 65A drive beam. Taking account 5% loss from coupler and waveguide transportation system, 1.26GW 26GHz short rf pulse is expected to deliver to the main accelerator. In fact, we have developed a prototype (version with no transverse mode damping) and performed an initial test at AWA 15MeV beamline. Despite some non-ideal experimental conditions, like bunch length is 2mm instead of 1mm and low beam current, a very good result, 20MW 26GHz rf pulse, was measured [12].

It is known that the parasitic HEM modes (transverse modes in dielectric-based structure) will cause Beam Breakup if they are not sufficiently suppressed. In the case of an iris-loaded metal accelerating structure, manifolds can be used to damp the parasitic (dipole) modes [15-17]. Using a similar principle, we can develope a transverse mode damped DWPE. Instead of a uniform outer conductor, we cut a number of slots around

the copper jacket of a conventional dielectric loaded decelerator so that only axial surface currents are allowed to flow along the copper inner surface. The non-axisymmetric hybrid modes that are comprised of all six cylindrical field components will require azimuthal surface currents on the region of the conductor boundary and thus will leak out past the slots. The inserted slabs are made from SiC, which is a very vacuum friendly material and has been used successfully in high power RF loads. The SiC will heavily attenuate the hybrid modes. Meanwhile, the TM01 (or generally TM0n) mode will maintain good propagation characteristics with only a slight deterioration of Q due to the increased surface current intensity between the slots (compared to a continuous conducting boundary). Since the ratio of total slot width to the overall circumference is small, this perturbation of the TM0n modes can be ignored. Details of transverse mode damping dielectric loaded accelerators can be found out in [18].

One of the missed issues in this article is the design of drive beam focusing optics. We assume the quad and BPM system similar to CLIC can be used in the DWPE beamline [19]. More detailed studies are needed in the future.

Main linac For similar reasons (low cost, potential high gradient capability, easy transverse mode damping, no electric field enhancement on surface, and broad bandwidth, etc.), we prefer to use Dielectric-Loaded Accelerating (DLA) structures as the main linacs of the proposed short pulse TBA collider. Major parameters of the 26 GHz DLA structure are summarized in Table 4. The 3-D EM modeling and simulated S-parameters are shown in Fig. 6, where a dielectric tapered transition is used to match the impedance between the rf coupler (not included in the simulation) and accelerating section. The length of the structure is supposed to be 300 mm to match the power

extractor. However, for this proof-principle design, we simulated one third of its length to reduce the simulation time. In the simulation, we can see that over 500MHz bandwidth (S11<-15dB) is obtained, which largely beats the bandwidth requirement to build up rf pulse in 3ns as long as the rf coupler meets the requirement (in general it is easy to achieve).

Beam loading of linear rf accelerator have been well studied [20]. For a constant impedance accelerating structure, the net voltage gain is given by

$$\begin{cases} V = V_0 \cos\theta - mI_0 \\ m = rL\left[1 - \dfrac{1-\exp(-\tau)}{\tau}\right] \end{cases}, \tag{3}$$

where, V_0 is the unloaded energy gain; θ is phase of the current bunches with respect to the crest of the external rf drive; I0 is the beam current; r is the shunt impedance per unit length; L is length of the structure; and τ is the attenuation factor for the structure. In this first round of parameter study, the main beam current inside a pulse is set up at 6.5A, which is 0.5nC per bunch, one bunch per 2 rf cycles. Its beam loading plot is shown in Fig. 7, where the operating point, 267MV/m of the loaded gradient, is marked in the dash line.

V. Drive Beam Accelerators

By nature of the short pulse high current beam structure (refer to the drive beam structure in Fig. 2), the drive beam is generated from an L band RF photocathode gun and subsequently accelerated to 0.86GeV by using standing wave accelerators. In order to

efficiently deliver rf power to the drive beam, a few preferences need to be considered in the design: 1) low rf reflection; 2) low wall losses of the structure; 3) heavy beam loading. In other words, it is required to design a standing wave structure behaving like a traveling wave accelerating structure while maintaining the pre-stored energy to be depleted by intensive short current bursts.

A significant feature of the designed drive beam linac tank is the strongly over coupled rf feeding. Its coupling coefficient is 10, which drags down loaded Q of the structure from 24000 down to 2182. The shunt impedance of one linac tank is 4.54MΩ, which is able to boost drive energy 1.62MeV/structure by a 30MW external rf drive. Figure 8 shows the beam loading effect of the designed drive beam linac tank. We use 10μs rf input pulse instead of 100μs as an illustration. We can see the rf reflection drops to zero in 1.5μs after the drive beam appears. The overall efficiency, ratio of beam power over input rf, is close to 86%. The drive beam within the first 1.5μs will be cut off due to the large energy spread. The nominal energy spread due to the short pulse high current drive beam (i.e. 'saw blade' cavity voltage ripple in the steady state) may be considered to correct using dual frequency technique [21]. The further study or exploration of new techniques is needed.

Number of klystrons to power the drive beam accelerator is a concern. In the current configuration, 533 klystrons are needed in one 150GeV module. One way to lower the number is to use higher peak power klystron. On the other hand, because of the flexibility of the short pulse TBA concept, we can reduce the local repetition rate to 2 and increase the machine repetition rate *f* to 50Hz. Thus the average beam power (drive and

main beam) and klystron number remains the same, but total cost of the klystrons will be much cheaper (the short pulse, high power klystron are relatively to build).

VI. Near Term Plan and Final Remarks

The Argonne Wakefield Accelerator facility located at Argonne National Laboratory has a unique capability of providing high quality, high charge, and short bunch length beams using a 1.3 GHz photoinjector RF gun [22]. According to the upgrade schedule, within the next three years the facility will be able to generate a 75 MeV bunch train with up to 50 nC charge in each bunch by using a new 1.3GHz rf photoinjector that comprises a high QE CsTe cathode, six standing wave linac tanks, and two additional 30 MW klystrons. It will provide a unique platform to test GW level power extraction and >250MV/m accelerating gradient. Meanwhile, a 26GHz broadband dielectric accelerator is under development, and a 26GHz full featured dielectric wakefield power extractor will be developed as well.

The core of this short pulse scheme is to jump out of the ordinary structure breakdown regime and achieve much higher gradient by simply shortening the rf pulse length. The introduced local repetition rate of the drive beam and the overall modular design make the scheme more flexible and expandable to meet different needs. Preliminary parameter study shows a reasonable performance (competitive beam power and efficiency) of the 3 TeV collider based on the short pulse TBA concept if a few critical assumptions can be proved, such as: drive beam generation and acceleration; GW RF generation and high gradient demonstration in structures. We would like to emphasize

that the proposed scheme does not strictly depend on whether the dielectric structure concept works or not, but any broad band accelerating structure that can sustain high gradients under short pulses can also be employed.

This work is supported by DOE, Office of Science, under contract No. DE-AC02-06CH11357 and DOE SBIR grant under contract No. DE-SC0004320.

References:

[1] www.linearcollider.org

[2] http://clic-study.web.cern.ch/clic-study

[3] I. Blumenfeld, *etc, Nature* 445 Feb. 2007 pp.741-744.

[4] W. P. Leemans, *etc. Nature Phy.* 2 Oct. 2006, pp.696-699.

[5] M. C. Thompson, *etc. Phy. Rev. Lett.* 100, 214801 (2008).

[6] V. Dolgashev, AAC10 presentation.

[7] F. Wang, AAC10 presentation.

[8] CLIC-Note-764

[9] W. Gai and C. Jing, "The Dielectric-Loaded Accelerating Strucutres", Periodic Structures, 2006: ISBN: 81-308-0032-2, Editors: Maurizio Bozzi and Luca Perregrini.

[10] F. Gao, *et al, Phys. Rev. S.T. Accel. Beams,* 11, 041301 (2008).

[11] F. Gao, *et al, IEEE, Nuclear Science*, Vol. 56, 1492-1497, 2009.

[12] C. Jing, *et al, Proc. IPAC10*, 2010, pp.4434-4436.

[13] M.E. Conde, et al, *Proceedings of the 2008 European Particle Accelerator Conference,* Genoa, Italy, June 2008, pp.2835-2837.

[14] E. Chojnacki, *et al, J. Appl. Phys.* 69 (1991) 6257.

[15] K.L.F. Bane, R.L. Gluckstern, *SLAC PUB-5783*, 1992.

[16] H. Deruyter *et al., Proc. of the 1990 Lin. Acc. Conf.*, Albuquerque, NM, Sept. 10-14, 1990,also in *SLAC PUB-5322*.

[17] J. Wang *et al., Proc. Of the 1991 IEEE Part. Acc. Conf.*, San Francisco, California, May 6-9, 1991, also in *SLAC-PUB-5498*.

[18] C. Jing, et al, Proc. PAC09, Vancouver, CA, 2009,

[19] E. Adli and D. Schulte, Proceedings of EPAC08, Genoa, Italy,2008, pp 547-549.

[20] P. Wilson, SLAC-PUB-2884.

[21] H.H. Braun and M. Valentini, Proceedings of the 1999 Particle Accelerator Conference, New York, 1999, pp.3402-3404.

[22] www.hep.anl.gov/awa

Table 1. Emerged technologies toward the future TeV scale Linear Collider (LC).

	LC based on the conventional metal accelerators	LC based on the short pulse dielectric TBA scheme	LC based on the plasma or laser wakefield acceleration
Frequency	microwave range	~millimeter wave	THz~ optical
Gradient	<150MV/m (warm) <40MV/m (cold)	~250MV/m	>10GV/m (plasma) >1GV/m (laser)
Pulse length	200~400ns (warm) 1.5ms (cold)	20~30ns	<1ps
Technology development	realistic	achievable	futuristic

Table 2. Some preliminary design parameters of 3-TeV short pulse linear collider

(informal name of ANL Flexible Linear Collider)

Main linac frequency	26GHz
Drive linac frequency	1.3GHz
Main linac loaded gradient	267MV/m
Main beam current (in pulse)	6.5A
Machine repetition rate	5Hz
Average drive beam current (one side)	80mA
Average drive beam power (one side)	68.8MW
Average main beam current (one side)	10.4μA
Average main beam power (one side)	15.6MW

Table 3. Parameters of 26GHz Dielectric Based Wakefield Power Extractor.

Geometric and accelerating parameters	**value**
ID / OD of dielectric tube	7 mm /9.068 mm
Dielectric constant	6.64
Length of dielectric tubes	300 mm
Vg	0.254c
R/Q	9788 Ω/m
Rf pulse rise time	2.9 ns
$BW_{_3dB}$ of the requested coupler	120MHz
Steady power (50nC/bunch, σ z=1mm)	1.33 GW
RF pulse duration (32 bunches)	22ns (flat top)
Peak Gradient	167MV/m
Energy loss of the beam in the steady state	20.5MeV

Table 4. Parameters of 26GHz Dielectric Based Accelerator.

Geometric and accelerating parameters	**value**
ID / OD of dielectric tube	3 mm /5.025 mm
Dielectric constant	9.7
Length of dielectric tubes	300 mm
Vg	11.13%c
Tfill	9ns
R/Q	21.98 kΩ/m
Q (loss tan=10^-4)	2295
Shunt impedance	50.44 MΩ/m
$BW_{_3dB}$ of the requested coupler	120 MHz
Eacc for 1.26GW input	316 MV/m
Eload for 1.26GW input	267 MV/m

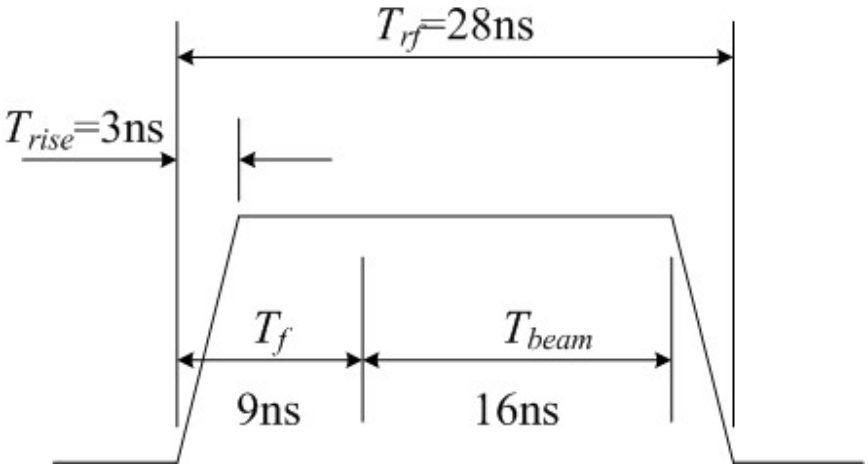


Fig. 1. The 26GHz rf pulse envelope for the short pulse TBA concept.

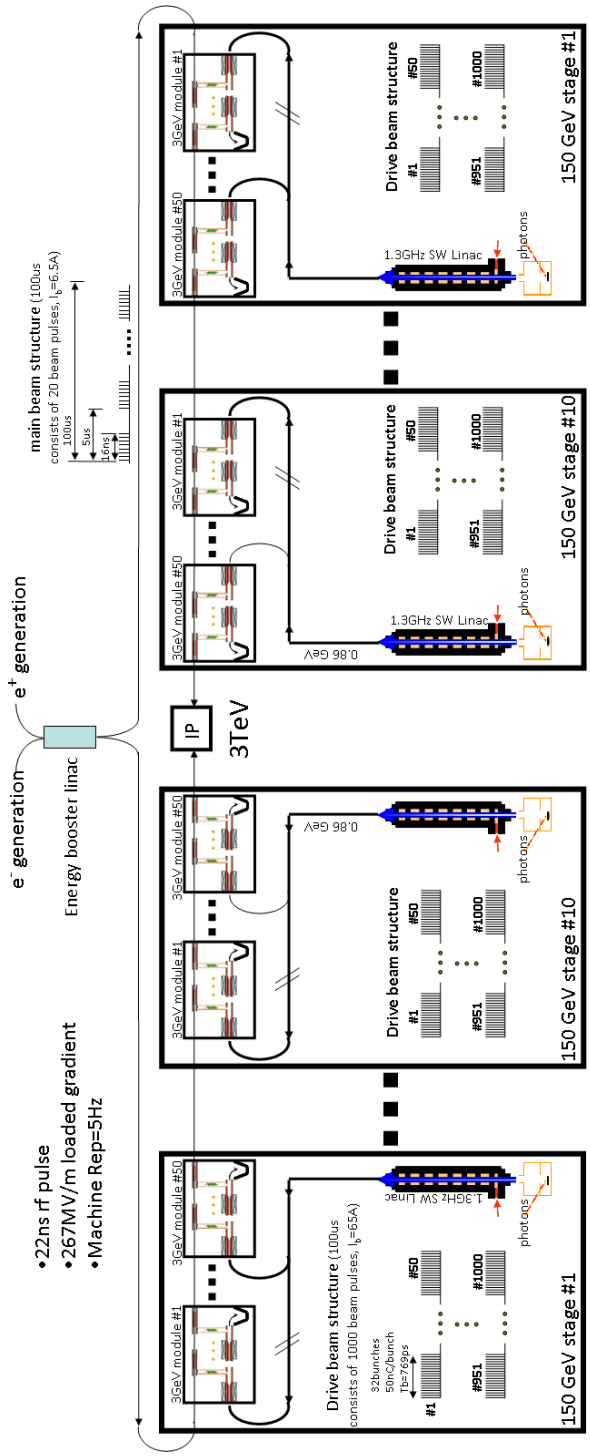


Fig.2. Conceptual layout of one side of Argonne 26GHz 3TeV Dielectric-based Short Pulse TBA Linear Collider .

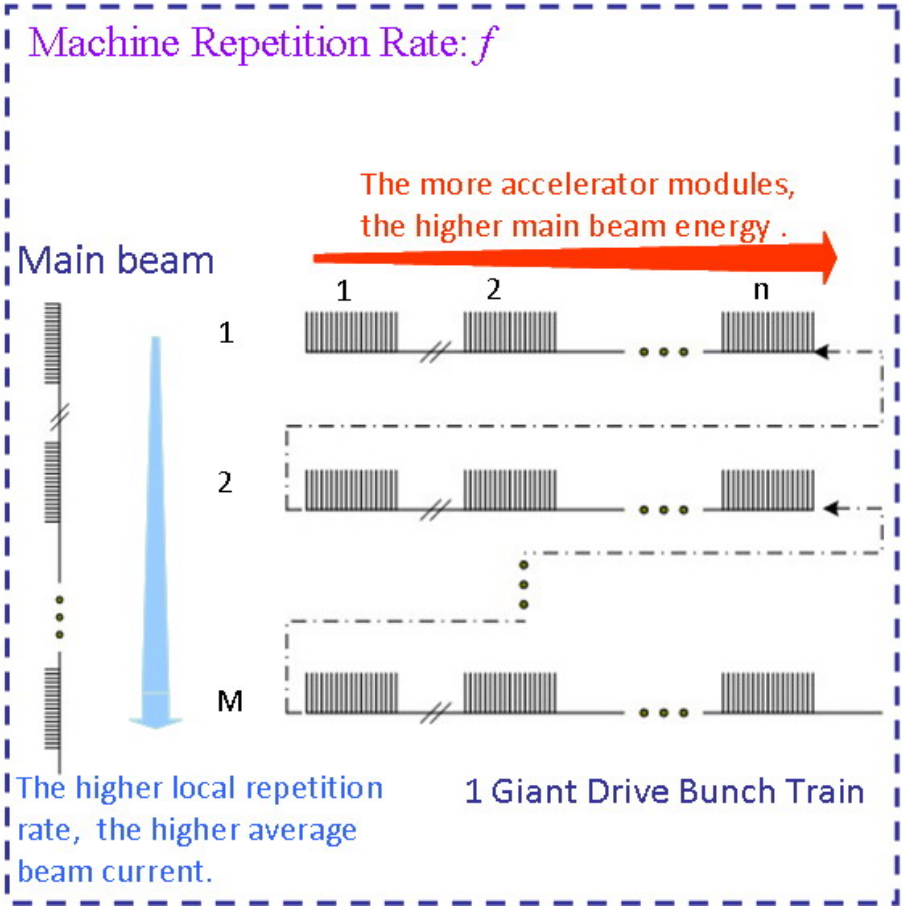


Fig. 3. Drive and main beam structures of the proposed short pulse TBA scheme.

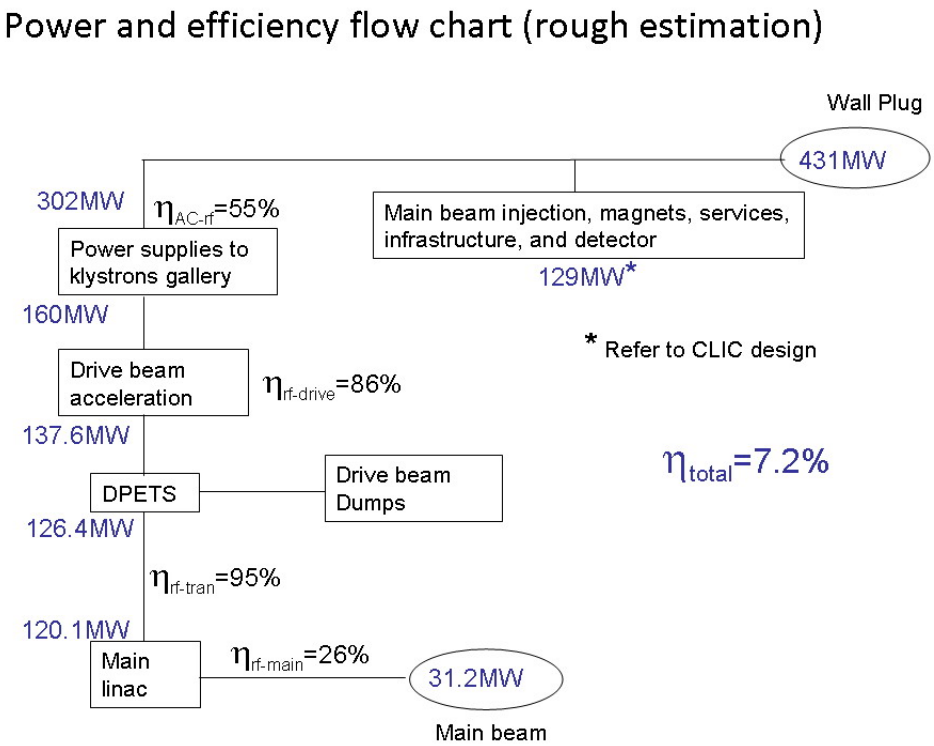


Fig. 4. Rough efficiency estimation with many assumptions.

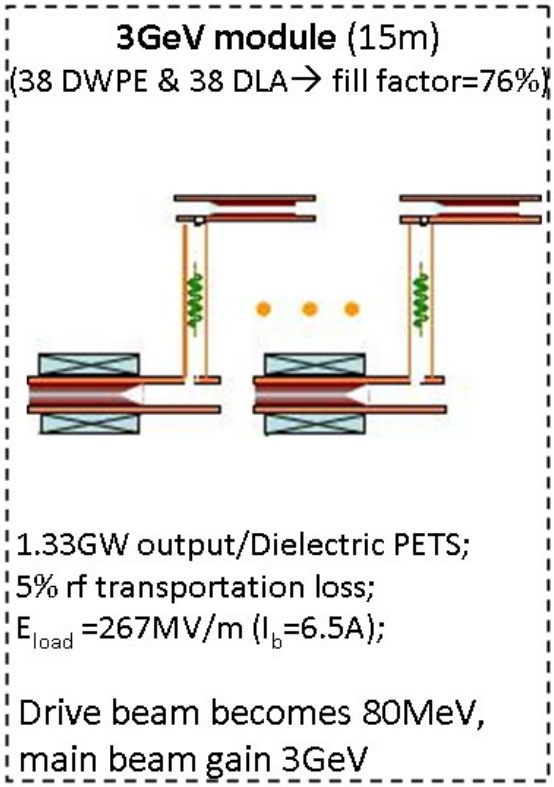
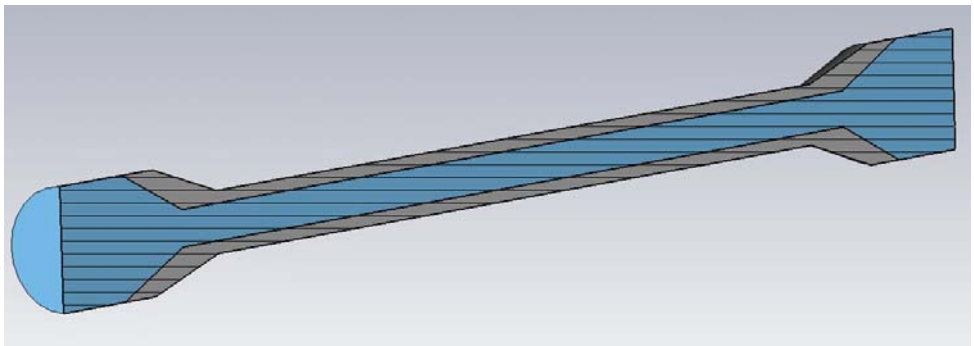
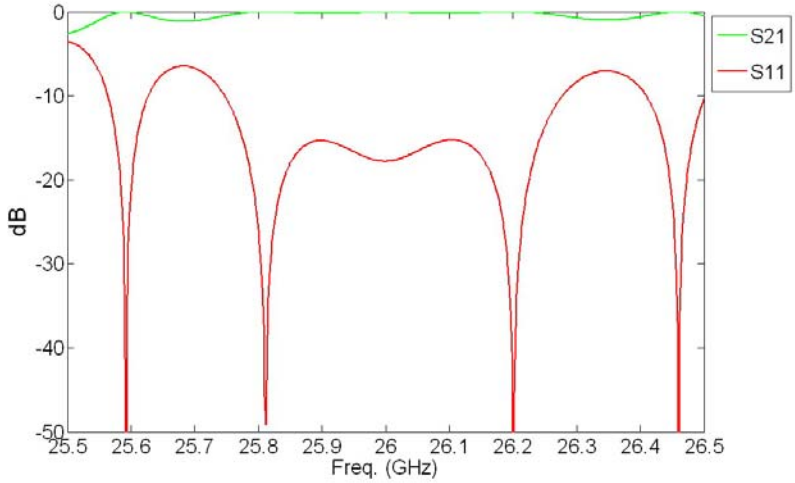


Fig. 5. Schematic layout of a 3GeV module.



(a)



(b)

Fig. 6. Dielectric (alumina) based broadband accelerating structure: a) 3D modeling in CST MicrowaveStudio®; b) the simulated S parameters.

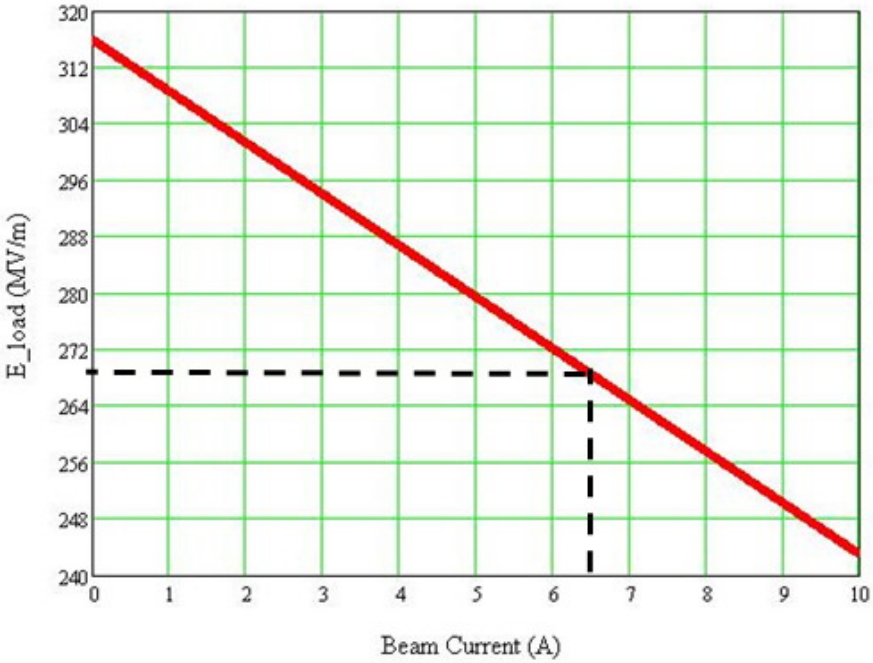
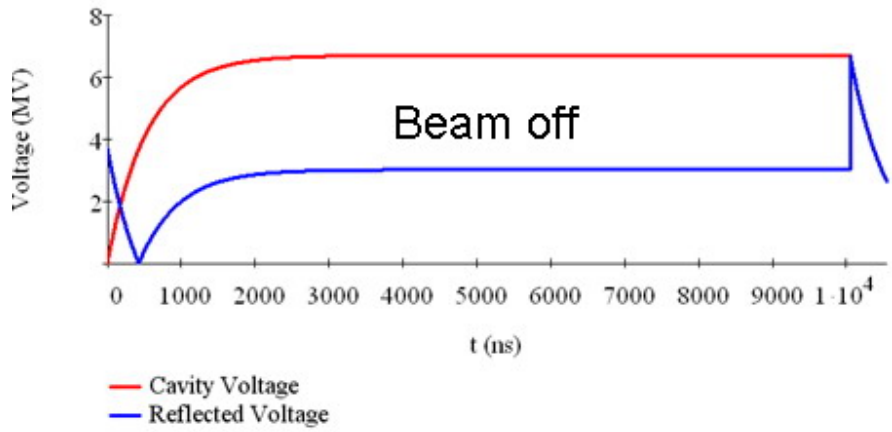
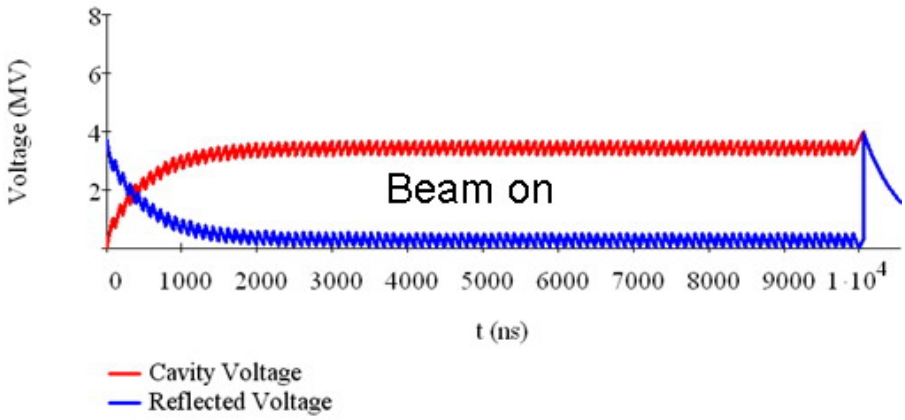


Fig. 7. Steady state beam loading of the main linac.



(a)



(b)

Figure. 8. Beam loading of the standing wave accelerator to boost energy of the drive beam: (a) cavity voltage when drive beam off; (b) beam on case.