Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

# A plasma wakefield acceleration experiment using CLARA beam

G. Xia [a,b,*], D. Angal-Kalinin [c], J. Clarke [c], J. Smith [d], E. Cormier-Michel [e], J. Jones [c], P.H. Williams [c], J.W. Mckenzie [c], B.L. Militsyn [c], K. Hanahoe [a,b], O. Mete [a,b], A. Aimidula [b,f], Q1 C. Welsch [b,f]

[a] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[b] The Cockcroft Institute, Sci-Tech Daresbury, Daresbury, Warrington, United Kingdom
[c] STFC/ASTeC, Daresbury, Warrington, United Kingdom
[d] Tech-X UK Corporation, Daresbury Innovation Centre, Warrington, United Kingdom
[e] Tech-X Corporation, Boulder, CO, USA
[f] The University of Liverpool, Liverpool, United Kingdom

ARTICLE INFO

Keywords:
Plasma accelerators
Wakefield
FEL
Particle-in-cell

ABSTRACT

We propose a Plasma Accelerator Research Station (PARS) based at proposed FEL test facility CLARA (Compact Linear Accelerator for Research and Applications) at Daresbury Laboratory. The idea is to use the relativistic electron beam from CLARA, to investigate some key issues in electron beam transport and in electron beam driven plasma wakefield acceleration, e.g. high gradient plasma wakefield excitation driven by a relativistic electron bunch, two bunch experiment for CLARA beam energy doubling, high transformer ratio, long bunch self-modulation and some other advanced beam dynamics issues. This paper presents the feasibility studies of electron beam transport to meet the requirements for beam driven wakefield acceleration and presents the plasma wakefield simulation results based on CLARA beam parameters. Other possible experiments which can be conducted at the PARS beam line are also discussed.





## 1. Introduction

Plasma accelerators utilize the breakdown medium “plasmas” as the accelerating structures and therefore avoid the further material breakdown limit posed by the conventional accelerating structures, e.g. copper or niobium RF cavities. In principle, the wavebreaking field can reach 100 GV/m for a plasma with density of $10^{18}$ cm$^{-3}$. Plasmas are therefore the ideal medium to sustain a very large electric field for particle beam acceleration.

Plasma based accelerators have achieved tremendous progress in recent decades [1,2]. With the advances in laser technology, especially with the introduction of the Chirped Pulse Amplification (CPA) [3], the cutting edge laser facility nowadays can routinely reach a few hundred Terawatts ($10^{12}$ W) or even Petawatts ($10^{15}$ W) peak power with very short pulse length (e.g. tens of femtoseconds). Employing such a laser pulse as drive beam, laser wakefield accelerators (LWFA) can achieve $\sim$GeV level electron beam within a few centimeter plasma channel and with an energy spread of only a few percent [4,5]. This scheme therefore has enormous potential for use in future compact light source [6] or particle colliders [7]. For the electron beam driven plasma wakefield accelerator (PWFA), the experiments conducted by a group of scientists from UCLA/USC/SLAC collaboration at the FFTB at SLAC have successfully demonstrated energy doubling for the SLC 42 GeV electron beam [8]. The resulting accelerating gradient in this experiment is about three orders of magnitude higher than the accelerating field of the SLC Linac [9]. Compared to the intrinsic limitations posed by LWFA scheme (e.g. depletion, diffraction and dephasing), the relativistic charged particle beam can in principle propagate in a plasma for a long distance due to large beam beta function (beta function of the beam is equivalent to the Rayleigh length of a laser beam). Therefore the beam driven PWFA has already attracted worldwide interests. It can potentially accelerate a particle beam to high energy due to its high accelerating gradient and relatively long acceleration length. In this paper we propose a new research facility PARS (Plasma Accelerator Research Station) for studying plasma wakefield acceleration at the CLARA facility based at Daresbury Laboratory.

This paper is structured as follows: in Section 2, the CLARA facility and the design strategy for the PARS beam line are introduced. Section 3 elaborates on the electron beam tracking results through the CLARA/PARS beam line. The beam parameter settings at the CLARA/PARS are given in Section 4. The detailed

Q3 Q2 * Corresponding author at: School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom. Tel./fax: +44 161 30 66569.
E-mail addresses: guoxing.xia@cockcroft.ac.uk, guoxing.xia@manchester.ac.uk (G. Xia).

0168-9002/$ - see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.nima.2013.10.092

particle-in-cell (PIC) simulation results on plasma wakefields driven by the electron beams at various plasma densities are presented in Section 5. Section 6 discusses some other research topics (issues), which can be investigated at the PARS beam line as well.

## 2. CLARA facility and PARS beam line

The aim of CLARA is to develop a normal conducting test accelerator able to generate longitudinally and transversely bright electron bunches and to use these bunches in the experimental production of stable, synchronized, ultrashort photon pulses of coherent light from a single pass FEL (free electron laser) with techniques directly applicable to the future generation of light source facilities [10]. The CLARA facility houses a photo-injector electron gun, normal conducting accelerating cavities, magnetic bunch compressor, fourth harmonic lineariser, dedicated beam diagnostic sections at low and high energies and FEL beam line, as illustrated in Fig. 1. The beam energy is 250 MeV and the maximum bunch charge is about 250 pC. The achievable bunch parameters in different operating modes are listed in Table 1 [11,12].

For the electron beam driven PWFA experiment at PARS, a dogleg will guide the full energy CLARA beam to a parallel beam line, offset by $\sim 1.5$ m from the CLARA beam axis, contained within the CLARA shielding area. The conceptual layout of the PARS beam line is also shown in Fig. 1. It consists of the dogleg beam line, final focus, plasma cell, energy spectrometer (phosphor screen) and final beam dump (not shown). The dogleg beam line consists of arrays of dipoles and quadrupoles to guide and focus the beam from the CLARA beam line to the PARS. The final focus, which is prior to the plasma cell, is designed to focus the electron beam transversely and to match the electron beam with the plasma. A variable 10–50 cm plasma cell (a DC discharge plasma source seems feasible) will be built to test the key issues in the PWFA experiments at various beam and plasma parameter ranges. An energy spectrometer, together with a phosphor screen, is employed to characterize the energy of electrons exiting the plasma cell. The final beam dump will absorb the energy of electrons after exiting the plasma cell. Prior to the final focus and plasma cell, a magnetic chicane may be needed to compress the bunch further to an extremely short length.

The proposed dogleg beam line design, using $-I$ transform between the dipoles using two FODO doublets, keeps the transverse beam emittance blow up due to coherent synchrotron radiation (CSR) within acceptable limits [13,14]. Fig. 2 illustrates the beam line design for PARS by using 4 dipoles, with each dipole bending angle of 6°. The optical functions are plotted in Fig. 3, from which we can see that the transverse dispersion function is fully suppressed at the straight section prior to the plasma cell.



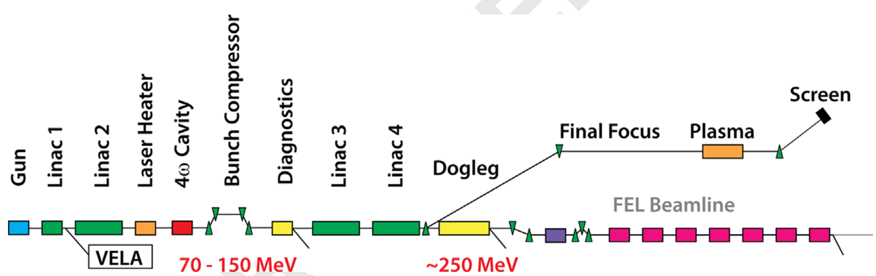


**Fig. 1.** Conceptual layout of the CLARA facility and the PARS beam line.

**Table 1**
Three operation regimes for the PWFA experiment at the CLARA/PARS facility.

| Operating modes | Long pulse | Short pulse | Ultra-short pulse |
|---|---|---|---|
| Beam energy (GeV) | 250 | 250 | 250 |
| Charge/bunch $Q$ (pC) | 250 | 250 | 20–100 |
| Electron/bunch $N_b$ ( $\times 10^9$) | 1.56 | 1.56 | 0.125–0625 |
| Bunch length rms (fs) | 250–800 (flat top) | 100–250 | $\leq 30$ |
| Bunch length (μm) | 75–240 | 30–75 | 9 |
| Bunch radius (μm) | 20–100 | 20–100 | 20–100 |
| Normalised emittance (mm mrad) | $\leq 1$ | $\leq 1$ | $\leq 1$ |
| Energy spread (%) | 1 | 1 | 1 |

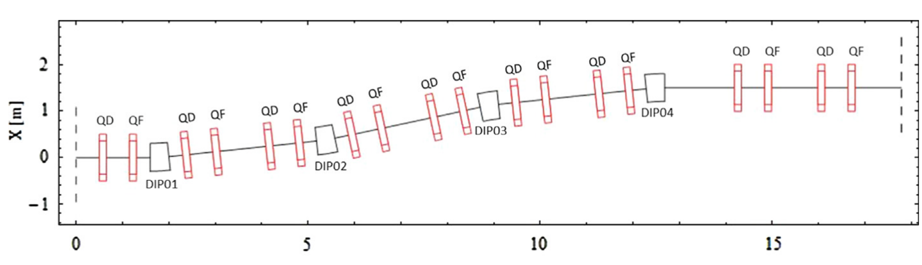


**Fig. 2.** The beam line design for PARS by using 4 identical dipoles.

Please cite this article as: G. Xia, et al., Nuclear Instruments & Methods in Physics Research A (2013), http://dx.doi.org/10.1016/j.nima.2013.10.092