# A CARBON JET BEAM PROFILE MONITOR FOR LEAR

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*Abstract*

CERN's Low Energy Antiproton Ring LEAR is now equipped with a non-destructive beam profile monitor. A pulsed carbon jet of 0.8 ms is used to minimize the disruption of the low energy beam. The jet is produced by a laser beam impinging on a solid carbon target. The atomic jet is collimated to form a thin curtain, which traverses the coasting antiproton beam. The electrons produced by the ionization of the jet are accelerated by electrodes before they hit a phosphorous screen. The image of the profile is acquired by a CCD camera and digitized for display on a workstation. This paper describes the techniques used, from generation of the carbon jet, to the analysis of the digitized image. Preliminary results and future improvements are discussed.

## I. INTRODUCTION

The LEAR machine [1] needed a non-destructive beam profile monitor principally for measuring the evolution of the beam size in the presence of electron cooling [2] and for monitoring the size of the beam in its interaction with an internal gas jet target[3]. Operations required the device to be able to operate with a beam intensity ranging from $10^7$ to $10^{11}$ particles having an energy in the range of 2 MeV to 1.3 GeV. It has been decided to adapt a gas curtain scheme already used in the Intersecting Storage Rings [4], where a continuous sodium curtain was used. Due to the small circumference of LEAR, and the low energy of its beams, a pulsed curtain was designed to avoid emittance blow-up induced by the device. A carbon jet of 0.8ms pulse length, produced by a LASER beam impinging on a solid carbon target is collimated to form a thin curtain inclined at 45° with the vertical. The carbon atoms are ionized by the coasting beam. The distribution of the electrons produced by the ionization provides a measurement of the beam distribution.

## II. DESCRIPTION OF THE APPARATUS

A schematic can be found on Fig. 1.

### A. *Generation of the carbon jet.*

We use a 1064nm YAG laser, delivering a 800 µs pulse of maximum energy 25J, with a maximum repetition rate of 0.5Hz to generate the carbon jet. The solid carbon target has the shape of the segment of a sphere. Stepping motors allow the target to be rotated about the centre of the sphere, thus letting the laser hit a different point. Each laser pulse drills a crater into the target. The latter is repositioned for the next shot, thus forming a honeycomb pattern. About 30% of the evaporated carbon (0.6mg) forms a 5000m/s atomic jet. This

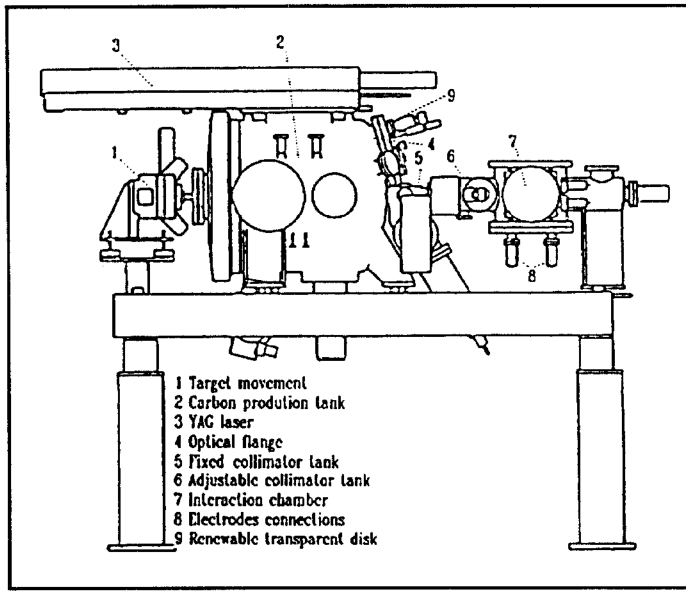


Fig. 1 : Schematic of the apparatus

jet then traverses a series of three (two fixed and one adjustable between 1 and 5 mm) collimators to form the thin curtain which is ionized by the antiproton beam in the interaction chamber.[5]

### B. *Accelerating electrodes*

The electrons produced in the ionization of the jet by the antiproton beam are accelerated by two chemically polished titanium plates. The purity of the titanium (>98.5%) plays an important role to avoid cold emission phenomena. Each plate has its own high voltage power supply, thus allowing few flexibility in the configuration of the field. Typically, the field ranges from 1 to 2 kV/cm, over a distance of 15 cm, yielding 15-30 keV electrons.

### C. *Light collection and amplification*

After traversing a 0.1 µm thick aluminium coating which serves as a grounded electrode, the electrons hit a phosphor (P20) coated fiber-optics window (90mm diameter). The emerging light is then guided through a fiber optics taper which reduces the image to a diameter of 25mm and feeds it into a light amplifier followed by a 625-line CCD camera which delivers a standard video signal (Fig. 2). For $10^9$ antiprotons at 309MeV/c, $10^5$ electrons are collected, yielding $2x10^8$ photons in the phosphorous screen [6].

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*D. Image acquisition*

The video signal is digitized in a CAMAC digitizer module [7] which is triggered from the laser pulse and holds the image in a 312x512 pixels format. The digitizer contents are read using control system routines [8], and the information on the profiles are computed on-line in the LEAR consoles (VAX workstations). The profiles can also be analysed by observing the video signal on an oscilloscope: a fast sweep (100 $\mu$s) representing one raster line gives the horizontal profile, while a slow sweep (20ms) of the full image gives the vertical profile.

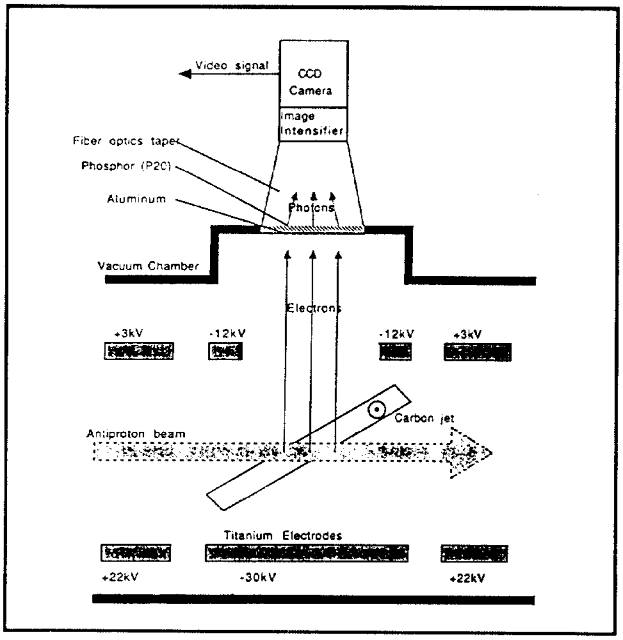


Fig. 2 : Profile production and acquisition

*E. Controls*

The local controls are entirely done in an HP6942A multiprogrammer crate, which communicates with an HP85 computer situated in the control room through a HPIB/RS232 link.

*F. Operation mode*

The laser pulse is synchronized with the video signal of the camera, and triggers the digitizer. In addition, to prevent carbon atoms polluting the optical window through which the laser beam enters the tank, the optical flange is in the region of a relatively high pressure ($4\times10^{-4}$ Torr) during operation. As the vacuum conductance has to be kept very low by using a conical tube between the flange and the tank, a gas injection into the tank takes place at a rate of $3\times10^{-5}$ Tl/s. It has to be compensated by a strong pumping scheme (described below).In these conditions, the optical window has to be renewed every 1000 impulsions. This is achieved by the rotation of a glass disc which allows 70 renewals in situ of the transparent surface [9].

*G. Vacuum system*

In order not to perturb the ultra-high vacuum ($<10^{-11}$ Torr) of the LEAR machine, a differential pumping scheme has been implemented. The collimators act as conductance limitations between the different device volumes. Table 1 shows the vacuum parameters. [10]

Table 1 : Vacuum parameters

| Volume | Pumping system | Design Pressure (Torr) |
|---|---|---|
| Optical flange | Gas injection ($3\times10^{-5}$ T l/s) | $4\times10^{-4}$ |
| Carbon production tank | - Cryogenic (3000 l/s)<br>- Turbomolecular (500 l/s) (in series with rotating primary) | $10^{-8}$ |
| Fixed collimator tank | - Ti sublimator (800 l/s)<br>- Ionic pump (50 l/s)<br>- Non evaporable Getter (1000 l/s) | $2\times10^{-10}$ |
| Adjustable collimator tank | - Ti sublimator (1000 l/s)<br>- Ionic pump (50 l/s) | $10^{-11}$ |
| Interaction chamber | - Ionic pump (60 l/s)<br>- Ti sublimator (1200 l/s) | $10^{-12}$ |

## III. PERTURBATION ON THE BEAM

*A. Vacuum effects*

The 1ms carbon jet has a local pressure of $10^{-5}$ Torr over a distance of 1 to 5 mm. The design pressure of LEAR is $10^{-12}$ Torr ($N_2$ equivalent for scattering) and its circumference is 78m. Thus one gets an average increase of the residual gas pressure by 30%, assuming one measure per 2 seconds (the maximum rate at which the device can operate). Calculation shows that the emittance blow-up during a continuous measurement process is less than 10% of the one induced by scattering on the residual gas [11]. Indeed, no emittance blow-up could be detected on the Schottky scans during the first experiments.

*B. Electrostatic effects*

The vertical electric field used to accelerate the electrons gives a 2 mrad vertical kick on a 105MeV/c antiproton beam, which needs to be compensated. Compensation electrodes are therefore installed on both sides of the device, each with its own high voltage power supply. In addition to the dipolar perturbation of the accelerating plates, the finite width of the plates creates a quadrupolar effect which led to a detuning of the betatron frequencies in the early days of operations with the device. It has been shown to be proportional to the value of the electrical potential between the two main and the auxiliary plates [12], so it could be cured with an appropriate adjustment of the various potentials.

## IV. RESULTS

### A. Problems encountered

A parasitic spot has been observed, which shows up even in the absence of the antiproton beam. Though the direct cause has not been found, evidence shows it is due to self-ionization of the carbon jet in the electric field. The brightest part of this spurious image was moved out of the area of interest with a careful adjustment of the electrical potentials. The remaining halo is first acquired without antiproton beam for calibration, then substracted by software from the beam image. More investigations are taking place in order to understand - and hopefully eliminate - this phenomenon, which makes difficult the observation of very low density profiles.

### B. Profile measurements

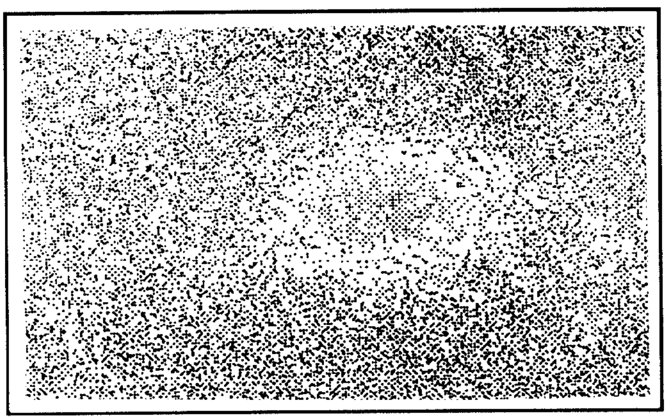

Fig. 3 : Digitized video signal

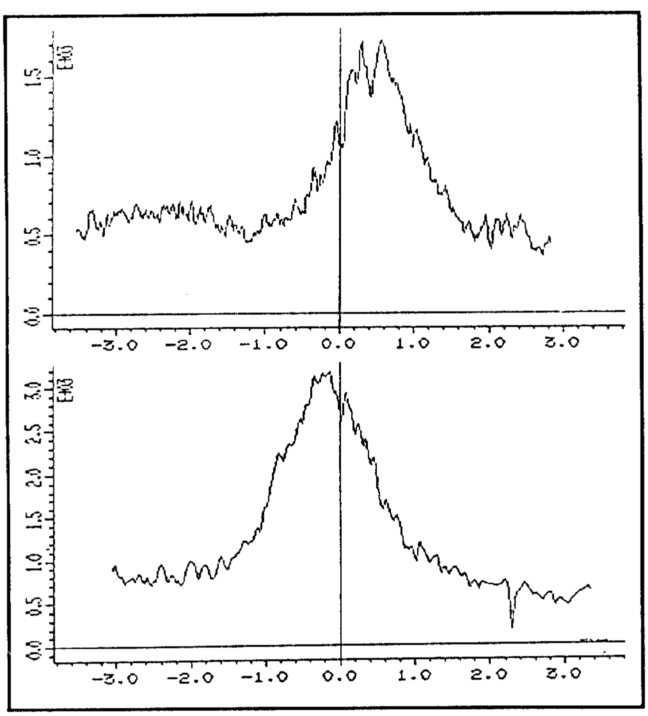


Fig. 4 : Horizontal and vertical beam profiles. The scales are expressed in centimeters.

Fig 3 shows a digitized picture of the image, as it is displayed on the workstations. Fig 4 shows the beam profiles extracted from this image.

## V. PROPOSED IMPROVEMENTS

### A. Helmholtz coils

In order to improve the sensitivity by better guidance of the electrons, Helmholtz coils have been designed. The sensitivity should increase from 2 mm to 0.7 mm with a field of 300 Gauss [13].

### B. Controls

For the moment, the device is routinely operated using a stand-alone micro-computer.It is desirable to integrate it into the LEAR control system, and to convert the controls to operate from the VAX workstations.

### C . Software

For full operationality, more sophisticated image processing is needed. Very good quality commercial software is available, which can be used to fulfill our needs for true image reconstruction, substraction, contour definition, etc.

## VI CONCLUSION

LEAR's carbon jet beam profile monitor, which is now entering its operational stage, promises efficient emittance controls during normal runs and for machine developments, but more time is needed to improve and understand this complex but beautiful device.

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