The ELENA Beam Diagnostics Systems

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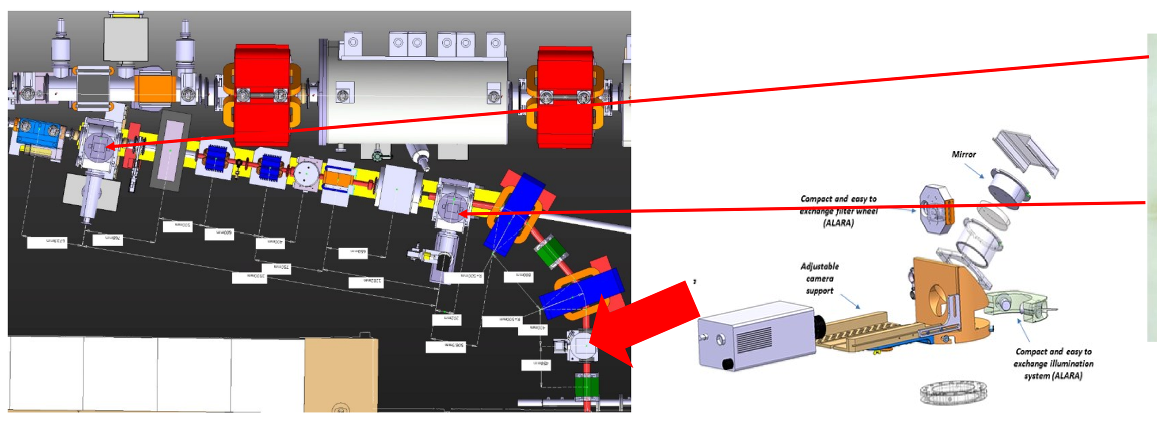
ELENA was approved as a CERN project in June 2011 and work is continuing in fine-tuning the machine parameters in order to meet all the physics requirements. Ring commissioning is scheduled for 2016 with the installation and setting-up of the electrostatic beam lines a year later.

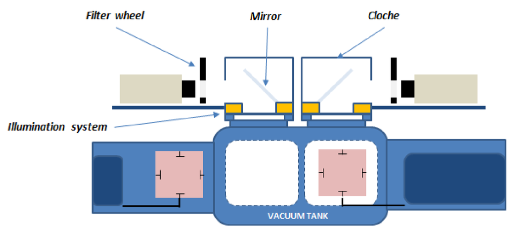
The biggest challenge for the beam instrumentation is to measure the parameters of a very low intensity antiproton beam in an energy range from 5.3 MeV to 100 keV. At such low energies the ELENA ring will operate with a dynamic vacuum of less than $2x10^{-12}$ Torr. Particular attention has to be paid 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.

Kin. Energy range	5.3 Mev	648 keV	100 keV
Momentum range	100 MeV/c	35 MeV/c	13.7 MeV/c
Circumference		30.4 m	
Tune		$Q_h = 2.3$ $Q_v = 1.3$	
Ring vacuum		3×10^{-12} Torr	
$N_{particles}$ injection		3×10^{7}	
$N_{particles}$ ejection		1.8×10^{7}	
$N_{bunches}$ ejection		1 to 4	
ε_h & ε_v at ejection		4 / 4 µm (95%)	
ΔP/P after cooling		2×10^{-4} (95%)	

Main parameters of the ELENA ring

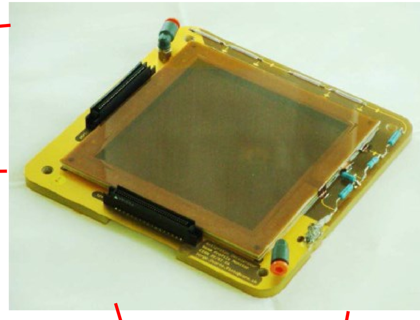


Al_2O_3 scintillating screens are installed in the transfer lines and coupled to a CCD camera have provided information on the antiproton beam position and size. One such device will be moved from its current location in the 7000 line and will be installed after the second bending magnet that will deflect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



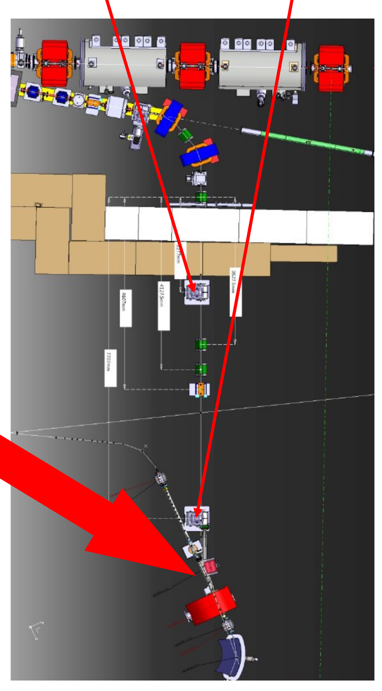
Proposed BTV setup for ELENA injection matching

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. The proposed setup consists of two distinct systems each incorporating a 6cm x 4 cm screen, a CCD camera, filter wheel, optical elements and a pneumatic in/out movement.



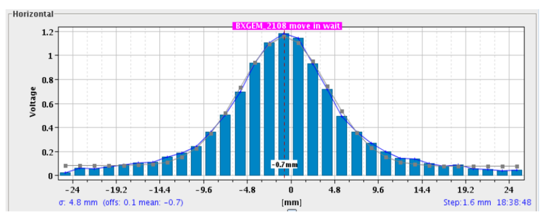
A GEM detector assembly

A GEM is a 50 µm thick foil of Kapton, copper clad on both sides, pierced with microscopic holes at a high density (our 10×10 cm² foils have about a million holes). A voltage of a few hundred volts applied to the top and bottom copper layers causes an electric field that focuses in the centre of these holes where it is just as strong as close to the wires of a wire chamber. Ionization electrons enter the holes from one side, are multiplied inside the holes, and then exit on the other side where they are collected by a strip pattern that integrates the charge and reads out the profile.



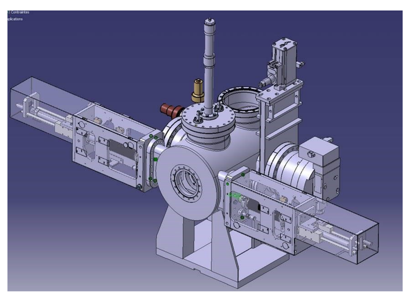
The detectors are made as light as possible to avoid scattering the low energy antiprotons and modifications have been made to the readout electronics to cope with the short spills of the AD. The cathode window is a crucial element when absorption and multiple scattering of the beam are of concern. In our design the cathode is also the gas enclosure, and it is stretched tight (~ 11 MPa) in order to avoid any deformation by the slight overpressure in the chamber. It is made of the same base material GEMs are made of: copper clad polyimide. The copper is etched away in the active area of the detector, leaving just a thin (~ 100 nm) layer of chromium which is there to act as a tie coat for a better adhesion of the copper layer to the polyimide substrate. The material traversed by the beam to enter the active volume of the detector thus amounts to 0.018% X_0. On the other end of the chamber, the gas enclosure is made of a 25 µm polyimide foil, adding 0.009% X_0.

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.



Horizontal profile of an antiproton beam at 5.3 MeV

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 via LVDT sensors gives an image of the beam profile.



The Linac 4 beam stopper system on which the ELENA scraper will be based

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. This pick-up will also be used to initially estimate the bunched beam intensity

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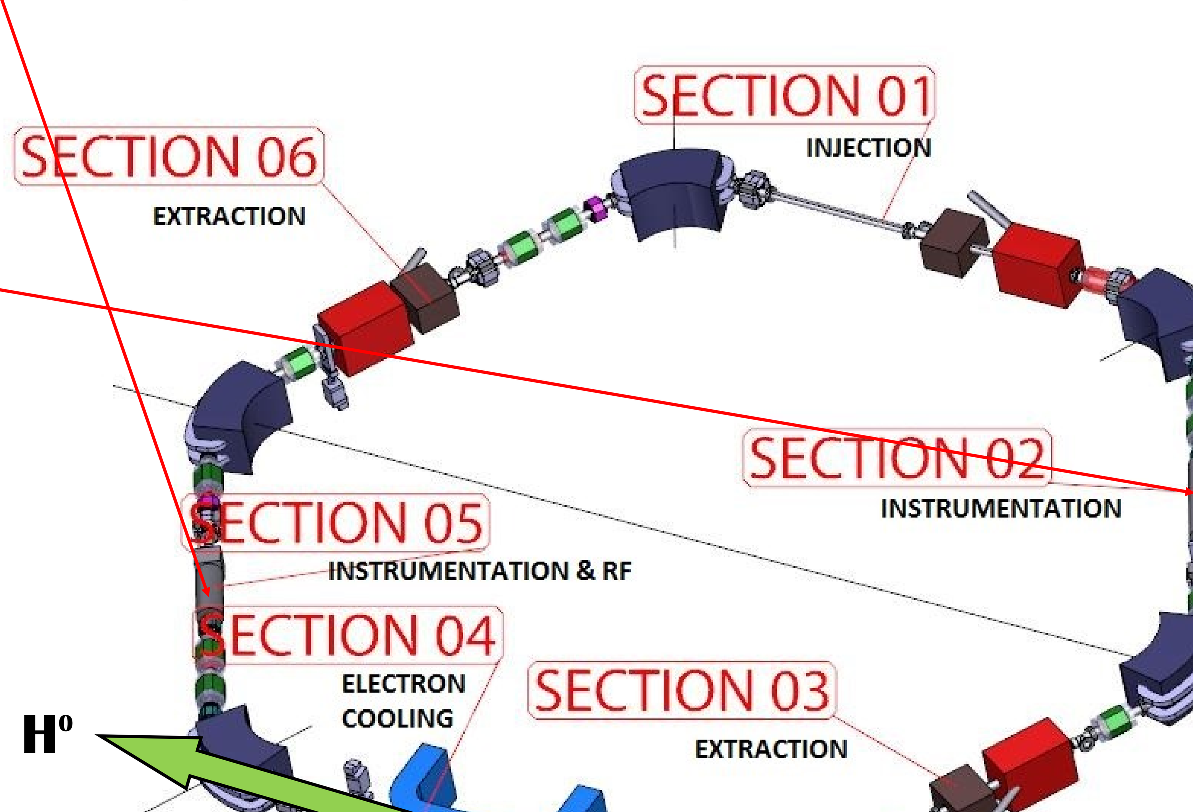
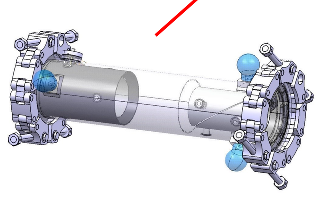
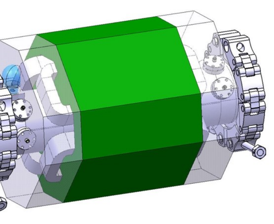


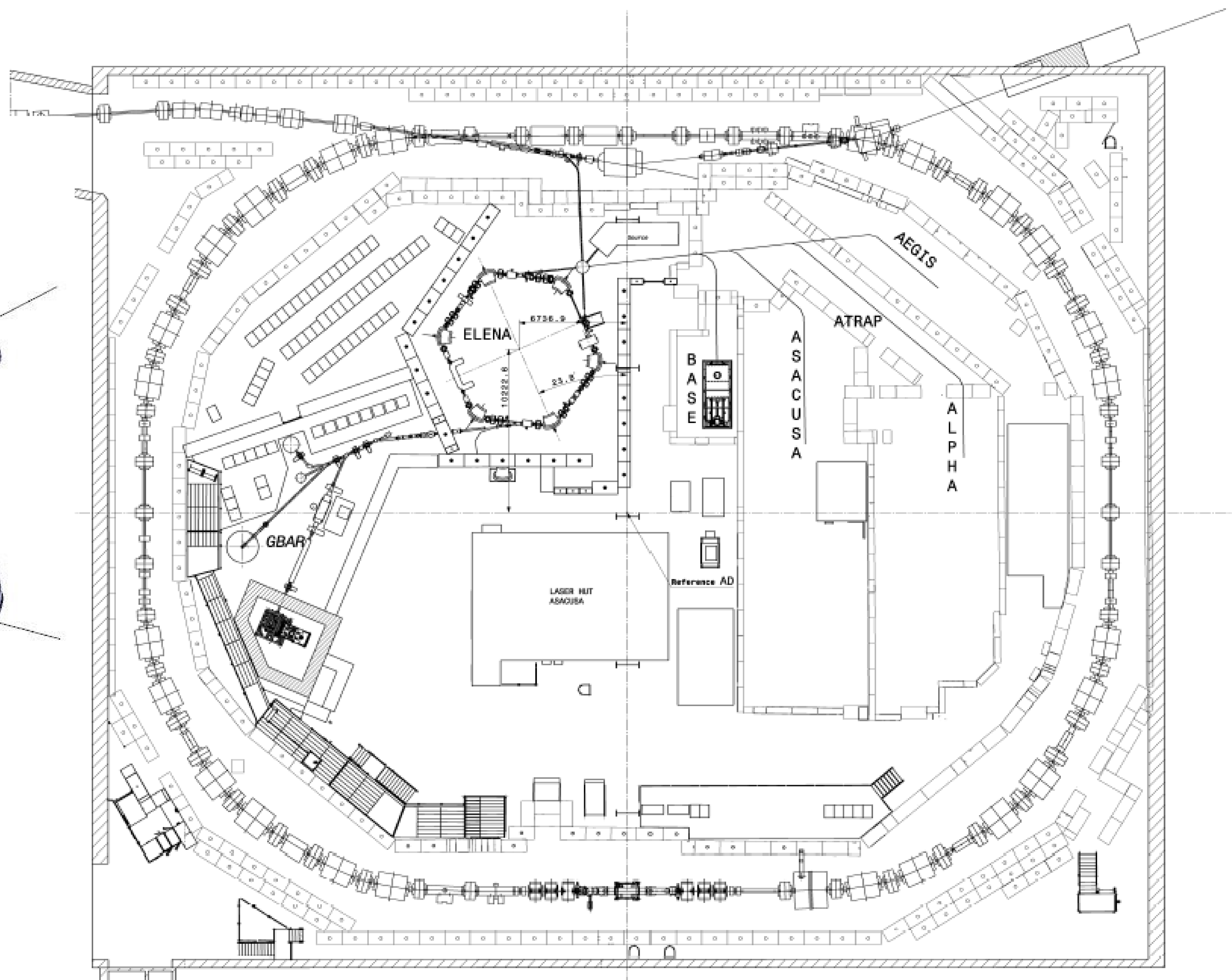
For commissioning at 100 keV with the proton source, optimisation of the electron cooler will be performed by measuring the recombination rate of electrons with the circulating protons. The choice of detector depends on the required information. A scintillator coupled to a photomultiplier will be used 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.



Dipole BPM assembly



Quadrupole BPM assembly



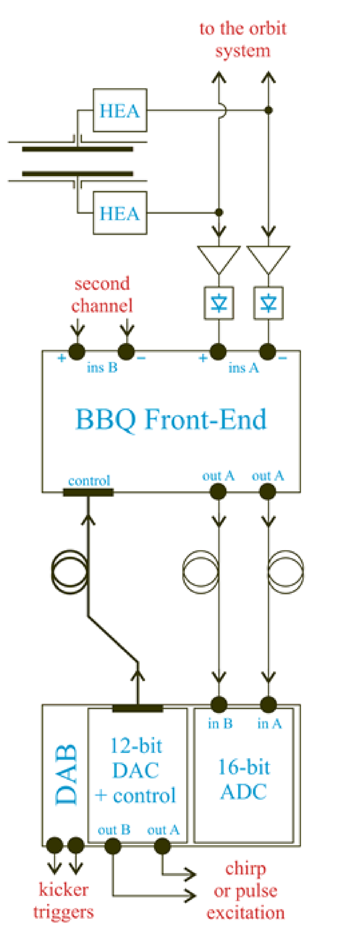
ELENA layout in the AD hall

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

The tune will be measured using a base-band tune (BBQ) setup used on nearly all the accelerators at CERN. It 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.



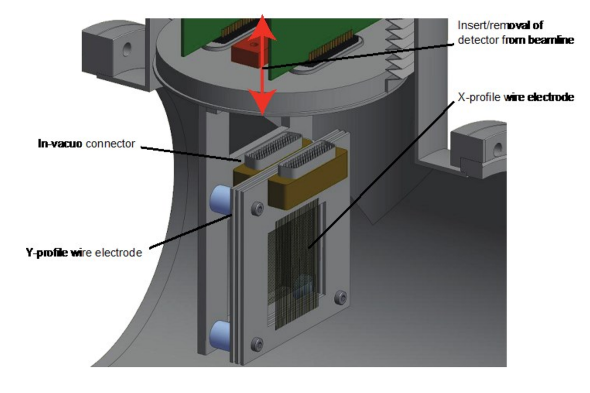
Block diagram of the ELENA BBQ tune measurement system

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 into a 100 mm diameter vacuum tank in order to have a position measurement in both planes.

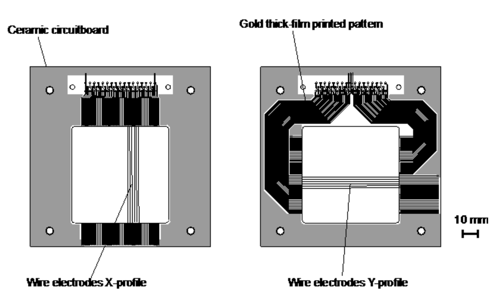
Electrode inner diameter	66mm
Electrode thickness	1mm
Electrode to support tube gap	10mm
Support tube inner diameter	88mm
Support tube thickness	1mm
Vacuum chamber inner diameter	97mm
Vacuum tube thickness	1.5mm
Feed through flanges	DN16CF
Electrode length	120mm
Overall length, Dipole	340.5mm
Overall length, quadrupole	432.5
BPM flanges	DN100 (conical)

BPM mechanical dimensions

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



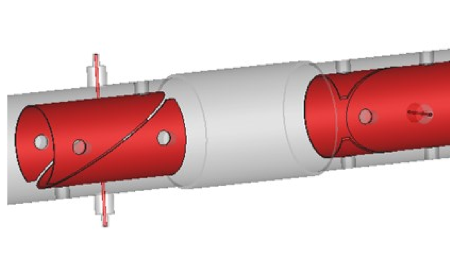
Cross-sectional view of beam profile monitor. Micro-wire grids are shown



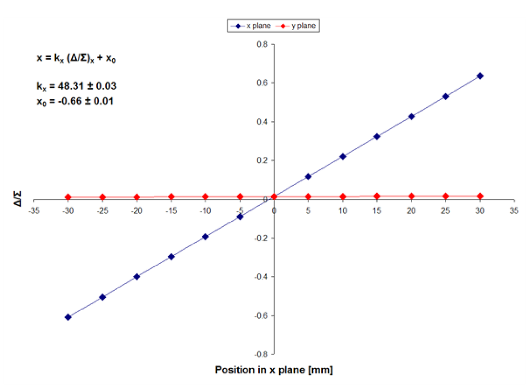
Top views of X and Y profile wire electrodes

The monitor consists of two position-sensitive photocathode grids providing the X and Y projections of the beam, sandwiched between three anode grids with a distance of 2 mm between them. Each grid has between 32 and 48 gold-coated tungsten wires of diameter 5–20 um stretched over a ceramic frame, with a pitch of 0.5–1.5 mm between neighbouring wires. They are manufactured by first printing a pattern of gold readout micros-trips along the edges of a ceramic frame measuring 100 mm x 90 mm x 2 mm with a 62 mm x 62 mm opening in the centre to allow the passage of the beam. Gold coated tungsten wires were stretched over the frame with a mechanical tension of 10–20 g. The two ends of each wire are then aligned and pressed onto the corresponding micro-strips with several kilograms of force, using an electrode tip made of tungsten. The wires are then embedded and fused into the micro-strips by applying a pulsed current on the tip. The grids are baked in vacuum at temperature of 80 °C to remove outgassing contamination from their surfaces, thereby allowing them to be used in ultrahigh vacuum p<10-10 mbar. A 50-pin, L-shaped connector made of stainless steel and alumina is soft-soldered to each board.

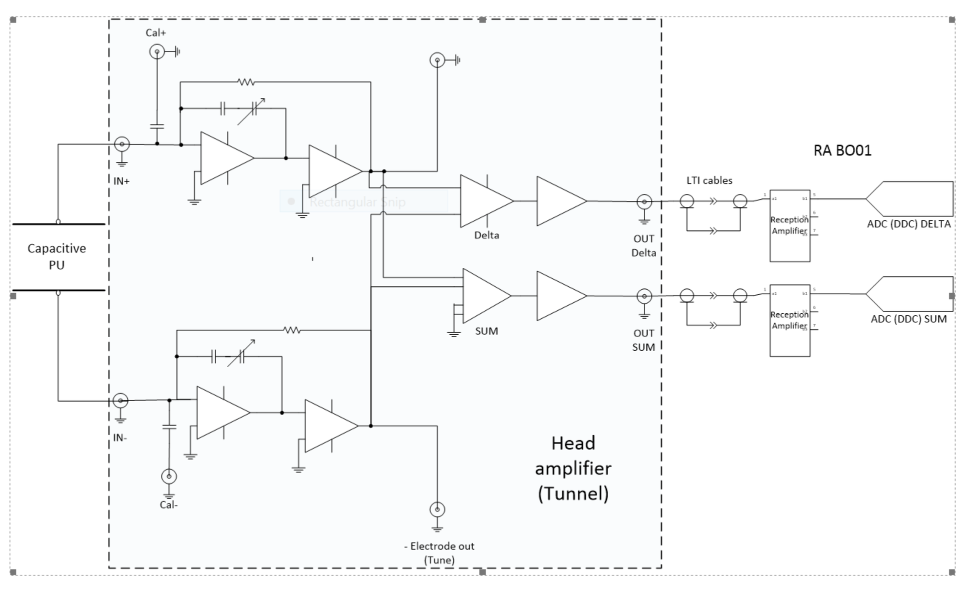
In order to test the response of the pick-up to particle beams at various velocities, a 3D model of the monitor was created in CST Particle Studio. With this model one can estimate the signal linearity, expected output voltage as function of beam energy, electrode capacitance, signal shape as function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



ELENA pickup in CST Microwave Studio

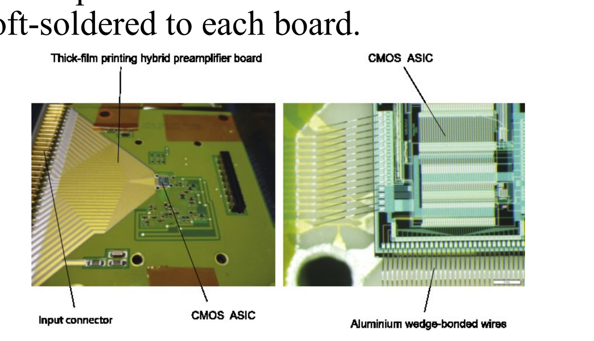


Signal linearity for x and y direction as found in CST Studio

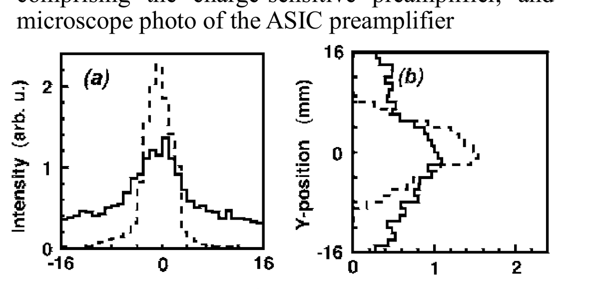


System hardware layout

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 Q_i ejected from the cathode wires on the X and Y grids with high sensitivity. The preamplifiers consisted of 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 analog-to-digital converter (ADC, AD9240).



Photographs of hybrid ceramic circuit board comprising the charge-sensitive preamplifier, and microscope photo of the ASIC preamplifier



The measured spatial profiles of a pulsed beam containing $2x10^{6}$ antiprotons (solid lines), and a laser beam of wavelength 289 nm (broken lines) overlapped on each other