INTEGRATION OF A TERAWATT LASER AT THE CERN SPS BEAM FOR THE AWAKE EXPERIMENT ON PROTON-DRIVEN PLASMA WAKE ACCELERATION

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Abstract

In the AWAKE experiment a high-power laser pulse ionizes rubidium atoms thus creating a plasma for proton-driven wakefield acceleration of electrons and seeding the self-modulation instability within the SPS proton bunch on the front of plasma creation. The same laser will also generate UV-pulses for production of a witness electron beam using an RF-photoinjector. A completely new underground laser laboratory was built in accordance with requirements for AWAKE laser installation. Optical beam lines for delivery of laser beams to the plasma cell and RF-photoinjector were designed. The means for laser beam control and diagnostics are developed.

INTRODUCTION

The Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) aims at studying plasma wakefield generation and electron acceleration driven by proton bunches [1]. For the AWAKE experiment a 400 GeV proton beam will be extracted from the CERN Super Proton Synchrotron, SPS, and utilized as a drive beam for wakefields in plasma to accelerate electrons from 10-20 MeV energy up to the GeV scale. A plasma will be generated in a 10 m long rubidium vapour cell via the over the barrier ionization by high intensity laser field. The short laser pulse propagating co-axially with the proton beam will seed a self-modulation instability within the proton bunch on the front of plasma creation. Thus, the long SPS proton bunch (σ_z=12 cm) will be transformed into a train of micro-bunches driving the periodic wakefield.

An electron beam [2] will be injected into the plasma cell at oblique angle to the proton beam for demonstration of the proton-driven plasma wakefield acceleration. The electron bunches for the witness beam will be produced in an RF-photoinjector using an UV beam generated from the same laser source.

The AWAKE facility is integrated in the underground area which previously was used for CERN Neutrinos to Gran Sasso facility (CNGS). The existing proton beam line TT41 was modified for focussing the proton beam to the plasma cell and merging with the laser and electron beams [3]. The TSG40 tunnel was refurbished to suit a class 4 laser installation and equipped with services needed for operation of the AWAKE laser. Two new tunnels were constructed for delivery of laser and electron beams to the plasma cells. The facility layout with laser beam lines is illustrated in Fig. 1. In following sections of this paper we describe the laser laboratory and design of laser beam lines.

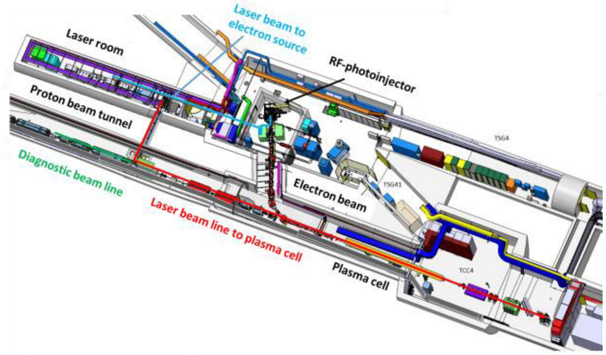

Figure 1: Layout of AWAKE facility with laser beam lines to plasma cell (in red), diagnostics beam line (in green) and to electron source (in blue).

LASER LABORATORY

AWAKE Laser Setup

The laser system CENTAURUS 100fs was built by Amplitude Technologies according to the AWAKE specifications. The laser system includes an erbium-doped fiber oscillator (Menlo model C-Fiber 780) and a chirped pulse amplification system consisting of a stretcher, regenerative amplifier, preamplifier, main amplifier, and a compressor. The frequency-doubled 780 nm output of 88 MHz passively mode-locked oscillator is amplified in Ti:Sapphire crystals pumped by 532 nm beams provided by Nd:YAG lasers. The laser parameters as measured during on-site acceptance tests are presented in Table 1.

Table 1: AWAKE Laser Parameters

Performance	Measured Value
Repetition Rate	10 Hz
Central Wavelength	780-785 nm
Spectral Bandwidth	24 nm
Pulse duration	120 fs
Output Energy (uncompressed)	663 mJ
Output Energy (after compression)	500 mJ
Secondary output (uncompressed)	3 mJ
Energy stability	1.02%
Beam pointing stability	4.2 µrad
Temporal intensity contrast	$2 \cdot 10^{-7}$
Polarization (linear)	250:1

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Laser Room

The space allocated for laser installation is a 18.5 m long and 2.5 m wide dead-end tunnel with round ceiling and side walls (R=1.55 m). As required for laser installation it was equipped with air conditioning systems capable to ensure clean room conditions of class 7 (ISO 16644-1), temperature stability within ±1ºC and the relative humidity >40%. According to CERN safety regulations, a special duct for fume extraction in case of fire detection was installed. The supply air duct is installed on the top part of the tunnel and the recirculation and extraction ducts are attached to the curved wall surfaces (see Fig. 2). This configuration allows the optimal distribution of the air inside the room and optimises the use of the space inside the room. Three optical tables with vibration dumping honeycomb internal structure and ferromagnetic high grade steel surface plates were arranged to form an optical surface of 7.2 m long and 1 m wide optical surface for laser installation.

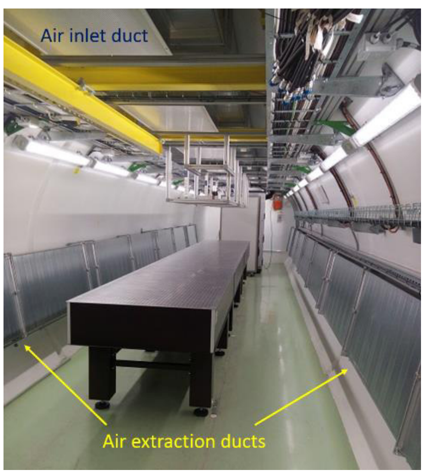

Figure 2: AWAKE laser room.

Four racks for laser control electronics and RF timing equipment are installed in the end of the room, while the space between the optical table and entrance was reserved for a vacuum tank of laser pulse compressor, pumping group, laser mirror vacuum tanks and a small table for laser beam diagnostics. Electrical, control and Ethernet cables, supplies for compressed air and laser cooling water, an exhaust pipe for pumping system, vacuum line connecting the laser room with the proton beam line have been installed and sealed before the clean room commissioning in order to minimize the contamination of the air ducts by the construction dust.

LASER BEAM LINES

The functional schematic of AWAKE laser beam lines is depicted in Fig. 3. As the laser beams are to be transported outside the laser room the system includes the laser safety shutters linked to the SPS access system. Thus laser experts can perform necessary work on setting up the laser beam lines, while access of other personnel to respective zones is prohibited. The function of laser beam dumps is to protect equipment from laser impact.

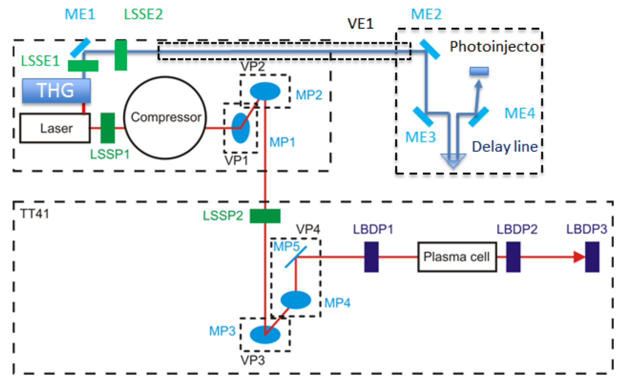

Figure 3: Functional schematic of the laser beam lines to the plasma cell and photoinjector indicating the mirrors (blue) and their surrounding vacuum tanks, the laser safety shutters (green) and laser beam dumps (violet).

Laser Beam Transport to the Plasma Cell

The laser beam line to the plasma cell starts at the output of the optical compressor in the laser lab and is transported to TT41 via a newly made 40 cm diameter tunnel TT42. Due to the altitude difference between the laser lab and TT41 the beam leaves the laser lab at a height of ~2 m and arrives in TT41 below floor level in a trench. There the laser beam crosses the TT41 tunnel under the proton beam line and then reflected up to the merging vessel where it is directed to the last mirror located very near the proton beam path (~ 6 mm between the proton beam axis and mirror edge) and then reflected towards the plasma cell (see Fig. 4). The whole laser beam line is enclosed in a vacuum system, which is attached to compressor's vacuum tank and to the proton beam line vacuum system at the merging point. The vacuum level at the proton beam side of the line is to be 10^{-7} mbar. The deflection of the laser beam is performed with dielectric mirrors held by motorized vacuum compatible mirror mounts (New Focus 8823-UHV and 8823-AC-UHV).

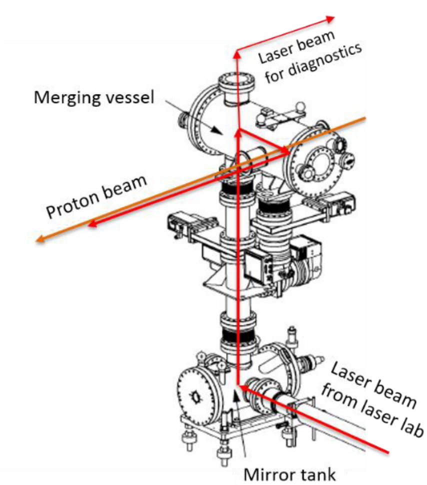

Figure 4: Assembly of mirror tank and merging vessel. The ionizing laser beam arrives in the trench and is directed towards the plasma cell. A small fraction of the beam is coupled out to the diagnostics beam line.

Focussing of the laser beam to the plasma cell will be performed with a three-lens telescope installed in the laser room before the pulse compressor. Three focusing geometries are being considered:

i. “Full energy” option, 650 mJ at the compressor’s input (proposed by Amplitude Technology);
ii. “Attenuated energy” option, 400 mJ at the compressor’s input (proposed by Amplitude Technology);
iii. “Smooth focusing” to provide very smooth change of the beam size within the plasma cell.

The calculation of laser beam size evolution along its propagation towards the plasma cell for these three focussing options is presented in Fig. 5.

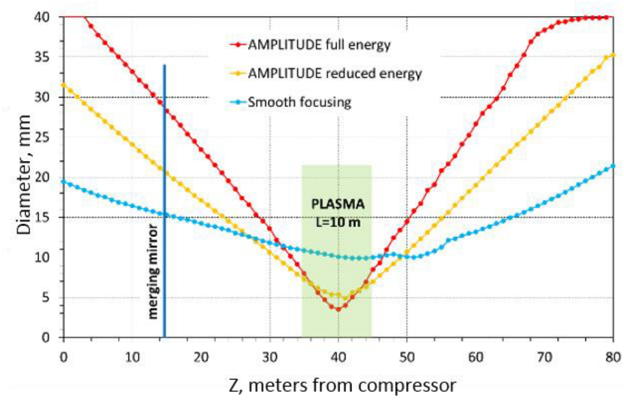

Figure 5: Laser beam diameter at 1% level of maximum.

Diagnostics Beam Line

A diagnostic beam line (Fig. 6) is prepared for installation in TT41 tunnel for measuring the beam properties of a low energy replica of the ionizing beam in exactly the distance which corresponds to the plasma cell location. This concept is also known as “virtual plasma”. The diagnostic beam line starts from the merging chamber viewport positioned above the MP4 mirror which transmit a small fraction (~1%) of the main laser beam. This beam is transported 8 m upstream the proton beam line and returns back to an optical table downstream the merging chamber. The laser beam will be imaged at positions corresponding to the beginning, centre and the end of plasma cell using CCD cameras.

Laser Beam to Photoinjector

The laser beam for the electron gun will be taken from the second output of the base version of the laser system, further amplified to ~30 mJ, compressed to 300 fs using an in-air pulse compressor, frequency converted to 260 nm via a third harmonics generation and stretched to the desired pulse length of 10 ps. The UV laser beam generated in the laser room will be deflected towards the ceiling and then transported in a vacuum pipe (primary vacuum conditions) to the electron gun room, where it is to be deflected down onto an optical table and from there into the gun vacuum system. The design of this line is completed, installation is planned for the second phase of AWAKE experiment in 2017.

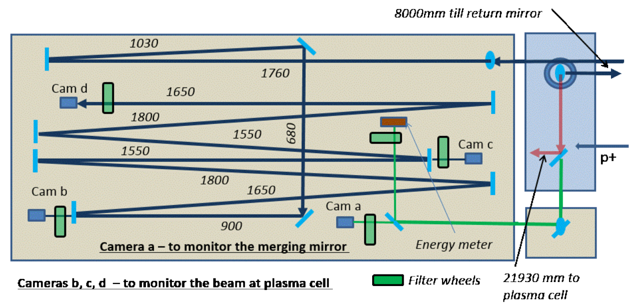

Figure 6: Setup on the optical table downstream the merging chamber with diagnostic equipment allowing monitoring the laser beam profile in the plasma cell. Distances between mirrors are in millimetres.

Control of Laser Beams

During the proton beam time the access to the AWAKE experimental area including the laser room is not permitted, wherefore all equipment must be controlled remotely. At CERN the accelerator control system is based on the Real-time FESA (Front-End Software Architecture) framework [4]. Accordingly, FESA classes are being developed for all laser beam elements, except the laser itself which has own local control interface accessible via standard remote desktop control tools. Locally installed Siemens PLC is used to control laser shutters, laser dumps, filter wheels, flip mounts, a mirror translator in air, interlocks and acquire laser pulse energy values from Maestro Gentec-EO energy meters. Pico-motors of New Focus mirror mounts and SmarAct mirror translator are equipped with own controllers, which are connected to a remote Front-End Computer via CERN Technical Network (Ethernet). For acquiring laser beam images from GigE digital cameras a National Instruments PXI system is being set up.

CONCLUSION

The infrastructure required for laser installation has been created in AWAKE experimental area. The laser beam line to the plasma cell is constructed, installation of equipment is progressing well towards commissioning planned for summer 2016 with a goal to begin the physics experiment in the end of this year.

ACKNOWLEDGEMENT

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