COMMISSIONING PREPARATION OF THE AWAKE PROTON BEAM LINE

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Abstract

The AWAKE experiment at CERN will use a proton bunch with an momentum of 400 GeV/c from the SPS to drive large amplitude wakefields in a plasma. This will require a ~830 m long transfer line from the SPS to the experiment. The preparations for the beam commissioning of the AWAKE proton transfer line are presented in this paper. They include the detailed planning of the commissioning steps, controls and beam instrumentation specifications as well as operational tools, which are developed for the steering and monitoring of the beam line. The installation of the transfer line has been finished and first beam is planned in summer 2016.

INTRODUCTION

The beam commissioning for the first phase of the Advanced Proton-Driven Plasma Wakefield Acceleration Experiment (AWAKE) at CERN [1] is currently being prepared. An overview of the different experimental stages of AWAKE is presented in [5]. The experimental goal of this first project phase is to study the dynamics of a long proton bunch, extracted from the CERN Super Proton Synchrotron (SPS) when propagating in a 10 m plasma channel. The proton beam is expected to experience the so called self-modulation instability [2], which will create micro-bunches corresponding to the plasma wavelength of 1 mm. The effect will be seeded by a short 4 TW laser pulse [3], which is used as well to ionize the rubidium vapor. Simulations predict that with this configuration a wakefield in the order of ~GeV/m can be obtained, using a bunch of $3{\cdot}10^{11}$ protons at 400 GeV/c and an rms length of 12 cm [4]. The amplitude of these wakefield will be sampled with an externally injected electron beam in the second phase of AWAKE.

The AWAKE Proton Beam Line

The integration of AWAKE within the CERN accelerator complex is shown in Figure 1. The proton beam will be extracted from the SPS into the TT40 transfer line from where it can be sent either into the TI8 line for injection into the Large Hadron Collider (LHC) or into TT41 towards AWAKE. The main part of the TT41 transfer line kept the configuration used for the CERN Neutrinos to Gran Sasso (CNGS) experiment. The transfer line is about 830 m from the SPS extraction point to the vapor source of AWAKE. Just the last ~80 m have been modified in order to match the proton beam into the vapor source and to create a chicane to merge the beam axis of the protons and the ionizing laser beam ~22 m upstream of the vapor source. The concept of

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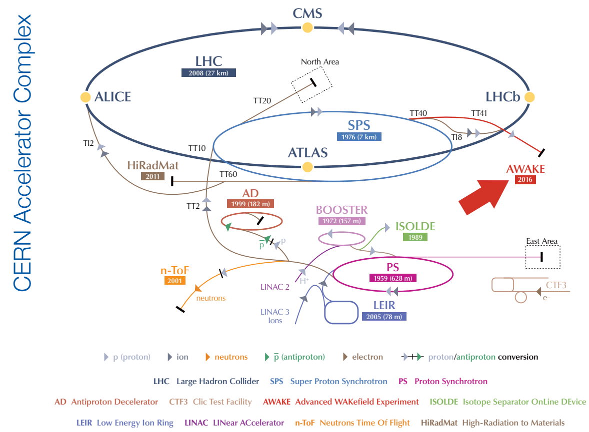

Figure 1: View of the AWAKE integration in the CERN accelerator complex.

the AWAKE transfer line has been presented in [6]. The main proton beam parameters are given in Table 1.

Table 1: Proton Beam Parameters

Parameter	Value
Momentum [MeV/c]	400 000
Momentum spread (1σ) [%]	±0.035
Relativistic gamma	426.3
Particles per bunch	$3{\cdot}10^{11}$
Charge per bunch [nC]	48
Bunch length (1σ) [mm]	120 (0.4 ns)
Norm. emittance [mm·mrad]	3.5
Repetition rate [Hz]	0.033
1σ spot size at focal point [μm]	200±20
β-function at focal point [m]	5
Dispersion at focal point [m]	0

REQUIREMENTS FOR BEAM INSTRUMENTATION

In total there are 25 beam position monitors (BPMs), 12 beam profile monitors (BTVs), 15 beam loss monitors (BLMs) and 2 beam current transformers (BCTs) distributed along the AWAKE proton beam line.

A special focus has been set on the beam measurements around the mirror, which is used to merge the laser and proton beam axis, and around the vapor source. Figure 2 shows a sketch of the set up in the two areas.

The laser merging mirror has to be protected from being hit by the proton beam in order to prevent damage but also

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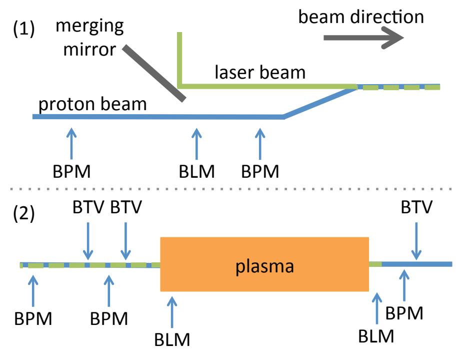

Figure 2: Locations of beam instrumentation around the laser merging mirror (1) and the vapor source/plasma (2).

electric charging of the mirror. Therefor, two BPMs with a resolution of 100 μm and a BLM have been installed around the mirror to monitor the beam position and the losses at that location. These elements are connected to the software interlock system (SIS) of the SPS and will prevent the following extraction event in case values are out of an established range. All BTVs downstream of the merging mirror will be protected from being hit by the high power laser pulse with a local interlock system of the laser.

For the analysis of the experimental results, it is important to provide well defined beam parameters at the vapor source. During operation, two BPMs upstream of the vapor source with a resolution of 50 μm will monitor the proton beam position and angle, at the entrance of the vapor source. More detailed analysis of the proton beam will be performed during the commissioning of the beam line. All three BTVs around the vapor source are able to detect the proton as well as the laser beam with a resolution of 50 μm (upstream of the vapor source) or 100 μm (downstream). The second last BTV upstream of the vapor source has an additional mode in connection with a streak camera to measure the synchronization between the laser pulse and the proton beam.

The minimum aperture is located at two irises with a diameter of 10 mm at both ends of the vapor source, which are needed to control the plasma density distribution [7]. Losses at these irises are detected by two BLMs. These ones and the two BPMs upstream of the vapor source are included in the SIS as well. The BPM and BTV downstream of the vapor source will be used for the steering of the proton beam.

At the two BTVs downstream of the plasma cell, the self-modulation instability will be measured indirectly, as described in [8].

BEAM COMMISSIONING STEPS

The beam commissioning of the primary proton beam line will be performed in several steps, which depend on the availability of the other systems in the AWAKE experiment. The main blocks are the first extraction tests after the hardware commissioning (HWC), the beam line commissioning without and with the laser beam and the final steering with the vapor source. An overview of these steps is shown in Figure 3, the preparations of the beam line for operation are presented in [9].

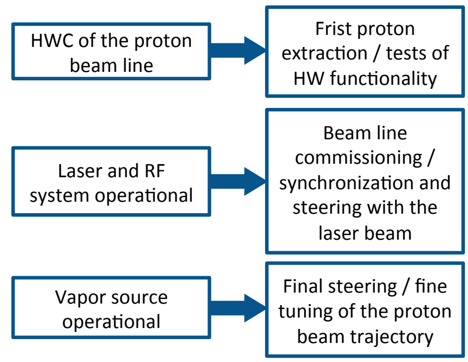

Figure 3: Beam commissioning steps.

First Proton Beam Extraction

Directly after the HWC of the power converters, magnets and beam instrumentation is finished and the vacuum has reached the operational level of 10^{-7} mbar the first beam will be extracted from the SPS into the AWAKE beam line without synchronization between the experiment equipment and the SPS.

The upper part of the transfer line TT40, which is common with the LHC injection via TI8, has already been commissioned during the start up of the LHC. Up to now, the switching magnets to change the beam direction between TI8 and TT41 are blocked from powering for safety reasons. When these magnets are pulsed, the proton beam is sent directly through the full TT41 beam line as there are no beam stoppers installed except the one in TT40. For this reason the first tests will be performed with a low intensity bunch of $5{\cdot}10^9$ protons, like the LHC pilot beam, to minimize the activation due to possible loss of the proton beam in the line. With this beam the general functionality of the beam line equipment, like magnet polarity, data acquisition, parameter logging and the operational applications, will be tested.

Proton Beam Line Commissioning and Alignment with the Laser Beam

The commissioning of the proton beam line will be done after the installation and commissioning of the AWAKE laser and when the RF timing system is fully operational. At this point the proton beam extraction will be triggered by a signal, which is generated from the laser oscillator of AWAKE, so that the laser pulse, experiment equipment and the proton bunch can be synchronized (see [10] for a detailed description of the RF system).

The beam line commissioning will include the steering of the proton beam to establish the reference trajectory, optics, aperture and emittance measurements as well as checks with the full intensity bunch of $3{\cdot}10^{11}$ protons.

The alignment of the proton beam with the laser beam will be the next step. The trajectory of the proton beam has to be optimized at the merging mirror, iterating the steering of the

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protons and the positioning of the laser mirror. The goal is to position the proton beam over the length of the vapor source inside the 2 mm diameter of the laser beam. Theoretical studies [6] show that the required pointing accuracy for both beams is 100 μm with a maximum angle of the proton beam trajectory of 15 μrad. This will be measured with the high resolution BPMs and BTVs around the merging mirror and the vapor source.

The longitudinal alignment of the two beams will be defined by the time delay between the laser pulse and SPS extraction, which is controlled via the RF system. The synchronization is required to have a precision of better than 100 ps, which will be measured with the streak camera at the second last BTV upstream of the vapor source.

When all these settings are defined shot-to-shot fluctuations of the proton beam will be recorded. Stability measurements with the full intensity beam will be performed over several hours, to configure the reference levels for the interlocks and warnings.

Final Steering with the Vapor Source

In a last step, the proton and laser beam trajectories will be optimized with the vapor source system completely installed. Only at this stage, the irises at the ends on the vapor source will be integrated and aligned with respect to the measured beam trajectory. Their aperture will be measured, a final steering will be performed and the reference levels for the BLMs at the vapor source will be defined.

CONTROLS AND OPERATIONAL APPLICATIONS

For all the described tests and measurements the beam line equipment has to be integrated in the CERN accelerator control system and operational applications have to be prepared.

The magnet cycles and the data acquisition will be triggered by the SPS pre-extraction signals for each bunch (every 30 seconds) and all recorded values will be published in the CERN accelerator control system and stored in the CERN measurement and logging databases. Generic applications are being updated with the newly installed equipment and special monitoring applications like fixed displays and a monitoring GUI for the transfer line are being developed.

The main applications for the steering of the proton beam are the BTV application ([11]) and YASP (Yet Another Steering Program [12]). The BTV application allows the measurement of beam profiles and position. The beam trajectory, measured with the BPMs along the beam line, is presented in YASP, where a reference trajectory can be defined for the beam line. Also the required trajectory corrections with the steering magnets can be calculated and applied here.

The emittance measurement will be done using three BTVs in the line and knobs will be prepared for the aperture measurements by introduction of trajectory bumps.

Fluctuations of the beam parameters can be seen on the fixed display during operation. History plots of the beam intensity, bunch length position and angle at the vapor source will be shown there. A dedicated application, the AWAKE Injection Monitor, is being developed for the monitoring of the beam in the transfer line. Here it is possible to check the signals of BCTs, BPMs and BLMs in the full proton beam line and to see a detailed representation of the values at the merging mirror and the vapor source. A screen shot of the application in its current state is presented in Figure 4.

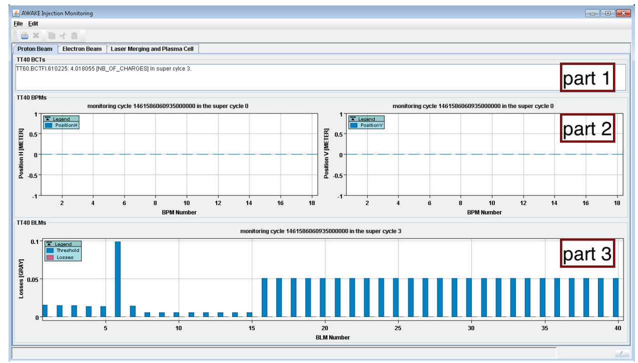

Figure 4: The AWAKE Injection Monitor GUI is being developed to monitor the bunch intensity (part 1), the horizontal and vertical positions (part 2) and the losses (part 3) along the proton transfer line and locally at the merging mirror and vapor source.

STATUS AND OUTLOOK

The installation of the AWAKE proton beam line has been finished and the hardware commissioning is about to start. Currently the controls are being set up with the updates of the logging parameters, operational applications, interlock systems and displays.

The last safety tests, which are needed to be allowed to send beam towards AWAKE, are scheduled for the end of June and afterwards the first extraction test can start. The full beam line commissioning and the alignment with the laser is planned for end of August this year. The final steering with the vapor source and afterwards the first experimental beam time is supposed to take place at the end of October.

ACKNOWLEDGMENT

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