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This note summarizes BETACOOL simulations with recently implemented parabolic distribution of electrons. It also shows differences between cooling of rms emittance of the whole distribution with non-Gausssian tails and emittance based on Gaussian fit.

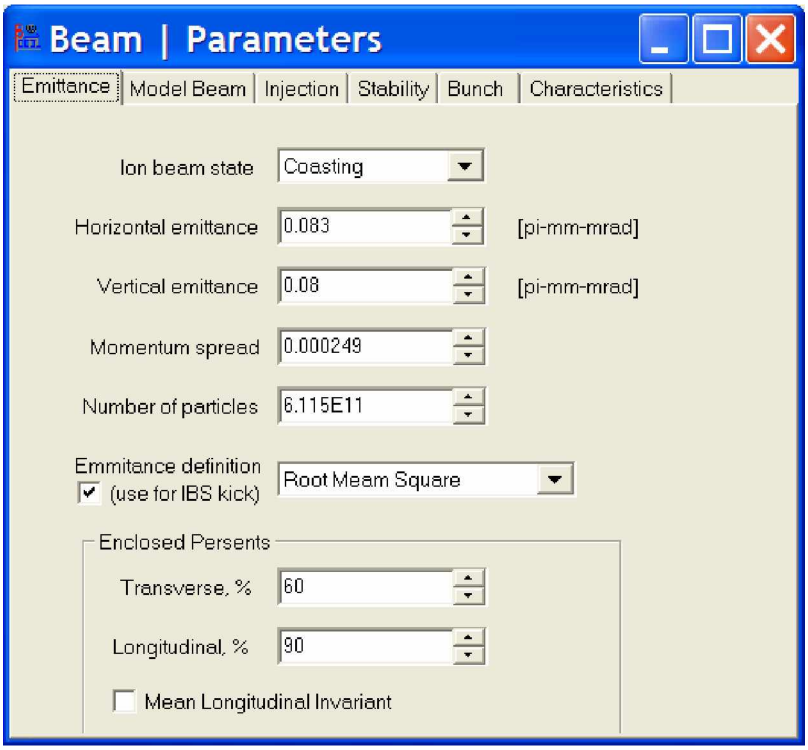
I. Low- intensity simulations –December 20, 2006 data:

1. Using assumption of uniform electron density

This section is repeated from previous Note for comparison.

Diffusion coefficients are chosen to fit the data during initial diffusion measurement. Velocity gradient is chosen so that one has agreement between measurements and simulations for the longitudinal cooling as well.

This in turn results is much less transverse cooling than measured.



Ion beam state: Coasting

Horizontal emittance: 0.083 [pi-mm-mrad]

Vertical emittance: 0.08 [pi-mm-mrad]

Momentum spread: 0.000249

Number of particles: 6.115E11

Emmitance definition: Root Meam Square

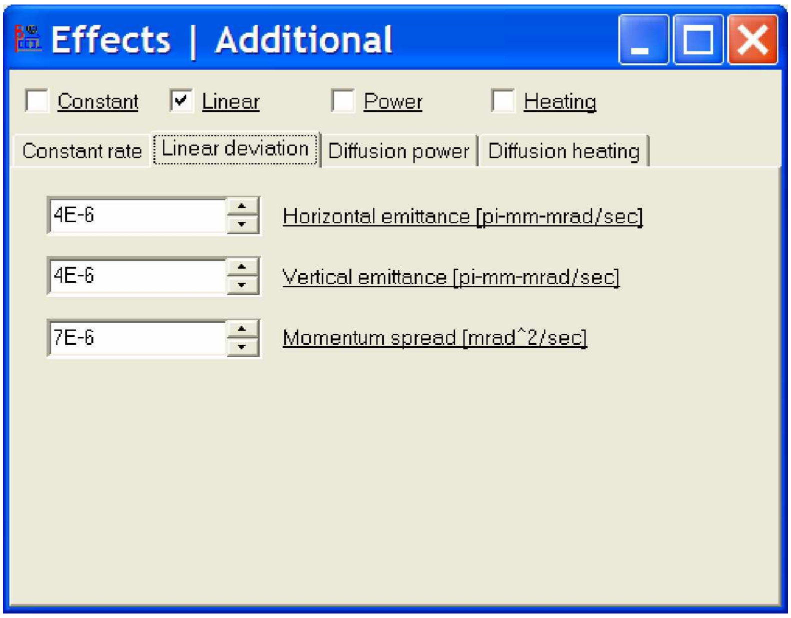
☑ (use for IBS kick)

Enclosed Persents

Transverse, %: 60

Longitudinal, %: 90

☐ Mean Longitudinal Invariant

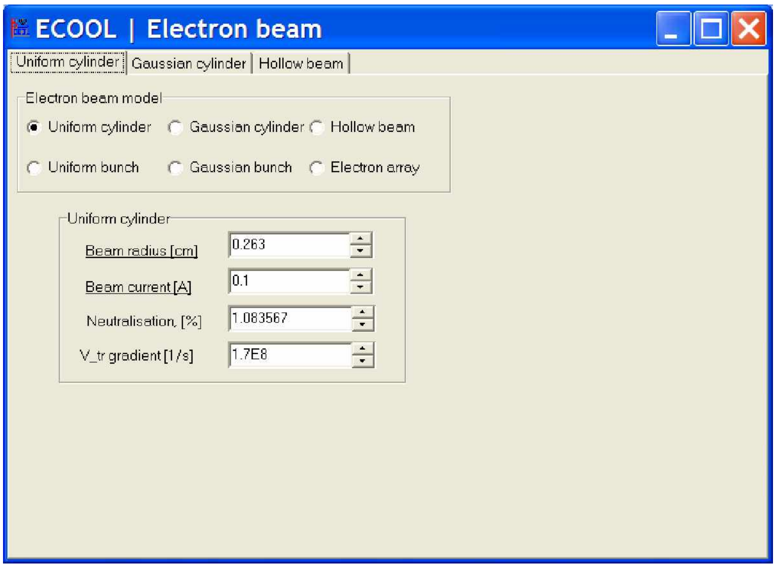


☐ Constant ☑ Linear ☐ Power ☐ Heating

4E-6 Horizontal emittance [pi-mm-mrad/sec]

4E-6 Vertical emittance [pi-mm-mrad/sec]

7E-6 Momentum spread [mrad^2/sec]



Electron beam model

● Uniform cylinder ○ Gaussian cylinder ○ Hollow beam

○ Uniform bunch ○ Gaussian bunch ○ Electron array

Uniform cylinder

Beam radius [cm] 0.263

Beam current [A] 0.1

Neutralisation, [%] 1.083567

V_tr gradient [1/s] 1.7E8

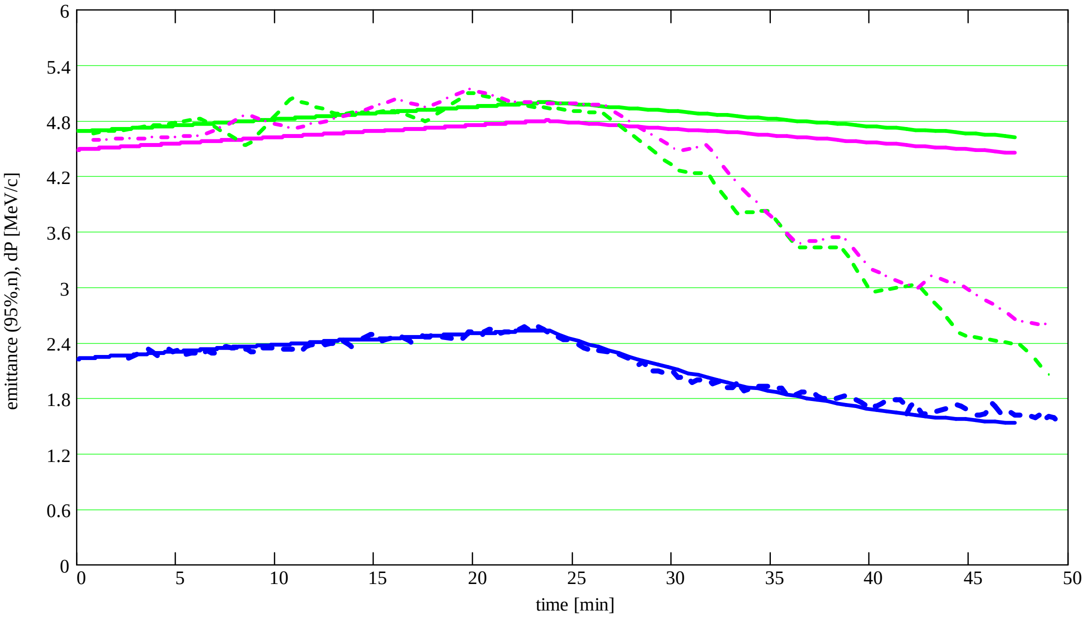


Fig.1. Measurements (12.20.06) and simulation (using Model Beam approach) for low intensity beam (N=50e10, 9 us) with dampers ON. Solid lines correspond to simulations. Dashed lines correspond to measurements. Green- vertical 95% normalized emittance [mm mrad]. Pink – horizontal 95% normalized emittance [mm mrad]. Blue – rms momentum deviation [MeV/c].

The diffusion coefficients were fitted to agree with the data. Then transverse velocity gradient was introduced to fit measured longitudinal cooling. With present (simplified) model of electron density distribution this results in much less transverse cooling than measured with FW. This observation is true for most of diffusion/cooling data December 2006 – March 2007.

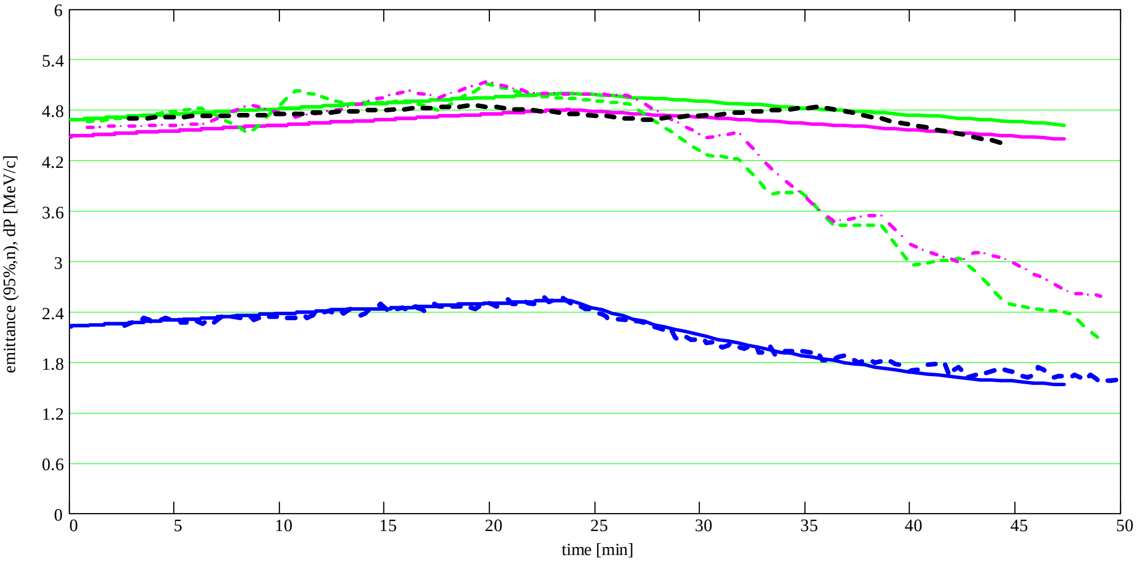


Fig. 2. Black line is measured emittance by Schottky, normalized by factor 1.7 to have the same initial emittances with FW and Schottky.

2. Using parabolic electron density

2.1 Extent of electron beam 2.6 cm.

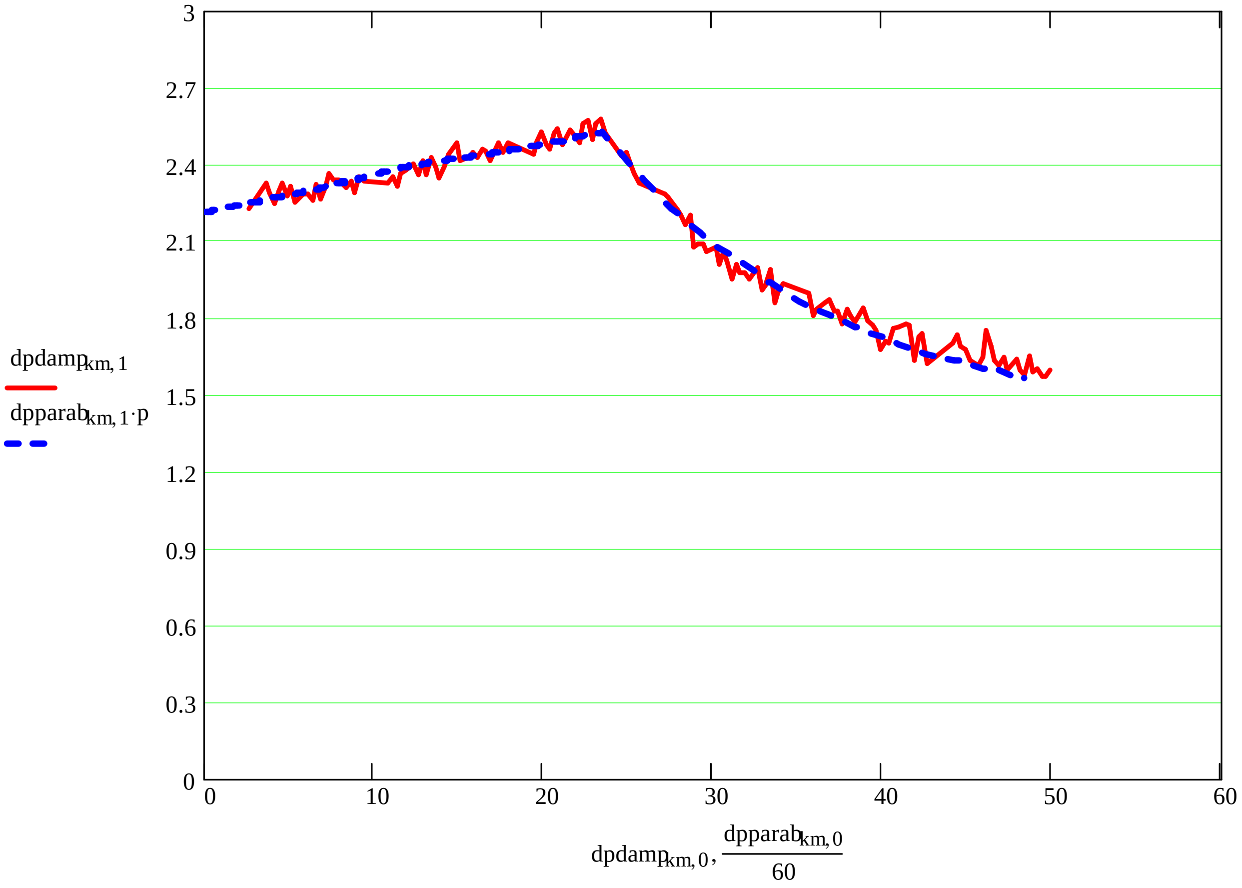


Fig. 3. Longitudinal diffusion and cooling – measurements (red) vs simulations (blue dash line). Simulations: parabolic electron distribution going to zero at 2.63 mm; velocity gradient 1.4e8 [1/s].

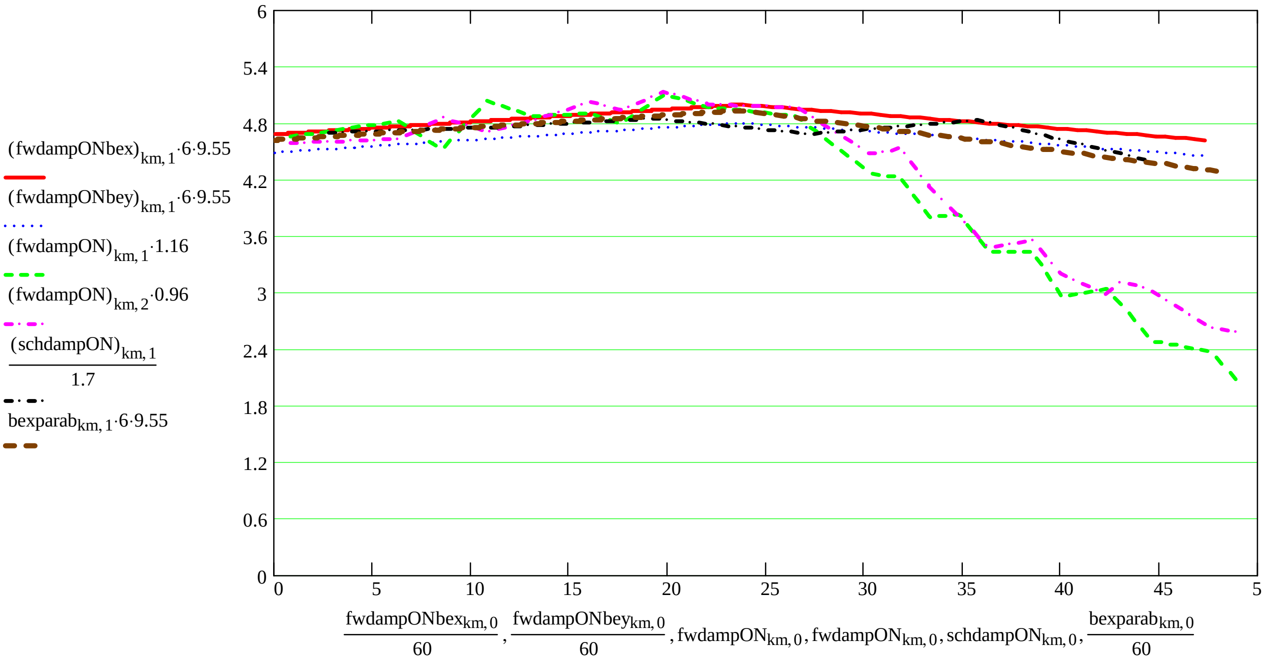


Fig. 4. Transverse cooling. With the parabolic electron density distribution (going to zero at 2.63mm) and velocity gradient (1.4e8 [1/s]) chosen to fit longitudinal cooling, transverse cooling observed (brown dash line) is still very weak. The slope of transverse cooling (rate) is slightly stronger than for the case of uniform distribution (red solid line).

2.2 Extent of electron beam 3.5cm.

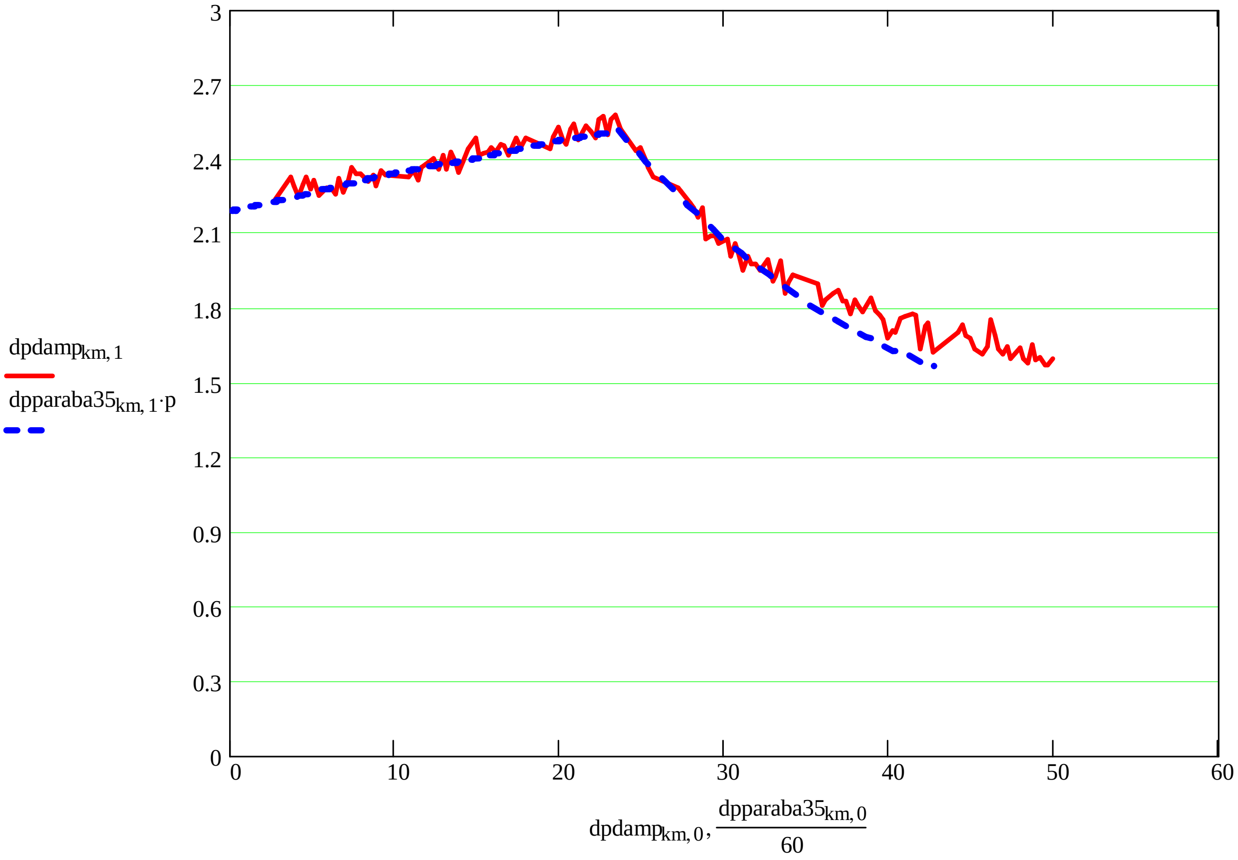


Fig. 5. Longitudinal diffusion and cooling – measurements (red) vs simulations (blue dash line). Simulations: parabolic electron distribution going to zero at 3.5 mm; velocity gradient 1.5e8 [1/s].

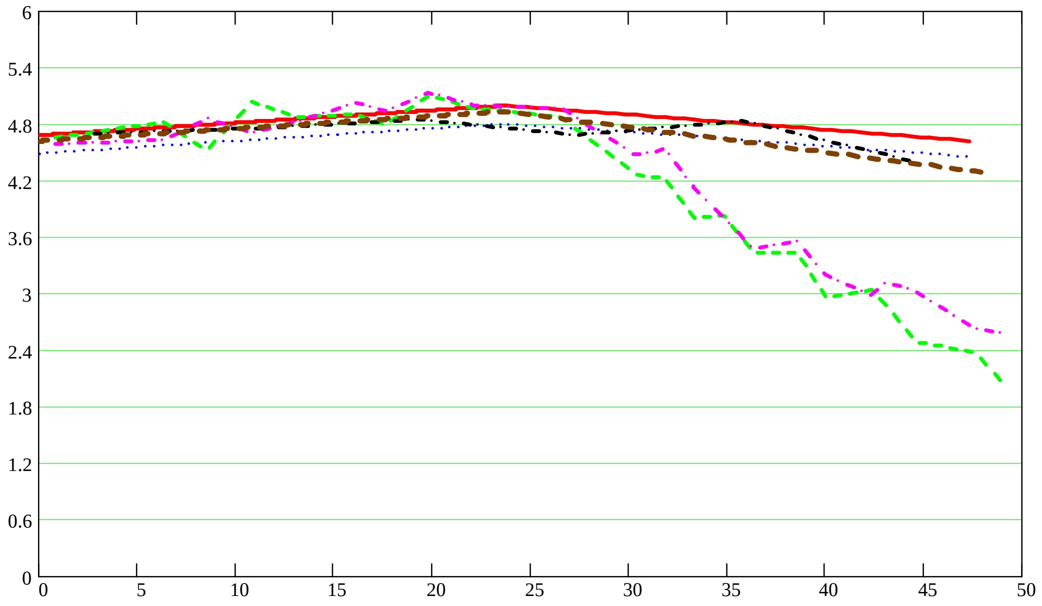


Fig. 6. Transverse cooling. With the parabolic electron density distribution (going to zero at 3.5 mm) and velocity gradient (1.5e8 [1/s]) chosen to fit longitudinal cooling, transverse cooling observed (brown dash line) is still very weak. The slope of transverse cooling (based on rms of the whole distribution) is slightly stronger than for the case of uniform distribution (red solid line).

For comparison with emittance of fitted Gaussian rather than true rms see Section III.

II. High- intensity simulation –RuPAC06 data:

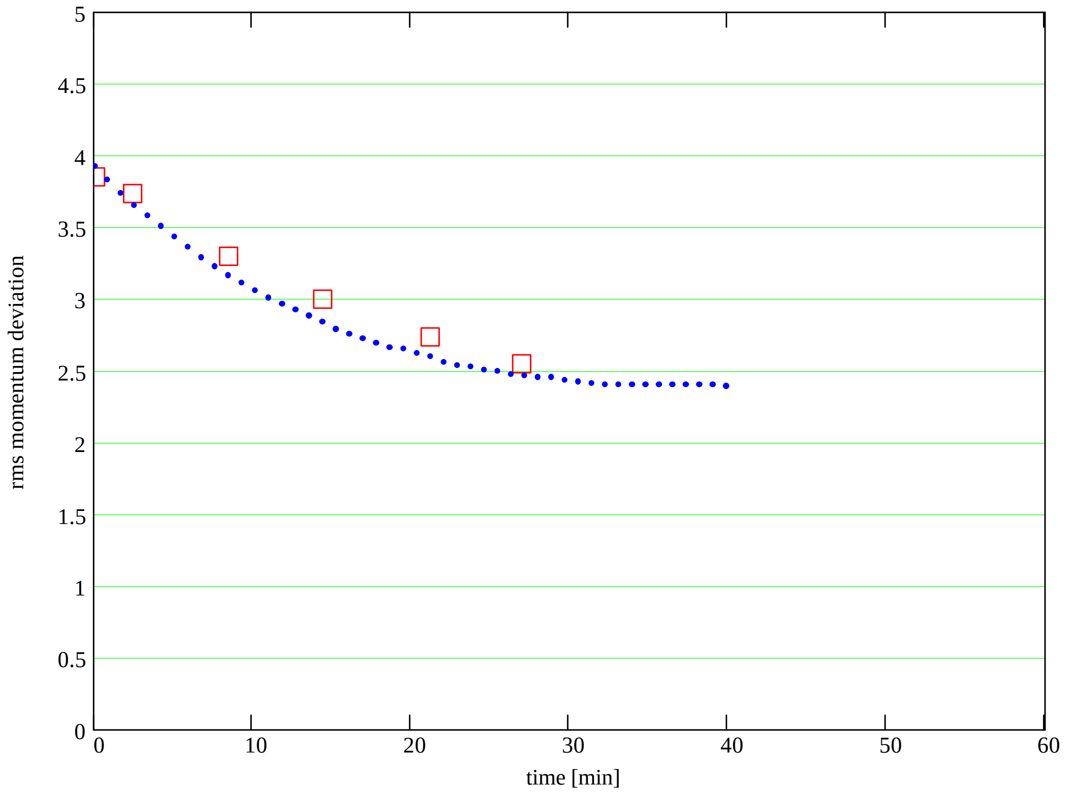


Fig. 7. Longitudinal rms momentum deviation: simulation (blue dash line) vs measurement.

As in low intensity case, we use parabolic electron distribution which goes to zero at radius of 3.5mm. Velocity gradient is chosen to fit measured longitudinal cooling.

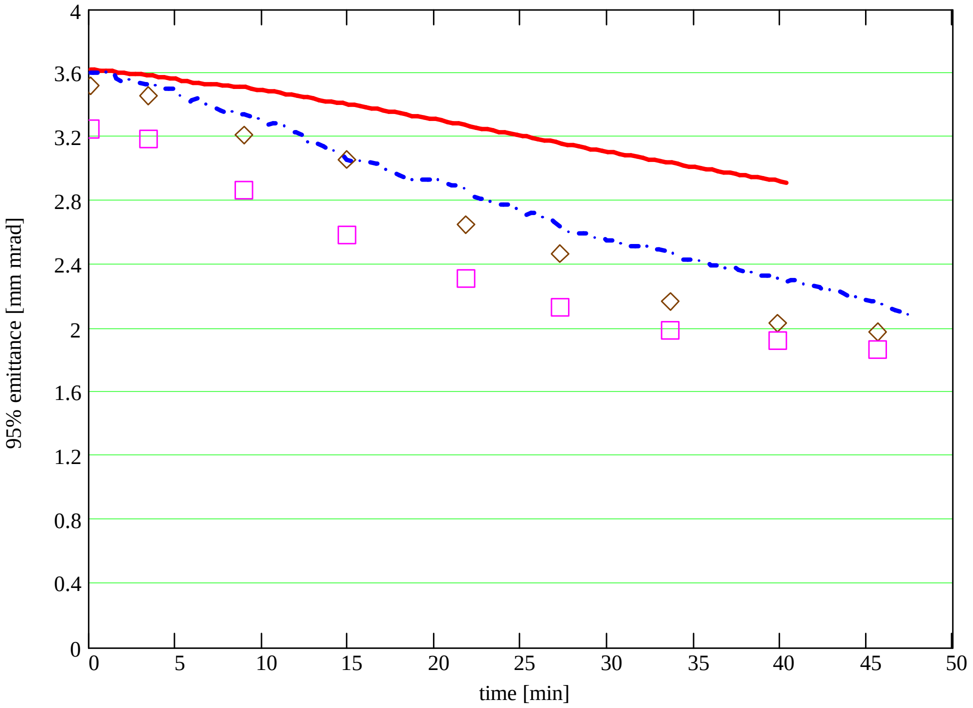


Fig.8. Transverse emittance. BETACOOL simulations: red (solid line) – true rms calculated from simulated in BETACOOL distribution including non-Gaussian tails (see Fig.9). Blue (dot-dash line) – calculated emittance based on Gaussian fit to the core of the distribution.

Clearly, when non-Gaussian tails are taken into account one gets larger values of rms emittance. While Gaussian fit to the core of the distribution results in smaller emittance values and gets closer to FW measurements which is based on similar procedure of fitting Gaussian to the distribution.

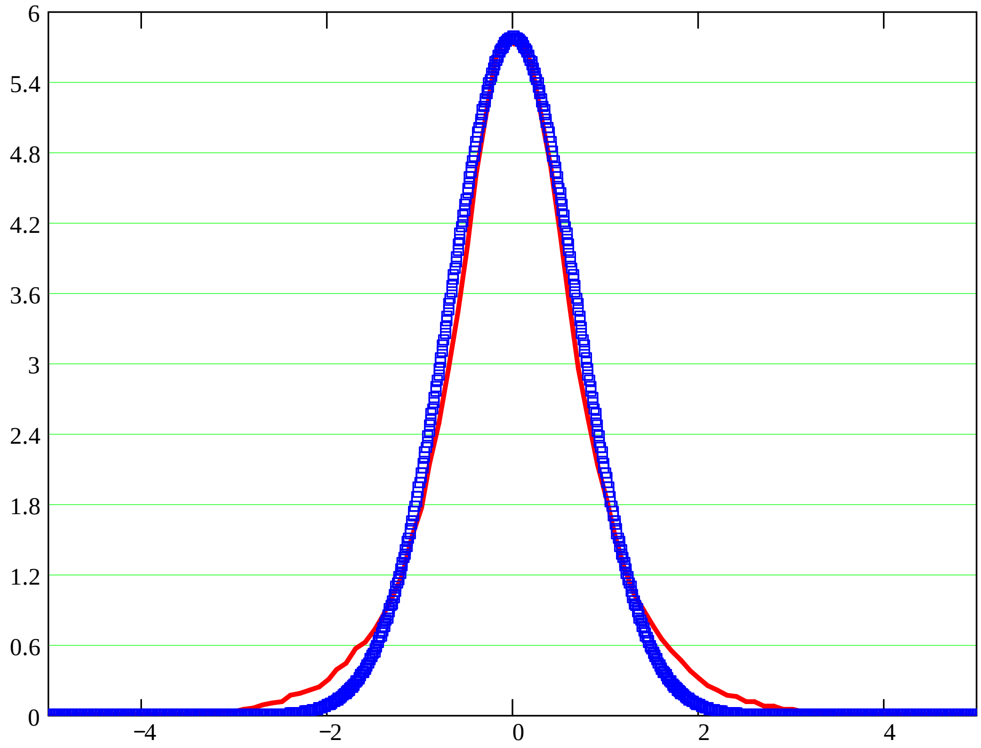


Fig.9. Red – simulated profile in BETACOOL after 40 minutes of cooling. Blue - fitted Gaussian results in rms sigma which is smaller than the one of the whole distribution, so that emittance calculated based on fitted Gaussian is also smaller.

Simulated rms emittance includes non-Gaussian tails which results in bigger emittance values (similar to Schottky measurements).

III. Low- intensity simulation –December 20, 2006 data:

We can also plot emittance based on fitted Gaussian, similar to high-intensity case in Section II.

Figures 10 shows simulated emittance for the whole distribution (brown dash curve) and emittance based on fitted Gaussian distribution (blue solid line). In this case, deviation from Gaussian profile in simulation after 20 minutes of cooling is relatively small (see Fig. 11) but the trend is clearly observed. The remaining difference with FW measurements is most likely related to fitting procedure in FW software (for example, fit after 10 minutes of cooling shown in Fig. 12 is far from being perfect), as well as numerical accuracy in simulated in BETACOOL profiles.

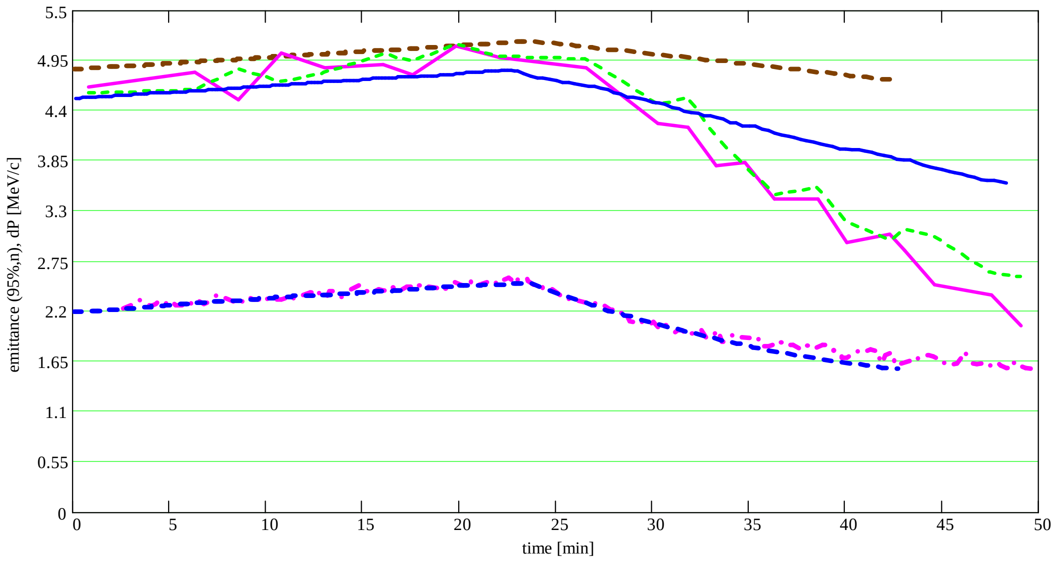


Fig. 10. Simulated emittances: Brown dash line – from rms emittance of the whole distribution including tails. Blue solid line – from fitted Gaussian to the core of the distribution.

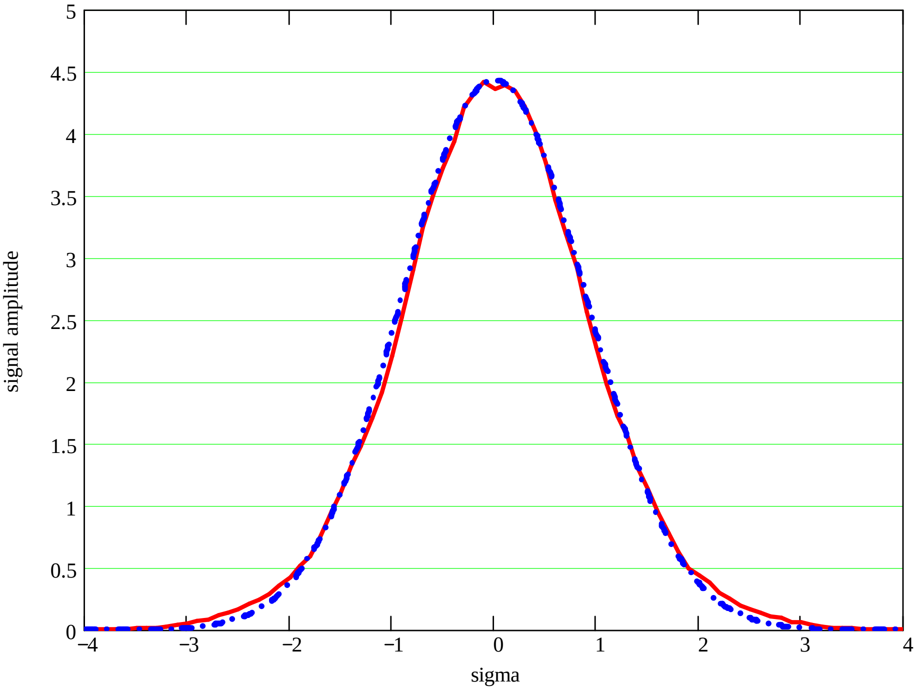


Fig. 11 Simulated with BETACOOL transverse profile after 20 minutes of cooling and Gaussian fit to the core.

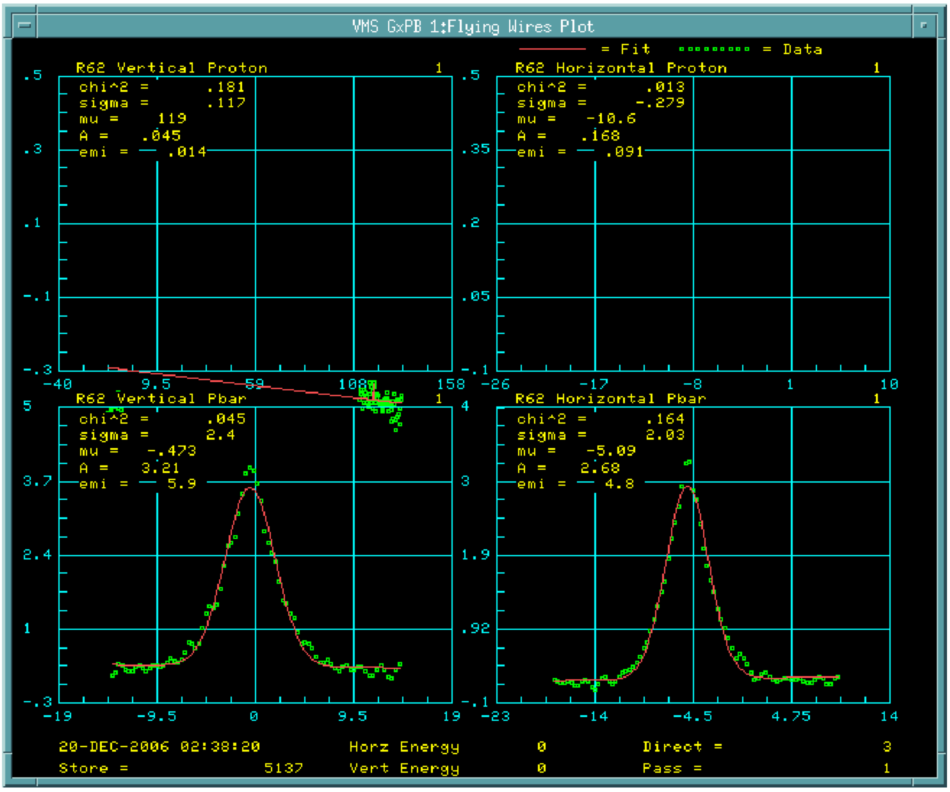


Fig. 13. FW fit after 10 minutes of cooling during these December 20, 2006 measurements.

Summary

1. The use of parabolic distribution rather than uniform requires smaller velocity gradient to fit longitudinal cooling.
2. Resulting transverse cooling rate of rms emittance from the whole distribution is slightly larger than for the case of uniform distribution but still much smaller than given by FW measurements.
3. One can clearly observe that transverse distribution deviates from Gaussian as a result of cooling. BETACOOL simulation calculates rms emittance from the whole distribution including non-Gaussian tails.
4. When one fits Gaussian distribution to the core of simulated BETACOOL distribution one gets smaller sigma and resulting emittance closer to FW measurements.
5. On can draw emittance in BETACOOL based on such procedure of fitted Guassian as well. This clearly results in smaller emittance values than based on rms of the whole distribution.
6. In fact, agreement based on fitted Gaussian and FW measurement gets pretty close.
7. Still remaining difference between FW and simulations with fitted Gaussian is most like related to FW fitting procedure – clearly fits for this measurements are not perfect – see Fig.13.

To summarize, there seems to be good agreement between simulation and measurements. Simulations with parabolic density and velocity gradient can fit longitudinal cooling very well. Resulting transverse cooling shows weak cooling when emittance is calculated based on rms of the whole distribution including non-Gaussian tails. When Gaussian fit is applied to the core of the distribution – recalculated emittance shows more rapid cooling and gets closer to FW measurements.