Ph.D. project description for Carl Andreas Lindstrøm

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Introduction

This is the PhD project description for the planned PhD work of Carl Andreas Lindstrøm, from here on called “the candidate”.

Background

Beam-driven plasma wakefield acceleration (PWFA) holds promise for accelerating fields orders of magnitude larger than conventional RF acceleration. Accelerating fields of the order of 10 of GV/m have already been demonstrated experimentally at a number of experiments [1]. In particular, energy doubling from 42 GeV to 85 GeV of a fraction of an electron bunch was demonstrated at the SLAC FFTB experiment [2]. The SLAC FACET two-bunch experiments has recently demonstrated high-efficient, high-gradient acceleration of an electron beam in a plasma [3] which is a major milestone in advancing PWFA as a viable accelerator technology. The recent results also highlight the potential PWFA has for future High-Energy Physics applications.

The overall aim of the PhD project is to further advance the maturity of PWFA as a technology option for future accelerator applications, including potentially a PWFA-based linear collider (“PWFALC”) [4]. One part of the project consists of studying critical challenges (to be defined below) of a PWFALC by theory and simulation. The other part of the project consists of participating in dedicated PWFA experiments at the FACET test-facility at SLAC [5] which aims to validate specific topics (to be defined below) linked to the PWFALC challenges to be studied in parallel.

The main PWFALC challenges to be studied in this project are :

- design of **plasma cell interstage** matching and injection optics
- component and beam tolerances for the matching and injection, with a specific focus on the **transverse tolerance** for the drive and witness beam in the plasma . This must include further studies of the **hosing instability** and beam break-up in plasmas [6].
- limitation and tolerances originating from synchrotron radiation (SR) in the plasma, including **matching tolerances due to SR** and emittance growth related to SR. In particular it is not clear how well the drive beam must be matched in

PWFA, as **self-focusing processes** leads to new beam equilibrium in the plasma which may lead to stable fields [7]. The matching requirements depend on the density ramp of the plasma. Another important related question to investigate is whether it is possible to drive a plasma stage with drive beam field ionization, i.e. without the use of a pre-ionized plasma.

The participation in the "E200" plasma experiment at FACET/SLAC (the candidate will be integrated in the E200 group) will focus on experiments investigating the above PWFALC challenges. There are two phases of the experiments planned; first phase: experiments where a witness bunch is separated from the main bunch using a notch collimator; a possible second phase, not yet funded: use of an external witness bunch injector if/when available at FACET.

Experiments during the first phase :

- continue the studies of the **transverse effects** in the E200 blow out regime experiments, using a long bunch and two bunches [6]. Successful experiments will be an important input to the study of transverse tolerances for a PWFALC design study for transverse tolerances

Experiments during the the second phase :

- develop an experimental plan for studying transverse effects using a witness bunch injector at SLAC. Experiments potentially in the 2016 run.
- General theory/simulation aid in the preparation of FACET witness beam injector experiments; with focus on the topics that relates to the PWFALC challenges :
    - study of matching vs beam loading vs emittance preservation using the witness bunch injector
    - what is the requirement for having a matched drive beam for a PWFALC? Is it possible, or even desirable to not have a drive beam matched to the plasma? Effects from synchrotron radiation, transverse tolerances, hosing and energy transfer efficiency, among other things must be studied.

Experiments with a witness beam injector at FACET depends the availability of such gun before FACET II. If the witness beam injector at FACET will not be available during the next ~3 years, we considered as an alternative to perform transverse experiments using the electron beam injector at the plasma wakefield experiment AWAKE [8], based at CERN, instead.

Synergies with other Oslo PhD student project

This project has synergies with the PhD project of Veronica Olsen [9]. Both project focuses on beam-driven PWFA. While the project for V. Olsen focuses on optimal acceleration using the self-modulated proton wake at AWAKE@CERN, this project for C. Lindstrøm focuses on features the single bunch wake at FACET@CERN. The underlying theory and tools for both projects are similar, so that the students may learn from each other and do some work together. However, the physics and experiments are sufficiently different so that there is no overlap between the two projects.

Co-supervisors

In order to integrate well into the experimental environments abroad, the following persons, both renowned experts in the field of plasma wakefield acceleration has agreed to be co-supervisor for the thesis.

Co-supervisor 1:

Dr. Mark Hogan, SLAC National Accelerator Laboratory, USA. FACET Scientific Leader, co-Principal Investigator of the FACET E200 plasma wakefield experiment.

Co-supervisor 2:

Dr. Patric Muggli, Max Planck Institut for Physics, Germany. Experiment responsible for the AWAKE collaboration. Dr. Muggli is also co-supervisor for the Oslo PhD student V. Olsen.

Milestones

2014 (study started Sep 1, 2014) :

* Complete most of the mandatory course work

* Get acquainted with the various aspects of conventional accelerator physics and plasma wakefield acceleration

* Participation at CERN Accelerator School with focus on plasma acceleration

2015

* Potential publication on staging of a PWFALC (with collaborators), Phys.Rev. STAB or similar

* Participate in PWFA experiments at FACET, focusing on transverse effects in a plasma (hosing and kicks)

* Perform an initial assessment of the parameter of an optimal FACET witness bunch injector, by simulation studies

* Theory/simulation study of transverse tolerances for drive-witness bunch offset in a PWFALC

2016

* Participate in PWFA experiments at FACET, focusing on transverse effects, using a witness bunch injector [if available]

* Theory/simulation study of drive beam injection tolerances

* Preparation of a publication about transverse effects and injection tolerances in a plasma stage, in a peer-reviewed journal, like Phys. Rev. ST-AB, or Phys. of Plasma

2017

* Theory/simulation study of self-focusing of a unmatched bunch, and whether unmatched drive bunches can be used to drive a wake in a PWFALC

* Potential publication on an overall concept for a PWFALC (with collaborators), Phys.Rev STAB or similar

* Potential to participate in the AWAKE experiment at CERN, if additional experimental results is desired/required

2018 *(PhD grant ending Sep 1, 2018) :*

* Preparation of a publication about drive beam self-focusing in a plasma stage, in a peer-reviewed journal, like Phys. Rev. ST-AB, or Phys. of Plasma

* Write-up and completion of Thesis

References

[1] P.Muggli ,M.J.Hogan, C.R.Physique10 (2009)

[2] I. Blumenfeld et al., Nature 445 741 (2007)

[3 M. Litos, E. Adli et al., Nature, 6 November (2014) (10.1038/nature13882)

[4] E. Adli et al. arXiv:1308.1145 (2013)

[5] M.J.Hogan et al. New J.Phys. 12, 055030 (2010), http://facet.slac.stanford.edu

[6] http://home.web.cern.ch/about/experiments/awake

[7] J. B. Rosenzweig et al., Demonstration of electron beam self-focusing in plasma wake fields, Phys. Fluids B 2, 1376 (1990).

[8] A. A. Geraci and D. H. Whittum, Physics of Plasmas, 7, 3431 (2000), C.Huang et al.,Phys.Rev.Lett.99,255001(2007), E. Adli et al. "Transverse effects in plasma wakefield acceleration at FACET", 15th Advanced Accelerator Concepts Workshop (2012)

[9] PhD project plan for V. Olsen, Dep. of Physics, University of Oslo

Signatures

Carl Andreas Lindstrøm

Erik Adli

Mark Hogan

Patric Muggli