Fermilab

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Thursday 26 Feb. 04

High Intensity Beam Problems Near Transition

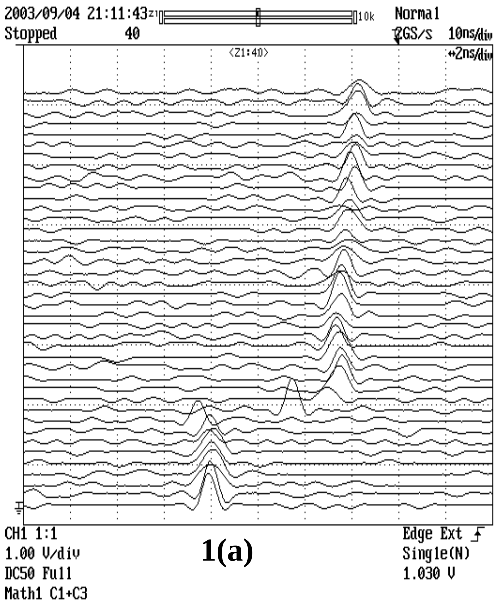
- Synchronous phase perilously close to 90° both sides of transition
- Real part of $Z_{||}$ crucial but uncertain
- Newly observed collective effect may complicate transition.
- New features in modeling code giving additional control and more complete information

Symptoms of Trouble Now

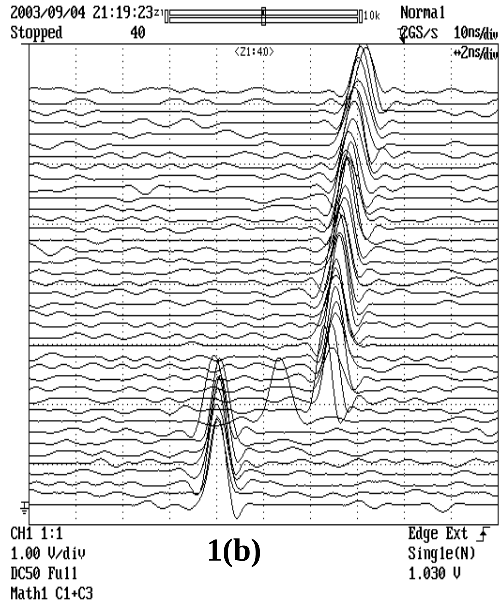
There are clear signs of problems and impending difficulty. The next slide shows in a moutain range display, with traces every 8 turns bracketing transition, the approach of synchronous phase to 90° with increasing intensity. The six displays were recorded at intensities of .4, 1.2, 1.9, 2.6, 3.5, and 5.2×10^{12}.

In the following slide, the output of a phase detector comparing rf to beam is shown around transition for intensities of .4, 1.9, 5.2×10^{12}. Noteworthy features include the fast spike to incorrect phase of nearly 170° for highest intensity and the dip to nearly 90° following transition.

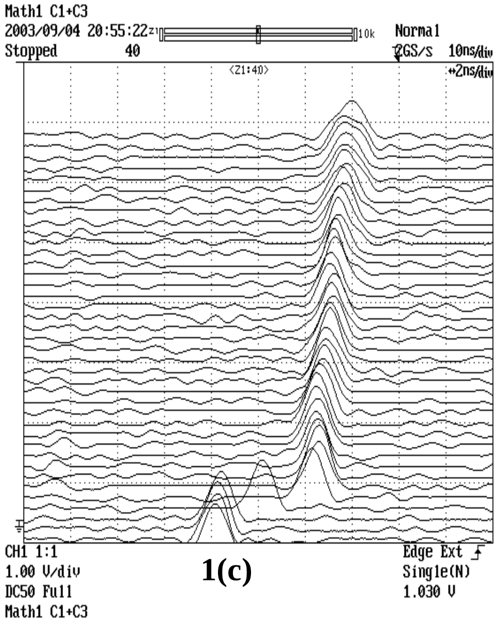
(Data and graphics from Yang Xi)



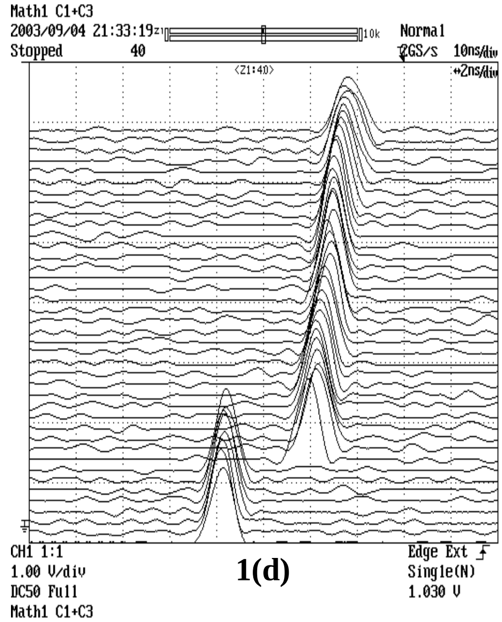
1(a)



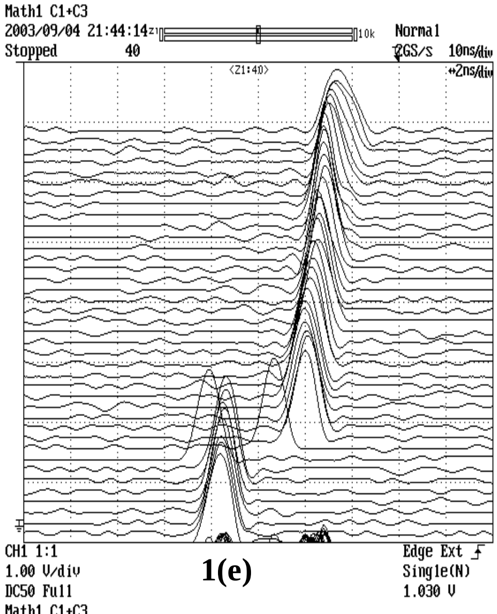
1(b)



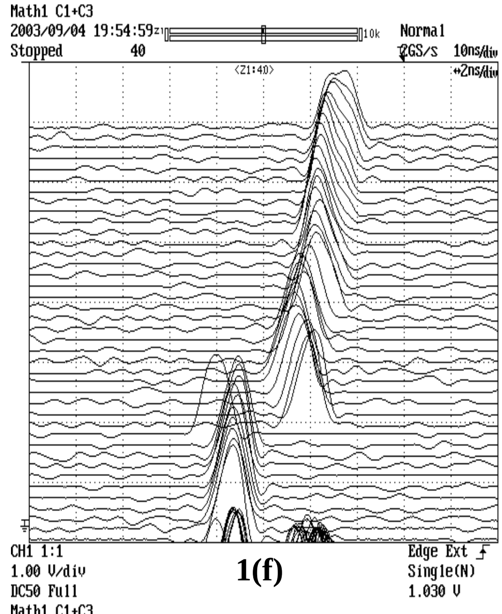
1(c)



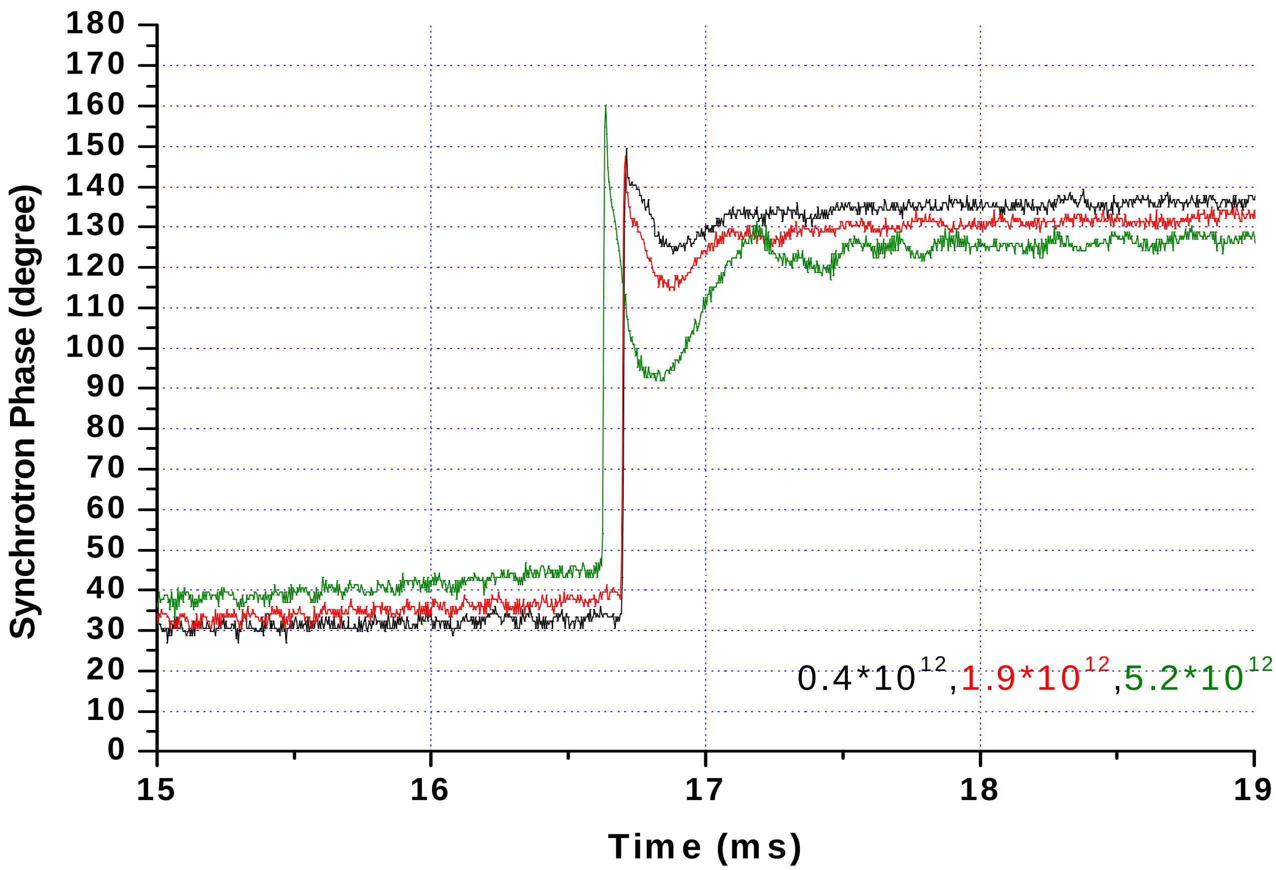
1(d)



1(e)



1(f)



Synchrotron Phase (degree)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
15
16
17
18
19
Time (ms)
0.4*10^12, 1.9*10^12, 5.2*10^12

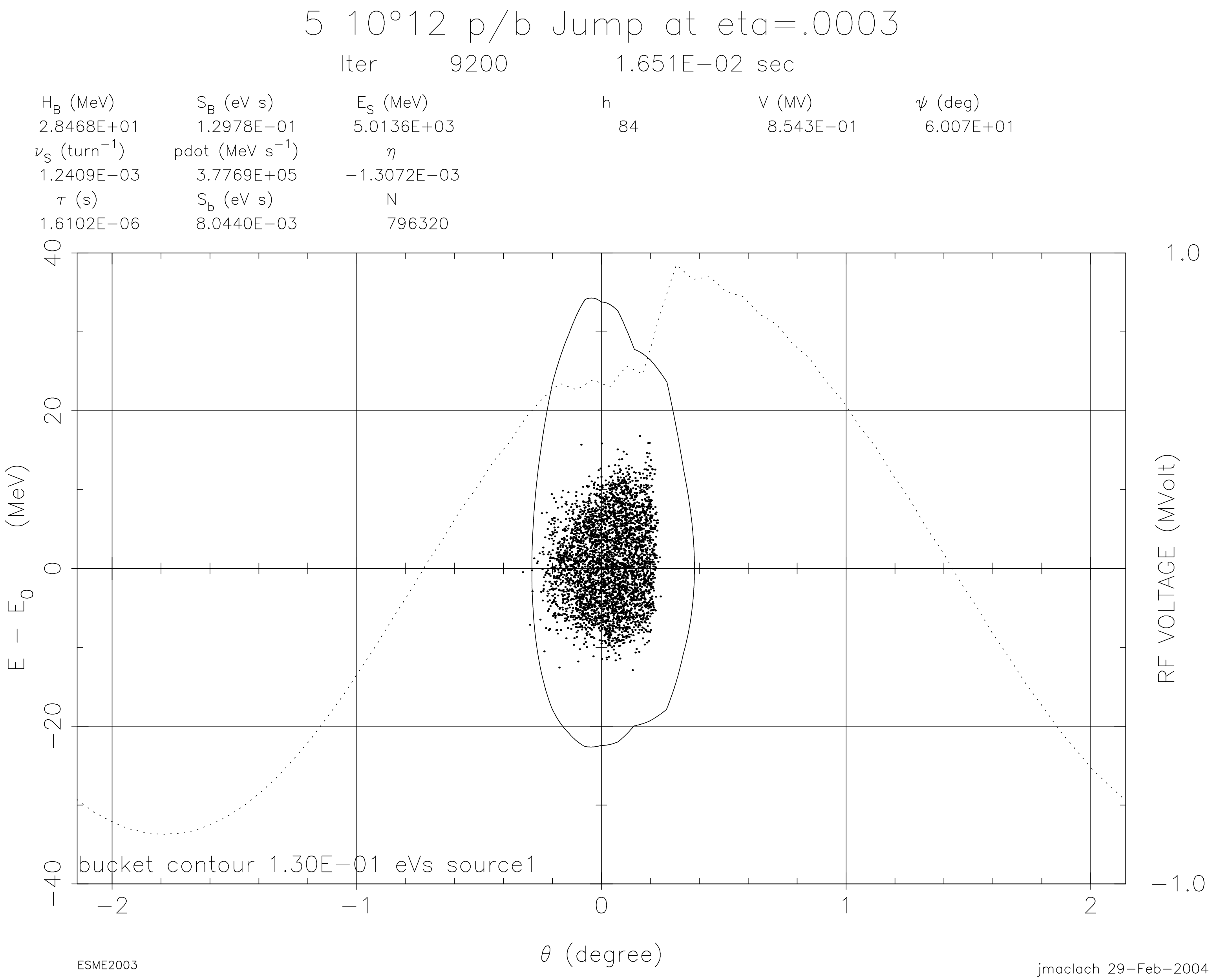
Transition Parameters analysis

γ_T	5.446	
$\dot{\gamma}$	419.2	s^{-1}
α_1 (ESME)	0.072	
rf amplitude	690.	kV
bunch area	0.0947	eVs
particles/bunch	$6 \cdot 10^{10}$	
harmonic number	84	
Transition energy	5.110	GeV
v/c at transition	0.9829	
rf frequency	52.20	MHz
circulation period	1.609	μs
$\dot{E}$	393.3	GeV/s
ϕ_s	1.161	rad
rms bunch length	0.5445	ns
geometric factor	4.515	
nonadiabatic time	0.2572	ms
nonlinear time	43.30	μs
$\eta_\circ(0)$ (Sorrenssen)	0.5107	
harmonic for $g_\circ/2$	23708	
fastest mode	13688	
"worst" mode	7903	
NMI threshold param.	1.372	
appx. peak current	6.696	A
$\lvert Z_{\parallel} \rvert$	29.19	Ω
$\frac{\Delta\varepsilon}{\varepsilon}$ (Jie Wei)	0.1280	

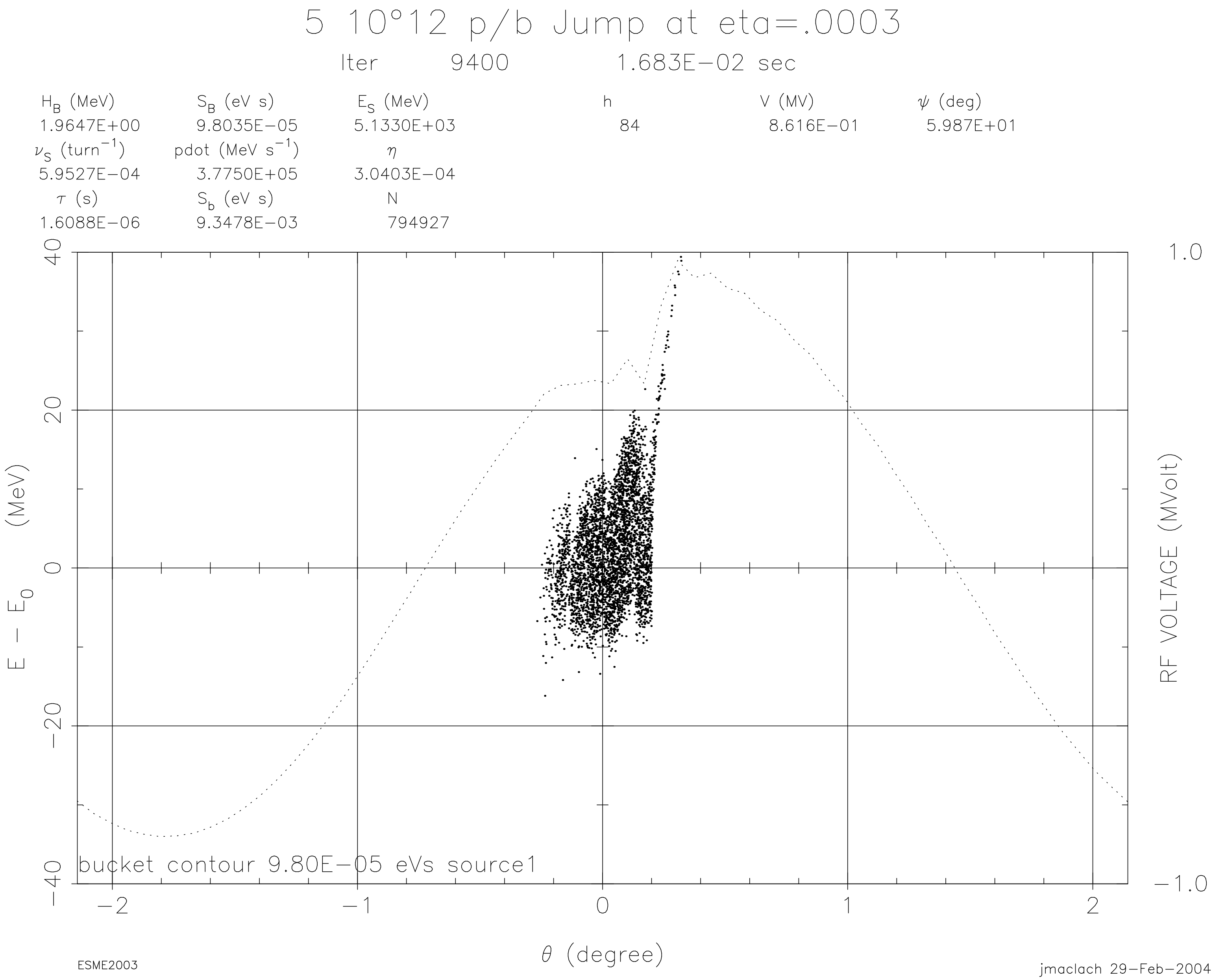
Parameters assumed in the modeling and derived quantities from the analysis of Sorrenssen, J. Wei, and W. Hardt.

Modeling

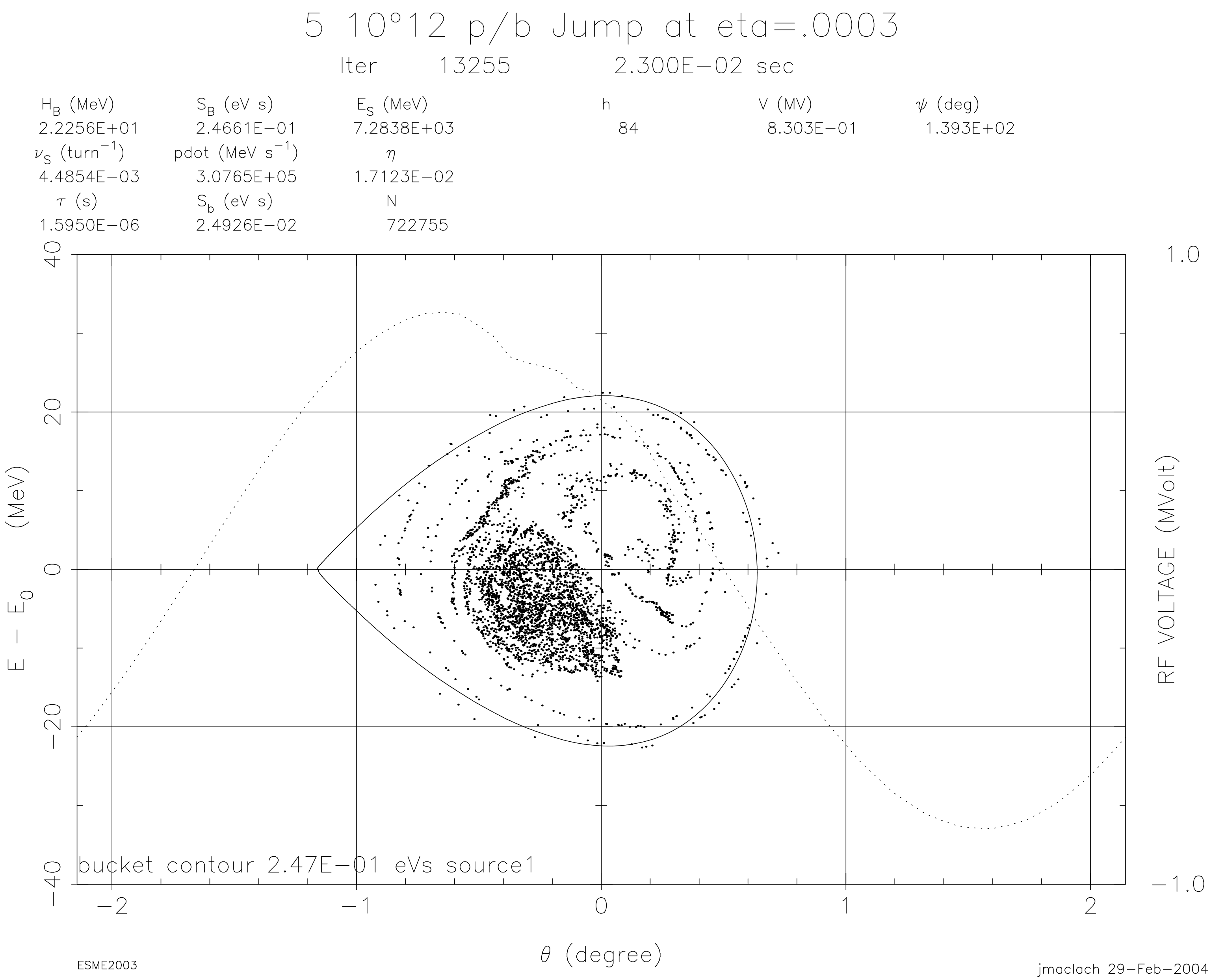
There follows a series of selected ESME output from a case with $6 \cdot 10^{10}$ protons/bunch *before* capture. These are not exactly the transparencies shown during the talk; they were available only in hard copy and could not be reproduced exactly. Unfortunately, the transition loss of about 9 % is worse than the ~ 2.5 % in the transparency.



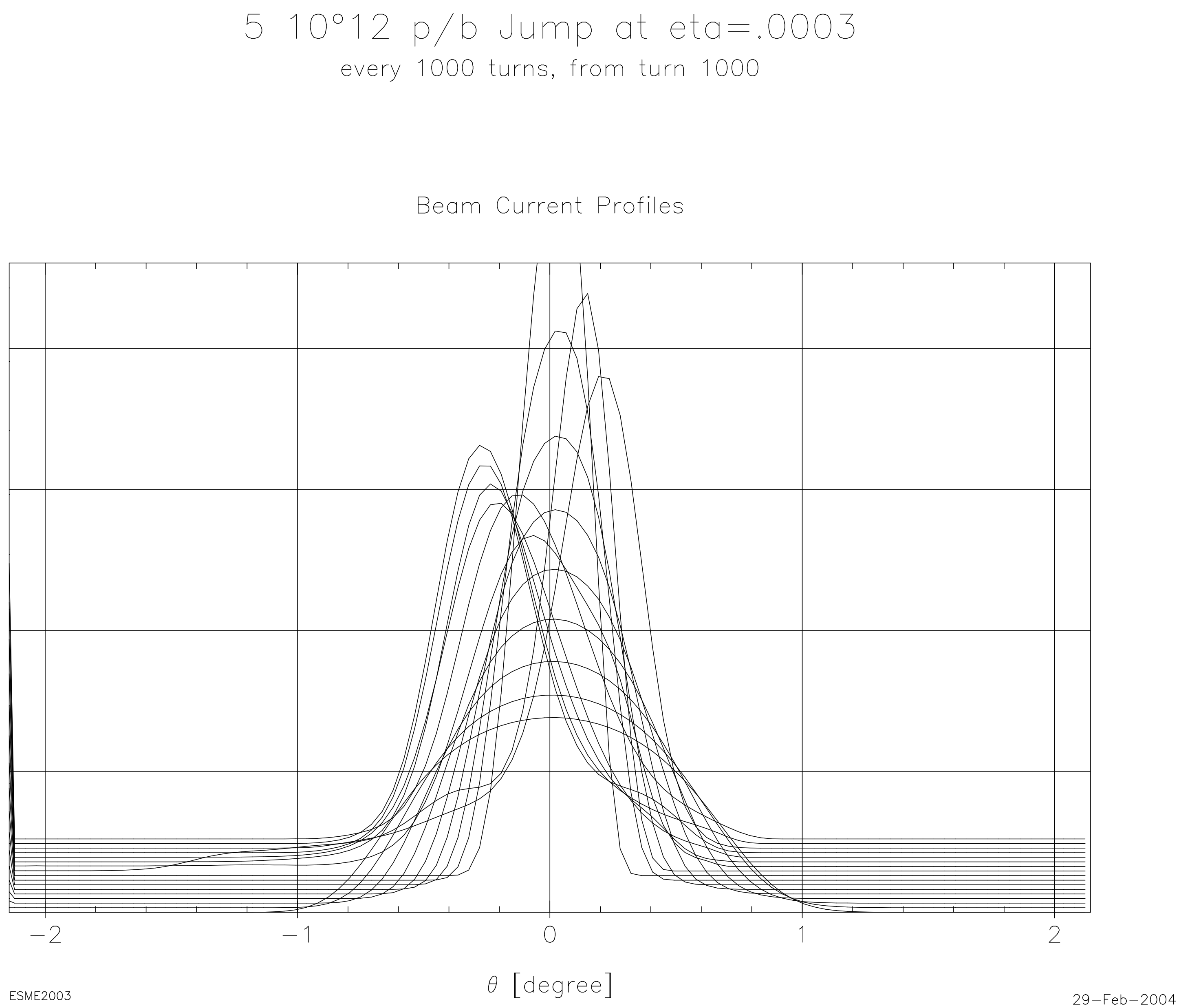
A bunch of $6 \cdot 10^{10}$ protons just before transition. The dotted curve is the sum of rf potential and the collective potential calculated from Crisp magnet impedance measurements and perfectly conducting wall space charge impedance.



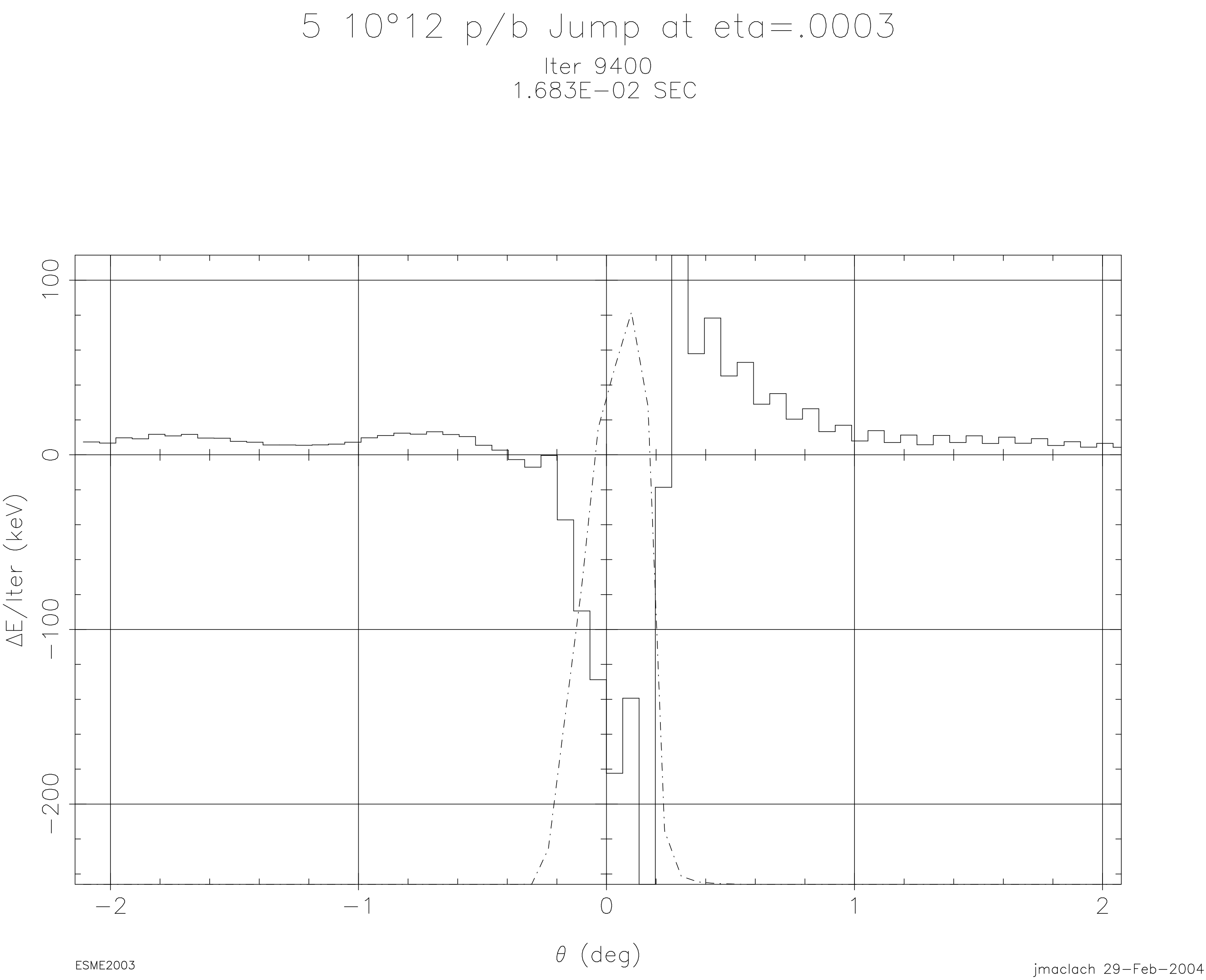
The same Booster bunch just after the transition phase jump. Note that the jump has been delayed until positive $\eta = 3 \cdot 10^{-4}$. This is a jump late by about 70 μs.



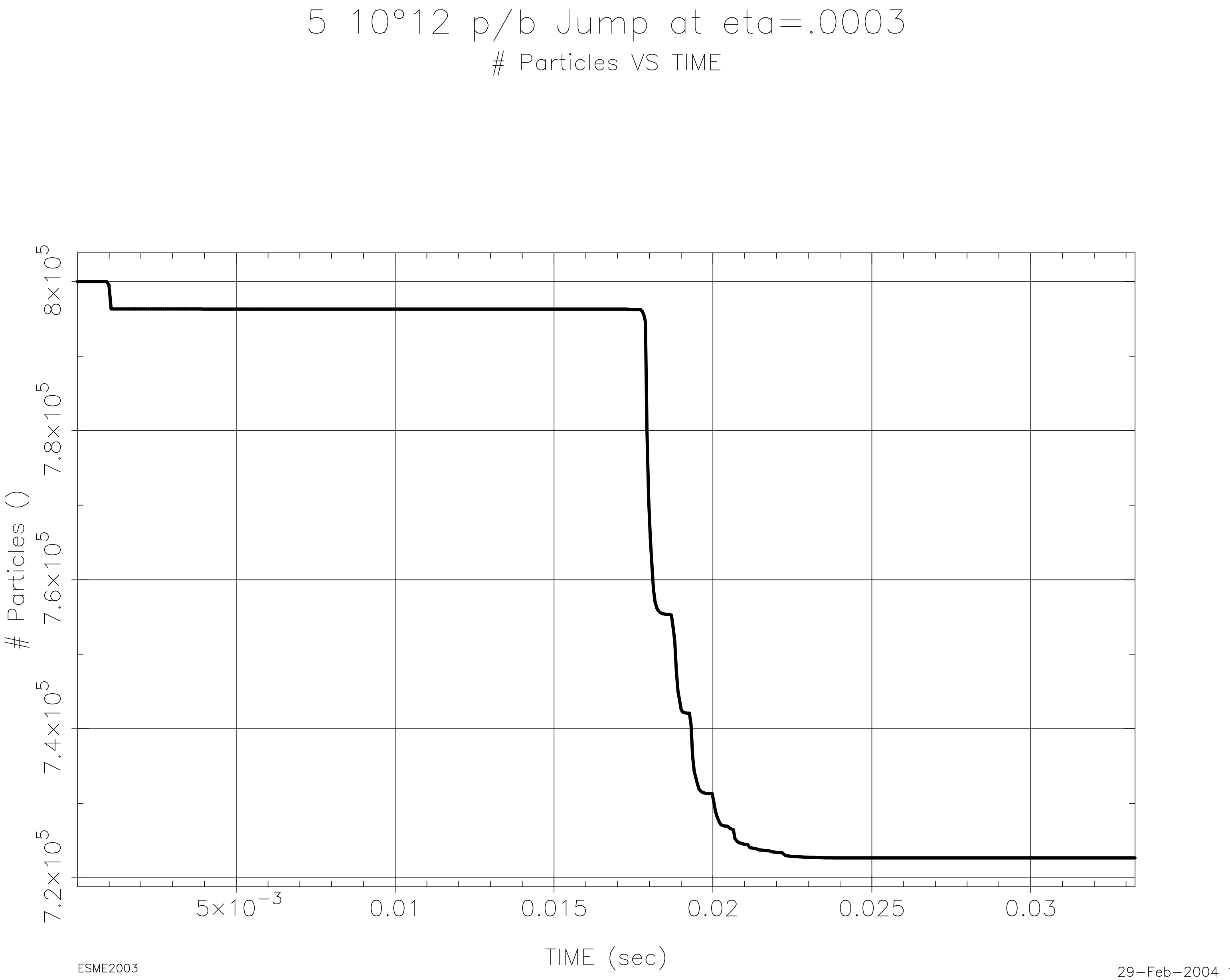
The same bunch at 23 ms. The total emittance is approximately .12 eVs (5× the rms emittance).



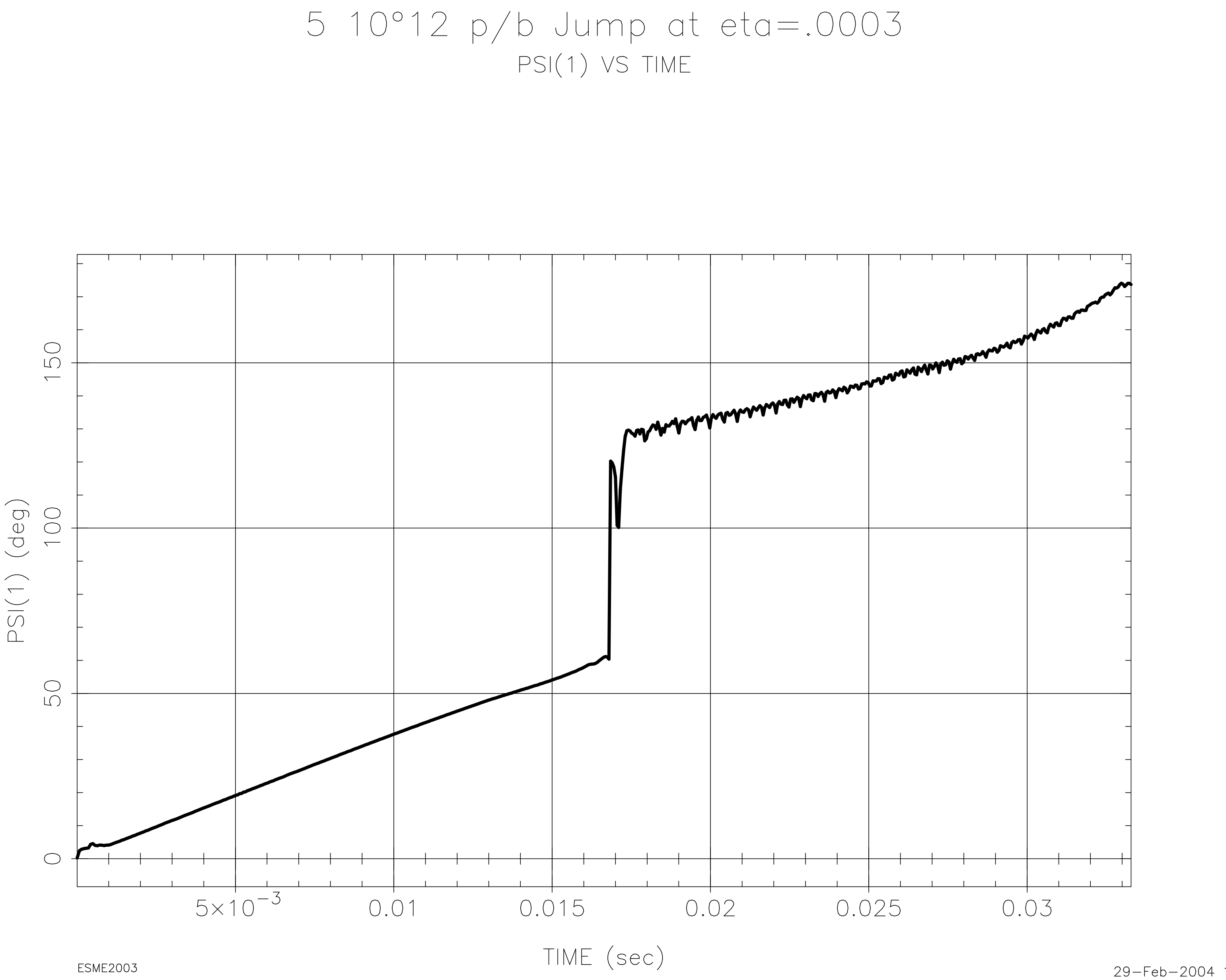
The mountain range plotted every 1000 turns ($\sim 1.8\ \mu$s) shows that the synchronous phase was generally correct; there is some lurching of the bunch to the inside and outside.



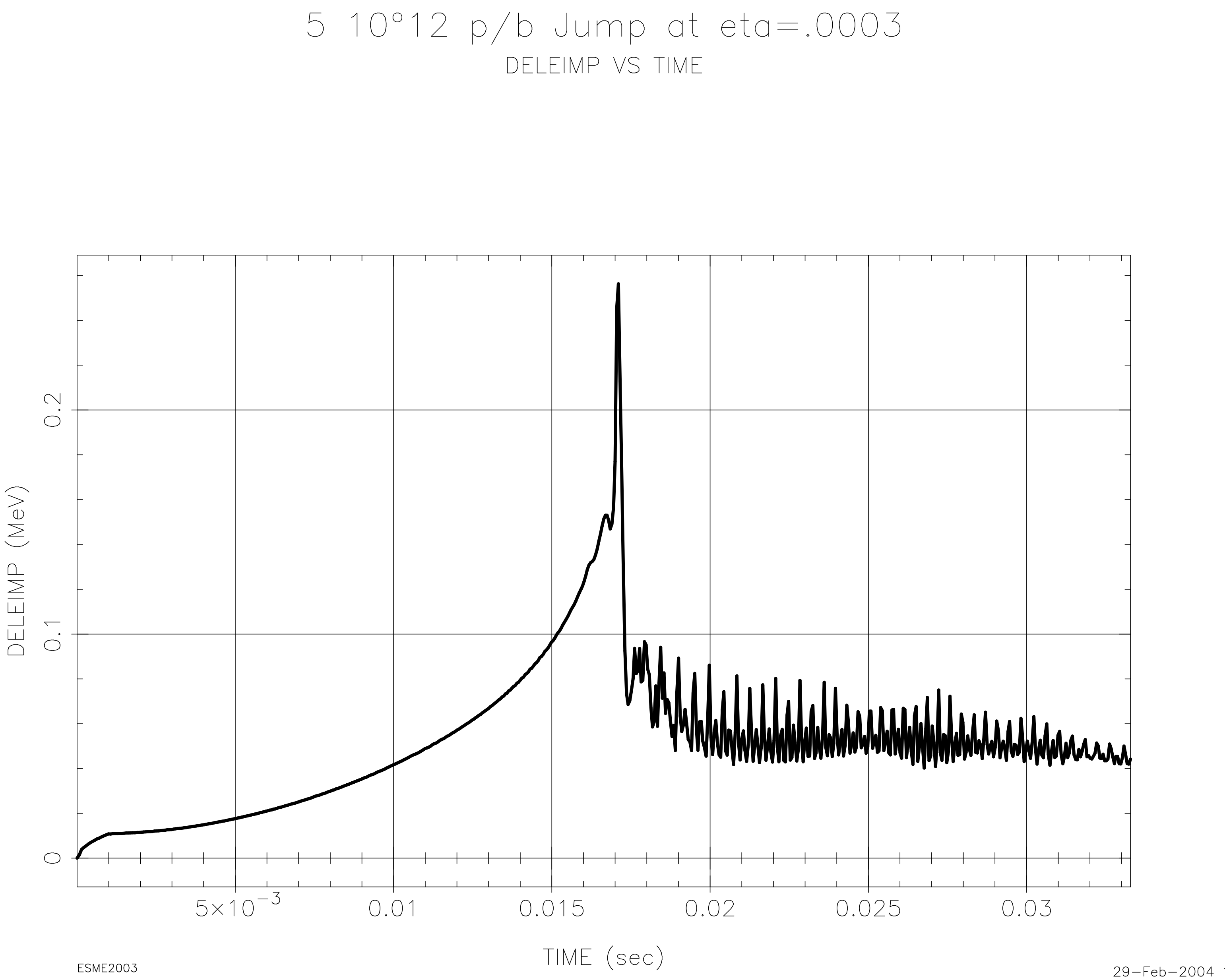
The collective potential at transition. Notice the real energy loss per turn to the longitudinal coupling impedance. This curve does not include the beam loading of the rf cavities.



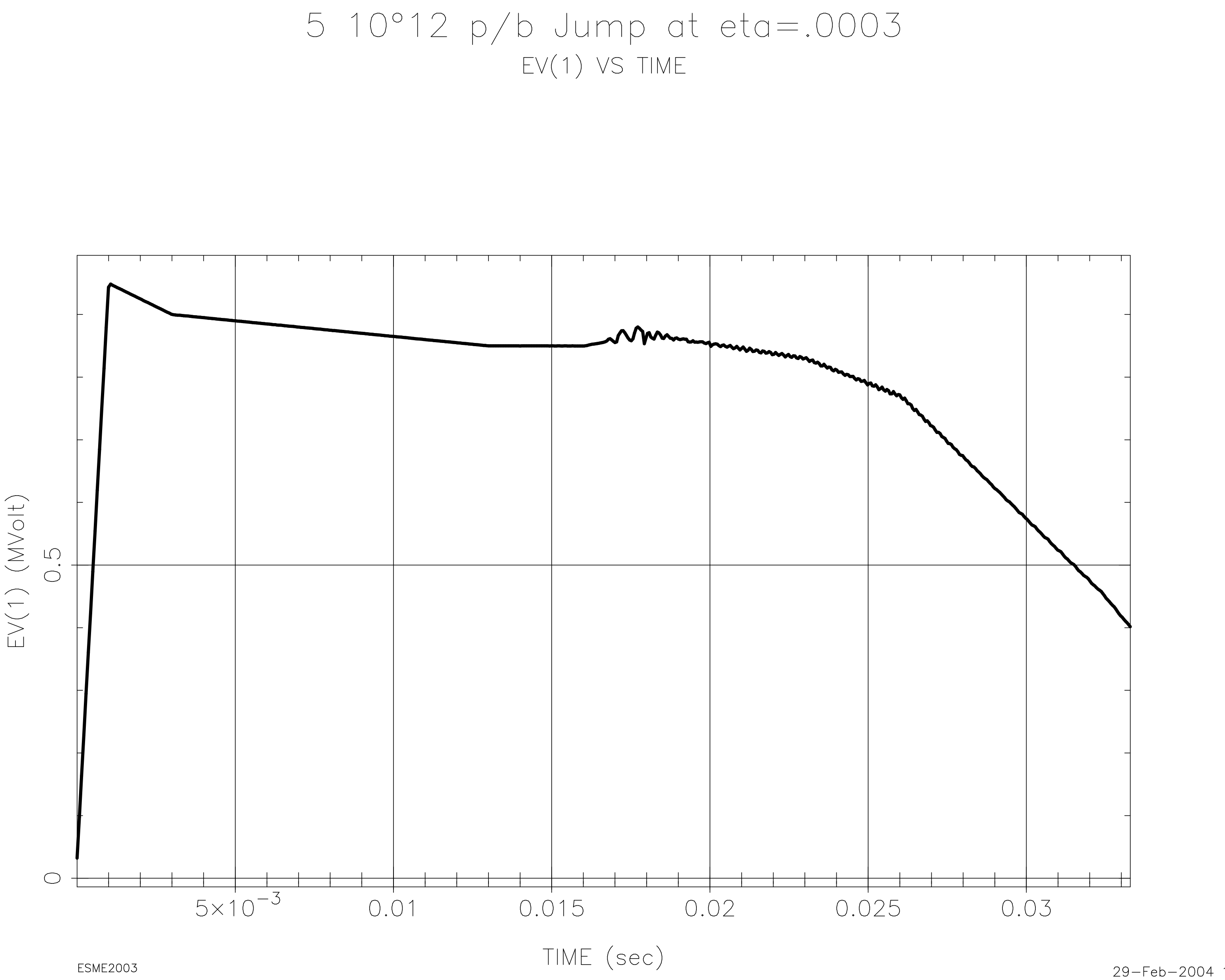
Particle loss through the entire Booster cycle. The transition loss is about 9 %.



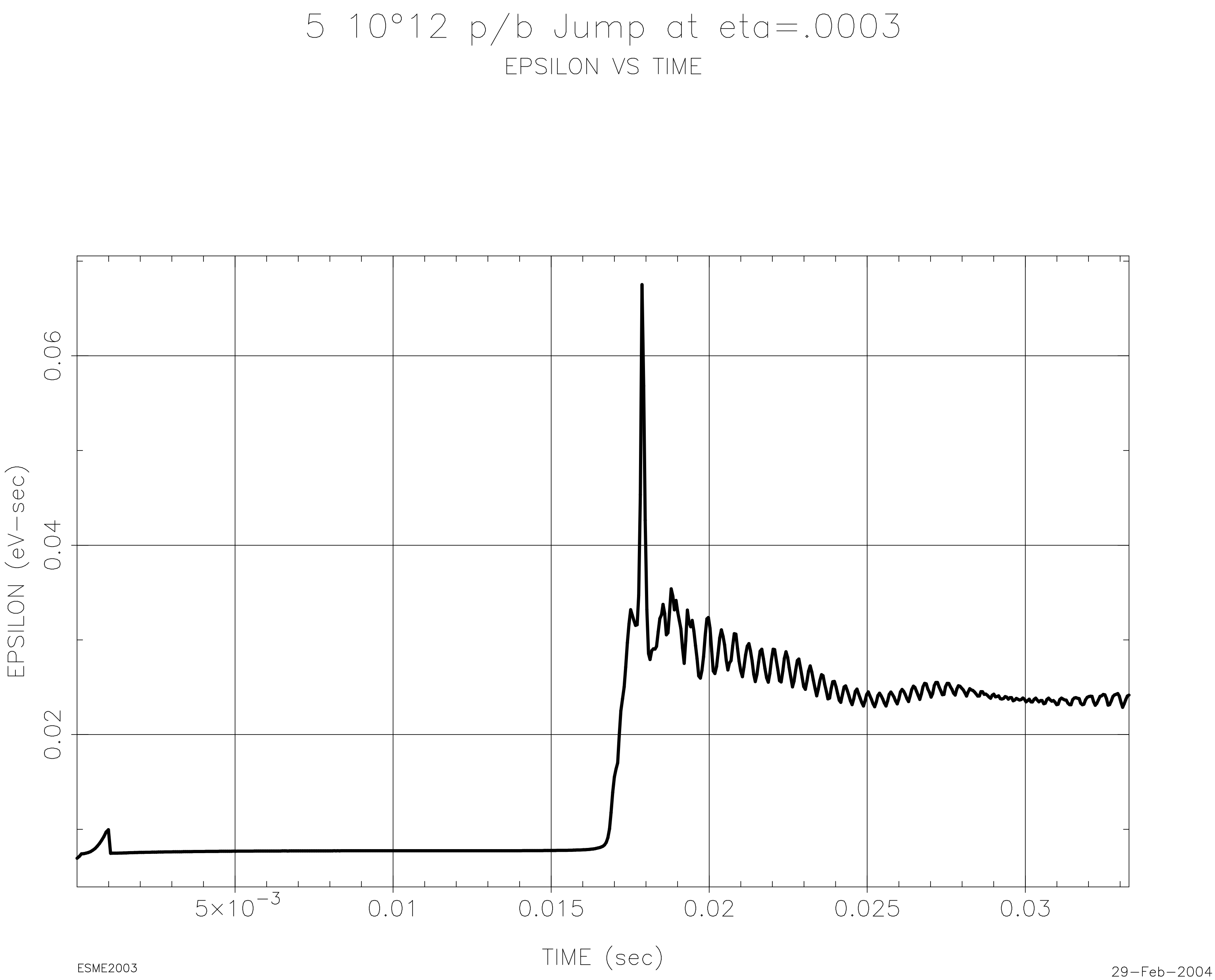
The synchronous phase throughout the Booster ramp.



The energy loss per turn to real part of longitudinal impedance (without cavity impedance) throughout the Booster ramp.



The rf voltage curve; the wiggles after transition result from an attempt to damp the shape oscillation.



The statistical (rms) emmitance during the Booster ramp. The dilution after all loss is about a factor three, giving a total bunch area of approximately .12 eVs.

New Facilities for Macrpoarticle Tracking in E, φ

The modeling looks plausibly close to actual Booster performance except, perhaps, for the > 100 kV energy loss to the real impedance near transition. Perhaps the impedance estimate is larger than the actual value. Modeling in this detail has been made possible, or at least practical, by new multiparticle features in ESME.

- synchronization including energy loss to real impedance
- optional history of energy loss to real impedance
- optional plot of rf potential plus collective potential
- number of macroparticles can be increased or reduced during the course of a tracking run to accomodate differing needs in collective potential calculation