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Summary of the MD on comparative measurements of electron cooling with protons and antiprotons

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Abstract

Comparative measurements of electron cooling with protons and antiprotons were made during two MD sessions of 40 hours each during weeks 12 and 13. Equilibrium points between stochastic heating and electron cooling were measured as well as the beam emittances and the longitudinal cooling force.

1. Electron cooling of protons

Cooling of protons was performed at the injection momentum of 308.6 MeV/c and also at 105 MeV/c. The necessary orbit and tune adjustments were applied in order to compensate the effect of the electron cooler solenoid and toroids after which the optimisation of the cooling process was made by adjusting the electron and proton trajectories and observing the H^0 formation rate. From the formation of H^0 atoms we were also able to determine the emittance of the cooled beam using the multiwire proportional chamber (MWPC) with a 2mm resolution situated at the exit of straight section 3 in LEAR. These measurements were complemented with scraper measurements and the results are shown in table 1. 95% emittances were calculated using the relationship $\varepsilon = 1/\beta\ [\ x^2 - (D/2\ \Delta p/p)^2\ ]$ where x is the beam half width (1.96σ)measured at the scraper or at the MWPC, and β is the beta function at these points. The contribution from the dispersion was in fact neglected in the calculations as the beam had a momentum spread of the order of 10^{-5}. The used values of the Twiss parameters are $\beta_{h,v(scraper)} = 6.56m, 15.94m$,$D_{(scraper)} = 0.975m$,$\beta_{h,v(MWPC)} = 45.9m, 21.75m$,$D_{(MWPC)} = 3.56m$ The large vertical emittance measured with the scrapers is due to the fact that the beam was very unstable in this plane hence making a correct evaluation impossble.

Table 1: Emittance measurements at 308.6 MeV/c

Two independent sets of measurements are compiled in the first and second rows.

H scraper in / out mm	V scraper top / bottom mm	H MWPC half width mm	V MWPC half width mm	ε scraper H / V π mm mrad	ε MWPC H / V π mm mrad
-2.3/5.4	15.5/-18.	7.32	9.45	2.25/17.6	1.16/4.1
-4./3.2	17./-18.	7.5	9.6	1.97/19.2	1.23/4.23

For the equilibrium measurements stochastic heating was used to blow up the beam longitudinally with the electron cooler on and the momentum spread was evaluated for various settings of the heating power. 5 μW/Hz of RF noise with a 10 kHz bandwidth was injected on a RF gap with a broadband impedance of 50Ω at a frequency of 13.126 MHz and the attenuation was varied in order to obtain the profiles shown in Figs. 1 to 3.

By stepping away the electron beam energy via the high voltage (HT) power supply and then resetting it to the operational value we were able to determine the longitudinal cooling time for small velocity differences. Fig. 4 shows one such measurement for a step in the electron beam energy from 27.29 kV to 27.39 kV, a change of 100 V, for a cooled beam. The spectrum analyser is set to a 0 Hz span in order to see the time evolution of the spectral density around a harmonic of the revolution frequency.

In order to decelerate to 105 MeV/c the electron cooling device was operated in a 'pulsed' mode. This meant that the solenoid was synchronised to the LEAR magnetic cycle and a monitoring programme on the ECOOL control system set the values for the correction coils as soon as the solenoid changed value. Once on a standard machine flat-top, the HT was pulsed from 0kV to the operational value in about 120 msec and was kept on for 6 secs before being reset to 0kV. In this manner we were able to decelerate to 105 MeV/c using stochastic cooling only at 609 MeV/c and thus saving some 15

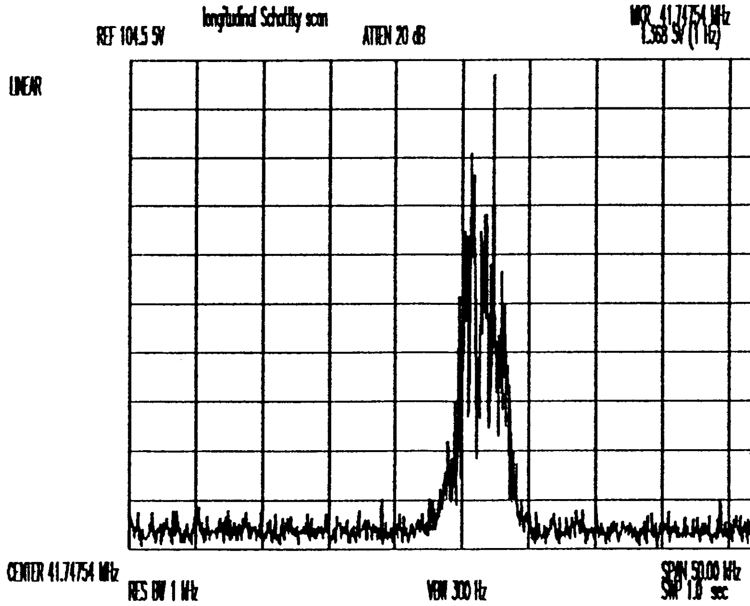

Figure 1: Longitudinal Schottky scan of a cooled beam of 0.51×10^9 protons at 308.6 MeV/c. No stochastic heating.

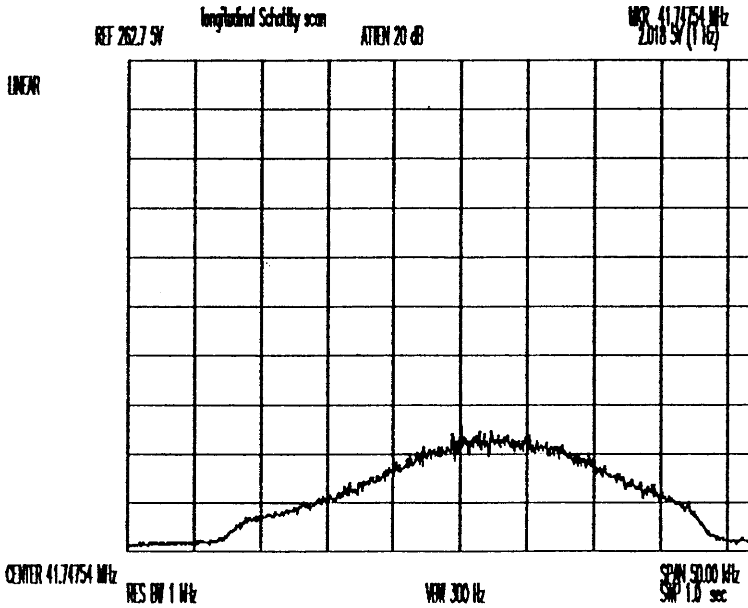

Figure 2: Longitudinal Schottky scan of a cooled beam of 1.65×10^9 protons at 308.6 MeV/c. 24dB attenuation was put on the stochastic heating.

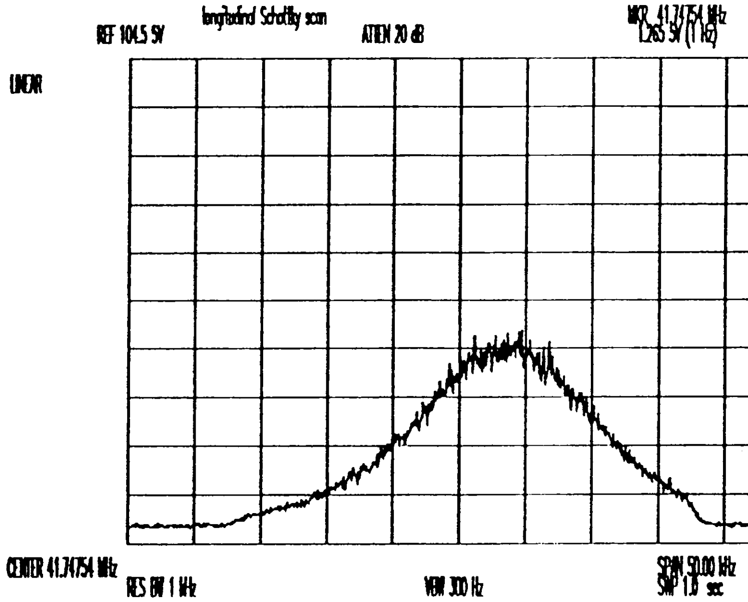

Figure 3: Longitudinal Schottky scan of a cooled beam of 0.52×10^9 protons at 308.6 MeV/c. 40dB attenuation was put on the stochastic heating.

minutes in cooling time. Some beam was also successfully decelerated to 61 MeV/c but more time is needed to optimise the tune and the orbits at this momentum.

At 105 MeV/c we were only able to perform equilibrium measurements between electron cooling and stochastic heating. This was mainly due to a short beam lifetime at this momentum which was probably caused by the relatively poor vacuum at that time in the LEAR ring. Lifetime measurements were also performed with and without electron cooling, but not a large difference was observed (see Appendix A).

An attempt to see the influence of the electron magnetisation on the cooling time was made at 105 MeV/c by increasing the solenoid field to twice its normal value. This operation however was abandoned as the orbit and tune corrections were found to be more delicate than expected and cooling was impossible without adjusting the electron beam energy.

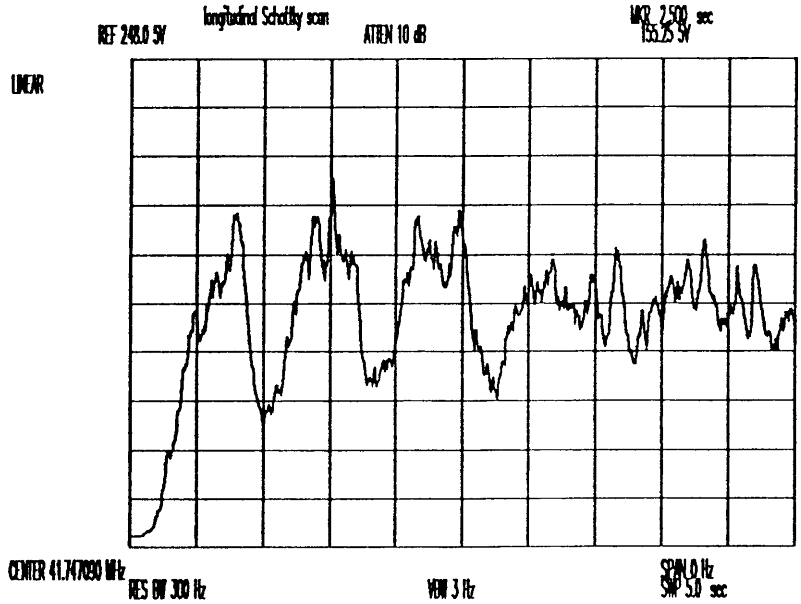

Figure 4: Longitudinal cooling time for a small change in electron energy. The energy of the electron beam was stepped up by 100 V and the time evolution of the peak longitudinal density was monitored on the spectrum analyser. As the high voltage power supply is stable only to 10^{-4} the electron beam energy will fluctuate with the same order of magnitude. This can be clearly seen in the above plot where the sensitivity of the central frequency (the resolution bandwidth) is very low (in this case 300 Hz) and hence any variation in the electron beam energy is represented by a dip in the scan.

2. Electron cooling of antiprotons

Due to the fact that the injection energy is higher for antiprotons it was decided to use the electron cooler in the 'pulsed' mode as described before. The beam was stochastically cooled at 609 MeV/c and then decelerated in the normal manner to 308.6 MeV/c. On this flat – top the electron cooler high voltage power supply was pulsed to the operational value for beam cooling. This was also performed on the 200 MeV/c and 105 MeV/c flat – tops.

With antiprotons much time was devoted to the optimisation of the longitudinal cooling. The electron beam was adjusted using the correction coils in the toroids and solenoid in order to obtain a well cooled and centred beam on the longitudinal Schottky scan (Fig. 5). The longitudinal distribution in the equilibrium between electron cooling and stochastic heating was analysed theoretically and yielded the curve shown in Fig. 6. The splitting of the Schottky signal in Fig. 7 is an excellent means of determining if we are in a regime of very strong longitudinal cooling. This behaviour corresponds to earlier results obtained with protons and merits a more detailed analysis.

This led to a rather poor cooling in the transverse plane with scraper measurements consequently giving rather large values which are supported by the results from the measurements of the transverse

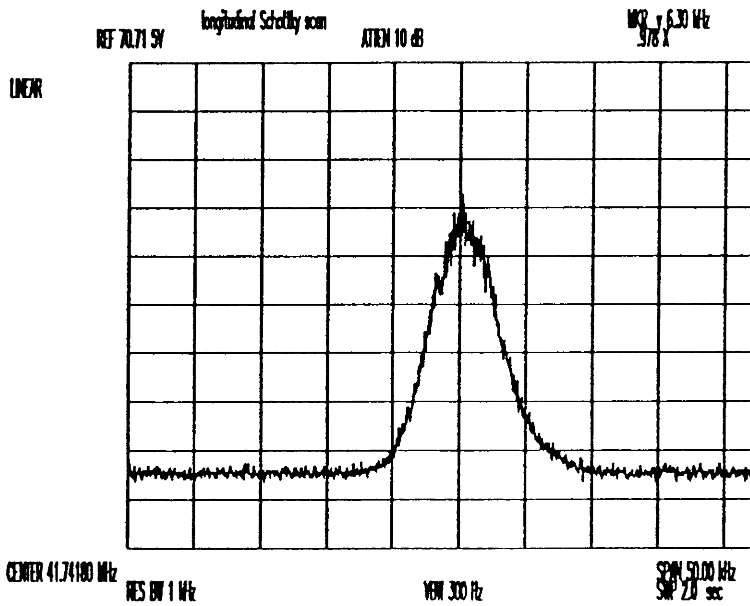

Figure 5: Longitudinal Schottky scan of electron cooling of 10^7 $\bar{p}$s at 308.6 MeV/c

Schottky spectra (Figs. 8 an 9). No explantion can be found to explain the large horizontal emittance obtained with electron cooling except if we assume some transverse coherent oscillation or some coupling between the horizontal and longitudinal planes. The transverse Schottky scans obtained (Figs. 8 and 9) show a very uncharacteristic behaviour that will have to be analysed in much more detail.

Table 2: Emittance measurements with $\bar{p}$s at 308.6 MeV/c

Comparative measurements were made between stochastic and electron cooling using the scrapers in the machine. The first row shows the beam size after 3 minutes of stochastic cooling and the second row shows the measured beam size during electron cooling.

H scraper in / out	V scraper top / bottom	ε scraper H / V
mm	mm	π mm mrad
-7.5/12.	18.5/-15.	14.4/17.6
-19./29.	10./-4.	87.8/3.

As with protons equilibrium measurements between stochastic heating and electron cooling were made at all three momenta. Fig. 10 shows the momentum spread as a function of heating noise for both protons and antiprotons at the different momenta.

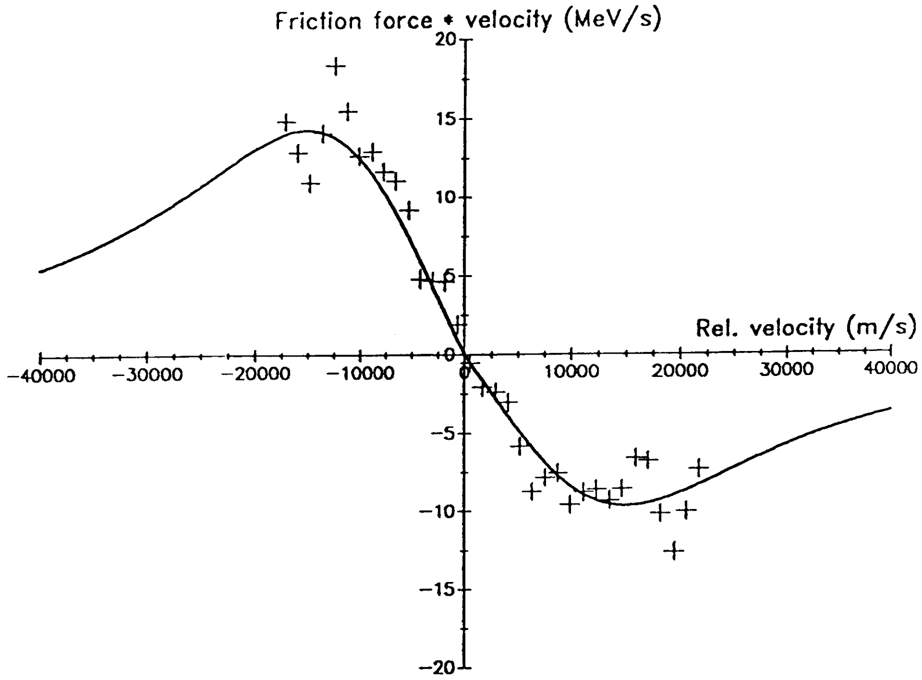

Figure 6: Frictional force (MeV s^{-1}) as a function of relative velocity difference for the beam in Fig 5 (crosses). It conforms with the theoretically predicted dispersion – like shape (solid line).

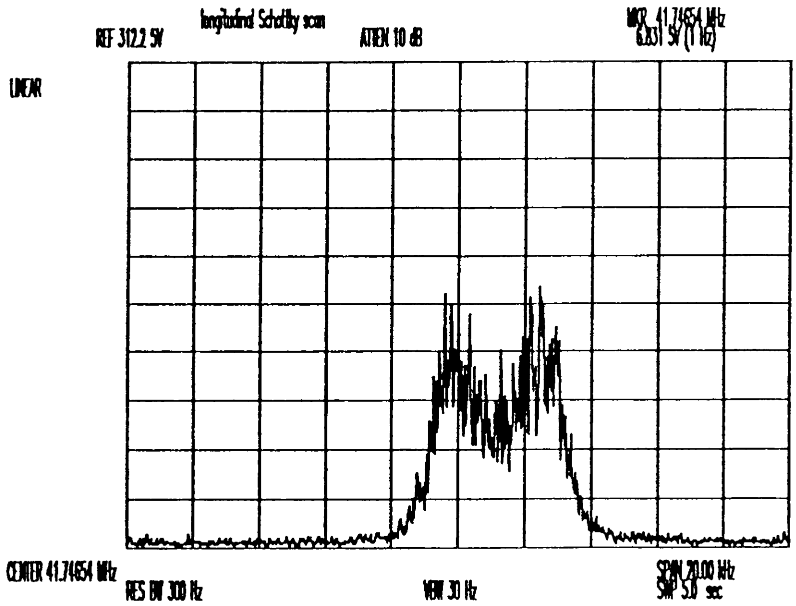

Figure 7: Longitudinal Schottky scan of an electron cooled beam of 1.2×10^9 $\bar{p}$s at 308.6 MeV/c.

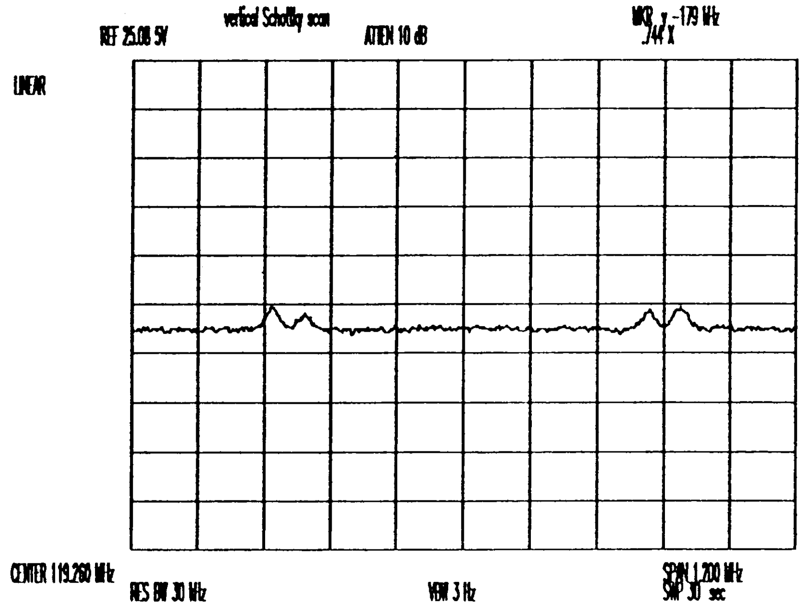

Figure 8: Vertical Schottky scan of an electron cooled beam of 1.2×10^9 $\bar{p}$s at 308.6 MeV/c.

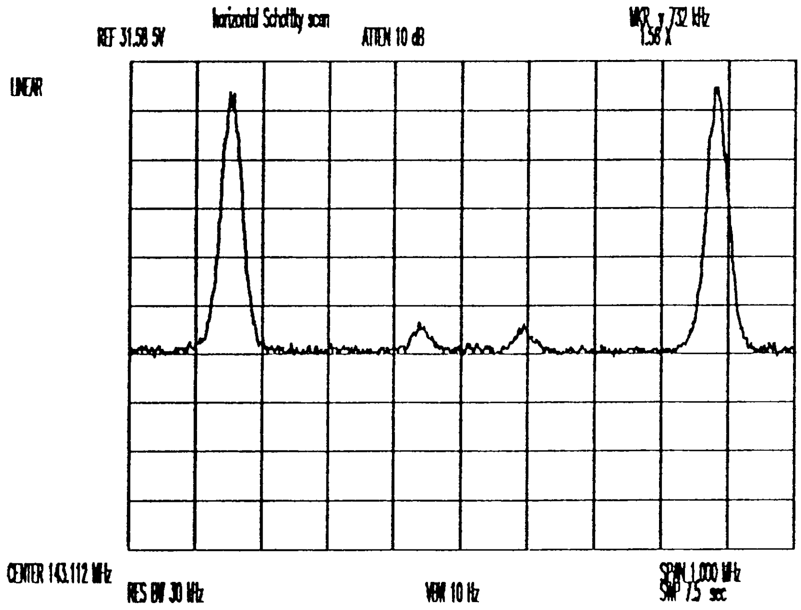

Figure 9: Horizontal Schottky scan of an electron cooled beam of 1.2×10^9 $\bar{p}$s at 308.6 MeV/c.

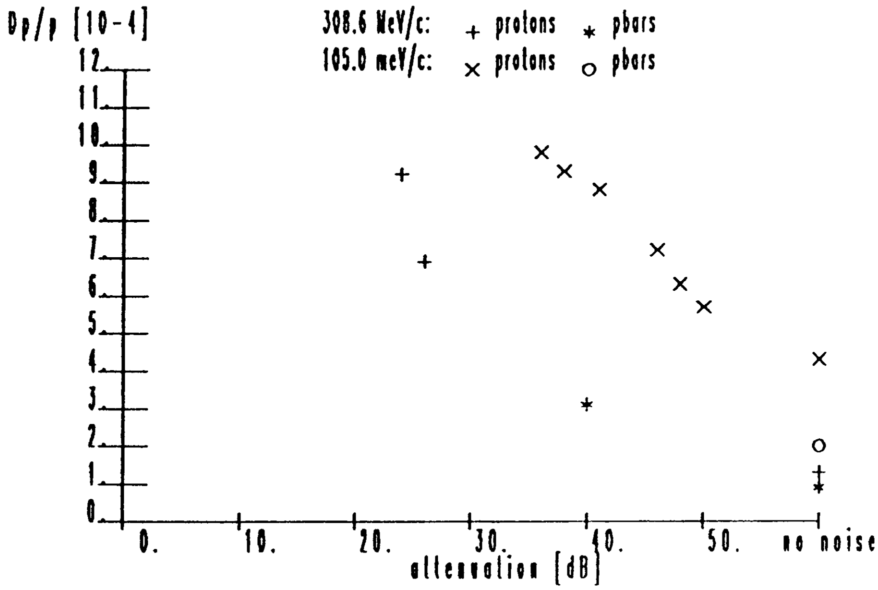

Figure 10: Plot of equlibrium momentum spread as a function of heating noise for protons and p̄s. Measurements were made at 308.6 MeV/c and at 105 MeV/c with 5 μW/Hz of heating noise injected at 13.126 MHz and 11.896 MHz respectively.

3. Acknowledgements

We would like to thank F. Ollenhauer, and M LeGras for their help in the development of much of the electronics needed for this MD and also G. Molinari and J.C. Bovigny who provided the hardware necessary for the wire chamber measurements.

Appendix A

Beam lifetime measurements at 105 MeV/c with protons

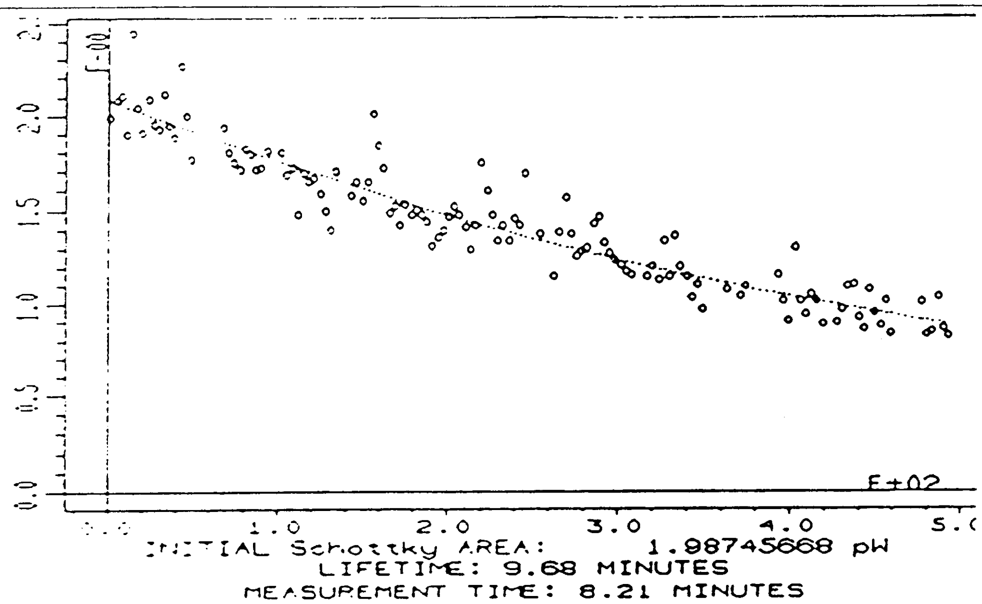

Figure 11: Beam lifetime with electron cooling off and 0.35×10^9 protons at the start of the measurement.

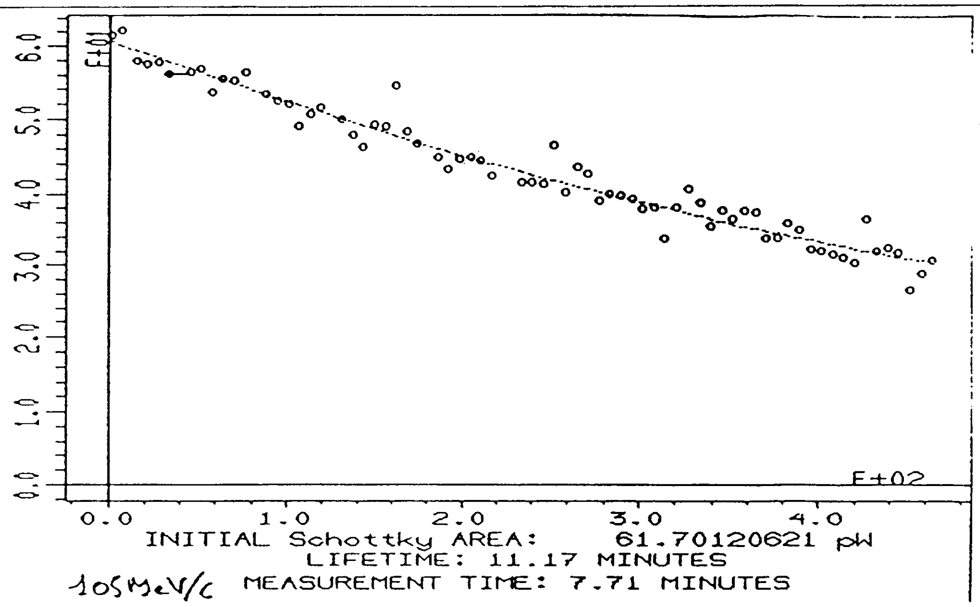

Figure 12: Beam lifetime with electron cooling on and 1.2×10^9 protons at the start of the measurement.