Measurements 12/06/06 and simulations with Betacool

A.Sidorin, Draft, 12/17/06

1. Friction force value

The antiproton beam was precooled with stochastic cooling. The SC was switched off and beam cooled down with electron cooling to equilibrium. The electron energy was shifted by 2 keV in negative direction relatively to usual operation. The equilibrium emittance (95% normalized) during measurement was varied very slightly and in both planes was about 0.4 $\pi\cdot$mm$\cdot$mrad.

The antiproton number was equal to $6.1\cdot10^{10}$. For the electron current of 50, 100, 200 and 300 mA the friction force was measured using the voltage step method. The electron energy in all cases was jumped by ΔE_e = +5 keV and the longitudinal Schottky spectrum was measured during a few minutes (5 – 6). The jump of antiproton relative momentum deviation is equal

$$\delta \frac{\Delta p}{p} = \frac{\gamma}{\gamma+1}\frac{\Delta E_e}{E_p}\frac{m_p}{m_e} = \frac{9.61}{10.61}\frac{5\cdot10^3}{8\cdot10^9}1836 = 1.037\cdot10^{-3}$$

During the measurements in five points over time the Schottky profiles, maximum position and rms spectrum width were recorded. A linear fit of the maximum position as function of time was used for the friction force estimation.

The maximum position f_{max} is recalculated into momentum as

$$pc = \frac{f_{\max}}{f_c\eta}8900_{[MeV/c]}$$

η = 0.0086, that corresponds to transition gamma of about 21.15, the central frequency f_c = 1750062000 Hz.

The results of the friction force measurements are listed in the Table 1 and shown in the Fig. 1.

Table 1. Friction force at different electron current, voltage jump is +5 kV

Electron current, A	Friction force, MeV/c per h
0.5	5.7
0.1	15.4
0.2	21.5
0.3	26.7

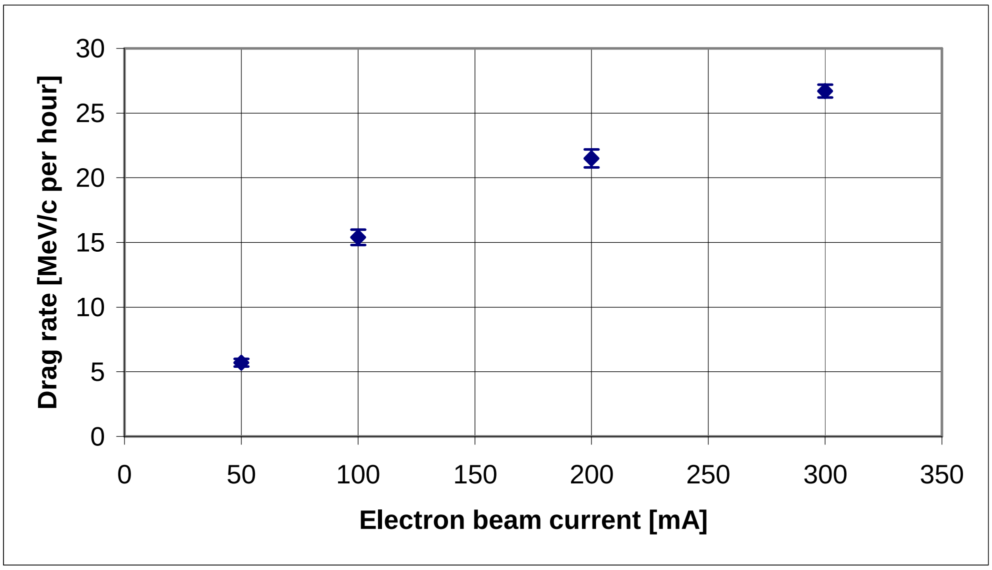


Fig. 1. Friction force as function of the electron current. Error bars correspond to accuracy of the linear fit.

The normalized 95% emittance of the antiproton beam during measurements was equal to about 0.4 π·mm·mrad in both planes and stays almost constant during measurements. The beam transverse profiles were measured using flying wire and the profile shape is closed to Gaussian. (The vertical emittance is about 20% larger than horizontal in accordance with flying wire measurements, the Schottky noise indicates vice verse). The corresponding rms unnormalized emittance is equal to about 0.0062 π·mm·mrad. The antiproton beam radius in the cooling section is

$$\sigma_p = \sqrt{\varepsilon\beta_{cool}} \approx 0.4 \text{ mm}$$

(the beta function in the cooling section β_{cool} = 30 m) that is sufficiently less than electron beam radius (it is right for large electron current, see Table 2). The electron beam trajectory is measured with BPMs and maximum deviation from the central position was about 0.2 mm. At these conditions one can assume that the friction force is determined by electron beam parameters in its central part mainly. The calculated current density in the centre of electron beam as function of electron beam current was presented by L.Prost and it is listed in the Table 2. Effective electron beam radius is calculated under assumption of uniform density across the beam.

Table 2. Current density in the center of electron beam and effective electron beam radius.

Current [A]	J_e [A/cm^2]	a_{eff} [cm]
0.02	0.2	0.178412
0.025	0.246	0.179857
0.04	0.35	0.190731
0.05	0.4	0.199471
0.1	0.56	0.238414
0.15	0.68	0.264982
0.2	0.77	0.287538
0.3	0.9	0.325735
0.4	0.98	0.360448
0.5	1.05	0.389328

The ratio of the measured values of the friction force and corresponding central density of the electron beam is shown in the Fig. 2. At electron currents of 0.1, 0.2 and 0.3 A the friction force is a linear function of the electron density (within the accuracy of measurements) and one can assume that electron temperature in the beam centre does not depends on electron current.

At 0.05 A the measured friction force is about two times less than it expected due to electron density variation. But at this current 3σ dimension of the antiproton beam is comparable with the effective electron beam radius (in measurements at this current the antiproton emittance was slightly larger than at another current) and simplified model of the electron beam can not be applied.

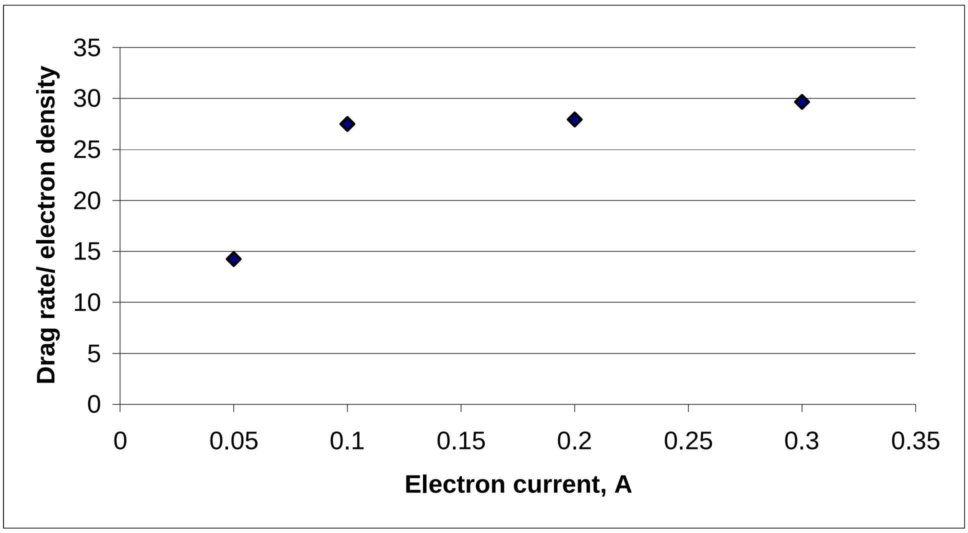


Fig. 2. Ratio of the friction force and central electron density

2. Electron velocity spread

Longitudinal relative momentum spread of electrons can not be less then the value determined by the ripple of HV power supply ΔU:

$$\sigma_{p,rippl} = \frac{\gamma}{\gamma+1}\frac{\Delta U}{\mathrm{E_e}}$$

which is about 300 V. That corresponds to

$$\sigma_{p,ripple} = \frac{9.606655}{10.606655}\frac{300\cdot 10^{-9}\cdot 1938}{8.0171} = 6.22257847423644\text{E-05}$$

The longitudinal velocity spread is

$$\Delta_{\|} \geq \beta c \sigma_{p,ripple} = 18566.369619364 \text{ m/s.}$$

The voltage step of 5 kV corresponds to velocity deviation in the particle frame

$$\delta V = \beta c \frac{\gamma}{\gamma+1}\frac{\Delta E_e}{E_p}\frac{m_p}{m_e} \approx 3\cdot 10^5 \text{ m/s.}$$

Initial momentum spread of antiproton beam was about $5\cdot10^{-5}$ that corresponds to the velocity spread of $1.5\cdot10^{4}$ m/s. The antiproton transverse velocity spread is

$$\Delta V_{\perp} = \beta\gamma c\sqrt{\frac{\varepsilon}{\beta_{cool}}} \approx 4\cdot10^{4}\ \text{m/s}.$$

Thus the antiproton velocity spread is sufficiently less than the velocity deviation and, in principle, we need to fit the friction only in the point $\delta V_{\perp} = 0$, $\delta V_{\parallel} = 3\cdot10^{5}$ m/s. In this point the friction force value very slightly depends on longitudinal electron velocity spread. For instance at electron transverse velocity spread of $3.3\cdot10^{5}$ m/s the friction force is presented in the Table 3.

Table 3. Longitudinal friction force in the particle frame in eV/m.

Longitudinal electron velocity spread, m/s	3D	Binney
18566	-0.004365417	-0.00397048
20000	-0.004366297	-0.003971944
25000	-0.004369871	-0.003977913
30000	-0.004374232	-0.003985229

The friction force values calculated with 3D and Binney formulae differ by about 10% (in 3D formula Coulomb logarithm is under the integral). However the force variation at the velocity spread change from 18566 to 30000 m/s is about 0.2%. During the measurements of the friction force the relative momentum deviation was changed by about $5\cdot10^{-5}$ that corresponds to the velocity deviation of $1.5\cdot10^{4}$ m/s. It means that the profile variation was measured at practically constant velocity deviation. Therefore at these experimental conditions the exact value (in reasonable range) of the longitudinal electron velocity spread does not play a role and for the friction force there is only one fitting parameter – transverse electron velocity spread.

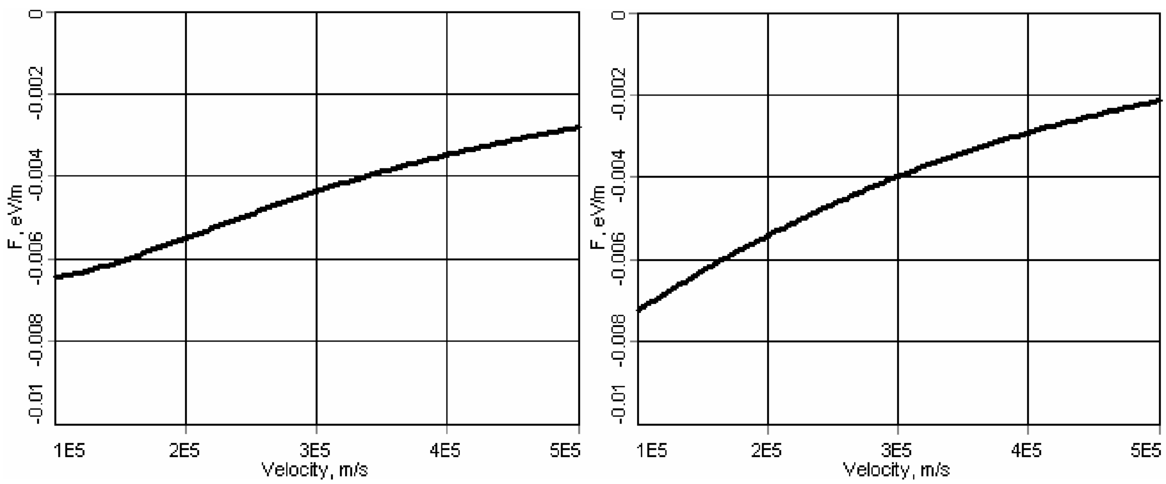


Fig. 3. Longitudinal component of the friction force as function of longitudinal velocity deviation at zero ion transverse velocity. Left plot – 3D integral, right plot – formula by Binney. $\Delta_{\parallel} = 3\cdot10^{4}$ m/s, $\Delta_{\perp} = 3.3\cdot10^{5}$ m/s.

Transverse electron velocity spread as function of angular spread is given by

$$\Delta_{\perp} = \beta\gamma c\theta$$

In the center of the electron beam the angular spread is determined mainly by the optics of electron gun and transport channel. The estimations give a value of 90 – 120 μrad. At the edge of electron beam the velocity spread increases due to drift velocity and envelope mismatch and can reach the value of about 200 μrad.

Angular spread [μrad]	Velocity spread [m/sec]
90	257971.2533
100	286634.7259
110	315298.1985
120	343961.6711
130	372625.1437
140	401288.6163
150	429952.0889
160	458615.5614
170	487279.034
180	515942.5066
190	544605.9792
200	573269.4518

Additional possibility in Betacool to fit the electron beam parameters is to use gradient of the transverse velocity spread

$$\frac{d\Delta_{\perp}}{dr} \approx \frac{\Delta_{\perp,edge} - \Delta_{\perp,centre}}{a_{eff}},$$

assuming that at the age of the beam the angular spread is about 200 μrad one can fit the friction force in the centre of the beam by $\Delta_{\perp,centre}$ and for simulation of profile evolution calculate the velocity gradient from the formula.

3. Transverse diffusion

Thus at electron beam currents of 0.1, 0.2 and 0.3 A one can assume that the electron velocity spread is almost independent on the beam current. In this case all three points has to be fitted with the same longitudinal and transverse electron velocity spread. The initial antiproton emittance and momentum spread are practically the same in all cases as well as the particle number, therefore one can assume that the diffusion power is the same also.

Power of transverse diffusion does not play a role in the process because the emittance was not changed significantly during measurements. It means that the sum of the cooling and heating rates was sufficiently less then inverse measurement duration:

$$\frac{1}{\tau_{cool}} + \frac{1}{\tau_{heat}} << \frac{1}{t_{meas}} \approx 3\cdot 10^{-3}\ \mathrm{sec}^{-1}$$

The transverse diffusion is determined by two processes mainly: heating due to scattering on residual gas atoms and heating by feed back system. The measured value of 95% normalized emittance growth due to scattering on residual gas atoms is about:

$$\frac{d\varepsilon}{dt} \approx 0.5\frac{\pi \cdot mm \cdot mrad}{h} = 2.42275056611776\cdot 10^{-6}\frac{\pi \cdot mm \cdot mrad}{\mathrm{sec}}\ \text{(geometry RMS)}.$$

Heating due to feed back was not known exactly at the moment of measurements (the measurements of the diffusion are scheduled for nearest experiment) but it is comparable with the heating on gas. At the heating rate of $2.4\cdot10^{-6}\ \frac{\pi\cdot mm\cdot mrad}{\sec}$, at typical electron beam parameters and antiproton emittance of about 0.006 π·mm·mrad the sum of the rates is negative at all electron currents and its value is of the order of 10^{-4} $\sec^{-1}$. (The beam parameters are closed to equilibrium between cooling and heating.) At transverse electron velocity spread of $3.3\cdot10^{5}$ m/s and longitudinal - $2\cdot10^{4}$ m/s minimum of the rates in the total range of the beam current corresponds to the heating rate of about $5.2\cdot10^{-6}\ \frac{\pi\cdot mm\cdot mrad}{\sec}$ (geometry RMS) or $\frac{d\varepsilon}{dt}\approx 1.1\frac{\pi\cdot mm\cdot mrad}{h}$ 95% normalized (Table 5).

Table 5. Sum of the rates, Binney formula for friction force.

Electron current, mA	Sum of rates, s^{-1}
50	$4.1\cdot10^{-4}$
100	$2.3\cdot10^{-4}$
200	$2.3\cdot10^{-6}$
300	$-1.3\cdot10^{-4}$

The longitudinal diffusion in antiproton beam has to satisfy two conditions: from the one hand the equilibrium momentum spread before the voltage jump has to be closed to measured value and from the other hand the longitudinal diffusion has to reproduce the evolution of rms momentum spread after the jump. It can be fulfilled by fitting of the diffusion power in equilibrium and dependence of the diffusion power on momentum spread.

4. Friction force fitting

To fit the electron transverse velocity spread in the centre of the beam the experimental points were recalculated into relative values and were compared with Model Beam simulations.

Electron current 300 mA

Time, sec	Relative momentum shift	RMS relative momentum spread
0.00	0.00E+00	5.01E-05
78.000	5.83E-05	6.56E-05
147.000	1.17E-04	8.13E-05
206.000	1.67E-04	9.91E-05
273.000	2.27E-04	1.21E-04

Electron current 200 mA

Time, sec	Relative momentum shift	RMS relative momentum spread
0.00	0.00E+00	4.80E-05
56.000	2.60E-05	5.55E-05
142.000	8.45E-05	7.06E-05
222.000	1.41E-04	8.79E-05
327.000	2.16E-04	1.13E-04

Electron current 100 mA

Time, sec	Relative momentum shift	RMS relative momentum spread
0.00	0.00E+00	5.10E-05
91.000	3.32E-05	6.27E-05
180.000	7.85E-05	7.78E-05
280.000	1.27E-04	9.75E-05

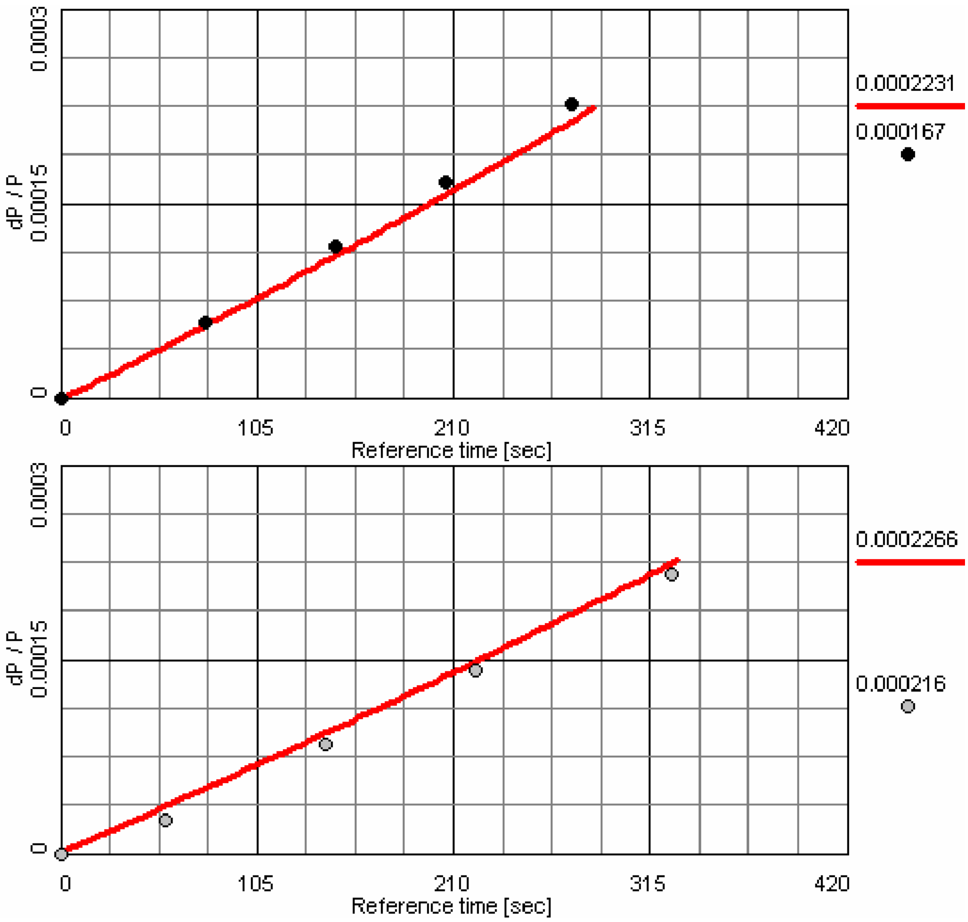
361.000	1.72E-04	1.14E-04

Electron current 50 mA

Time, sec	Relative momentum shift	RMS relative momentum spread
0.00	0.00E+00	6.45E-05
85.000	8.84E-06	7.15E-05
200.000	2.89E-05	8.31E-05
296.000	4.84E-05	9.14E-05
413.000	7.23E-05	1.00E-04

The simulations were performed at 1000 model particles with 5 second integration step. The electron beam radius as function of beam current was taken from the Table 2. Initial momentum deviation was assumed to be zero. The electron longitudinal velocity spread was chosen to be equal 20000 m/s. In the simulations the electron transverse velocity spread was used as a fitting parameter in order reproduce measured evolution of the momentum deviation at electron current of 100, 200, 300 mA. The friction force was calculated in accordance with Binney model. Best coincidence corresponds to the transverse velocity spread of about 360000 m/s (Fig. 4). At this value the angular spread is between 120 and 130 μrad.

Longitudinal diffusion was set to zero, transverse diffusion corresponded to about $\frac{d\varepsilon}{dt} \approx 1.1 \frac{\pi \cdot mm \cdot mrad}{h}$ 95% normalized. During 300 seconds of cooling the emittance increased from 0.0062 π·mm·mrad to 0.0075 π·mm·mrad.



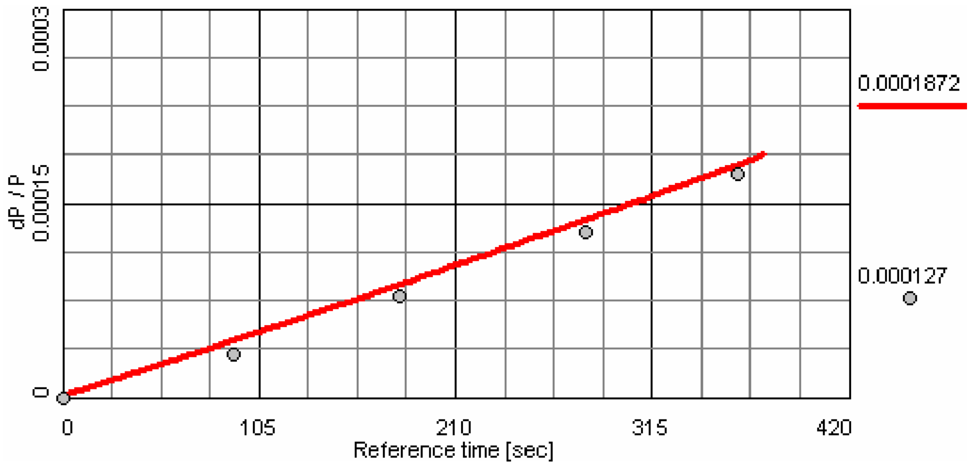


Fig. 4. Momentum deviation evolution at electron current (from up to down) 300, 200 and 100 mA. The transverse velocity spread in all the plots is equal to 360000 m/s. The circles are experimental points, the lines – simulations.

Possible influence of the velocity gradient on the dynamics of the process was investigated at electron current 300 mA assuming that at the edge of the beam angular spread is 200 µrad. The velocity gradient in this case is equal to about $8.5 \cdot 10^{7}$ s^{-1}. From the Fig. 5 one can see that the velocity gradient influence is less than the accuracy of the simulations. Therefore for profile evolution simulation the velocity gradient was put zero.

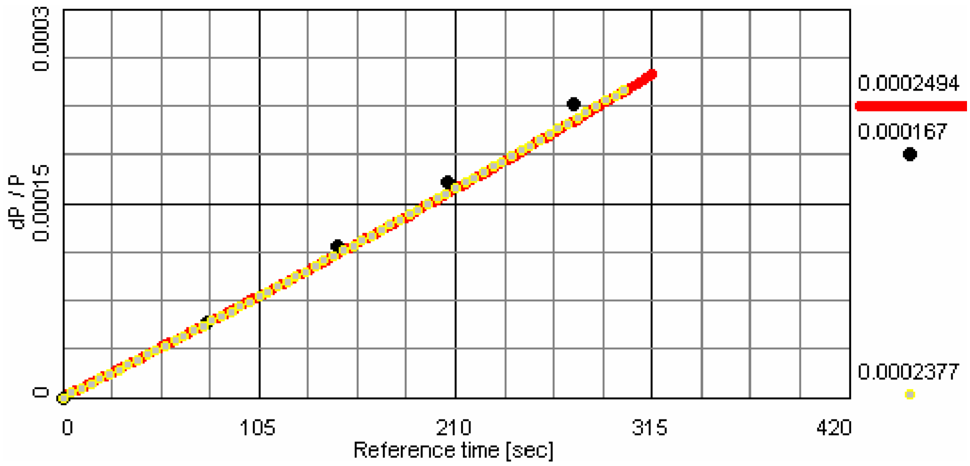


Fig. 5. Black circles are experimental points, yellow circles – zero velocity gradient, red line – velocity gradient of $8.5 \cdot 10^{7}$ s^{-1}.

5. RMS profile width

There are two general sources of the rms profile width increase: derivative of the friction force in given point of the velocity deviation and diffusion in the antiproton beam. Diffusion in antiproton beam does not depend on the electron current. Therefore the difference in rms profile width evolution at different currents can be used for estimation of the friction force derivative.

For instance in the Fig. 6 the momentum spread evolution at 300 and 200 mA of electron current is shown. The difference between two curves corresponds to momentum spread growth of about $5 \cdot 10^{-8}$ mrad/sec. In simulations the increase of the momentum spread without diffusion in the antiproton beam (Fig. 7) is about two times less than this value, which corresponds to the friction slope shown in the Fig. 3. Electron velocity gradient of $8.5 \cdot 10^{7}$ s^{-1} does not influence on the spread growth rate.

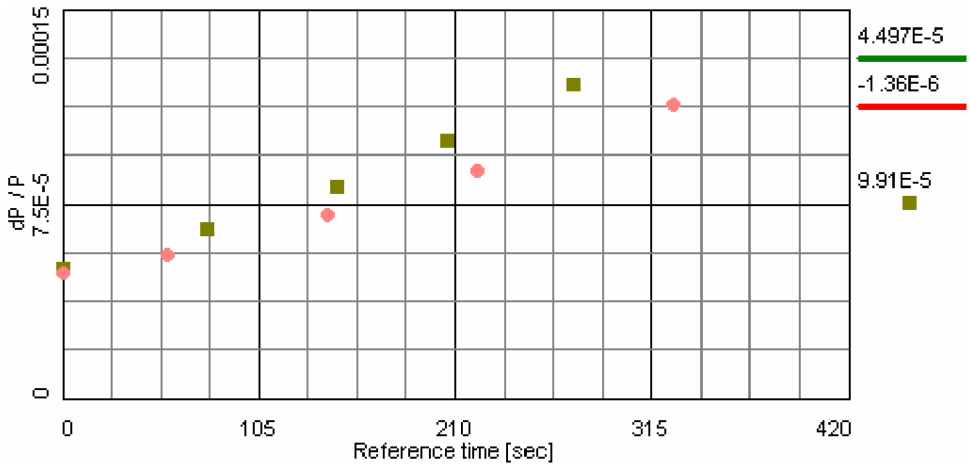


Fig. 6. Experimental points of rms momentum spread at 300 mA (squares) and 200 mA (circles) electron current.

The simulations were performed at 2000 model particle and 1 second integration step.

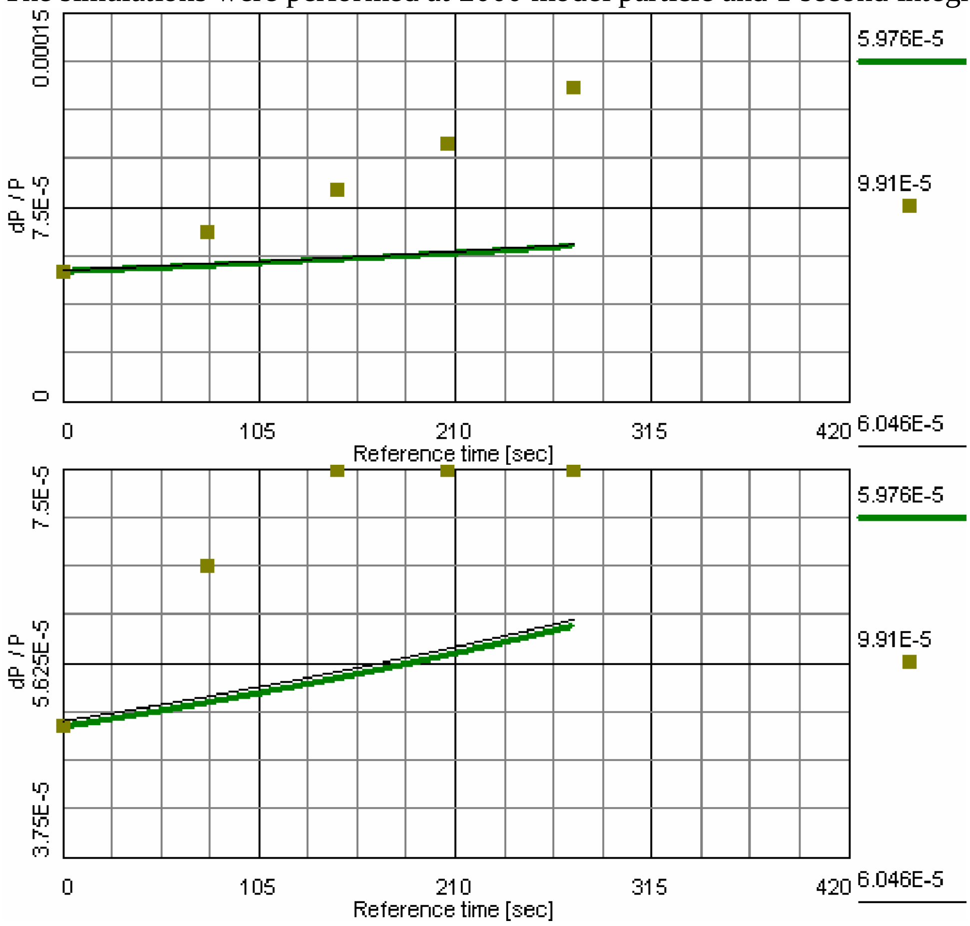


Fig. 7. Evolution of the momentum spread due to frequency derivative over momentum deviation (gray line) and over momentum deviation plus over radial coordinate (due to gradient of electron velocity corresponding to 120 μrad in centre of the beam and 200 μrad at the adge) – black thin line. Bottom plot is in small scale on momentum axis.

In this situation using power of longitudinal diffusion as a fitting parameter one can not fit by the same value the dependencies at different electron currents. For instance at the top plot in Fig. 8 the experimental points are fitted by some value of longitudinal diffusion power in antiproton beam. The same diffusion power leads to sufficient overestimation of the momentum spread growth at 100 mA of electron current (bottom plot in the Fig. 8).

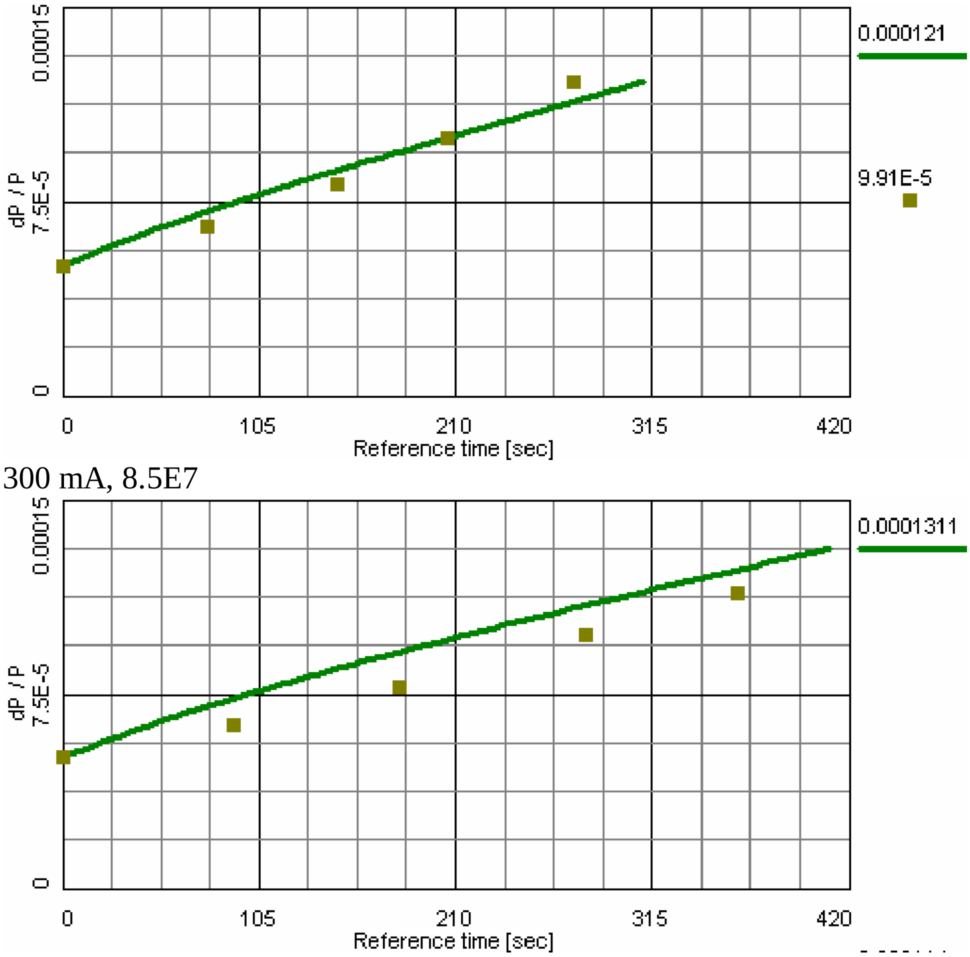


Fig. 8. The momentum spread time dependencies at the same value of longitudinal diffusion power. Electron current is 300 mA at the top plot and 100 mA at the bottom. Lines present the simulation results, squares are measured points.

Short conclusions from this consideration can be the following:

- derivative of the friction force over velocity is very small to explain measured evolution of the profile width, therefore the process is determined by friction force derivative over radial co-ordinate,
- in the frame of the electron beam model as a uniform cylinder at some effective radius and linear gradient of transverse velocity spread over radius the friction force derivative over radius is negligible at realistic values of the electron angular spread at the axis and at the edge,
- to reproduce the experimental results the electron beam model has to take into account variation of the electron density and angular spread over radius on the basis of simulations or measurements of the electron beam parameters.

Any case even in the frame of existing in Betacool model of electron beam one can try to estimate gradient of the friction force along radius required for explanation of the experiments. For this goal one can use electron velocity spread in the center of the beam and the velocity spread gradient as a fitting parameters to reproduce required growth of the profile width due to the friction derivative. The longitudinal diffusion power in antiproton beam is a third fitting parameter in this case. To be in the field of realistic electron beam parameters the minimum electron angular spread in the centre of the beam we need to fix at value of 90 μrad, that corresponds to about 250000 m/s of velocity spread. For instance, for this value of central velocity spread the experimental results were fitted for three electron currents by the same values of the velocity gradient and longitudinal diffusion power in antiproton beam (Fig. 9).

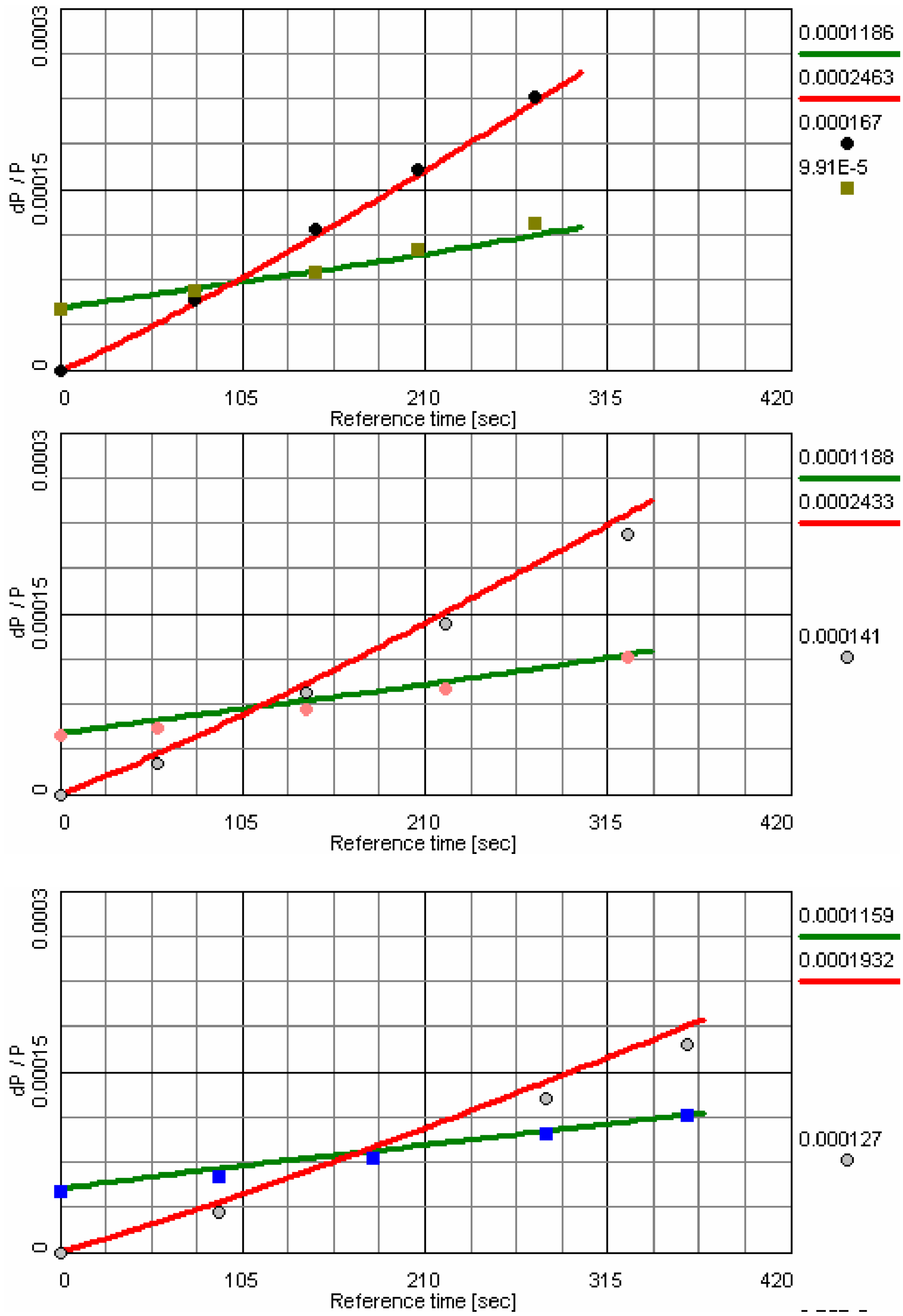


Fig. 9. Evolution of momentum deviation from its initial position and rms momentum spread in antiproton beam after the voltage jump. Transverse electron velocity spread is 250000 m/s, the velocity gradient is $6.5 \cdot 10^{8}$ s^{-1}, longitudinal diffusion power in antiproton beam is $1.9 \cdot 10^{-5}$ $mrad^2/s$. Electron current from top to bottom is 300 mA, 200 mA and 100 mA. Solid red lines are the simulated momentum deviation, solid gray lines are the simulated rms momentum spread, points are measured values.

The velocity gradient of $6.5 \cdot 10^{8}$ s^{-1} used in simulations correspond (for 300 mA electron beam) to the electron angular spread at the edge of the beam of about 800 μrad. However in these simulations the gradient of the velocity spread is used to fit derivative of the friction force over radius. Extremely large value of the gradient indicates that the electron density is not uniform even at radius of antiproton beam (rms is about 0.4 mm).

Reasonable coincidence of the simulations with the experimental points for three values of the electron current at the same fitting parameters indicates that the friction derivative over the radius depends on electron current slightly.

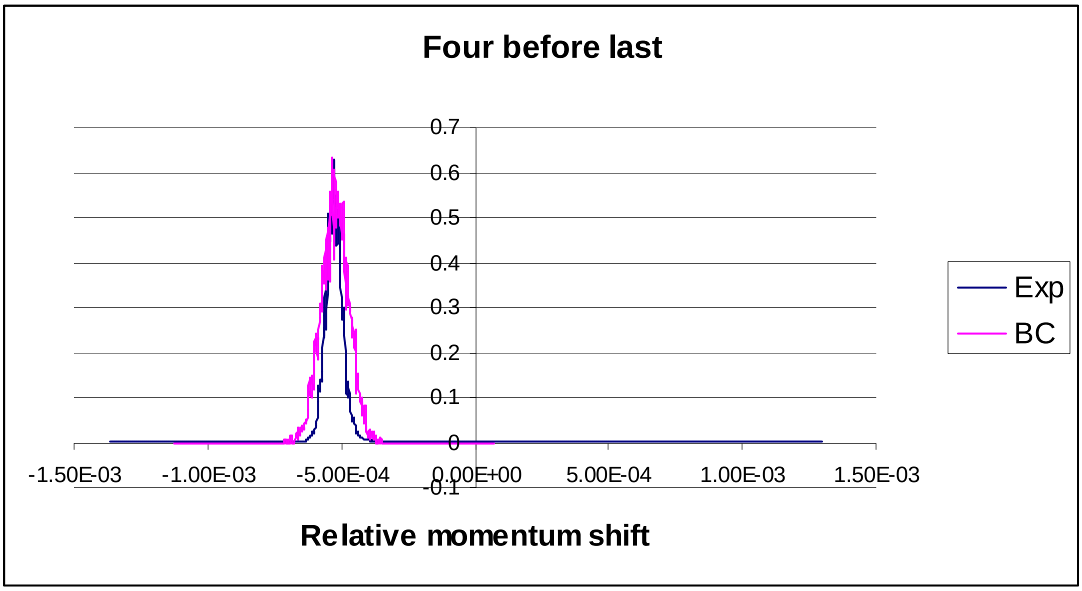
It should be noted that the power of longitudinal diffusion in the antiproton beam used for fitting leads to equilibrium momentum spread by about 2 times less then in experiments.

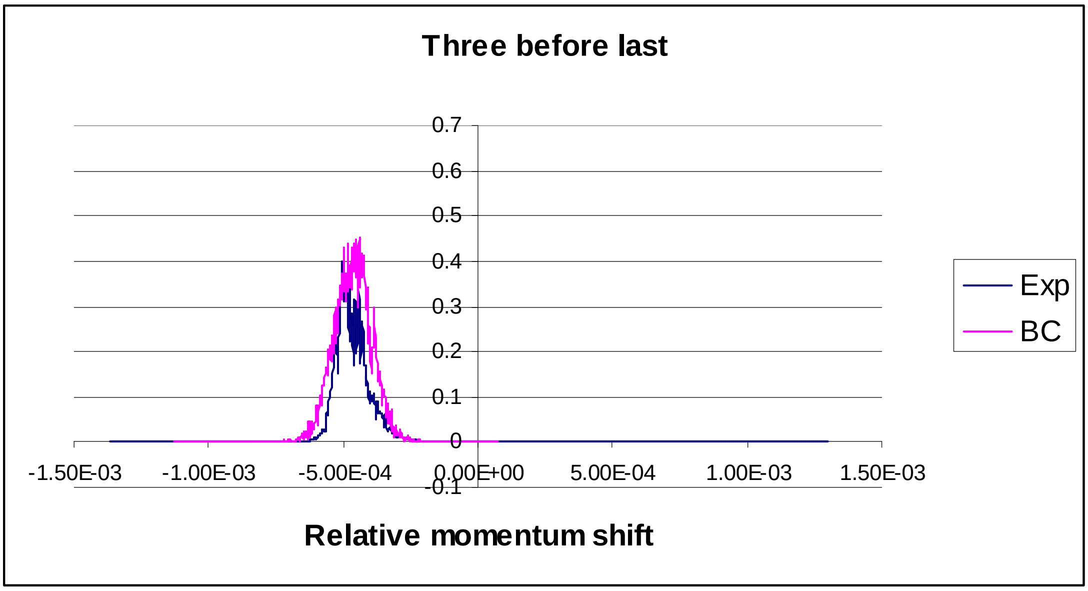
6. Profile shape

To reproduce evolution of profile shape 5 traces at 300 mA were calculated with 6000 of model particles at the integration step of 5 seconds. The experimental traces were recalculated into linear scale; the simulated traces were scaled to have the same amplitude of the function in the first trace. The time from the voltage jump is closed for measured and simulated traces Table 6.

Measured traces, time, sec	Calculated traces, time, sec
0.00	0
78.000	80
147.000	150
206.000	210
273.000	270

Experimental (Exp) and simulated (BC) traces are shown in the Fig. 10.




Three before last
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0
-0.1
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Relative momentum shift
Exp
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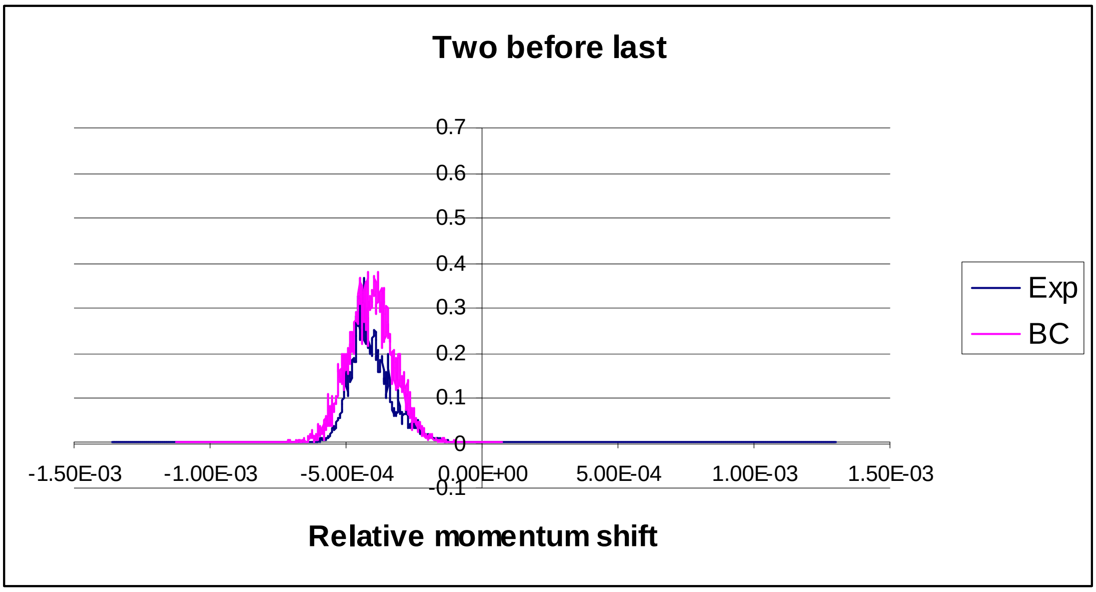
Two before last
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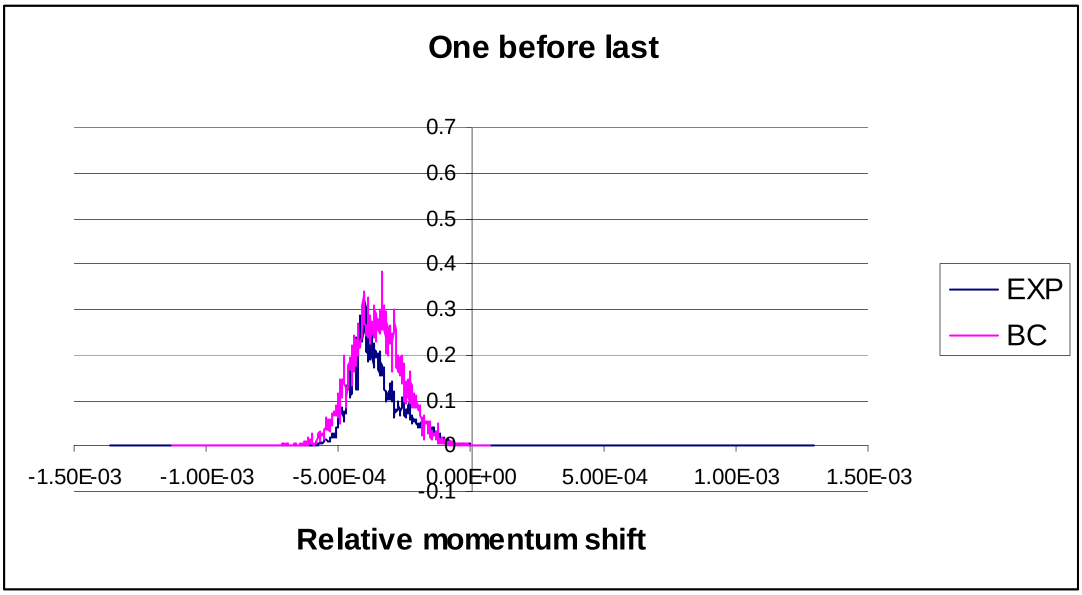
Relative momentum shift
Exp
BC


One before last
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Relative momentum shift
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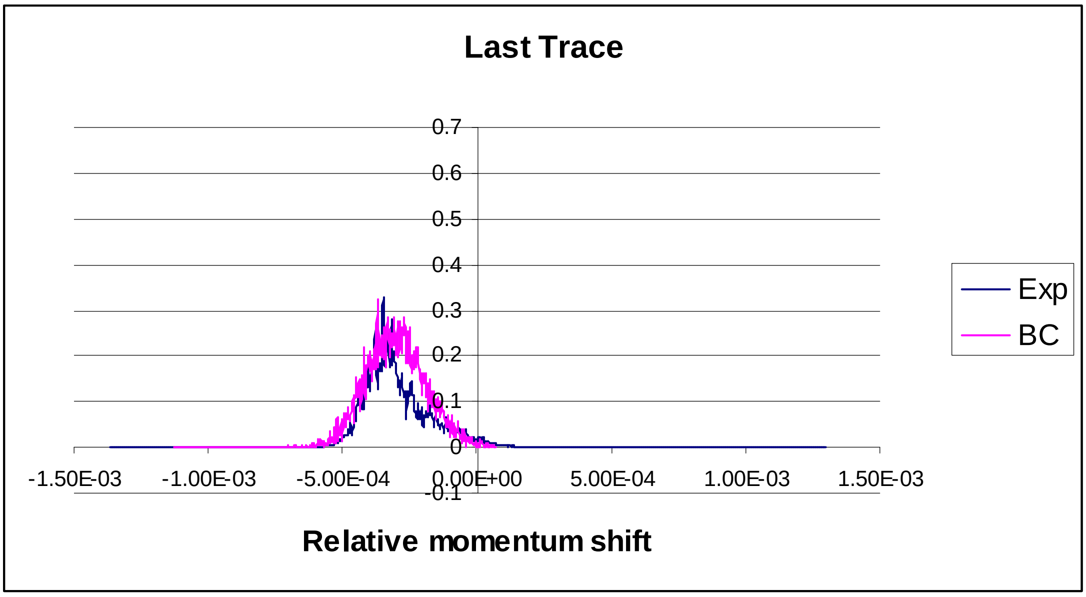


Fig. 10. 300 mA electron current, the fitting parameters are the same as in Fig. 9.

First of all the width of all simulated profiles is wider than experimental. Initial profile in simulations was generated in accordance with measured rms profile width. The reason of the disagreement is obvious from experimental profiles in logarithmic scale (Fig. 11). Real profiles have very long tails, which does not reflect a physics of the process, but give an impact in calculation of rms width.

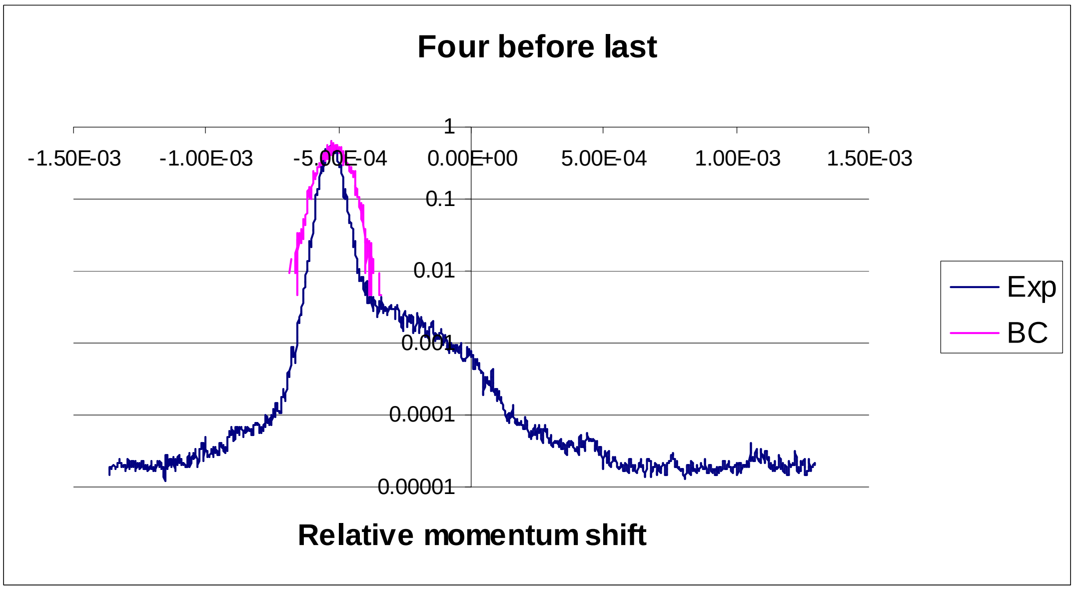


Fig. 11. Log scale.

From Fig. 10 one can see that simulations reproduce reasonably the left slope of the profiles, however the inclination of the right slope in experimental profiles is larger than in simulations. It means that the real derivative of the friction force over radius is larger than used in simulations.

7. Fit of profile width

To provide more realistic comparison of profile shape evolution with simulations, the width of the central part of the experimental distribution (Fig. 11) was estimated from Full Width on Half Maximum of the profile. From this fit the initial relative momentum spread can be estimated as

$3{\cdot}10^{-5}$ instead of $5{\cdot}10^{-5}$ from rms width. At low momentum spread the friction force variation along the velocity spread is about 1.5 times less. Therefore at the same power of longitudinal diffusion to reproduce qualitatively the evolution of momentum spread in time the velocity gradient in electron beam was increased in simulations to $8{\cdot}10^{8}$ s^{-1} (Fig. 12).

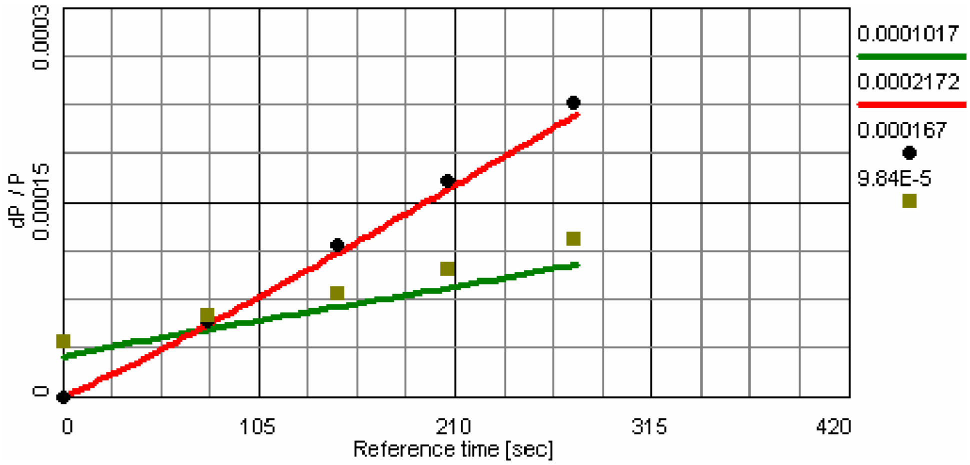
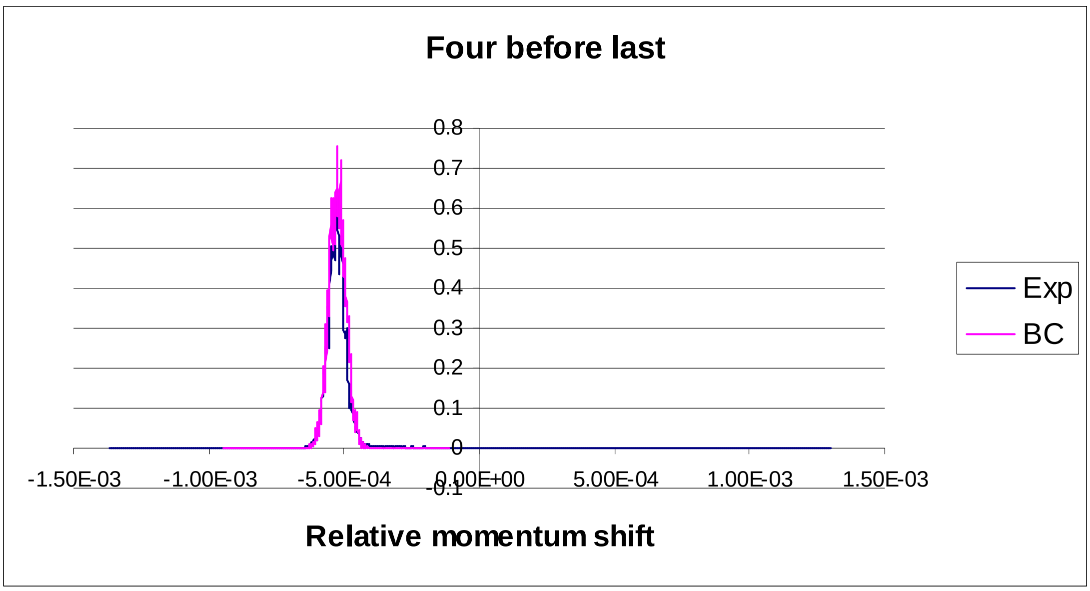
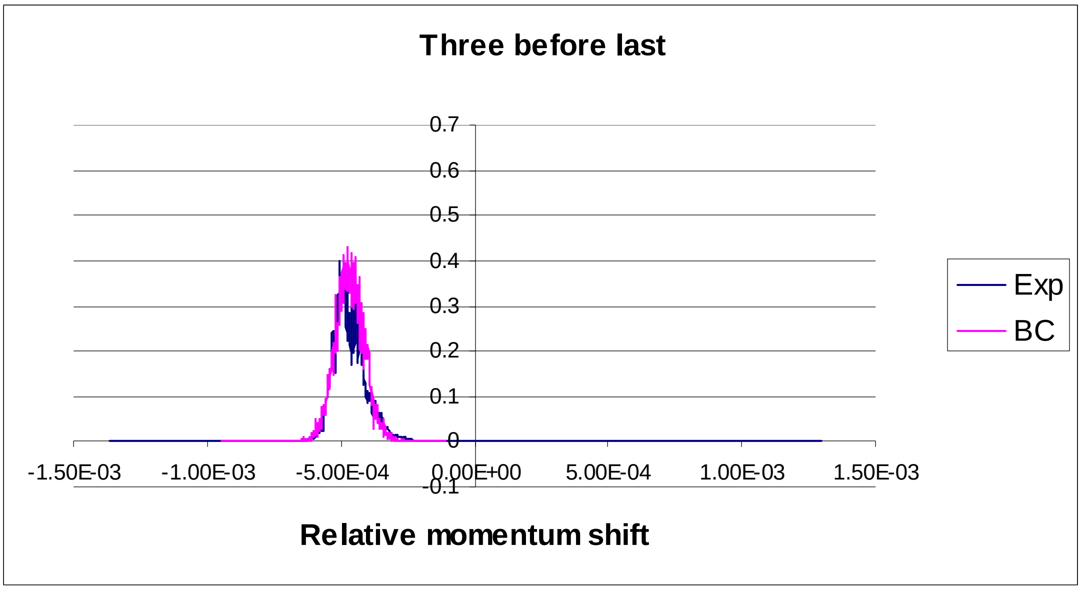


Fig. 12. Evolution of momentum deviation from its initial position and rms momentum spread in antiproton beam after the voltage jump (300 mA of electron current). Transverse electron velocity spread is 250000 m/s, the velocity gradient is $8{\cdot}10^{8}$ s^{-1}, longitudinal diffusion power in antiproton beam is $1.9{\cdot}10^{-5}$ $mrad^2/s$. Solid red line is the simulated momentum deviation, solid gray lines is the simulated rms momentum spread, points are measured values, the measured momentum spread corresponds to rms profile width.

Such a fit permits to reproduce the profile shape evolution with sufficiently better accuracy than in Fig. 10 (Fig. 13). However even in this case long tail in the right slope of the distribution (it is clearly seen from the last trace) can not be simulated correctly.




Three before last
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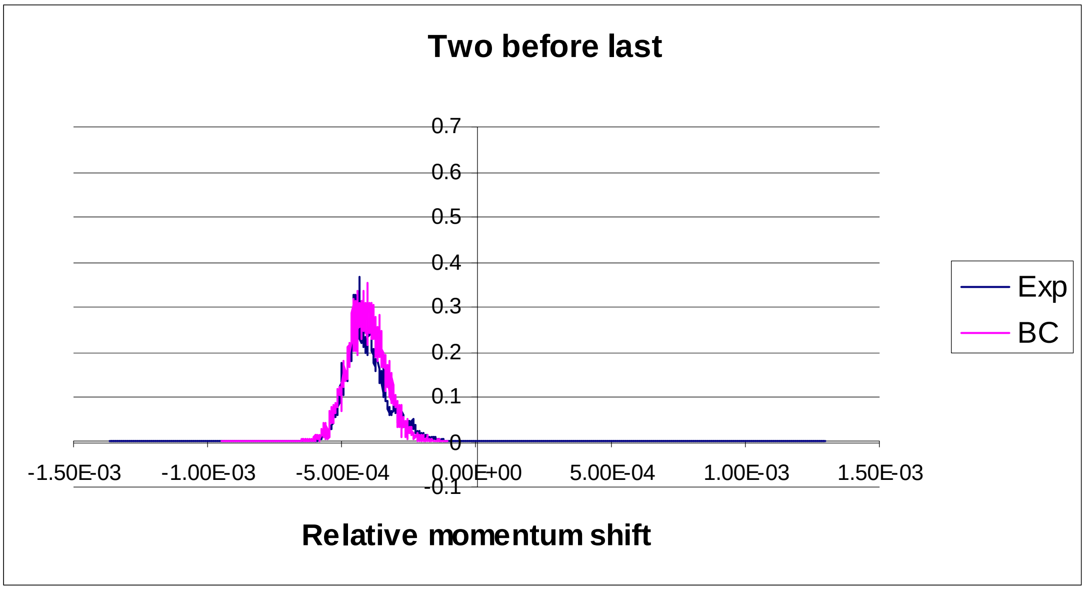
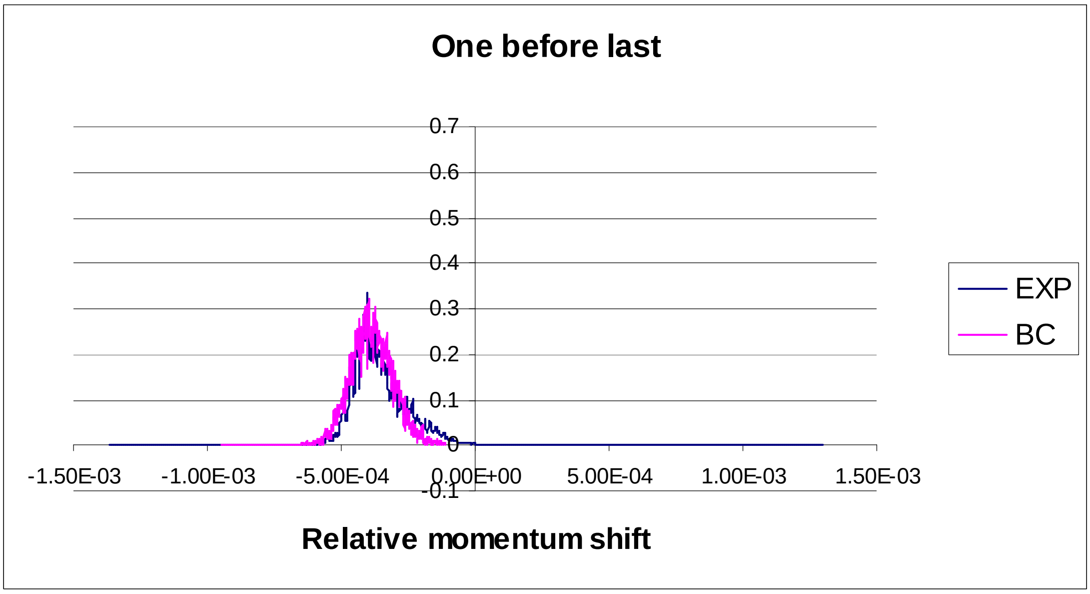
-1.00E-03
-5.00E-04
0.00E+00
5.00E-04
1.00E-03
1.50E-03
Relative momentum shift
Exp
BC


Two before last
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-1.50E-03
-1.00E-03
-5.00E-04
0.00E+00
5.00E-04
1.00E-03
1.50E-03
Relative momentum shift
Exp
BC


One before last
0.7
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0.00E+00
5.00E-04
1.00E-03
1.50E-03
Relative momentum shift
EXP
BC

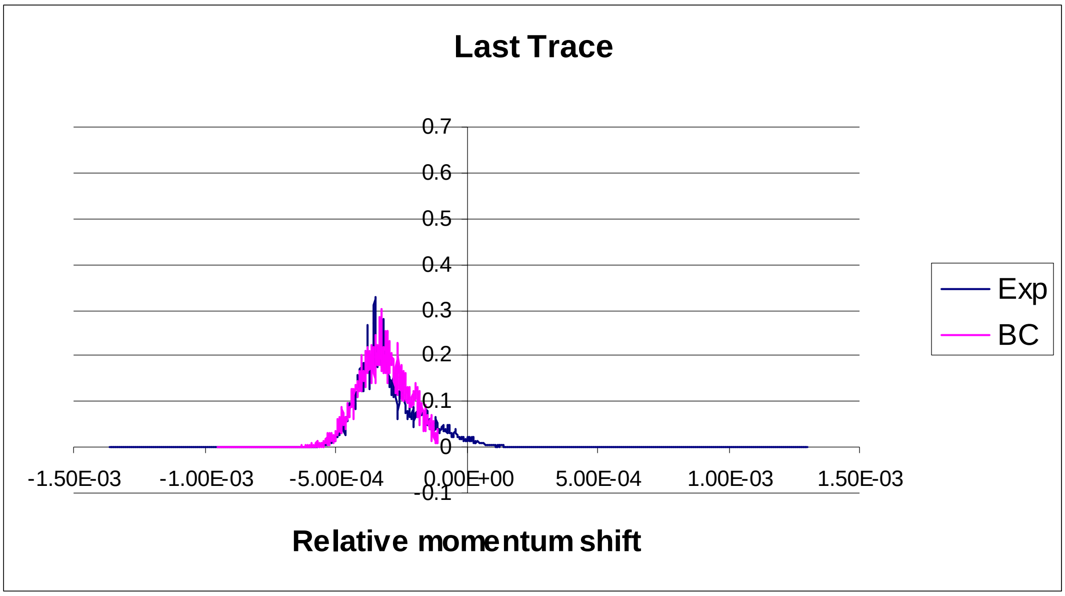

Fig. 13. 300 mA electron current, the fitting parameters are the same as in Fig. 12.

8. Longitudinal diffusion and equilibrium momentum spread

The power of longitudinal diffusion in the antiproton beam used in simulation ($1.9{\cdot}10^{-5}$ mrad^2/s) can not explain the value of equilibrium momentum spread observed in experiment. At equal velocities of antiprotons and electrons the simulations show relatively fast decrease of the momentum spread to the equilibrium value which is equal to about $1.75{\cdot}10^{-5}$ (Fig. 14).

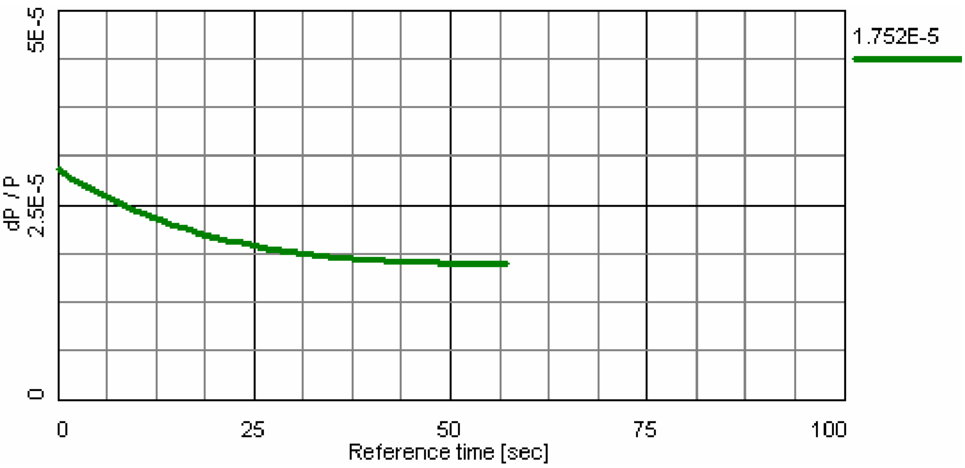

Fig. 14. Evolution of relative momentum spread at equal energies of antiprotons and electrons.

This disagreement between the simulations and experiment can be explained by peculiarity of the model of the cooling process using in simulations. In the current version of the program diffusion in the electron beam is neglected. However the temperature of longitudinal degree of freedom of antiproton beam is equal to

$$T_{\parallel} = m_p c^2 \beta^2 \sigma_p^2 ,$$

that corresponds to about 0.84 eV at $\sigma_p = 3{\cdot}10^{-5}$ and 0.28 eV at $\sigma_p = 1.75{\cdot}10^{-5}$. The temperature of transverse degree of freedom of the electrons in the center of the beam is equal 0.35 eV (at the velocity spread of 250000 m/s). Thus the diffusion in the electron beam can play a sufficient role in the cooling process and influences on equilibrium antiproton beam parameters. After jump of the electron energy this diffusion becomes to be zero because of large velocity deviation of antiprotons.

Sufficient influence of the diffusion in the electron beam is specific peculiarity of non magnetized cooling. In magnetized collisions the transverse motion of electron is suppressed and equilibrium ion temperature corresponds to temperature of longitudinal degree of freedom of the electrons. Electron longitudinal temperature is usually sufficiently less than transverse one (for Recycler cooler the longitudinal temperature is about 2.3 meV) and the diffusion can be neglected in magnetized case.

Conclusion

Linear dependence of the friction force on electron density in the centre of the beam at currents of 100, 200 and 300 mA indicates that electron beam quality slightly depends (or dependent during measurements) on current in this range.

At +5 kV step large variation of the value of the longitudinal electron velocity spread does not influence on the friction force practically.

Transverse diffusion in antiproton beam at realistic power leads to measured equilibrium transverse emittances at all electron currents.

The friction force values coincide with theoretical prediction at reasonable transverse electron velocity spread in the centre of the beam.

The model of electron beam with uniform density and linear increase of transverse velocity spread with radius can not explain evolution of profile width. The derivative of the friction force over radius in experiment is three – four times larger than predicted by this model.

Artificial increase of the transverse velocity gradient in electron beam permits to fit evolution of the profile width together with the friction force value, but it does not reproduce exactly the evolution of profile shape.

Recommendations

To exclude longitudinal diffusion from the fitting parameters it is necessary to measure it in equilibrium by switch off the electron beam for the same time as for measurements and record of profiles at the same periodicity.

In simulation of equilibrium antiproton beam parameters the diffusion in the electron beam has to be taken into account.

For generation of initial distribution in simulations it is better to use FWHM of the measured traces instead rms.

Simplest modification of the electron beam model in simulations is to use parabolic profile of density. At small emittance value it will reflect the first order effect.