CERN AWAKE FACILITY READINESS FOR FIRST BEAM

C. Bracco, M. Bernardini, A. Butterworth, H. Damerau, S. Doebert, V.N. Fedosseev, E. Feldbaumer, E. Gschwendtner, W. Höfle, A. Pardons, E. Shaposhnikova, H. Vincke
CERN, Geneva, Switzerland

Abstract

The AWAKE project at CERN was approved in August 2013 and since then an important effort was made to be able to probe the acceleration of electrons before the 2^{nd} Long Shutdown (LS2) of the CERN accelerators in 2019-2020. After finishing the installation,he next steps in the challenging AWAKE schedule will be a dry run of all the beam line systems at the end of the HW commissioning in June 2016, and then first proton beam sent to the plasma cell. The current status of the project is presented together with an outlook over the foreseen work for operation with electrons in 2018.

INTRODUCTION

AWAKE at CERN [2] is the first proof-of-principle experiment that will use high energy (400 GeV/c) and high intensity (up to $3{\cdot}10^{11}$) proton bunches to generate plasma wakefield acceleration. Proton bunches from the Super Proton Synchrotron (SPS) will be extracted towards the TT41 beam line which hosted the CERN Neutrinos to Gran Sasso (CNGS) facility until 2012. The AWAKE experimental apparatus will be installed at the end of the line and will consist of a 10 m long rubidium (Rb) vapour plasma cell and various diagnostics. The goal is to achieve accelerating gradients of ~1 GV/m in the plasma. The measurement program of AWAKE consists of two main phases. Phase I will be dedicated to understand the physics of the proton Self-Modulation Instability (SMI) process in the plasma [1]. A 4 TW laser, co-propagating with the proton bunch, will be used to ionise the Rb gas into plasma and seed the SMI in a controlled way. A witness bunch of ~15 MeV electrons will be injected in the plasma during Phase II to probe the accelerating wakefields and produce GeV electron bunches.

HISTORY AND PRESENT STATUS

The first kick-off meeting of the AWAKE collaboration was held in Lisbon in June 2012. Feasibility studies were then performed to identify a possible location for the experiment in the CERN accelerator complex and quantify the required budget and manpower. The CNGS area was chosen for AWAKE facility and detailed integration studies were carried out to define the facility layout (the most updated version is shown in Fig. 1) and all the needed services and infrastructures. These studies were collected in the AWAKE Design Report which was submitted in March 2013 and brought the project approval by the CERN management five months later. Since then a huge effort was made to be able to probing the electron acceleration before LS2 which will start at the beginning of 2019.

The area was cleared from dismissed components of the CNGS facility and the main civil engineering works were completed already by the end of ssummer 2014. A tunnel was dug for the electron beam line [3] to connect the room where the RF gun [4] will be installed and the proton beam line (see picture g in Fig. 1). Two cores were drilled: one for the laser beam line [5] from the clean room to the proton line and the other for the optical line of the streak camera used for synchronisation measurements between the beams [6]. In 2015 all the services and infrastructures (e.g. cooling and ventilation, shielding, water and compressed air, GSM, internet, etc.) needed for Phase I were ready. Several cabling campaigns were performed and racks installed for the powering and control systems of the different equipment (vacuum, diagnostics, etc.). Important decontamination works were accomplished and the area was declassified from a limited stay (< 2 mSv/h) to a supervised radiation area (< 15 μSv/h) in December 2015. This was a fundamental step since, due to the nature of the experiment, frequent accesses to the experimental zone will be required.

A complex system is being put in place to insure a safe access of the personnel to the area. Different access rules had to be worked out to take into account the presence of the laser, electron and proton beams, the RF gun and its klystron, the cables and the racks. For the same reason, the fire safety aspects had to be revised and new fire doors, walls, smoke detectors, dry-risers for water are being added and the ventilation ducts are being modified. The full access system will have to be validated in formal tests just before the first beam extraction.

The last ~ 80 m of the proton beam line had to be modified to comply with the experiment specifications [7]. Twelve magnets were refurbished and reinstalled according to the new geometric and optics requirements. The installation of the magnets, the beam diagnostics and all the related vacuum components is completed (picture a and d in Fig. 1). All the elements were precisely aligned with respect to the beam reference system.

The laser room is ready for the installation of all the components (picture f in Fig. 1). The vacuum system to transport the laser beam from the laser room to the laser-proton merging point is completed. It includes three laser mirror tanks, a vacuum laser beam shutter and a merging vessel (see pictures e, b, and c in Fig. 1 respectively). The installation of the laser, the compressor, the beam transport optics, the dumps and the diagnostics is ongoing; details can be found in [5].

The plasma cell, without Rb, was installed in February 2016 (picture h in Fig. 1). The custom-designed ends equipped with irises and a continuous flux of Rb to maintain the required plasma uniformity [8] will be ready in Septem-

ISBN 978-3-95450-147-2

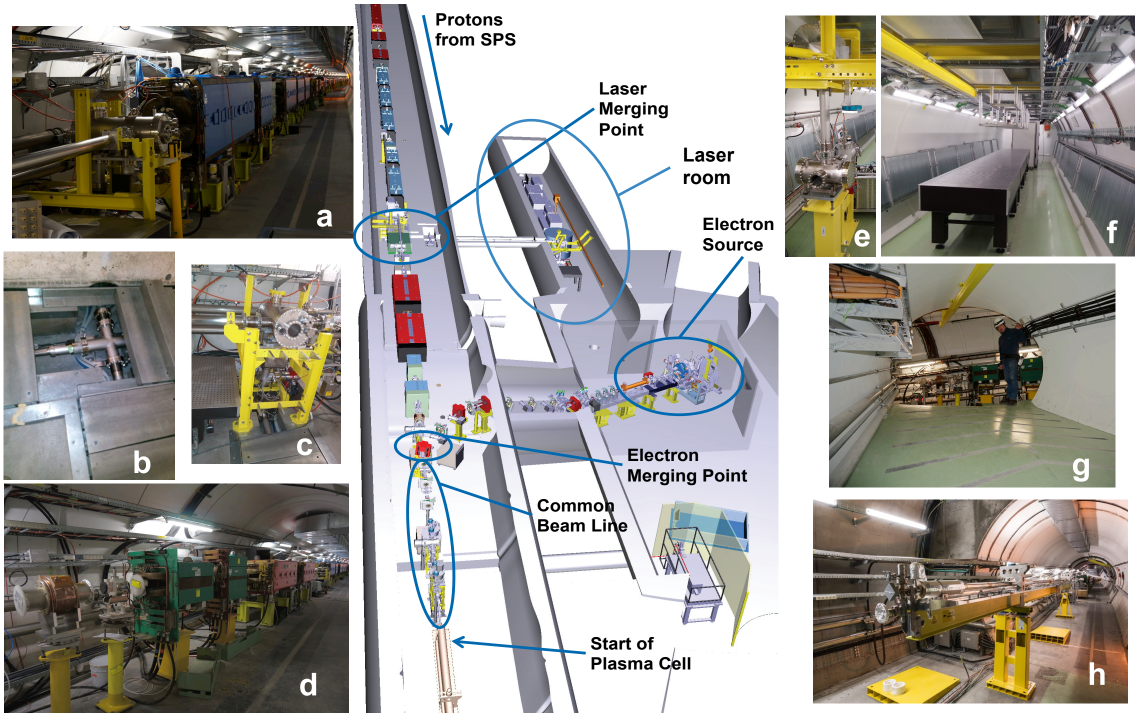

Figure 1: Layout of the CERN AWAKE facility and pictures showing the present status of the proton beam line (a and d), the laser room and beam line (b, c, e and f), the plasma cell (h) and the tunnel for the electron beam line (g).

ber 2016. Dummy ends, constituted of standard 40 mm diameter vacuum pipes, will be installed in the meantime to allow for the first commissioning of the proton and the laser beams.

Five weeks (from week 19 until week 23) will be dedicated to the Hardware Commissioning (HWC) of the proton beam line. Works are ongoing to finalise all the controls, firmware, software and data logging aspects for that period.

PROTON BEAM LINE HWC

The pre-requirements and foreseen tests for the HWC of the different equipment of the proton beam line are presented.

Vacuum System

The majority of the HWC activities for vacuum are performed already during the installation and pumping down periods. This concerns leak detection, checks of pumps, gauges and valve movements. Only the correct behaviour of the Beam Interlock System (BIS) [9] logic, which prevents the beam extraction from the SPS if a valve is closed, has to be tested during the HWC.

Beam Diagnostics

Proton beam diagnostics consist of Beam Position Monitors (BPMs), Beam Loss Monitors (BLMs), Beam Current Transformers (BCTs) and Beam Profile Monitors (BTVs) [7]. A new electronics had to be developed for the BPMs to be compatible with single bunch operation and will be installed at the end of May this year. Polarity checks and calibration measurements will be done during the HWC to quantify and scale possible offsets. For the BLMs only connection checks are needed. BCTs will have to be calibrated to define the relation between ADC signal and number of charges. The actuators for the movement of the screens, filters and mirrors of the BTVs have to be checked. The screens need to be calibrated to establish the pixels-to-mm conversion. Filters, final focusing mirrors and the time profile of the streak camera will have to be aligned. A timing signal (either from the SPS or a dummy one) will be needed to check the ps resolution of the streak camera.

BIS

Several systems are connected to the BIS and only if all of them give a beam permit the extraction from the SPS is allowed. The channels are divided in un-maskable (position of vacuum valves, laser dump and proton beam stoppers plus Warm Interlock Magnets (WIC) [10] to survey magnet overheating) and maskable interlocks (current surveillance of the TT41 magnets with a separate check for the main dipoles and the Fast Magnet Current Change Monitor (FMCM) [11]). BLMs and BPMs are checked by the Software Interlock System (SIS) [12] which prevents the following extraction in case of acquisitions outside predefined thresholds [13]. During the HWC, the correctness of the interlock logic has to be checked for each system. Since AWAKE and LHC beams share the same SPS extraction point and the initial part of the transfer line [7], the extraction towards the right destination (either LHC or AWAKE) has to be verified. No modification is allowed after the BIS validation.

Magnets, Power Converters and WIC

The magnets of the TT41 proton line have not been pulsed over the last four years. Moreover the final part of the line was completely redesigned and all the magnets were displaced and re-cabled. An additional power converter was installed to feed two new dipoles in series and the polarity of a quadrupole of the final matching section was swapped. The optics at the beginning of the line was matched with the new SPS Q20 optics [14]. At present the switch magnets which are powered to deviate the beam into TT41 are locked to the LHC destination. The control of the electronic power switches of the main dipoles has to be upgraded and fully re-qualified.

A well established sequence of tests and acceptance criteria were defined for the HWC of the TT41 magnets . Required conditions before and during the checks, correct sequence, detailed procedures and list of circuits to be tested were prepared. The tests include: Electrical Quality Assurance (ELQA) of the warm circuits, polarity checks, performance of all the generators and WIC response both for the magnets and the power converters. A heat run of all the magnets of the line at nominal current will also be performed. Part of these activities are in conflict with the LHC operation because of the common section of the beam line. For these reason the tests are scheduled at the turn of the first LHC Technical Stop (TS: week 21, 22 and 23) and will complete the HWC period.

Dry Run

The formal access system test is foreseen for week 24 and will be followed by a dry run in preparation for the first beam extraction up to the end of the AWAKE transfer line at the end of June 2016. This will consist in a final and global check of all the previously mentioned systems, their functionalities and the related controls. The Graphic User Interfaces (GUI) for measurements and equipment and beam controls will have to be available and fully operational in the CERN Control Centre (CCC). The correct acquisition and logging of all the required data will have to be checked. Thresholds will have to be setup to further verify all the interlocks. The correct triggering of the diagnostics with the SPS timing will have to be assessed together with the pulsing of all the magnets at the real operational current.

Once the line will be qualified as ready for operation the commissioning with beam period will start. All the details about this phase can be found in [15].

NEXT STEPS AND FUTURE OUTLOOKS

The proton beam commissioning and operation period will be interleaved with installation phases. The completion of the laser beam line is planned for the end of July 2016 and will be followed by the laser commissioning. The hardware for the synchronisation between the laser and the SPS RF system [16], will become operational in the second half of August. The Rb vapour source will be fully installed and ready for the commissioning at the end of September. The SMI diagnostics will be ready already in July 2016. The Phase I physics program will then start in October and continue in 2017 with eight weeks a year of measurements.

The installation of the RF gun (including the klystron and the waveguides, all recuperated from the CLIC Test Facility (CTF3)) and the electron beam line will also take place in 2017. Quadrupoles and correctors of the primary beam line are under production and should be delivered to CERN within the first half of next year. The power converters for these magnets will be recuperated by CTF3. The main dipoles are fabricated at CERN as well as their generators. The part of the line just upstream of the plasma cell will have to be modified to host the electron magnets and the diagnostics. Two quadrupoles and a spectrometer will be installed a few meters downstream of the plasma cell to focus and measure the accelerated electron beam [17]. The spectrometer optical line should be installed within April 2017. The ultimate milestone is to be ready to start the Phase II physics program at the beginning of 2018 and continue all along the year.

REFERENCES

[1] N. Kumar, K. Lotov and A. Pukhov, “Self-modulation instability of a long proton bunch in plasmas”, in *Phys. Rev. Lett.*, vol. 104, p. 255003, 2010.

[2] P. Muggli, C. Bracco *et al.*, “AWAKE, the advanced proton driven plasma wakefield acceleration experiment”, presented at IPAC’16, Busan, Korea, May 2016, paper WEPMY019.

[3] J.S. Schmidt *et al.*, “The AWAKE electron primary beam line”, in *Proc. of IPAC’15*, Richmond, USA, paper WEPWA039, p. 2584.

[4] K. Pepitone *et al.*, “The electron accelerator for the AWAKE Experiment at CERN”, to be published in Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated equipment.

[5] V. N. Fedosseev *et al.*, “Integration of a terawatt laser at the CERN SPS beam for the AWAKE experiment on proton-driven plasma wake acceleration”, presented at IPAC’16, Busan, Korea, May 2016, paper WEPMY020.

[6] E. Gschwendtner *et al.*, “AWAKE, the advanced proton driven plasma wakefield acceleration experiment at CERN”, to be published in Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated equipment.

[7] C. Bracco *et al.*, “Beam transfer line design for a plasma wakefield accelerator experiment (AWAKE) at the CERN SPS”, in *Proc. of IPAC’13*, Shanghai, China, paper TUPEA051, p. 1247.

[8] E. Oz *et al.*, “A novel Rb vapor plasma source for plasma wakefield accelerators”, in *Nucl. Instr. Meth. Phys. Res. A*, vol. 740, no. 11, p. 197, 2014.

[9] B. Puccio *et al.*, “The CERN beam interlock system: principle and operational experience”, in *Proc. of IPAC’10*, Kyoto, Japan, paper WEPEB073, p. 2866.

[10] R. Harrison *et al.*, “Powering interlock systems at CERN with industrial controllers”, in *Proc. of ICALEPCS’05*, Geneva, Switzerland, paper PO2.036-3.

ISBN 978-3-95450-147-2

[11] M. Werner *et al.*, “Requirements for the fast magnet current change monitors (FMCM) in the LHC and SPS-LHC transfer lines”, LHC Engineering Specification, LHC-CIW-ES-0002, CERN, Geneva, Switzerland, 2002.

[12] J. Wozniak *et al.*, “Software interlock system”, in *Proc. of ICALEPCS’07*, Knoxville, Tennessee, USA, paper WPPB03, p. 403.

[13] C. Bracco *et al.*, “The Challenge of interfacing the primary beam lines for the AWAKE project at CERN”, in *Proc. of IPAC’14*, Dresden, Germany, paper TUPME077, p. 1534.

[14] H. Bartosik, G. Arduini, and Y. Papaphilippou, “Optics considerations for lowering transition energy in the SPS”, in *Proc. of IPAC’11*, San Sebastian, Spain, paper MOPS012, p. 619.

[15] J. S. Schmidt *et al.*, “Commissioning preparation of the AWAKE proton beam line”, presented at IPAC’16, Busan, Korea, May 2016, paper TUPMR052.

[16] H. Damerau *et al.*, “RF synchronisation and distribution for AWAKE at CERN”, presented at IPAC’16, Busan, Korea, May 2016, paper THPMY039.

[17] L. C. Deacon *et al.*, “A spectrometer for proton driven plasma accelerated electrons at AWAKE - recent developments”, presented at IPAC’16, Busan, Korea, May 2016, paper WEPMY024.