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RF Photo Injector Based Two Beam Acceleration Research Plan at Argonne

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Abstract: We present a new configuration of the AWA which will enable us to generate 20 nC bunches (average current of 30 A) with a pulse length of 1 mm and emittance less than 100 mm-mrad using RF photocathode technology. The only additional requirement is to upgrade the photocathode to a high quantum efficiency material ($5x10^{-3}$). Potential applications of this beam to Two Beam Acceleration Research and Wakefield Acceleration are discussed.

Introduction

As discussed in a recent CLIC report[1], conventional acceleration schemes become increasingly difficult to implement for energies beyond 3 TeV. A possible alternative is the use of the two beam acceleration (TBA) method. There are many versions of the TBA. I will not discuss the general scheme and differences between each TBA. The most well developed TBA scheme is the one presented in the CLIC report. One of the major requirements is to generate a pulse train of 20 nC bunches (average current of 30 A) with a pulse length of 1 mm and emittance less than 100 mm-mrad. Although it would be exciting to obtain this 30 A beam over the entire RF pulse in excess of 5 μs, we believe that we can demonstrate some of the necessary physics using 30 – 60 ns pulses available at the AWA.

In this note, we propose using RF photocathode based technology to generate a train of electron pulses with 20 nC charge, 1 mm pulse length and emittance of 40 mm-mrad using the existing AWA facility and the upgraded RF photocathode gun [2]. Total number of pulses can be as large as 64, therefore total length of the pulse train is about 50 ns (about of 30% in the TBA design [1]). In the following section, we discuss our approach to the problem and each individual component. At the end we discuss the impact of this gun on TBA research and also to wakefield acceleration in general.

The goal of this plan is ONLY to demonstrate that we can generate, accelerate and propagate high intensity electron pulse trains in L-BAND structure for the use of testing TBA concepts and for Wakefield Acceleration. Many other aspects of the TBA such as the transfer structure, combiner ring etc are not included here although the option of Argonne involvement in these areas in the future should be considered.

AWA Resources

This electron beam generation scheme uses all existing AWA facility components such as RF, lasers and RF guns. The table below shows are the AWA resources already available or under construction.

Laser	5 mJ single pulse	Can be split into 64 pulses using existing optics with 50 μJ each
RF	L Band 30 MW, 5μs	Extension to 8 μs in progress
RF waveguide	Available	
New RF photocathode gun (1 ½ Cell)	80 – 100 MV/m, 10 MeV energy output. 50 J stored energy.	Under construction, will be in operation in a year

One additional requirement for this facility is relatively high QE photocathode material. The minimum is 10^{-3}, to be conservative 0.005 would relax the laser optics requirements. We have not had experience in operating high QE cathodes, but since our new RF photocathode gun will be operated under the ultra-high vacuum (10^{-9}), there is no reason for us to not duplicate QEs TTF or LANL techniques already demonstrated at where 0.1 QEs are achieve routinely.

Beam Generation Scheme

The following Figure shows a block diagram the upgraded facility.

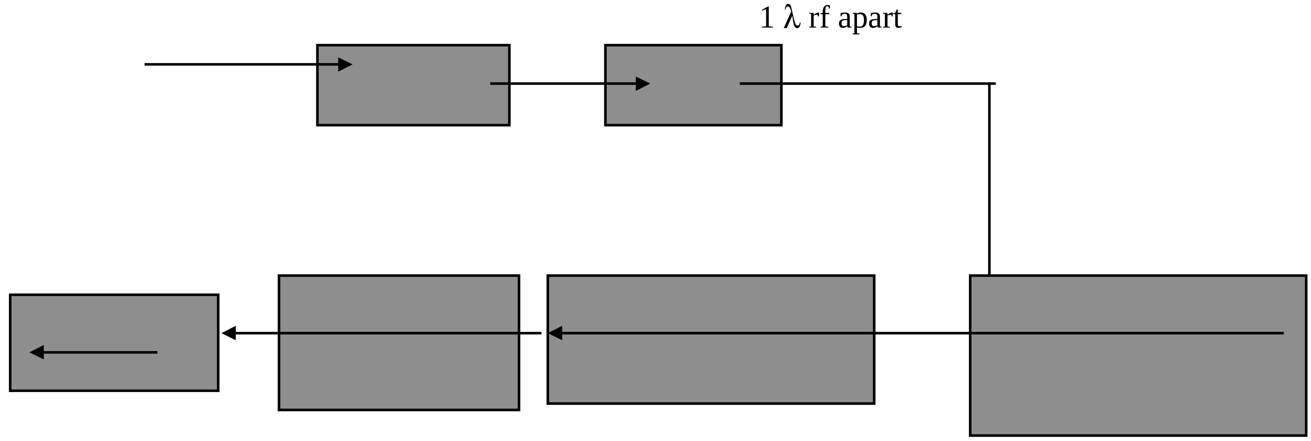

Figure 1. Reconfigured upgraded AWA facility for multiple pulse operation. It is identical to the single pulse for high charge (40 – 100 nC) set-up but with multiple laser splitter and a high QE cathode.

Possible DUTs in Figure 1:

1. Dielectric step-up transformer. Will achieve 100 MV/m with current proof of principle structure. Will easily access the 200 - 500 MV/m regime.
2. Testing Two Beam Acceleration Concept. Generation, Propagation and Acceleration of 20 nC, 5 - 10 ps electron pulses.

The new RF photocathode gun and linac have been simulated intensively using PARMELA, SUPERFISH and URMEL. The linac has been used in AWA for 4 years now. The laser splitter has been demonstrated at the AWA, as has the generation of multiple drive bunches using the split laser beam. We will discuss some of the beam physics issues in the next section.

Beam Physics Issues.

Among the beam physics topics which can be studied are:

1. Beam loading: The total beam will extract 10 J energy out of 50 J stored in the new RF gun. Therefore, 10% of energy drop from bunch head to tail is expected without any compensation. This may be corrected by properly spacing the laser pulses and using linac rf to correct this.

2. Transverse instability: Unlike the present beam, this high current beam will be subject to bunch to bunch instabilities. Since we have a laser photocathode based injector, we could systematically study the transverse wakefield effects by displacing laser spot on the PC differently for each individual bunch.

3. Time resolved measurements of each individual beamlet. Study the bunch – bunch effect due to both longitudinal and transverse WF effects, such as beam emittance growth and energy spread of trailing bunches.

Possible test devices.

We can divide these into two categories: Wakefield accelerator related and TBA.

Wakefield structures: We can easily achieve 200 – 500 MV/m gradients using multiple pulses in a collinear WF scheme, due to the fact that low loss microwave dielectric materials are available. The scheme is showing in Figure 2.

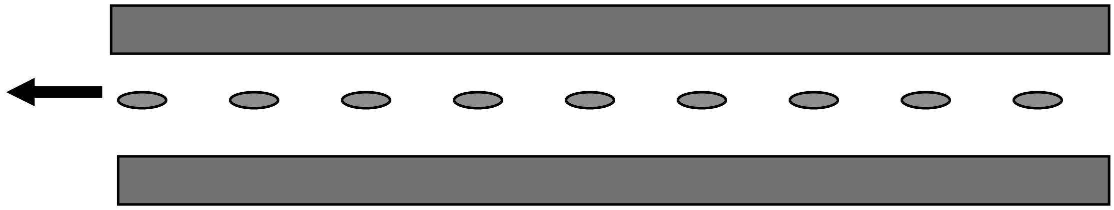

Figure 2. Wakefield generation using a multiple pulse train.

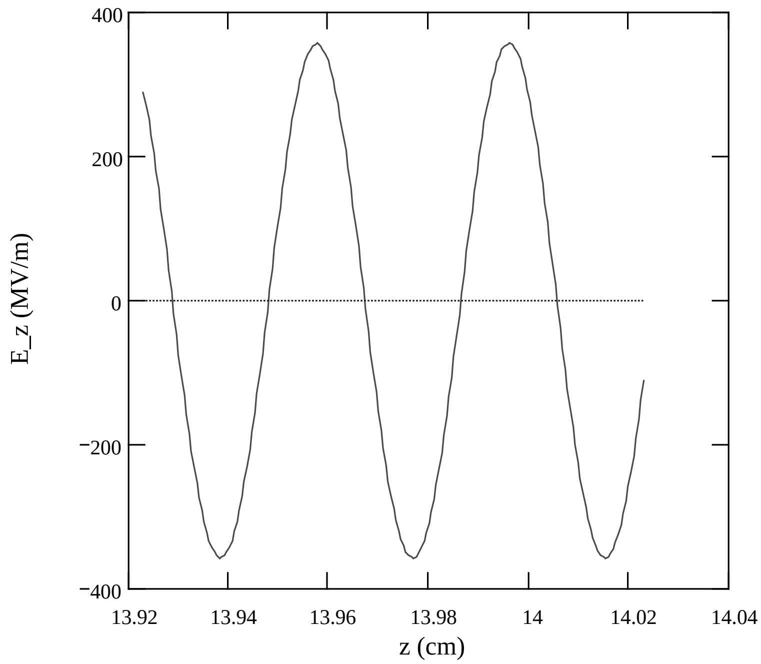

Figure 3. Excited WF amplitude after 60^{th} pulse in a 7.8 GHz structure with inner radius of 3 mm, outer radius b of 8.9 mm and dielectric constant of 4.6. The gradient is nearly 400 MV/m.

By using the step-up transformer scheme proposed at AWA, one can easily achieve even higher gradients.

Two Beam Acceleration Test:

1) High efficiency linac: achieving 95% RF to beam efficiency and minimize the transverse effects. J. Haimson did much preliminary works on this. However we still need to study the transverse effect, particularly in the coupling cell. This is beyond our present capabilities and resources available. It would be extremely useful to have a collaborator to work on this.

2) Testing TBA structures: Use the drive beam to excite and extract RF. Testing the transverse and longitudinal effects of these high current beam in the transfer structures.

Work needing to be done (near term):

- Investigation of photocathode preparation chamber (Cs based).
- Detailed beam loading calculations in both gun and linac tank.
- Design of high efficiency Linac with good transverse WF damping capabilities.

Summary:

It is very interesting that when we simply relax the QE rquirements of the newly upgraded the RF photoinjector we could generate this high average current beam without changing existing AWA configuration. This greatly expands the AWA capabilities to long multi-pulse trains, useful for studying physics of the CLIC version of TBA. It should be noted that achieving high quality 30 A beam itself is a great success. Meanwhile, we still have the capablility to generate single pulses of up to 100 nC, 10 ps for plasma and dielectric wakefield acceleration experiments by simply switching the laser pulse from multiple to single pulse operation.

References:

1. H. Braun et al, CLIC Note 364 “The CLIC RF Power Source: A novel scheme of two beam acceleration for e+e- linear colliders”, August, 98.
2. W. Gai et al, “A high charge and short pulse RF photocathode gun for wakefield acceleration” NIM A 410, p431-436, 1998.