AD STATUS AND CONSOLIDATION PLANS

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Abstract

The CERN Antiproton Decelerator (AD) has now completed its 12th year of supplying low-energy antiproton beams for the successful physics program.

Most of the machine's key components are in operation since more than 25 years and prompted by the approval of the ELENA project, a substantial consolidation program is now being launched to ensure continued reliable operation. Over the course of the next few years a progressive renovation of the AD-Target area and the AD-ring with all the associated systems will take place.

Status and performance of the AD are presented along with an overview of planned and ongoing consolidation activities with emphasis on stochastic and electron beam cooling.

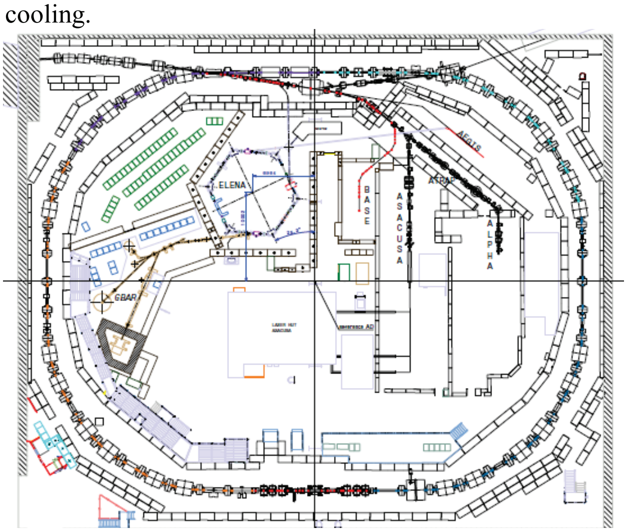

Figure 1: Layout of AD, ELENA and experimental areas.

INTRODUCTION

With 5360 realized physics hours and a beam availability of 90%, 2012 was the best year ever for the CERN Antiproton Decelerator (AD) with antiprotons at 100 and 500 MeV/c supplied to the ALPHA, ACE, ATRAP, ASACUSA and AEGIS experiments.

For the medium and long-term future, several options exist for upgrades and consolidation of the facility as well as for extension of the physics program.

A major improvement to the facility, the recently approved ELENA ring [1], is a small post-decelerator which will be installed in the existing AD building. ELENA will greatly increase ejected beam density and intensity thereby increasing the number of trapped antiprotons at the experiments by up to two orders of magnitude.

To reliably produce antiprotons and deliver them to ELENA for the next 10–20 years, all AD sub-systems have to be renovated or renewed. In total, a budget of some 18 MCHF has been allocated for AD consolidation during the period 2013 to 2020.

Layout of AD, the future ELENA ring and the experimental areas can be seen in Fig.1.

AD PERFORMANCE

Deceleration efficiencies of around 85% (3.57 GeV/c to 100 MeV/c) were maintained throughout the year with beam intensities of 3.5 to $4.0*10^7$ ejected in one single bunch at 100 MeV/c per 100s machine cycle. Machine performance in terms of quality and stability of the ejected beam was in 2012 more constant than during previous years. Length of the ejected single bunch stayed quite constant over the year at around 150 ns. At 100 MeV/c after final cooling, transverse emittances of less than 1 pi.mm.mrad were obtained for 80 and 95% of the beam in the horizontal and vertical planes respectively. During the start-up, a significant amount of time was spent setting-up the machine for efficient beam-ccoling at low energies. As a result, emittances of the extracted beam remained small throughout the run and previously observed degradations needing re-tuning could be avoided. Problems with long tails and halo-like structures in the horizontal beam profile were also reduced. Measured horizontal beam profile after cooling at 100 MeV/c can be seen in Fig. 2.

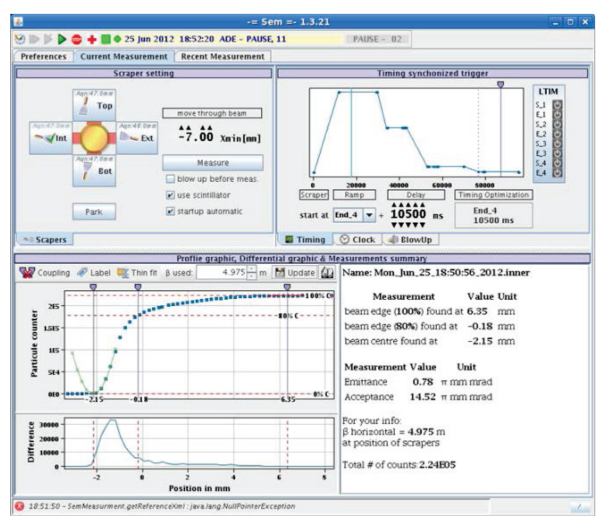

Figure 2: Horizontal beam profile after cooling at 100MeV/c as measured with scraper and scintillating detector.

ISBN 978-3-95450-140-3

AD STUDIES IN 2012

Longitudinal Emittances at 100MeV/c

Due to its layout, the future ELENA transfer line's momentum dispersion is large. In order to reduce the size of the beam and reduce transfer losses, attempts were made to minimize the dp/p. It had previously been found that the cooling rate is relatively fast compared to the dp/p increase taking place during the bunching process for ejection. Tests with extended durations of the adiabatic RF-voltage increase during capture showed that significant reductions can be obtained. Obtained final momentum spread with different durations are shown below:

- 500ms (nominal): (rms) dp/p = $\mathbf{4.1*10^{-4}}$
- 2000ms: (rms) dp/p = $\mathbf{2.6*10^{-4}}$
- 5000ms: (rms) dp/p = $\mathbf{1.3*10^{-4}}$

Ejection Line Optics

Thanks to the recently installed GEM-detectors with better resolution, better models with could be established for the ejection lines after peforming kick response measurements. This is important both for efficient transfer through the ASACUSA RFQD and for matching of the future AD to ELENA transfer line. 3D modelling of the dipole fringe fields was performed using the CST package and after introducing these as corrections in MAD, much better optics fit could be obtained. Further improvements could be had after slight corrections of the quadrupole fields and by shielding the beamline as it passes through an un-used large dipole with remanent fields. As a result, good optics fit have been obtained for all transfer lines except for sections passing under the ATRAP solenoids. These fringe-fields are difficult to model and cause discrepancies for the ALPHA line and for the last part of the two ATRAP lines.

AD CONSOLIDATION

Target Area

The AD target area (see Fig. 3) is undergoing important consolidation activities during LS1; this is the first step of a general overhaul of the antiproton production area, which will continue in the next years in the "ELENA era" of the AD machine exploitation. The most significant update will involve the control system of the target and horn support carriages, which have not been upgraded since their conception in the late 80s. A control system based on PLCs will be implemented, allowing for a safer and more reliable operation. In support of this activity, a vast campaign of FLUKA Monte Carlo [2] simulations – cross-checked by in-situ radiation and particle fluence measurement – has been performed [3]: these simulations have confirmed the effect of the magnetic spectrometer in selecting a narrow antiproton energy for injection in the AD machine, allowed to estimate the energy deposition in the various elements of the target area (in view of a future cooling system update) and enabled to quantify the decrease in antiproton fluence for a horn misalignment (the most critical one) (roughly 30-40% for a 2 mm transversal plane shift).

A series of machine development tests have been also performed in the AD target area, varying the horn current intensity as well as the distance between target and horn (i.e. varying the focusing length of the magnetic lens). These allowed optimizing the operational parameters of the target area as well as studying the sensitivity of the antiproton production. The results of this "phase-space" scan have been cross-checked by means of FLUKA Monte Carlo simulations, yielding a general agreement within 20-30%.

An improvement of the target, focussing horn and magnet handling system as well as of the local and remote inspection capabilities is also being performed. The hydraulic and electronics of the existing service vehicle – capable of remotely disconnecting the target and horn carriages as well as the magnetic spectrometer dipoles/quadrupoles – has been completely refurbished. In collaboration with other CERN programs, a dedicated remotely manipulated robot will be used in the area for general inspections, reducing the dose rate for personnel intervening in the area.

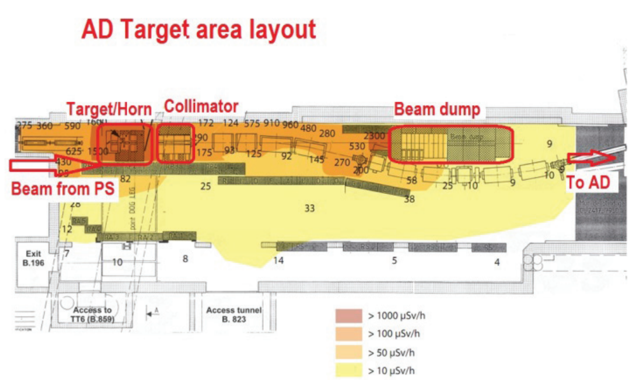

Figure 3: Layout of the production target area.

Stochastic Cooling

The stochastic cooling systems are presently being renovated and the majority will be finalised in time for the 2014 start-up. Apart from verification and repairs of signal transmission hardware, many system components are being replaced in order to comply with new standards and eliminate ageing equipment.

The old in-house developed power supplies with thyristor control have been replaced by 48 modern switch mode power supplies, one per power amplifier including a modern PLC system for control, acquisition and interlock handling. The output of the power amplifiers is monitored with RF power detectors, measuring RMS value. These detectors have to be calibrated together with the directional couplers at the output of the amplifiers, to correct for variations in the coupling with lines. With the modification of the water cooling system, filters had to be added to protect the amplifiers and the kickers against polluted water.

ISBN 978-3-95450-140-3

The systems for dynamic and static delay and attenuator control (“Platform Fritz”) have been upgraded with a PLC and the old VME control and timing have been disconnected. This was successfully tested during the 2012 run and is ready for operation. Additional LED indicators were installed, both on the platform and further along the transmission lines, where relays are used to switch the delays for cooling at different beam energies so that the state of the equipment can be verified visually. Each relay has a separate control wire, therefore remote measurement of the coil resistance is possible, and this will help to identify faults or open connections.

The notch filter delay line of the longitudinal system will be re-located to make space for ELENA. To further gain space in the AD hall, investigations will be done for the possible use of optical delay lines instead of the present coaxial cable. Both delay lines could initially be operational simultaneously in order to compare performance and reliability.

The pick-up tanks and the kicker tanks have motor control to adjust the spacing between the slot-line structures as a function of the cooling cycle. This motor control is being modernized since most of the equipment is obsolete and has no spare parts available. Additionally, it is controlled in a very complicated way with VME based function generators, serial link transmitters/receivers, DAC:s, and analogue position control with velocity and position feedback which can become unstable under certain conditions.

Electron Cooling

The current electron cooler at the AD was recycled from the previous ICE and LEAR machines at CERN and is now close to 40 years old. Its main parameters can be seen in Table 1. As part of the AD consolidation program it has been decided to build a new electron cooler for the AD incorporating all the advances in electron cooling from the intervening period such as e.g. adiabatic expansion, variable density electron beam and electrostatic deflector plates for efficient collection of the electron beam.

Table 1: AD Electron Cooler Main Parameters

Momentum pbar	300 MeV/c	100 MeV/c
Electron energy	35 keV	2.8 keV
Electron current	2.5 A	100 mA
Cooling length	1.5 m	
Drift magnet field	590 Gauss	
Electron beam radius	25 mm	
Cooling time	16 s	15 s
Final $\varepsilon_x / \varepsilon_y$	3 / 3 (π × mm × mrad)	0.8 / 0.5 (π × mm × mrad)
Final dp/p	10^{-4}	$< 7 \times 10^{-5}$

The preliminary design studies for the new electron cooler are being launched with an aim to install it at the AD during LS2 scheduled for 2018.

RF Systems

The C02 (2 MHz) cavity tuning and HV power supplies will be renewed with modern and more compact devices during LS1 as the present units are occupying floor space where the ELENA ring will be installed. The controls interface and interlock system will be renewed at the same time.

For the C02 beam control system, it is expected, although not formally planned yet, that the AD LLRF system will be upgraded to the Digital LLLRF (DLLRF) family [4] currently under development for all circular machines in CERN’s Meyrin site. In particular, the same DLLRF will be used for the ELENA decelerator, which will further decelerate the AD antiproton beam.

This new DLLRF family is an evolution of the system successfully operational in LEIR since 2006 [5]. The main benefits of the DLLRF approach are its remote controllability, built-in diagnostics and extensive signal observation capabilities. Its digital nature grants an excellent repeatability as well as the implementation of extensive archiving capabilities; this will allow recalling previously-validated sets of control parameters.

Regarding the 2 C10 (10 MHz) systems used for bunch rotation at injection, a solution has to be found for renewal of the final power stages where obsolete TH116 triode tubes are used. Only a few spares are available at this moment and a complete re-design of the system might be necessary to ensure continued operation.

Vacuum System

The vacuum system of AD is the subject of many interventions. The majority of them are related to taking care of known problems on AD, such as small leaks, replacement of vacuum gauges and broken titanium-sublimation pumps' filaments, dented bellows, installation of modified diagnostics vacuum chambers, maintenance and upgrade to cryopumps' cold heads, replacement of ion-pumps, refurbishment of the electron-cooler gun. Another part of the consolidation program has been carried out towards the installation of the future ELENA ring. One of the major issues is the necessary displacement of many vacuum control crates installed in the area where ELENA and some new experimental beam lines will be placed. This program has involved moving ion-pump power supplies, gauge controllers, profibus units, cabling and more. The AD consolidation program for this latter part is sticking to schedule, some delays have occurred in areas related to refurbishing of AD ring magnets and displacement of experimental components.

Magnets

Degradation of the coil shimming has been observed in several of the 24 AD ring bending magnets as movement of the coils in relation to the yokes has gradually

ISBN 978-3-95450-140-3

increased over the last few years. To identify renovation needs, one of the bending units will be removed from the ring enclosure, opened up and rebuilt, possibly with new coils. Condition of the coils and coil shims will determine the course of action for the remaining units. For the moment, no action is planned for the 57 ring quadrupoles as these seem to be in a better condition. For the remaining magnets in the ring and transfer lines, the spare part situation is satisfactory.

Instrumentation

In order to measure tunes during the deceleration ramps, replacement of the present multiplexing system based on a network analyser is desirable. Recent investigations with AD beam under production conditions indicate that the requirements for an AD tune measurement system are compatible with a “BBQ” system, already used elsewhere in the LHC injector chain [6], and connected to the 5.7 MHz Schottky pickup. For the AD, signal levels at 10mV or lower are expected where diode detection will not be efficient. The signal can however be directly amplified to volt-level where only the BBQ-DAQ module-unit is then required to acquire the data. A similar approach has been successfully tested with modern large memory ADCs by the AD team, but this turned out to be difficult to integrate into AD controls.

An alternative solution to consolidating the current AD orbit acquisition system may be an approach which exploits the large memory of modern ADC VME modules (e.g. SIS3302). The Δ and Σ signals of each pickup are directly sampled using a synchronous clock derived from the f_{rev} or by unsynchronized oversampling at ~100MS/s and then normalized and post-processed by the hosting FEC software in a relatively direct approach. Such a solution would rely mainly on COTS electronics, eliminating many of the specific maintenance needs of this system, in particular the multiplexer and network analyser. This would imply parallel acquisition of all channels requiring a minimum of 15 SIS3302 ADCs for the two planes. The distribution of electronics into one or several crates still has to be studied in this case.

The ionisation profile monitors, which non-destructively measure the circulating beam profile throughout the deceleration cycle, will be upgraded to a strip read-out system similar to what has been implemented on LEIR [7]. The two monitors will be installed in vacuum sector 42 and will share a common gas injection system. The resolution of the readout will be 1mm in each plane and, considering the low ion-electron pair production rate, it is hoped to have a time resolution of around 100 ms.

In addition the local control system will be replaced by a VME based system that will be fully integrated into the AD controls. An application program running on the workstations will provide the operators an interface where they will be able to change the main parameters of the IPMs and display the time evolution of the beam profile and position at the position of the monitors.

REFERENCES

[1] P.Belochitskii: “ELENA project status”, THPM1HA02, IPAC'13, Shanghai, China.

[2] A. Ferrari, P.R. Sala, A. Fassó, J. Ranft, FLUKA: a multi-particle transport code, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

[3] M. Calviani, E. Nowak, FLUKA implementation and preliminary studies of the AD-target area, ATS/Note/2012/069 (TECH), EDMS 1235761.

[4] M.E. Angoletta et al., “CERN’s LEIR Digital LLRF: System Overview and Operational Experience”, IPAC ‘10, Kyoto, Japan, May 2010, p. 1464.

[5] M. E. Angoletta et al. “CERN’s PS Booster LLRF Renovation: Plans and Initial Beam Tests”, IPAC ‘10, Kyoto, Japan, May 2010, p. 1461.

[6] M. Gasior, R. Jones: “The principle and first results of betatron tune measurements by direct diode detection”, LHC-project report 853, CERN.

[7] First Results from the LEIR Ionization Profile Monitors, C. Bal, V. Prieto, R. Sautier, G. Tranquille, DIPAC’07, 20-23 May 2007, Venice.

ISBN 978-3-95450-140-3