THE ELENA BEAM DIAGNOSTICS SYSTEMS

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Abstract

The Extra Low ENergy Antiproton ring (ELENA) to be built at CERN is aimed at substantially increasing the number of antiprotons to the low energy antiproton physics community. It will be a small machine which will decelerate low intensity beams ($<4x10^7$) from 5.3 MeV to 100 keV and will be equipped with an electron cooler to avoid beam losses during the deceleration and to significantly reduce beam phase space at extraction. To measure the beam parameters from the extraction point of the Antiproton Decelerator (AD), through the ELENA ring and all the way to the experiments, many systems will be needed to ensure that the desired beam characteristics are obtained. Particular attention needs to be paid to the performance of the electron cooler which depends on reliable instrumentation in order to efficiently cool the antiprotons. This contribution will present the different monitors that have been proposed to measure the various beam parameters as well as some of the developments going on to further improve the ELENA diagnostics.

INTRODUCTION

ELENA was approved as a CERN project in June 2011 and work is continuing in fine-tuning the machine parameters in order to meet all the physics requirements [1]. Ring commissioning is scheduled for 2016 with the installation and setting-up of the electrostatic beam lines a year later.

The biggest challenge for the beam instrumentation is to measure all the parameters of a very low intensity antiproton beam in an energy range from 5.3 MeV to 100 keV. At such low energies the ELENA ring will operate with a dynamic vacuum of less than $2x10^{-12}$ Torr. Particular attention has to be paid to design of all the elements that will be installed in the ring as they will be baked-out at 300°C and must be NEG coated. The layout of the new ring is shown in Fig. 1. One sees the AD-ELENA transfer line, the ELENA ring and the new 100 keV electrostatic beam lines to the experiments.

AD-ELENA TRANSFER LINE

As the antiprotons are transported from the AD to ELENA their position and transverse profile will be measured by four gas electron multiplier detectors (GEM) and luminescent screen monitors (BTV).

GEMs have been deployed extensively in the present AD experimental areas [2] and give excellent results for both position and profile measurements. Like multi-wire proportional chambers these detectors are also gas-filled, and essentially the same physical phenomenon is exploited to multiply ionization charge. Two such detectors are already installed in the existing 7000 line just after extraction from the AD. Another two GEMs will be installed in the new part of the transfer line; one after the AD shielding and a second before the ELENA injection septum.

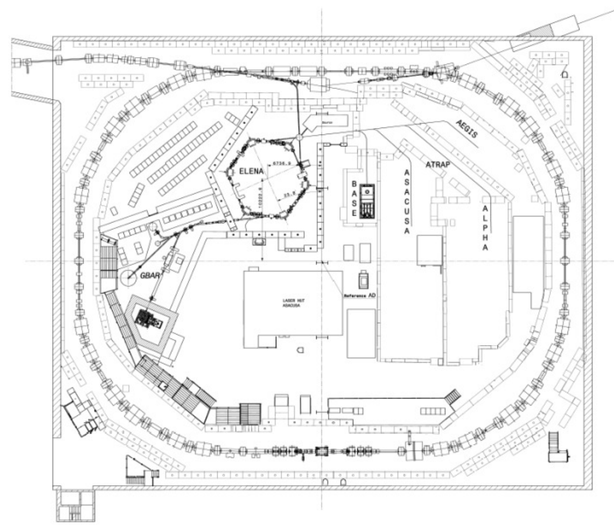

Figure 1: ELENA layout in the AD hall.

At present in the AD, Al_2O_3 scintillating screens are installed in the transfer lines and coupled to a CCD camera have provided information on the antiproton beam position and size. One such device will be moved from its current location in the 7000 line and will be installed after the second bending magnet that will deflect the antiproton beam from the AD to ELENA.

A new system is also being developed that will be capable of measuring the beam position and size just before the injection kicker and at the first turn in the ring. It consists of two distinct systems each incorporating a 6 cm x 4 cm screen, a CCD camera, filter wheel, optical elements and a pneumatic in/out movement.

ELENA RING

Beam Position

The ELENA orbit measurement system will consist of 20 circular BPMs mounted inside the ring quadrupoles and dipoles. The proposed design is based on a stainless steel body containing 2 diagonally cut plates. Two such elements will be inserted in to a 100 mm diameter vacuum tank in order to have a position measurement in both planes [3].

Both difference and sum signals will be generated in the head amplifier. After signal amplification by low noise amplifiers located very near to the BPMs, the

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ISBN 978-3-95450-127-4

difference and sum signals will be transported by ~50m cables, digitized and processed using digital Δ/Σ normalization for the position calculations.

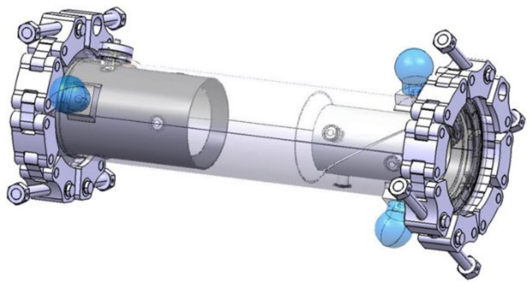

Figure 2: Dipole BPM assembly.

In order to test the response of the pick-up to particle beams at various velocities, a 3D model of the monitor was created in CST Particle Studio. With this model one can estimate the signal linearity, expected output voltage as function of beam energy, electrode capacitance, signal shape as function of beam position and shape, pickup bandwidth, as well as the longitudinal coupling impedance and the effects from wake fields.

Tune Measurement

Base-Band Tune (BBQ) measurement systems are highly sensitive and based on a direct diode detection principle [4]. The AD will soon be equipped with such a system and it is planned to use a similar setup for ELENA.

As with all BBQ setups the system will consist of:

- Diode detectors, converting beam-induced pulses from electrodes of a position pick-up to slower varying signals, from which DC offsets corresponding to the beam orbit is removed with series capacitors.
- An analogue front-end amplifying and filtering the detector signals.
- Two 16-bit ADC for parallel acquisition of horizontal and vertical betatron oscillation signals.
- A VME, FPGA based Digital Acquisition Board (DAB) providing the read-out and processing of the ADC samples, spectra calculation, data buffering and storing for subsequent transmission through the VME bus to a front-end computer.
- Two 12-bit DACs implemented as a DAB mezzanine, used to generate signals for beam chirp excitation, independently for horizontal and vertical machine planes; the DAB can also provide tune kicker triggers synchronised with the acquisition.

The optimisation of the diode detectors and filters depends on the beam signal bandwidth and expected amplitudes from the machine tune pick-up. If the orbit pick-up is used, the expected signal level is about 4 mV and this will need to be amplified by at least 20 dB with a high impedance J-FET amplifier. A dedicated strip-line pick-up and kicker for the tune measurement could be installed in two quadrupole magnets in sectors 3 and 6 of the ring. Their integration is at present being studied.

Profile Measurement

The profile of the circulating beam will be measured destructively using a scraper system. In this device a blade is moved quickly across the beam and creates a particle shower due to the interaction of the beam with the blade. A simultaneous detection of the intensity of the particle shower outside the vacuum chamber with a scintillator/photomultiplier assembly and the blade position gives an image of the beam profile.

Longitudinal Schottky Diagnostics

To measure the efficiency of the electron cooler a magnetic Schottky pick-up similar to what has been used on the AD will be installed. The design of this system is under the responsibility of the radio frequency (RF) group and is discussed elsewhere [5]. This pick-up will also be used to initially estimate the bunched beam intensity.

Recombination Monitor

During the electron cooling process the centre of mass energy difference between the electrons and circulating beam becomes very small. The probability of the capture of an electron by radiative or di-electronic recombination is enhanced. For proton beams, neutral hydrogen atoms are formed and travel straight towards a detector.

For commissioning at 100 keV with the proton source, optimisation of the electron cooler will be performed by measuring the recombination rate of electrons with the circulating protons. The choice of detector depends on the required information. A scintillator coupled to a photomultiplier will be used to measure the recombination rate from which the transverse energy of the electron beam can be evaluated. It will be a good means to correct any angular deviations between the electron and ion beams as the maximum signal is obtained when the beams are correctly aligned. Using an imaging monitor such as a GEM behind the scintillator, one can derive the profile and position of the proton beam from the profile and position of the recombined beam.

EXPERIMENTAL BEAM LINES

The 100 keV antiproton beam extracted from ELENA will be transported to seven experiments using electrostatic beam lines of total length >100 m. The dipoles and quadrupoles comprising the beam lines must be precisely tuned to focus the antiprotons into the acceptance of the trap experiments. The repetition rate of antiprotons extracted from ELENA is relatively low (0.01 Hz), and so to facilitate rapid tuning, the position of the beam at several positions along the beam lines must be measured simultaneously. A set of micro-wire beam profile monitors will be installed for this purpose. They are based on the devices used by the ASACUSA collaboration since 1999 to measure 100 keV antiproton

ISBN 978-3-95450-127-4

or proton beams that emerged from the Radiofrequency Quadrupole Decelerator (RFQD).

The semi-non-destructive monitor allows most of the antiprotons to pass through without any degradation, while the small portion (1-3%) intercepted by the wires produces the signal. The device is sensitive to antiproton, proton, and H^- beams of energies between E =10 keV and 5.3 MeV. It consists of two position-sensitive photocathode grids providing the X and Y projections of the beam, sandwiched between three anode grids with a distance l = 2 mm between them. Each grid consists of between 32 and 48 gold-coated tungsten wires of diameter d = 5–20 µm stretched over a ceramic frame, with a pitch 0.5–1.5 mm between neighbouring wires.

The cathode grids at ground potential are irradiated by the beam, and the secondary electrons emitted from them are accelerated toward the anode grids biased at 50 V. The beam profile is obtained by using charge-sensitive preamplifiers to measure the charge Qi ejected from the cathode wires on the X- and Y-grids with high sensitivity. The preamplifiers are application-specific integrated circuits (ASIC, IDEAS VA32 or VA64) mounted on hybrid ceramic circuit boards. The amplitude V_o of its output signal is related to the input charge Q_i by a conversion ratio dV_o/dQ_i = 0.45 V/pC. The preamplifier has a shaping time constant of 500 ns, and a full range between -1.5 and 1.5 pC. This voltage signal is amplified using a bipolar operational amplifier (Analog Devices AD8051) and digitized using a CMOS analogue-to-digital converter (ADC, AD9240).

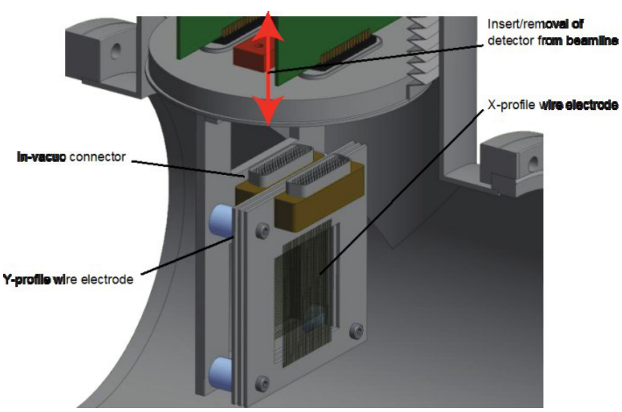

Figure 3: Cross-sectional view of vacuum chamber.

The gain of each preamplifier channel will be calibrated in-situ using a precision pulsar mounted on the readout board. The 50 volts needed to bias the electrodes is generated by a small, RF shielded switching regulator with a ripple of a few mV. A field programmable gate array (FPGA, Altera Cyclone V) controls the ASIC, ADC, anode bias voltage, and pneumatic motion feed-through.

The X and Y profiles of a pulsed beam containing $2x10^6$ antiprotons of energy 100 keV provided by the ASACUSA RFQD is shown in Fig. 4. Similar profiles will be obtained in the ELENA case.

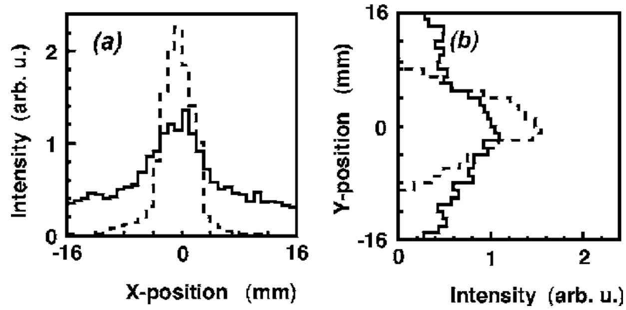

Figure 4: The measured spatial profiles of a pulsed beam containing $2x10^6$ antiprotons (solid lines), and a laser beam of wavelength 289 nm (broken lines).

FUTURE DEVELOPMENTS

Calculations on Schottky signal levels show that the S/N-ratio from a single BPM is ~12dB. By digitally adding the 20 sum signals from the BPMs this value is improved by 13 dB. After applying time of flight corrections it should therefore be possible to measure the longitudinal beam distribution for un-bunched beams and the current intensity when the beam is bunched.

If the summing of the BPM sum signals is successful it is foreseen to replace the magnetic Schottky pick-up with a cryogenic current comparator (CCC) used with a SQUID magnetometer as a magnetic field null detector to measure the circulating beam intensity. A prototype is under development for the AD [6] which could then be installed on ELENA if shown to give reliable values of the beam current.

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ISBN 978-3-95450-127-4