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BETACOOL simulations and comparison to ESME calculations

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Introduction

In the context of the Accord with the Joint Institute for Nuclear Research in Dubna, Russia, longitudinal dynamics calculations in the presence of barrier buckets were implemented into the Betacool code. In order to validate the new numerical algorithms used in Betacool, several simulations were carried out and compared to results obtained from the well-established ESME code [*Ref*], which capabilities go beyond those of Betacool for longitudinal dynamics simulations for accelerators.

In each case presented below, the initial distribution of particles was generated in ESME and *translated* into a format readable by the Betacool program. Then, equivalent simulations for the distribution considered were carried out in parallel with the two codes and the results compared looking at the final distribution as well as its second moment. Note that because the purpose of this exercise was to cross-check Betacool new capabilities, details pertaining to the way parameters were set in Betacool are explicitly shown here, whereas ESME running parameters are not. Nevertheless, the ‘physics’ included in these simulations was the same for both codes and relatively simple (e.g.: there is no space charge, IBS or other beam scattering effects).

The parameters for barrier bucket (BB) simulations are defined in the window “Ring | Barrier Bucket” (Fig.1). Three options of BB models are avaialble in BETACOOL: 2 barriers (either analytical or numerical model), stationary bucket and moving bucket. The position and duration of BB are defined in circumference units in the range -0.5 < s <= 0.5 and the amplitude of buckets are given in kV (2 barriers) or Volts (in files). A detailed description of the Barrier Bucket models and utilization are presented in “Summary of the new options in BETACOOL code”.

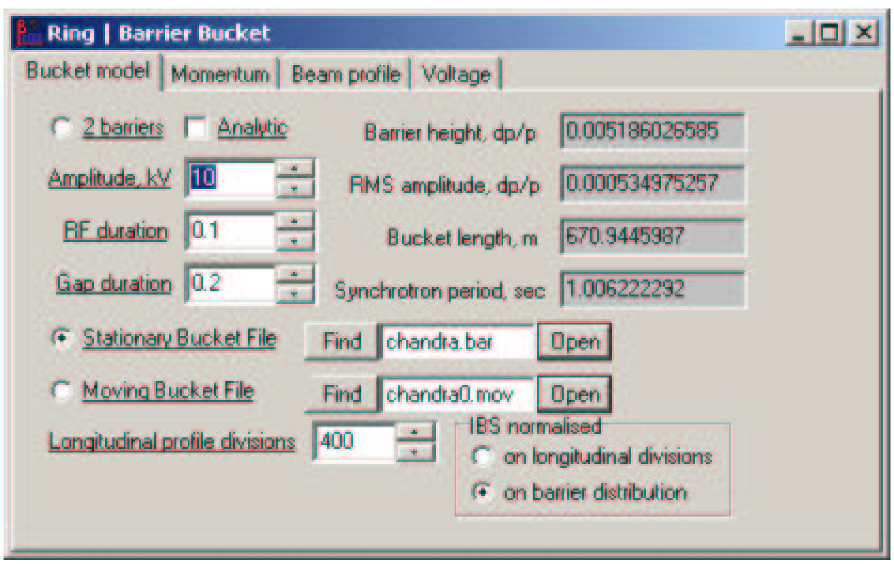
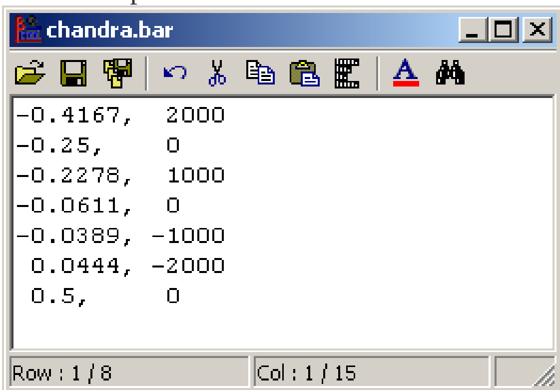


Fig.1. Parameters of BB.

1. Stationary bucket

The first example (input file “chandra.bld”) shows a comparison of longitudinal particle dynamics for stationary BB without any cooling or heating processes. The file with stationary BB (Fig.2 (left), file “chandra.bar”) has two columns: first is the position of the barriers in units of circumference, second is the amplitude in volts. The first barrier (which can have zero amplitude) always starts from position -0.5 hence the file can not contain the position -0.5. If the barrier position 0.5 is not included in the file it means that the last barrier has position 0.5 with zero amplitude. The red line in Fig.2b is the amplitude distribution, the blue line is the integral of the barrier amplitudes [kV*m] normalized to the maximum amplitude of the barriers.



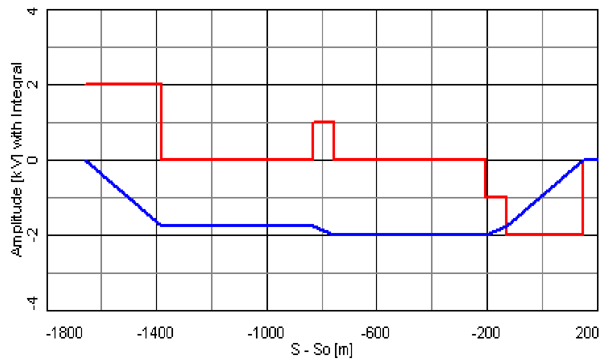
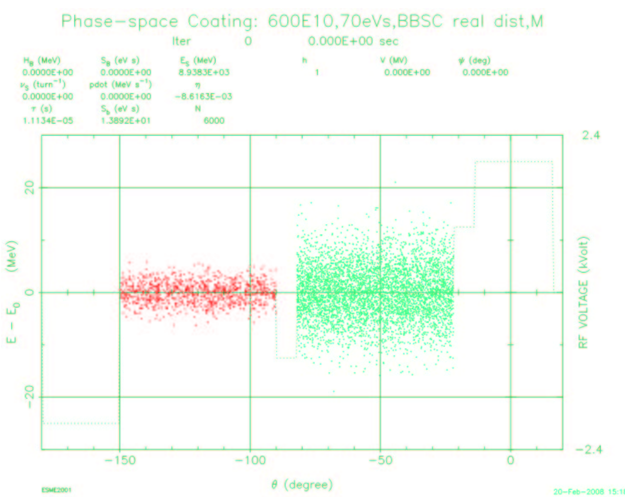


Fig.2. (left) File for definition of stationary BB, (right) amplitude and integral distributions.

1.1. Initial distribution

The initial distribution of particles was generated by the ESME program and translated into the BETACOOL units (Fig.3). In Betacool (Fig.3, right), the red line is the barrier distribution in units of momentum spread and the blue line is the average momentum spread over each barrier length.



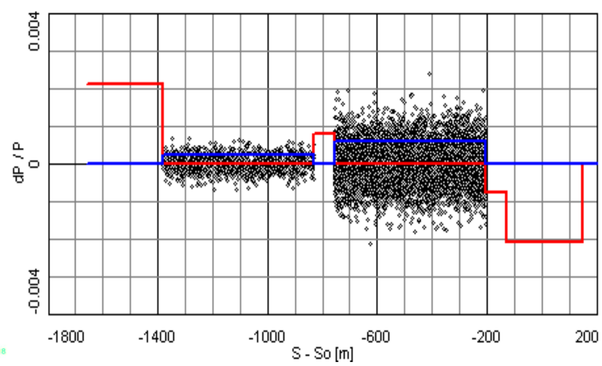


Fig.3. (left) Longitudinal distribution of model particles in ESME; (right) Longitudinal distribution of model particles and barrier bucket in momentum space in Betacool

The beam profile along the longitudinal coordinate shows the particle density normalized to the line density of a coasting beam (Fig.4, right). This value is used for the simulation of IBS over each barrier length. The black line is the integral of particles normalized to the maximum value of the longitudinal profile. The momentum distribution is presented in arbitrary units in Fig.5. In ESME (Fig. 5, left), the x-axis is the energy deviation from the nominal. In Betacool (Fig.5, right), one sigma on the x-axis corresponds to the initial value of the rms momentum spread. Fig.6 shows a direct comparison between ESME and Betacool for the initial distributions.

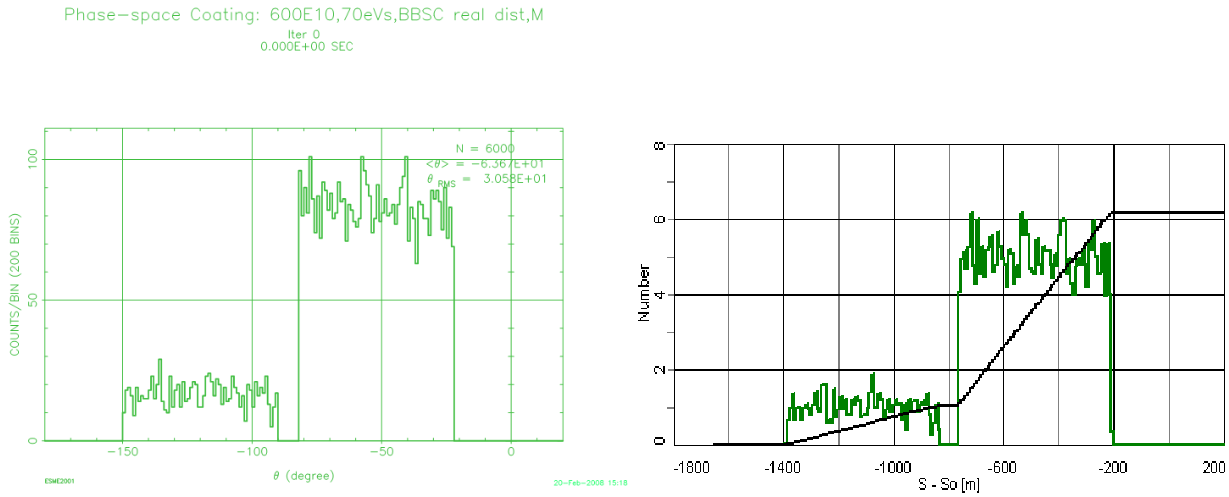


Fig.4. Longitudinal beam profile along longitudinal coordinate. (left) in ESME; (right) in Betacool.

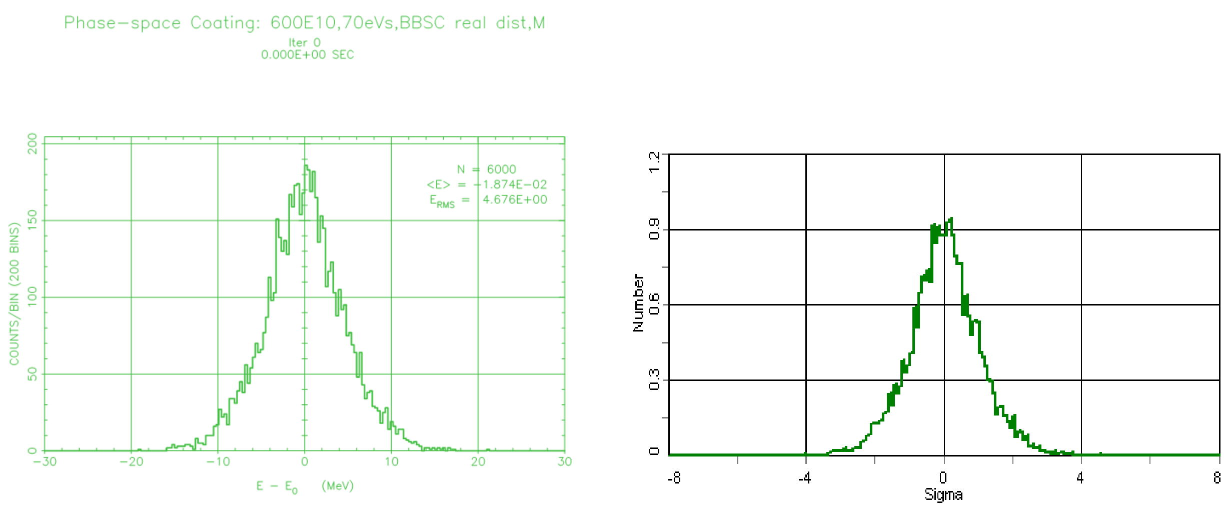


Fig.5. Longitudinal beam profile for momentum spread. (left) in ESME; (right) in Betacool.

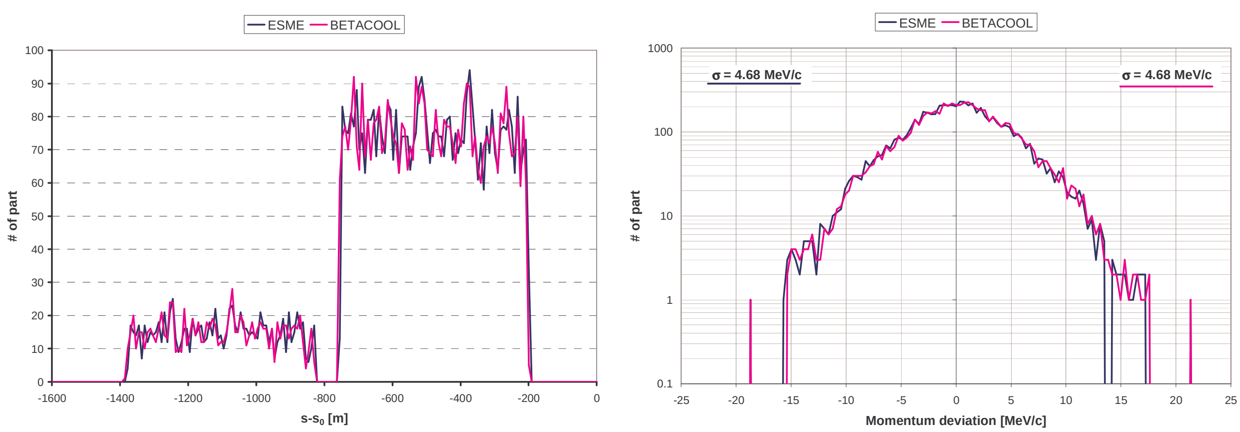


Fig.6 (left) Longitudinal beam profiles along the longitudinal coordinate;
(right) Momentum spread distributions. Initial distributions.

1.2. Distribution after 15 sec

The simulation consisted in letting evolve the initial distribution, which was not in equilibrium, without any other effects. The final distributions after 15 sec (real time) have good agreement with ESME results (Fig.7-10).

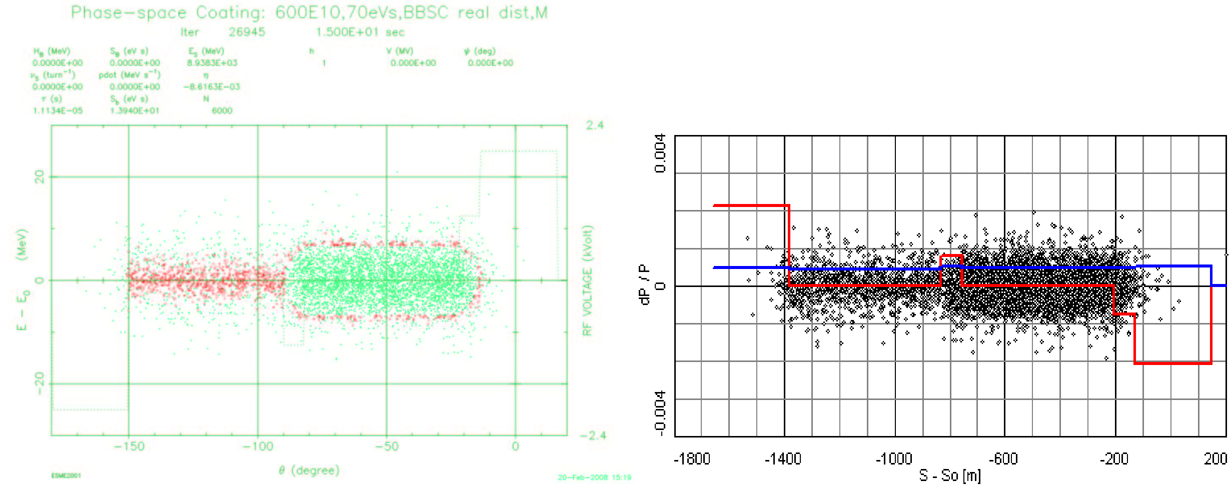


Fig. 7. Longitudinal distribution of model particles and barrier buckets in momentum space. (left) in ESME; (right) in Betacool.

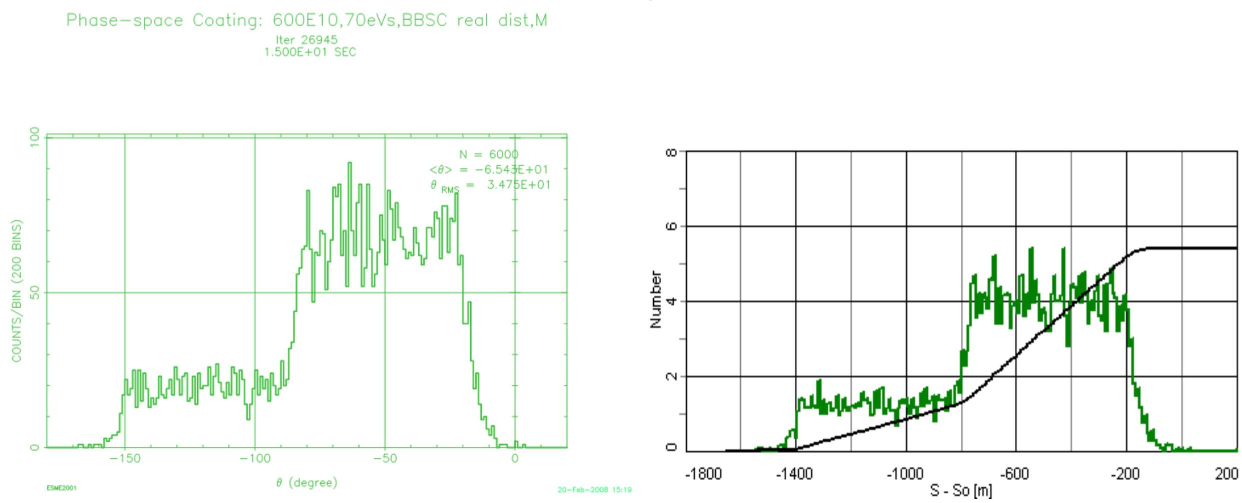


Fig.8. Longitudinal beam profile along longitudinal coordinate. (left) in ESME; (right) in Betacool.

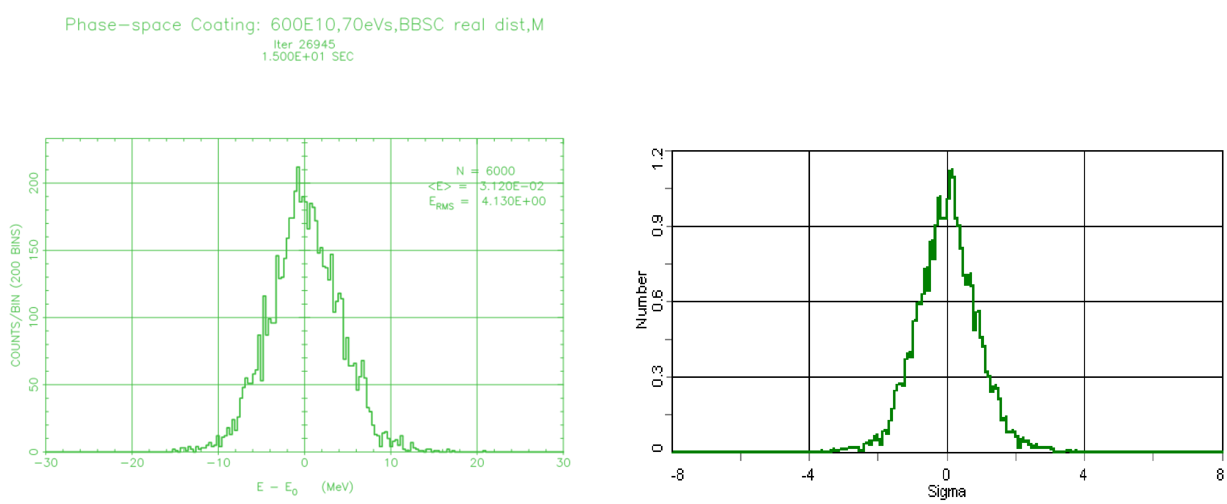


Fig.9. Longitudinal beam profile for momentum spread. (left) in ESME; (right) in Betacool.

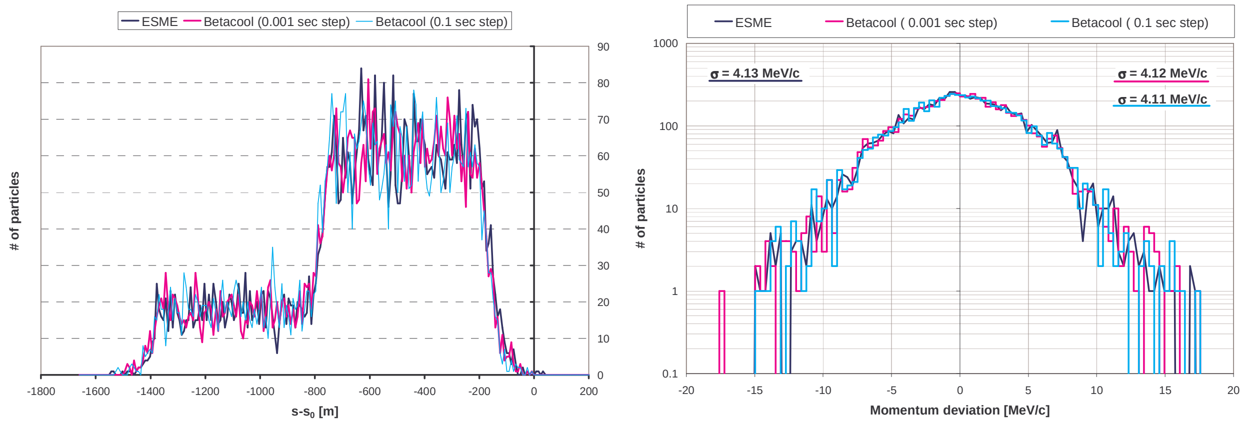


Fig.10. (left) Longitudinal beam profiles along the longitudinal coordinate;
(right) Momentum spread distributions. Final distributions.
For BETACOOL, two sets of data with different integration steps are shown.

The final momentum spreads also agree, and, for BETACOOL, does not depend on the integration step within 0.1 to 0.001 seconds (and probably even a larger integration step is possible to speed up the calculation).

2. Moving barrier bucket

The moving barrier option can be used for manipulation of particles in the longitudinal phase space. Input files for moving barriers (Fig.11, left) can have any number of columns: the first column is the time in seconds; each other pairs define the position of the barriers in circumference units and the amplitude in volts. Consecutive rows determine the initial and final conditions (for both the position and the amplitude). Increments of the position and amplitude for each integration step are linear.

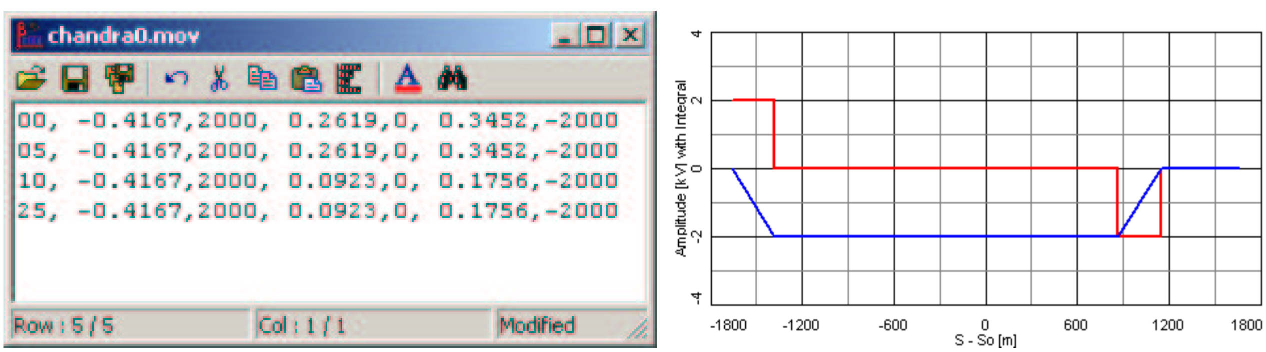


Fig.11. (left) File for definition of stationary BB, (right) amplitude and integral distributions.

2.1. Initial distribution

The initial distribution of particles was generated by the ESME program and was translated into BETACOOL (Fig.12 – 15).

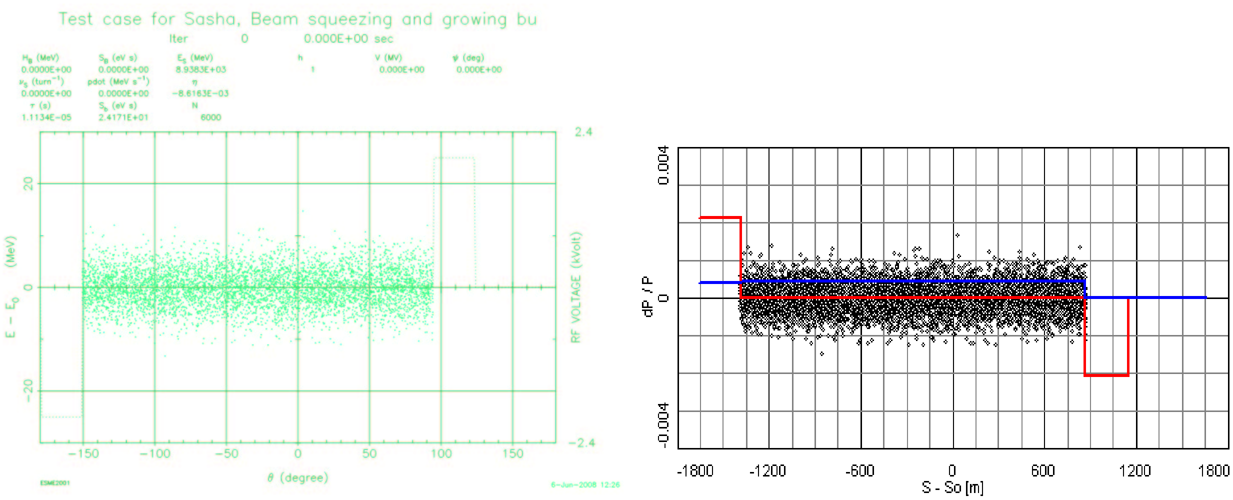


Fig.12. Longitudinal distribution of model particles and barrier buckets in momentum space. (left) in ESME; (right) in Betacool.

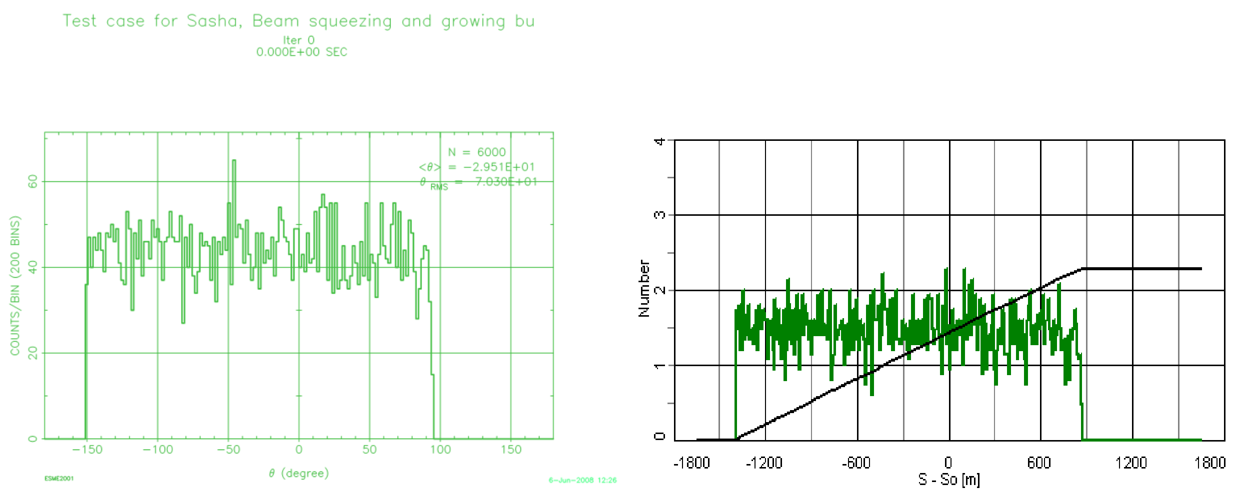


Fig.13. Longitudinal beam profile along the longitudinal coordinate. (left) in ESME; (right) in Betacool.

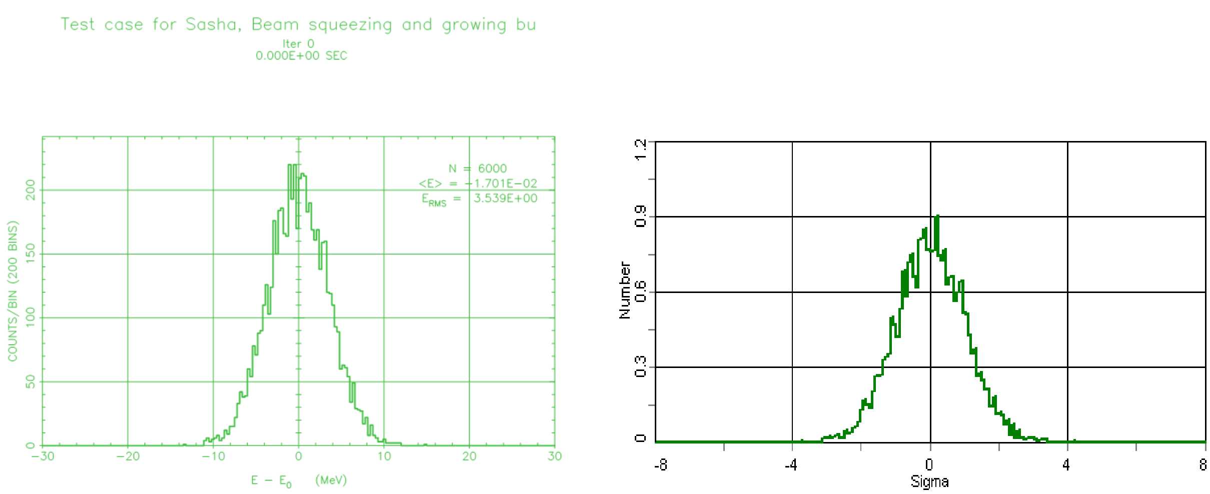


Fig.14. Longitudinal beam profile for momentum spread. (left) in ESME; (right) in Betacool.

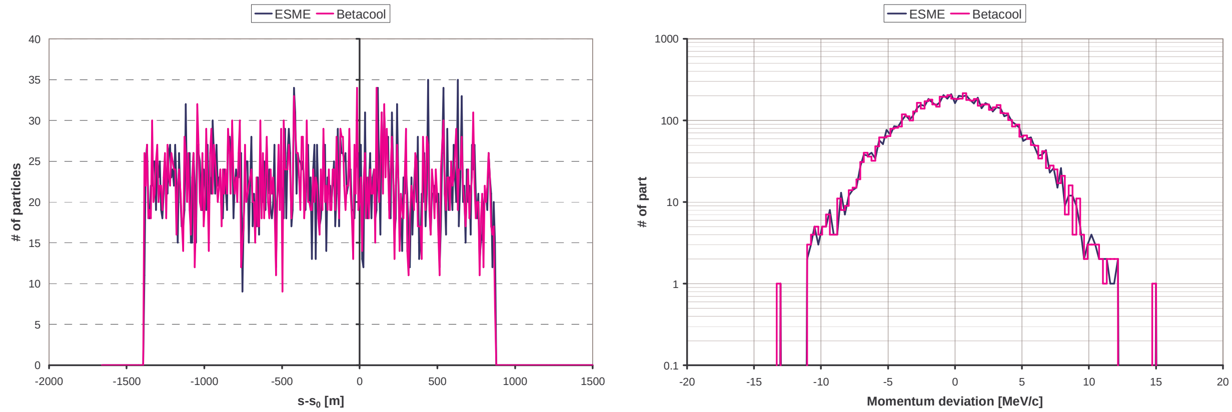


Fig.15 (left) Longitudinal beam profiles along the longitudinal coordinate; (right) Momentum spread distributions. Initial distributions.

2.2. Distribution after 25 sec

In this example, the simulation entailed reproducing a ‘squeeze’, where the beam bunch length is reduced relatively slowly. The real time sequence was the following: wait for 5 seconds (from initial distribution), squeeze for 5 seconds, and wait for 10 seconds. Longitudinal beam profiles and momentum spread distributions in the final state are shown in Fig.16-19.

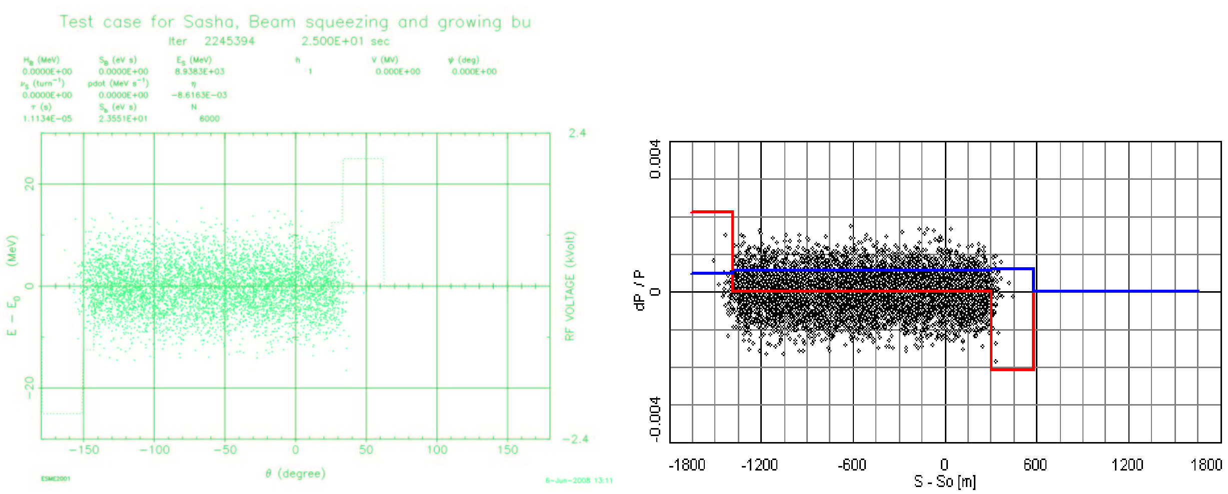


Fig.16. Longitudinal distribution of model particles and barrier bucket in momentum space. (left) in ESME; (right) in Betacool.

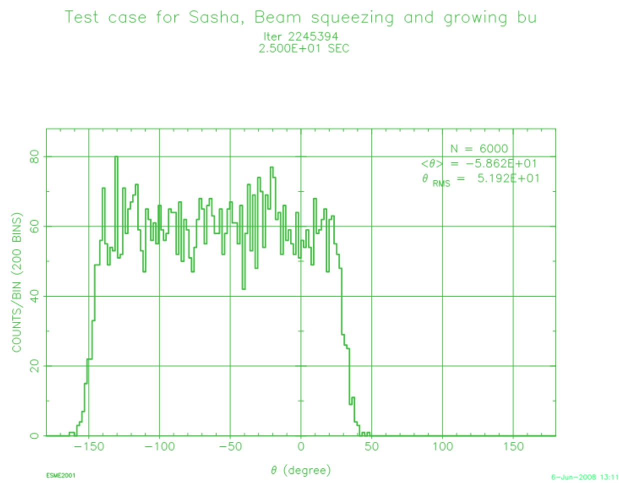


Fig.17. Longitudinal beam profile along longitudinal coordinate. (left) in ESME; (right) in Betacool.

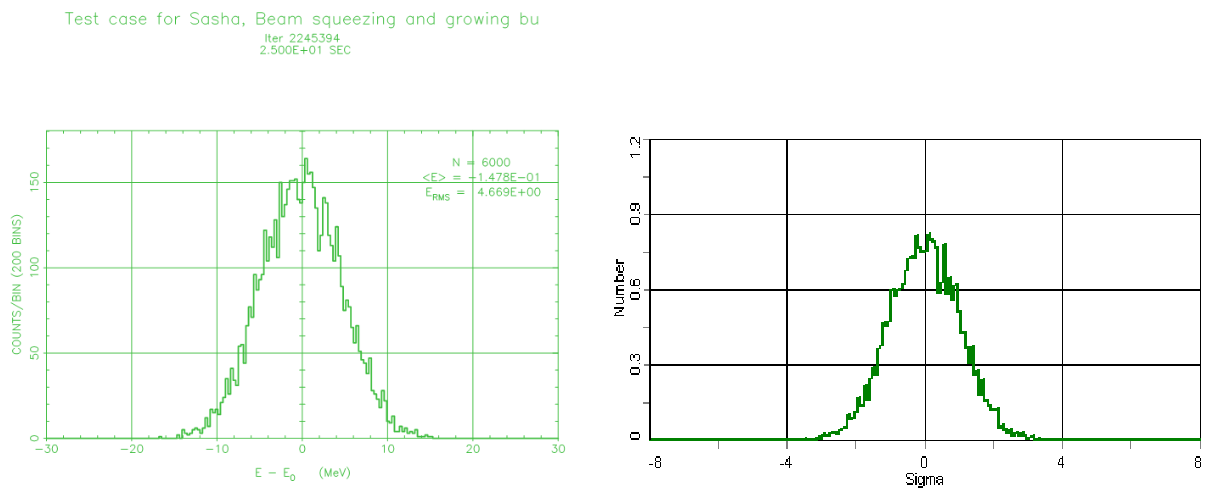


Fig.18. Longitudinal beam profile for momentum spread. (left) in ESME; (right) in Betacool.

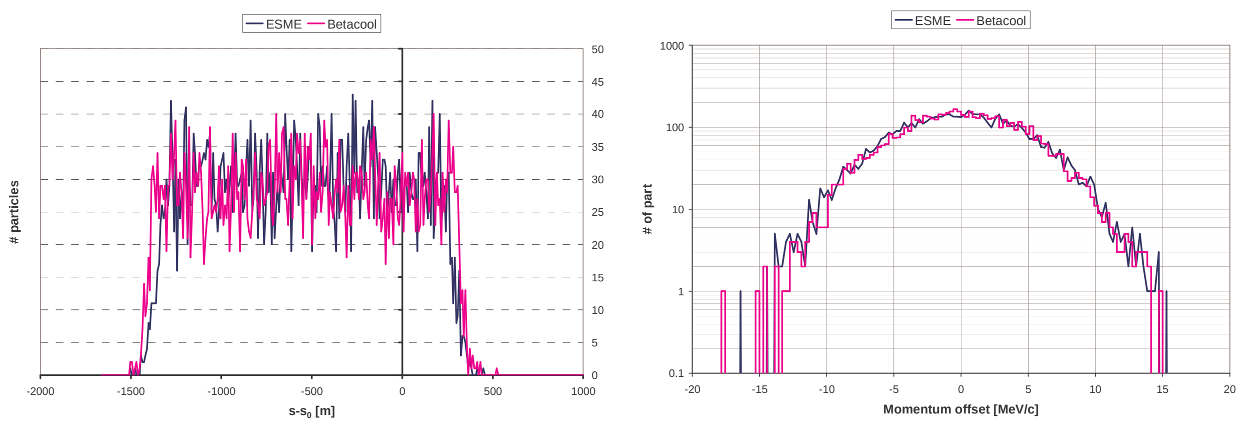


Fig.19. (left) Longitudinal beam profiles along the longitudinal coordinate; (right) Momentum spread distributions. Final distributions.

Although the agreement appears to be pretty good, a slightly more quantitative analysis shows bigger discrepancies than for the stationary bucket case. The bunch length (defined as twice the rms) is 1438 m in ESME while it is 1479 m in BETACOOL (a ~3% relative difference). This is actually visible in Fig.19a in which one can see that the edges of the beam fall more rapidly in the Betacool case than in the ESME simulation, hence extending the ‘flat-top’. Also, even though the momentum distributions overlap very well in Fig.19 (right), the rms momentum spreads are somewhat different: 4.67 MeV/c in ESME and 4.49 MeV/c in BETACOOL. The relative difference here is 4%, while the momentum spread agreed almost exactly for the stationary bucket case.

3. Summary

The two examples above illustrate that the implementation of longitudinal dynamics in BETACOOL is appropriate and agrees with the well established (and more advanced) code ESME, even in the case of moving barriers, which is more difficult to reproduce correctly (for instance, it is important to make sure that the integration step size is much smaller than the synchrotron period).

Ref: *ESME, J. MacLachlan, www-ap.fnal.gov\ESME*