Summary Report of Working Group 4: e-Beam Driven Accelerators

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Abstract. The working group considered high transformer ration schemes for an afterburner based on the design of a future linear collider. The main linac produces high charge beams of 100 GeV. A multiple stage plasma based accelerator would accelerate a portion of this beam to 500 GeV. The length of each plasma stage is expected to be of the order of a few meters while the isochronous beam transport required for multiple stages would occupy about a kilometer. Discussions in the working group were centered on issues to be addressed: ion motion in the plasma channel, positron side of accelerator … The state of present e-beam driven plasma and dielectric Wakefield accelerators is very mature and closely resembles parameters of the afterburner for ILC. The main result of this working group is a multistage afterburner scheme of an afterburner for ILC and discussion of the experimental program to address main issues.

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WORKING GROUP GOAL

The working group charge was given as follows:

> The working group will review and identify the critical experiments that should be performed to study the feasibility of a plasma-based accelerator for a linear collider. These include, but are not limited to, two-bunch PWFA experiments, propagation in long plasmas leading to energy gains of the order of the incoming beam energy, stability of the propagation in long plasmas, optimization of the transformer ratio and of the loading of the wake by the beam.

The working group was arranged around talks presenting the latest status of the PWFA experiments. The invited topics were used to seed discussions on the staging of afterburner, high transformer ratio, ion motion and hollow plasma channels and positron acceleration. The current text summarized discussions in the working groups and refers to some of the presentations in the working group. The references were done in the assumption that those speakers would report their work in these proceedings.

The goals of the working group were defined as:

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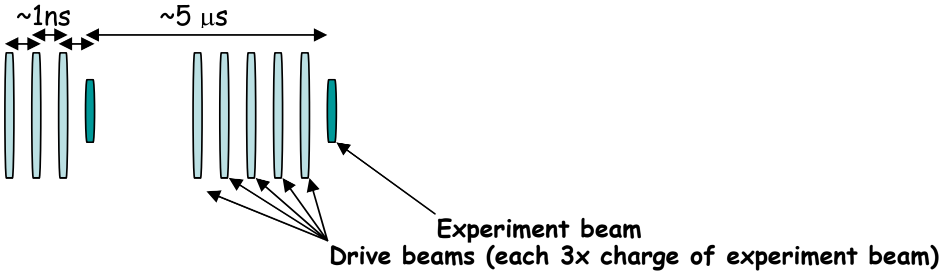

FIGURE 1. Beam structure delivered by main, 100 GeV, linac.

1. To consider the existing design of the afterburner in light of the recent experimental results from SLAC, examine parameters and consider relevant of the existing experimental programs.
2. To discuss the most important issues for realization of afterburner for ILC and propose relevant experiments that need to be performed.
3. To identify computational tools and necessary advances for these experiments.
4. To identify generation of bunches suitable for PWFA and discuss possible facilities where this experiment could be performed.

AFTERBURNER DESIGN

Previous Design

An energy doubler (250 GeV → 500 GeV) was considered in detail at the previous AAC workshop in 2004. It relied on the two bunch (drive and witness) structure. The witness bunch would have ¼ of the ILC beam and the drive beam would be 3 times the witness. The total beam power in the linac would be preserved while luminosity would remain the same with a short plasma lens to compensate for the decrease in the charge at IP. The hose instability, positron acceleration, energy spectrum and plasma lens for final focus were identified as the main issues at the time. The need to demonstrate high gradient sustained over long distance (~1 m) and two beams PWFA were identified as a key experimental direction.

New Design

High transformer ratio of the plasma accelerator was the main theme of discussion in the working group. The Strawman designs were considered with acceleration from 100 GeV to 500 GeV. One proposal utilized a single stage of plasma accelerator with the properly shaped drive beam structure.

Multiple stages were considered as an alternative. The train of drive bunches would be accelerated to 100 GeV in the main linac, and then separated to independently drive each plasma accelerator. The witness beam will go through every stage gaining approximately 100 GeV per stage. The control over head erosion, hosing and possibility of the feedback and control over the acceleration process are among obvious advantages of this approach.

Simpler synchronization and transport lines were considered among advantages of the single stage high transformer ratio approach.

It is important to note that any plasma wakefield accelerator scheme requires approximately 2 times more AC wall power when compared to a conventional linac. The drive beam has a charge approximately 3 times larger charge than a witness beam and is discarded after it excites the wake. The witness beam gains the energy of the drive beam. Wall power is the same for the doubler scheme and high transformer ratio. The savings are expected from the shorter accelerator that is driven harder.

We propose to increase the repetition rate of the system from 5Hz to 50Hz. This will result in the 2 times more AC power utilized in the 5 time shorter linac. We accounted for 50% efficiency of afterburner for the same beam power or luminosity at the interaction region. Bunch spacing is increased ~10 times in order for RF to refill SC cavities. We plan to replace each of the bunches of conventional ILC with a mini-train of four drive beams and one witness.

This approach also requires the redesign of the final focus as the energy spread from the plasma accelerator is expected to be of the order of ~5%. Separator/combiner optics for the drive and witness beam would require serious consideration. It would need to have an isohronousity of the order of 3μm/5%.

We do not change requirements for the injection system of the witness beams. We rely on the same number of bunches per second extracted from the dumping ring. A higher repetition rate, combined with the smaller number of witness bunches per train might offer additional savings for the injection system with a possibly shorter damping ring.

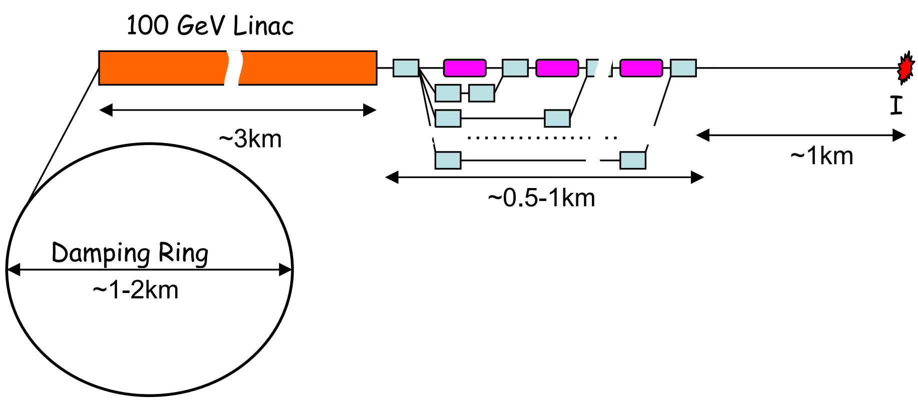

FIGURE 2. Schematic of the proposed multistage afterburner.

ISSUES

There are two main issues that were discussed for scaling of the E167x experiments toward the discussed above afterburner:

1. Timing control of the bunch arrival in different stages
2. Lack of the positron acceleration program
3. Ion motion of the plasma due to extreme intensity of the witness beam.

The discussion in the working group was concentrated around ion motion problem as a new concern. It was realized that the witness beam in the ILC design is so dense that ions collapse completely on the time scale of the beam. As a result, a simple extension of the SLAC experiment is not applicable. The use of heavier atoms was considered as one of the possible solutions. It was pointed out that because lithium ions completely collapse before they reach the tail, argon's increase in focusing force might still be acceptable.

Synchrotron radiation, multiple ionization and nuclear scattering were pointed out as potential items of concern. A more radical suggestion was to use a hollow plasma channel for the electron beam. This approach is already considered presently for the positron beam and could be a solution for the ion motion problem. It also was discussed that the attempt to use an unnatural set of parameters dictated by ILC might not be optimal combination for linac-afterburner. A completely different LC-consistent parameter set may be needed to optimize the performance of the combined accelerator.

DISCUSSION OF FUTURE EXPERIMENTS

A number of key experiments for the realization of the afterburner were discussed at the working group. Importance of a two beam experiment at high energy was emphasized to better understand beam loading and optimal charge ratio in the drive/witness beam. Recent results from the experiment at Brookhaven at low energy were presented. Continuation of these experiments could bring about a better understanding of the issue, gaining experience with the control over timing, but would unlikely replace the need for verification at high energy. Staging of beam driving accelerator stages and achieving high transformer ratio with a properly shaped drive beam were discussed as well as other important experimental directions. It was discussed that this set of experiments can be effectively conducted at low energy facilities and other than plasma medium (dielectric tubes as an example.) The positron beam acceleration is the only experimental direction that was identified at a previous AAC workshop and was not addressed experimentally. While considerable progress has been made in terms of the simulation the experimental program is lacking primarily due to absence of the positron beams available for experiments. Ion motion was discussed as a main issue for scaling SLAC experiment E167 to ILC afterburner. This discussion led to suggestions of a series of experiments at different facilities that would potentially lead to better understanding and control of the problem. Two proposals of experiments were discussed in details. An experiment with high intensity, low energy electron beams is aimed at the direct measurement of ion velocities in the path of the electron beam. This experiment would offer direct information but requires very difficult instrumentation. The study of ion collapse in a plasma lens would offer indirect information in a much easier experimental scheme. Studies of a heavier ion plasma and hollow plasma channels were discussed as a pass to the possible solution of the problem.

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