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## OPTIMIZING THE CERN PLASMA LENS FOR ANTI-PROTON COLLECTION

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### ABSTRACT

The optimization of a plasma lens for use in a specific high-energy accelerator beam focusing application is outlined taking the example of the CERN antiproton ( $\bar{p}$ ) collector plasma lens. The preparations and the off-line testing of the  $\bar{p}$  plasma lens in the laboratory are reported. The adjustments during two beam tests at the CERN Antiproton Accumulator (AAC) are described. After optimization of the accelerator components and of the intrinsic lens parameters, antiproton yields were measured and analysed. The laboratory and the beam tests also allowed to extrapolation of the long-term performance of potential future plasma lenses in defined accelerator applications, such as rare particle collection or heavy-ion beam focusing.

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## Abstract

The optimization of a plasma lens for use in a specific high-energy accelerator beam focusing application is outlined taking the example of the CERN antiproton ( $\bar{p}$ ) collector plasma lens. The preparations and the off-line testing of the  $\bar{p}$  plasma lens in the laboratory are reported. The adjustments during two beam tests at the CERN  $\bar{p}$  accumulator (AAC) are described. After optimization of the accelerator components and of the intrinsic lens parameters, antiproton yields were measured and analysed. The laboratory and the beam tests also allowed to extrapolation of the long-term performance of potential future plasma lenses in defined accelerator applications, such as rare particle collection or heavy-ion beam focusing.

## 1 Introduction

The development of plasma lenses at CERN started in 1983 [1]-[3] and culminated in two beam tests performed at the CERN antiproton source in 1991 [4]-[7] and 1992. The lens was designed to collect a 3.5 GeV/c  $\bar{p}$  beam generated by a 26 GeV/c proton beam impinging on an iridium conversion target, and to transfer the antiprotons via a beam transport channel into the antiproton collector ring (AC). The beam tests were prepared by careful studies of the plasma dynamics, of the long-term behaviour of the plasma lens and of the dedicated pulse generators in an off-line laboratory environment. Both beam tests lasted approximately one week. Implied were measurements concerning the plasma stability and the focusing properties of the plasma lens with a 3.5 GeV/c proton beam, which was sent from the AC through the lens in inverse direction, and measurements of antiproton yield with a proton beam on the production target.

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## 2 Laboratory Tests

The plasma dynamics in the lens was studied by measurements of current and voltage waveforms, of magnetic field distributions, and by fast photography of the plasma column [3]-[5]. These investigations were performed by varying many of the system parameters, such as lens geometry, filling-gas type and pressure, pulse generator characteristics (charging voltage, circuit parameters, current-feed geometry) and the main plasma lens components (electrode and insulator tube shape and material, beam windows and their protection screens). Figure 1 shows a typical set of current, voltage, and magnetic field waveforms for a 900 Pa helium fill and 12.5 kV charging voltage. During the beam test, magnetic field measurement with pick-up coils is not possible, but the voltage waveforms indicate proper working of the lens or malfunctioning due to wall currents or plasma instabilities.

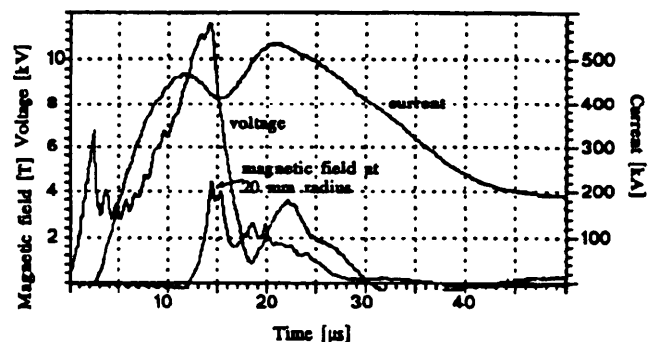


Figure 1

The effect of high-Z gas admixtures to the basic helium filling was studied with respect to pinch dynamics and long-term behaviour. Generally, heavier gases such as  $N_2$  increase the field gradients while shifting the pinch

time nearer to the current maximum, which is given by the pulse generator parameters. Destruction rates of electrodes and insulator tube are similar to those of pure helium provided the concentration of the added gas remains below a few per-cent.

A second series of tests was devoted to the study of the long-term behaviour of plasma lens prototypes as a function of the main parameters of lens and of the peripheral components. Evaporation and erosion rates of insulator tubes and electrodes were measured and the fatigue properties of the beam windows determined for different insulator (quartz,  $\text{Al}_2\text{O}_3$ , AlN, BN) and electrode materials (stainless steel, tungsten, graphite). During the beam tests  $\text{Al}_2\text{O}_3$  insulator tubes and graphite electrodes were used.

### 3 Tests with Inverse Proton Beam

The beam test of the plasma lens in 1991 started with a low-intensity proton beam, which was ejected from the AC in inverse direction through the plasma lens. The main aim was the determination of the symmetry of the focused beam observed on a luminescent screen and of the range of stable focusing as a function of the charging voltage and plasma lens pressure. The parameter setting of the external beam transport channel had been not optimized with the protons during the first run. The results of the inverse proton beam test have been reported in references [6] and [7]. Pinch currents up to 370 kA and gradients of 170 T/m were deduced from the focused proton beam spots.

In the 1992 beam test with the inverse proton beam, an improved, movable, luminescent screen and a fast-gated camera were used for observation, which allowed for a better determination of the spot size of the focused beam. The spatial stability and symmetry of the focused proton beam were investigated in the range from 10 to 12.5 kV charging voltage and from 900 to 1400 Pa helium pressure.

Figure 2 shows the beam spot position, size  $2\sigma$  and shape for three charging voltages (10, 11, 12 kV) with a 1400 Pa helium fill as a function of delay between the beam pulse and the plasma lens discharge. Figure 3 shows a series of beam spots measured at different moments in time during a plasma lens discharge at 12.5 kV and 1150 Pa on the screen positioned 133 mm behind the lens. The beam-spot size at 12.5 kV and 1300 Pa helium at fixed delay time is plotted as a function of distance between lens and luminescent screen (target) in Fig. 4. In this case the focus is positioned just in between the limits of the screen movement. The envelope shows a minimum radius of 2.8 mm, which is mainly determined by the emittance which is about 100 mm

mrad. This value is approaching the emittance blow-up calculated and measured at the AC for a beam going from the target into the AC ring. The resulting field gradient of the plasma lens is calculated from the minimum focus radius and the focus length as 165 T/m, in good agreement with the results of 1991.

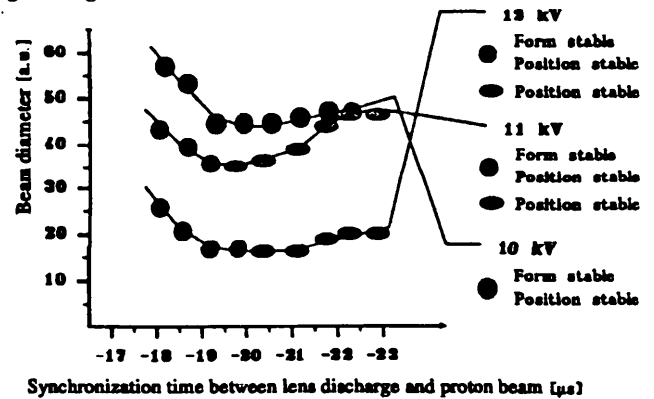


Figure 2

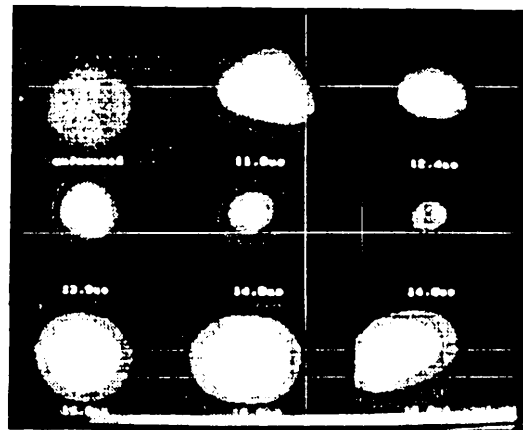


Figure 3

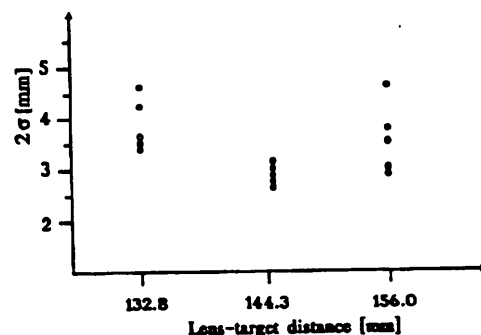


Figure 4

Finally the influence of  $\text{N}_2$  admixtures in the range from 1.5 to 4.5% was studied at 1200 Pa total pressure.

The position of the focus was stable, but slightly decentered. At lower pressure no further experiments with nitrogen were carried out.

#### 4 Antiproton Yield Measurements

During the plasma lens test with the  $\bar{p}$  production beam in 1991, the plasma lens was mostly operated with a fixed setting of charging voltage and helium pressure. Only parameters of the production beam, of the dogleg beam steering and of the AC were optimized. Antiproton yields up to  $62 \times 10^{-7}$  were measured [6],[7]. Even without plasma-lens parameter optimization the yield reached values that compared well with other collector lens systems, which have delivered  $\bar{p}$ 's for several years. The plasma lens underwent 20 000 pulses during this run, but not all at the full stored energy of 60 kJ. The evaporation make was 0.85 mg/shot.

The  $\bar{p}$  production test in 1992 started with a plasma lens setting that was found favourable after the inverse proton beam test. Then the machine and plasma lens parameter (pressure and charging voltage) settings were iteratively optimized. Figure 5 demonstrates the yield optimization by variation of lens-target distance and synchronization time at constant filling gas pressure and charging voltage. The yield values were generally lower than those measured in 1991, in spite of the same gradients and a more stable functioning of the lens compared with the 1991 run. Frequently the yield dropped down by a factor of up to three. Sometimes the yield recovered to the previous level, sometimes it did not, while the lens was working well and stably. Therefore variation and limitation of the yield could not be attributed not to the plasma plasma lens, but rather to fluctuations and marginal adjustments of the primary production beam or to the beam handling in the AC. The same yield values were measured with the same parameter settings at low ( $2 \times 10^{12}$ ) and high ( $1.3 \times 10^{13}$ ) primary proton beam intensities.

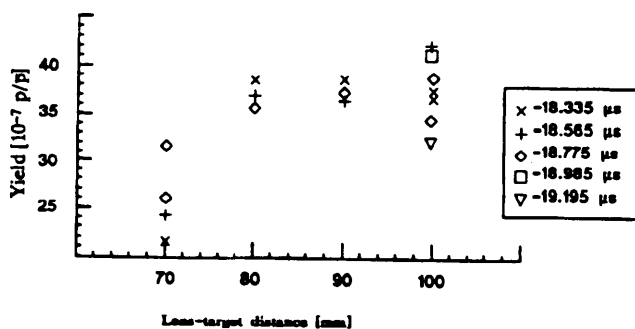


Figure 5

The plasma lens made again 20 000 pulses in a very stable operation without any failure at a stored pulse energy of 55 kJ.

#### 5 Conclusion

The knowledge and experience gained during several years of R&D in laboratory tests and during the two beam tests with the  $\bar{p}$  plasma lens now forms the basis for a new, efficient technology of charged, high-energy particle focusing. Future plasma lens systems can be built with stored energy per pulse in the range of 100 kJ and with average power in the range of 30 kW according to required specifications. Since  $\bar{p}$  physics at CERN no longer needs high rates, low-intensity  $\bar{p}$  collection may be satisfactory with lithium lenses [8]. Plasma lenses, however, are envisaged for heavy ion focusing at GSI and potentially as collector lenses for rare particles such as pions at high-intensity neutrino experiments.

#### References

- [1] J. Christiansen, K. Frank, H. Riege, R. Seeböck, "Studies of a plasma lens with pseudospark geometry", Int. Report, CERN/PS/AA/84-10 (1984).
- [2] B. Autin, H. Riege, E. Boggasch, K. Frank, L. De Menna, and G. Miano, *IEEE Trans. Plasma Sci.* PS-15 (1987) 226.
- [3] F. Dothan, H. Riege, E. Boggasch, and K. Frank, *J. Appl. Phys.* 62 (1987) 3583.
- [4] J. Christiansen, K. Frank, M. Stetter, R. Tkotz, G. Le Dallic, M. Lubrano, R. Kowalewicz, S. Milner, and H. Riege, CERN/PS 90-30 (AR) (1990), and Proc. European Particle Accelerator Conf. (EPAC 90), Nice, 1990, p.343 (1990).
- [5] R. Tkotz, "Entwicklung einer Z-Pinch Plasmalinse zur Fokussierung von  $\bar{p}$  für das CERN ACOL Projekt", Dissertation, Universität Erlangen-Nürnberg (1992).
- [6] R. Kowalewicz, M. Lubrano, S. Milner, F. Pedersen, H. Riege, J. Christiansen, K. Frank, M. Stetter, and R. Tkotz, in Proc. Particle Accelerator Conf. (PAC 91), San Francisco, (1991).
- [7] R. Kowalewicz, M. Lubrano di Scampamorte, S. Maury, S. Milner, H. Riege, J. Christiansen, K. Frank, U. Neuner, M. Stetter, and R. Tkotz, in Proc. European Particle Accelerator Conf. (EPAC 92), Berlin, (1992).
- [8] P. Sievers, R. Bellone, A. Ijspeert, P. Zanasco, *IEEE Trans. Nucl. Sci* NS-32 (1985) 3066.