

ARGONNE FLEXIBLE LINEAR COLLIDER

C. Jing[#], S. Antipov, P. Schoessow, and A. Kanareykin, Euclid Techlabs LLC, Solon, OH, USA
J.G. Power, M. Conde, and W. Gai, Argonne National Laboratory, Argonne, IL, USA

Abstract

We propose the Argonne Flexible Linear Collider design (the informal name for our 3-TeV short pulse linear collider). It is based on a short rf pulse (~22 ns flat top), high gradient (>250 MV/m) Two Beam Accelerator (TBA) design. This 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. This preliminary study shows that an efficient (~7% overall), 31 MW beam power collider may be achievable. We also present a novel staging design using a series of rf delay lines to replace the 180 degree drive beam arcs of a conventional TBA scheme. The concept is scalable from the GeV to the TeV scale.

SHORT RF PULSE ACCELERATION

Although the physics behind rf breakdown is not yet fully understood, observations in extensive experiments reveal that the rf breakdown threshold in accelerating structures increases while the rf pulse length decreases [1]. 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. In addition, rf power sources on the order of ~GW are required to power accelerating structures to achieve tens of hundreds of MV/m, which implies that a new type of power source other than the klystron is needed. Because of 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.

One issue related to the short rf pulse accelerator concept is the rf overhead, which is defined by the ratio of the rf transient time (i.e. the filling time in a traveling wave accelerator and the rise/fall time of the rf pulse) over the 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 enhancing the rf-to-beam efficiency and hence the overall machine efficiency. In order to achieve a competitive rf-to-beam efficiency, a number of strategies have been

considered in a short pulse collider design: 1) using a two beam acceleration scheme in the main linacs to avoid the slow rise time of klystrons; 2) using broadband accelerating structures; 3) main linac design with a relatively large group velocity and relatively short length to reduce the filling time; 4) main linac design with a relatively high frequency and optimal beam loading to improve rf-to-beam efficiency. Figure 1 shows the rf pulse structure we propose for a 26 GHz short pulse TBA collider, which has a 9 ns filling time (~30 cm long accelerating structure and group velocity of ~11% of the speed of light) and 3 ns of rf rise/fall time, resulting in 16 ns beam time over a total 28 ns rf pulse length ($T_{beam}/T_{rf}=57.1\%$).

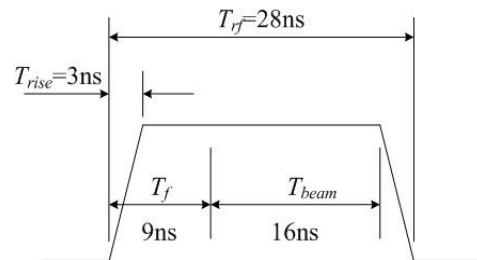


Figure 1: The 26 GHz rf pulse envelope for the short pulse TBA concept. A broadband and high group velocity (0.1 c) structure is needed to obtain the fast rf rise and filling times.

SHORT PULSE COLLIDER

The proposed 3-TeV linear collider scheme uses a modular design (for details refer to [2]). A simplified layout is shown in Fig. 2 (Positron generation and final beam delivery are not discussed in this article). It consists of ten 150 GeV stages in one side of machine. Each 150 GeV stage is made up of fifty discrete 3 GeV modules sharing one drive beam source, which resembles the CLIC scheme but with a few crucial differences. First, in each 150 GeV stage, 1000 (=50×20) short (~24 ns) micro drive pulses pass through 50 modules with a local beam pulse repetition rate of 20 (also representing a 20 5 μs-long macro bunch train). Each module provides a 3 GeV gain, which adds up to 150 GeV after 50 modules. Overall, these 1000 micro drive beam pulses, organized by 20 repetitive 5 μs long macro bunches, form a 100 μs giant beam pulse. The machine repetition rate is 5 Hz.

Second, to match the local beam pulse repetition rate of 20, the main beam consists of 20 short beam pulses in the same 100 μs period of time. The main beam current inside a pulse is 6.5 A, which is 0.5 nC per bunch, one

*Work supported by the Department of Energy SBIR program under Contract #DE-SC0004320.

[#]jingchg@hep.anl.gov

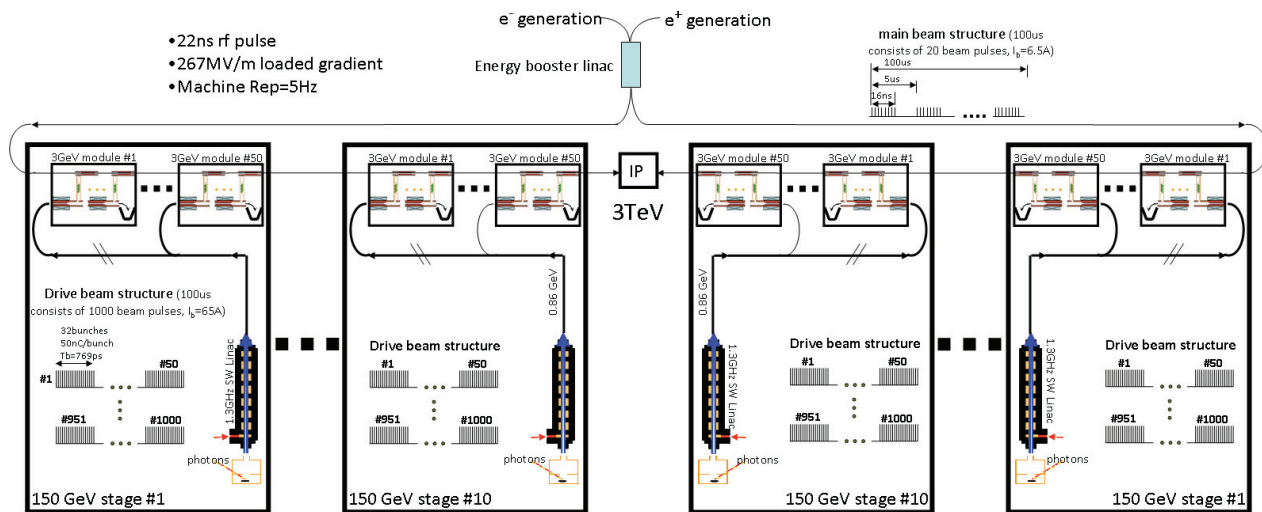


Figure 2: The conceptual layout of the Argonne Flexible Collider.

bunch per 2 rf cycles. The purpose of introducing the local drive beam repetition rate is to increase the average beam current so that it can develop a beam power comparable to the long pulse design.

Another obvious difference from the CLIC scheme is that the drive beam in this short pulse scheme is generated by a 1.3 GHz rf photoinjector in each 150 GeV stage with a high QE cathode, which can provide 50 nC/bunch with a bunch separation of 769 ps (32 sequential bunches form a ~24 ns micro drive pulse). Finally, to achieve a high rf-to-beam efficiency in the main linacs under the short rf pulse condition, we choose a high frequency (26 GHz), high group velocity (~11% c), dielectric based structure (broadband rf coupling), which in turn provides ~270 MV/m gradient (with the assumption of no breakdowns at this level in a 20 ns pulse duration), ~9 ns filling time, and ~3 ns rise time. Table 1 summarizes some preliminary design parameters. It should be emphasized that the parameters presented in the table are not optimized and may change as research continues.

To some extent, the wall plug efficiency has become as important a factor as the luminosity and cost in considering the next generation linear collider design. Major sub-efficiencies in the power flow chain used to calculate the overall efficiency include the efficiency from the wall plug to power supplies and then to the klystrons' rf output, the rf-to-drive beam efficiency, the efficiency of the wakefield power extraction, and the rf-to-main beam efficiency. Here we consider a very rough estimate. The calculation starts from the final main beam power, 31.2 MW, from the parameter list in Table 1.

Revisiting Fig. 2, the main beam consists of twenty 16 ns long micro bunches during the period of a 100 μs giant drive beam pulse. Each 16 ns micro-bunch has 208 individual bunches with 0.5 nC in each. These 208 bunches are distributed every two 26 GHz rf cycles, corresponding to 6.5 A beam current inside a microbunch.

Table 1: Some Preliminary Design Parameters of the ANL Flexible Linear Collider

Parameters	Value
Main linac frequency	26 GHz
Drive linac frequency	1.3 GHz
Main linac loaded gradient	267 MV/m
Average drive beam current (one side)	80 mA
Average drive beam power (one side)	68.8 MW
Average main beam current (one side)	10.4 μA
Average main beam power (one side)	15.6 MW

The loaded gradient of the main linacs is 267 MV/m, calculated from the 1.264 GW input rf and 6.5 A beam loading. Each main accelerating structure is 0.3 m in length. Plugging these numbers into Eqn. 1, 26% rf to main beam efficiency is obtained. Calculating backward, 120 MW of rf input to the main linacs is obtained. With the assumption of 5% rf transport loss, the average output power from the power extractors is ~126 MW. 137.6 MW of average drive beam power can be obtained similarly from the beam parameters. In every 150 GeV stage, the drive beam is boosted to 0.86 GeV through a series of L-band standing wave linacs before the entrance to each 3 GeV module. The L-band high coupling coefficient drive beam energy booster has been studied numerically. 86% rf to drive beam efficiency can be achieved [2]. Therefore, the rf power from the klystrons is 160 MW. For simplicity, 55% efficiency of AC to rf output of the klystron gallery (including klystrons, modulators, and accessories) is assumed; from this it can be inferred that 302 MW power is being supplied to the klystron gallery. Before 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 [3] to complete the power flow chain, with the result that 431 MW AC power from the wall plug is estimated to generate 31.2 MW beam power, a total efficiency of 7.2%.

STAGING WITH RF DELAY

As shown in Fig. 2, each 150 GeV stage can be broken into 50 3 GeV modules. Every 3 GeV module contains 38 0.3 m-long two beam accelerator pairs (wakefield power extractor and main accelerator). The drive beam energy is 0.86 GeV at the entrance of the first wakefield power extractor. It loses 20.5 MeV per every wakefield power extractor and provides 1.33 GW, 22 ns rf output. After 38 extractors, the drive beam energy drops to 80 MeV and is then dumped at the end of the 3 GeV module. The total length of one module is 15 m, which matches the time periodicity of micro drive bunches (100 ns). The drive beam pulses are evenly distributed along a common transport line in parallel but traveling in the 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 the wakefield power extractor matches with the main beam. A series of 180 degree bending arcs in the drive beamline is used to feed each 3 GeV module. One of the main challenges in this staging design is the concern of quality degradation of the high charge drive beam due to Coherent Synchrotron Radiation (CSR) in the arc. Therefore, it is an urgent need to demonstrate beam staging for TBA concept.

Lately, we have been exploring other staging approaches to avoid the 180° arc in the drive beamline. Figure 3 shows one of them. It uses different rf delays among the TBA pairs to synchronize the timing between drive and main beam so that the need for the arc is avoided. In this design, the drive beam is branched out to each module by a fast kicker (high voltage stripline or traveling wave deflector). The first micro drive bunch train (#1) enters the last (from main beam point of view) power extractor (the m^{th}) in Module 1. The generated rf is transported through a longer rf waveguide which provides a delay time t_{dm} . The delay time of the rf transport line in the $(m-1)^{\text{th}}$ TBA pair is $t_{d(m-1)}$. At the exit of the first power extractor, bunch train #1 is dumped after exhausting most of its energy. At the moment the rf from the 1st power extractor fills the 1st accelerating structure, the main beam is launched. Because the rf filling time for each accelerating structure is the same, if we assume the rf delay of the transport line in the first TBA pair $t_{d1}=0$, then $t_{d2}=2L_s/c$, $t_{dm}=2*(m-1)*L_s/c$, where m is the number of structures in each module and L_s is the length of a single structure. It also should be pointed out that, because the directions of drive and main beams remain opposite, the rf feed port of the accelerating structure in each TBA pair described in Fig. 2 and Fig. 3 are reversed.

Using parameters of Argonne Flexible Linear Collider design shown in Fig. 2, we have 38 30 cm-long structures in one module; the requested shortest delay is then $2*0.3 m/c=2 ns$; the longest delay is $2*(38-1)*0.3 m/c=74 ns$. In order to reduce rf losses in the delay line, we consider the most commonly used circular overmoded waveguide working at the TE₀₁ mode (air filled, copper wall, a=0.7 in, f=26 GHz). Figure 4 shows its rf delay and

power loss curves. At 26 GHz, the delay=3.6 ns/m and power loss=0.22%/m, thus the longest delay line is $74 ns/3.6 ns=20.6 m$ and the rf loss is $0.22\%*20.6=4.5\%$.

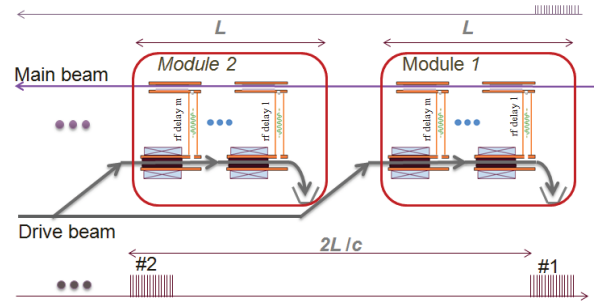


Figure 3: A novel staging design to avoid 180 degree bending of high current drive beam.

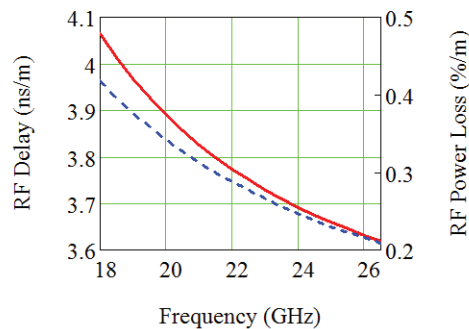


Figure 4: rf delay and power loss of a 1-meter long circular overmoded copper waveguide working at the TE₀₁ mode at 26 GHz.

SUMMARY

We propose a high energy linear collider based on a short rf pulse, high gradient dielectric TBA scheme. The core of this short pulse concept is to avoid the ordinary structure breakdown regime and achieve a much higher gradient by simply shortening the rf pulse length. The introduction of the local repetition rate of the drive beam, the overall modular design, and the new staging approach make this approach more flexible and expandable to meet different needs.

REFERENCES

- [1]. F. Wang, *et al*, *Proc. Advanced Accelerator Concepts: 14th Workshop*, edited by S. Gold and G. Nusinovich, (2010):280-285.
- [2]. C. Jing and W. Gai, *WF-Note-239*, <http://www.hep.anl.gov/awa/links/wfnotes.htm>
- [3]. H. Braun, *et al*, *CLIC-Note-764*, <http://cdsweb.cern.ch/record/1132079>.