CAPTURE_SPC simulation studies of the IPNS RCS and a preliminary look at the FERMILAB BOOSTER

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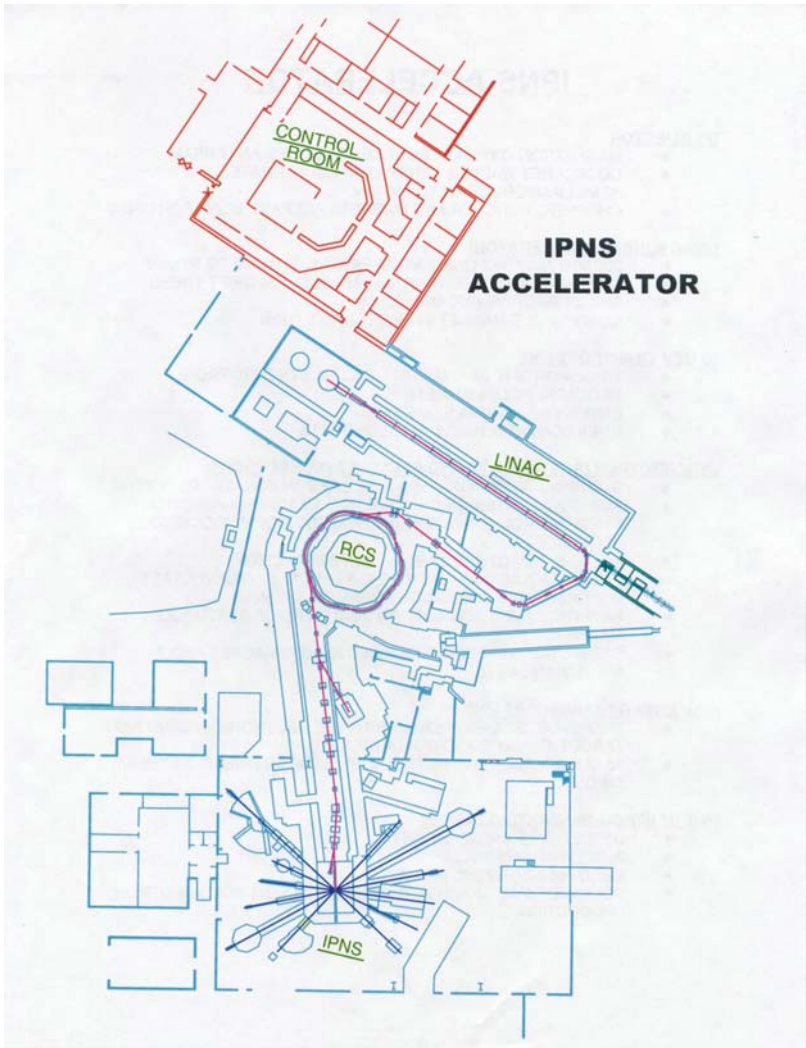
Motivation

- Wish to increase the current limit in the RCS
  - presently 3.4×10^{12} protons per bunch
  - Limited by space-charge at injection and current-driven instability later
- Second Harmonic (SH) rf helps with both injection and acceleration bottlenecks
- Quantify physical picture the RCS
  - Will Phase Modulation (PM) be necessary with SH rf?
- Work with RAL ISIS in their SH rf campaign
  - SH rf being added throughout the full cycle

IPNS Accelerator Facility



CAPTURE_SPC

Tracking code for injection and acceleration in synchrotrons

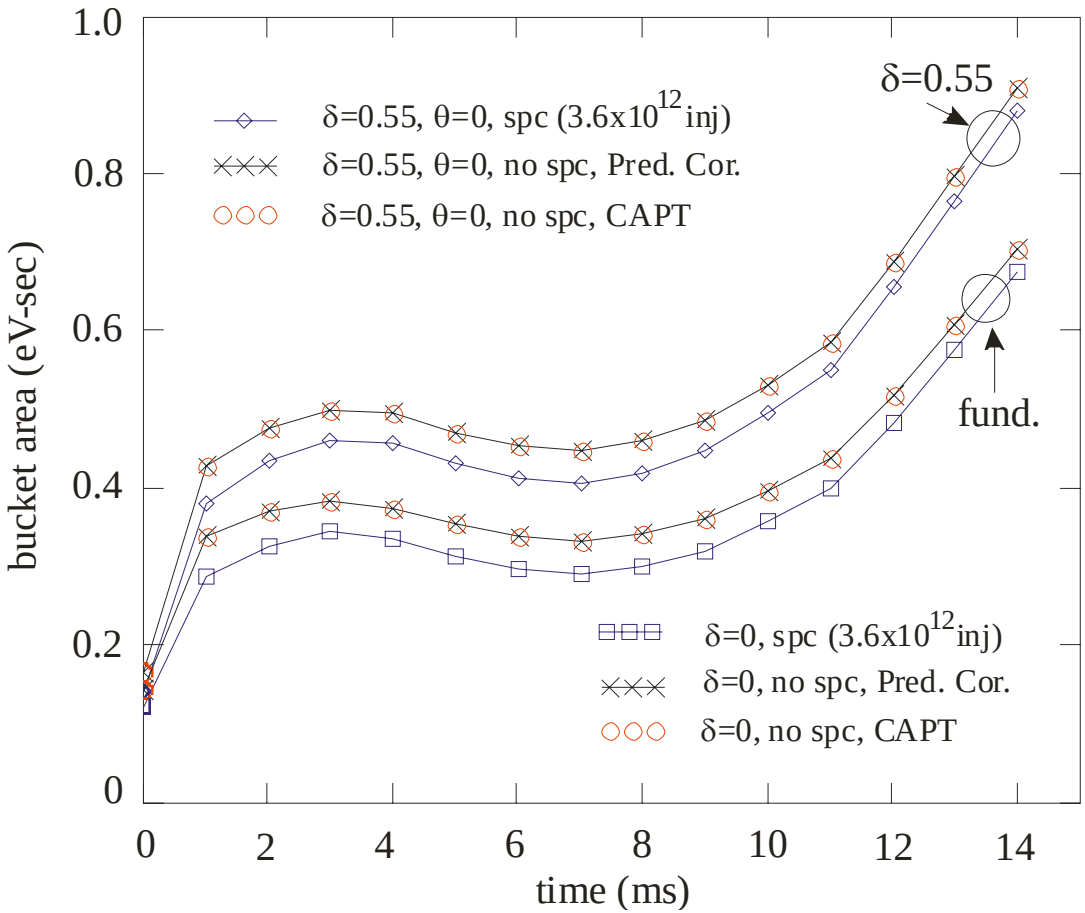
- Monte-Carlo based
- Symplectic, 2nd-order “leap-frog” time step[1]
- Cloud-in-cell smoothing of statistical fluctuations introduced by binning of charge.

$$W_{n+1/2} = W_{n-1/2} + \frac{eV_n\tau}{2\pi}(\sin\phi_n - \sin\phi_{s,n}) + \frac{eg_o}{4\pi\varepsilon_o}\frac{h^2\tau}{R\gamma_{s,n}^2}\left(\frac{d\lambda(\phi)}{d\phi}\right)_n$$

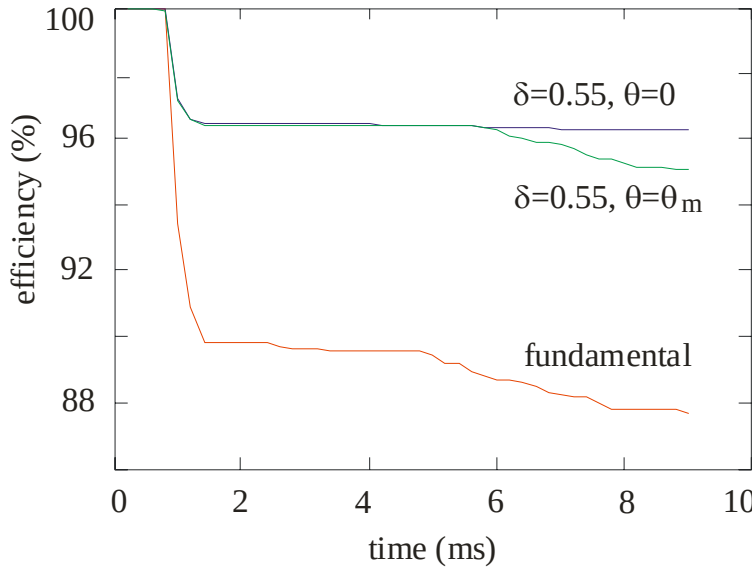
$$\phi_{n+1} = \phi_n + h\tau\left(\frac{\eta_s\omega_s^2 W}{\beta_s^2 E_s}\right)_{n+1/2} + \phi_{s,n+1/2} - \phi_{s,n-1/2}$$

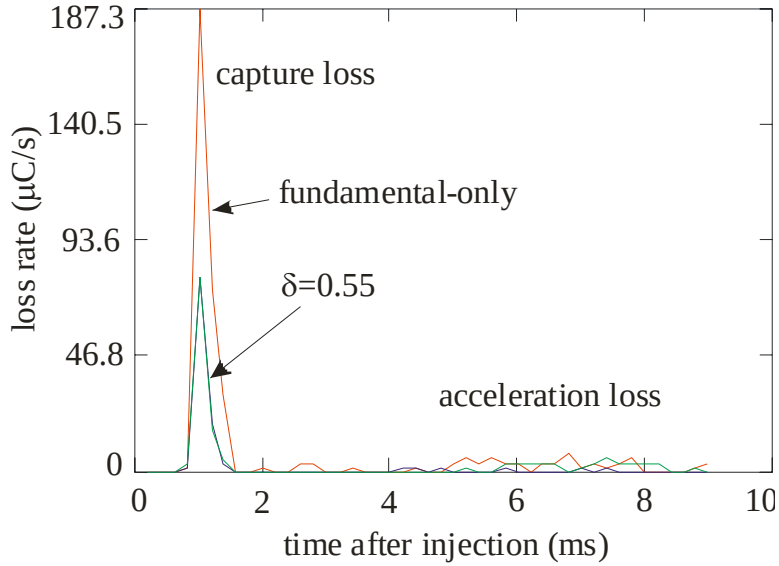
1. K. R. Symon, “Synchrotron Motion with Space-Charge,” ANL Report NSA-94-3 (April 4, 1994).

Comparison of “Leap Frog” with Predictor-Corrector for the IPNS RCS (no space charge in P-C)



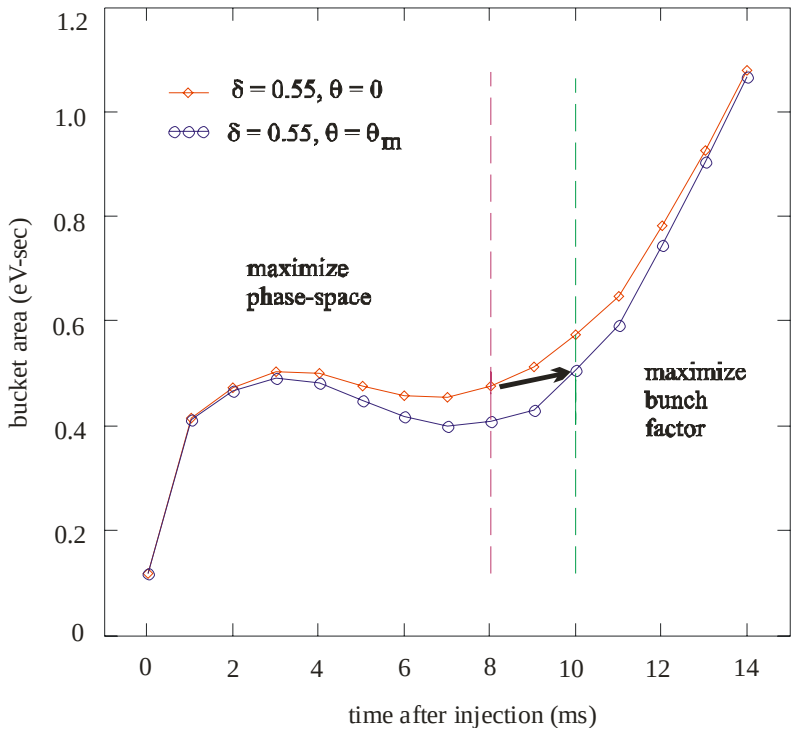
Simulation of injection capture loss in the RCS with and w/o SH rf





Full Cycle SH—need to adjust SH phase

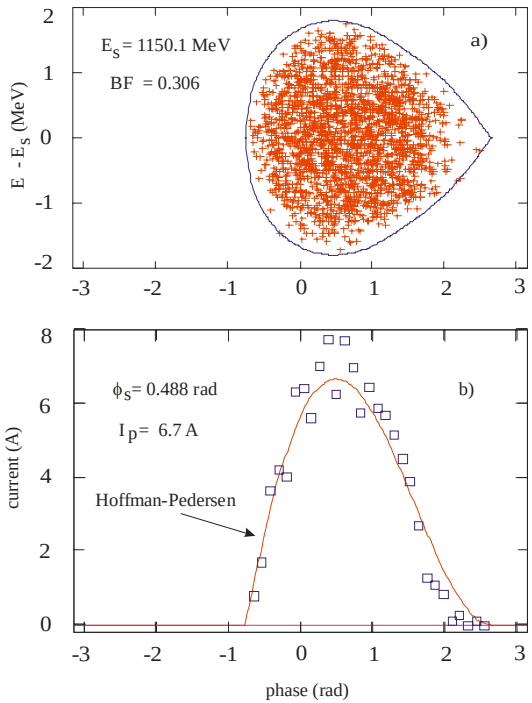
Phase-Space Modification for
Reducing Acceleration Losses
using phased, SH rf

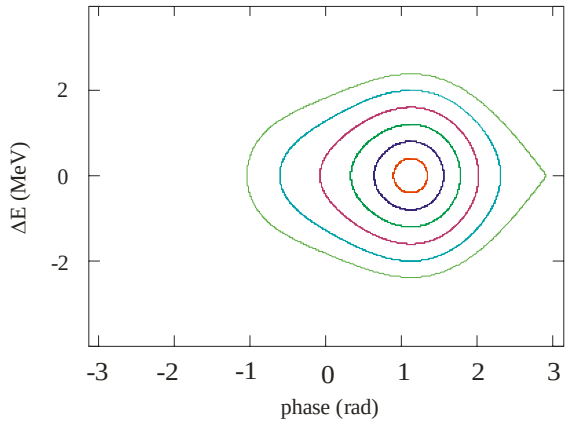


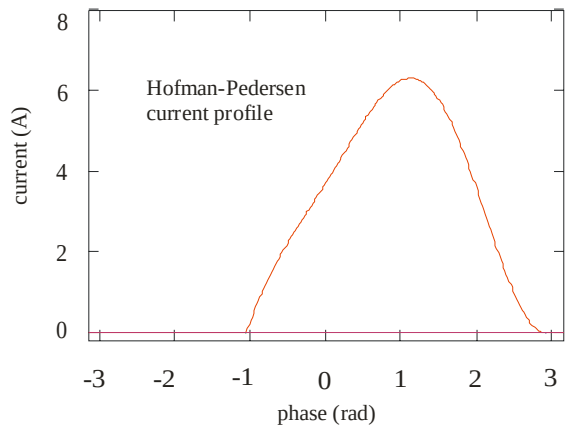
Phase-space distributions and current profiles—using Hofmann-Pedersen for analytic results

Phase-Space and Current Profile from CAPTURE_SPC

t=8 ms, fundamental rf only



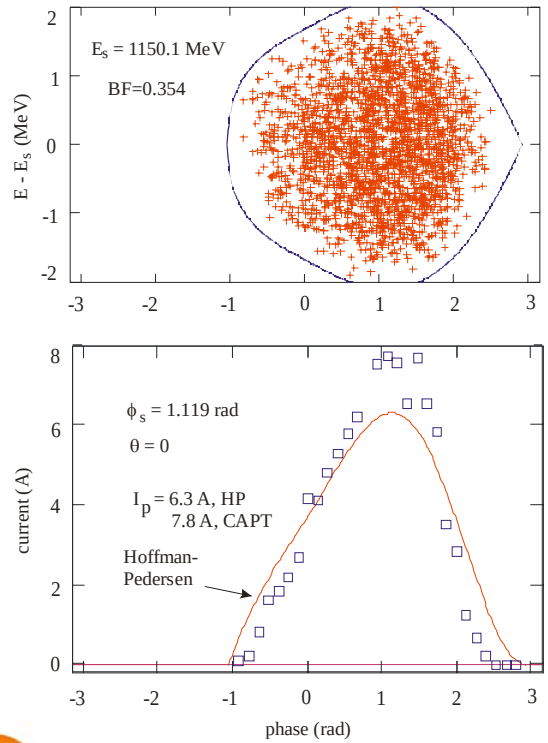




Phase-space distributions and current profiles

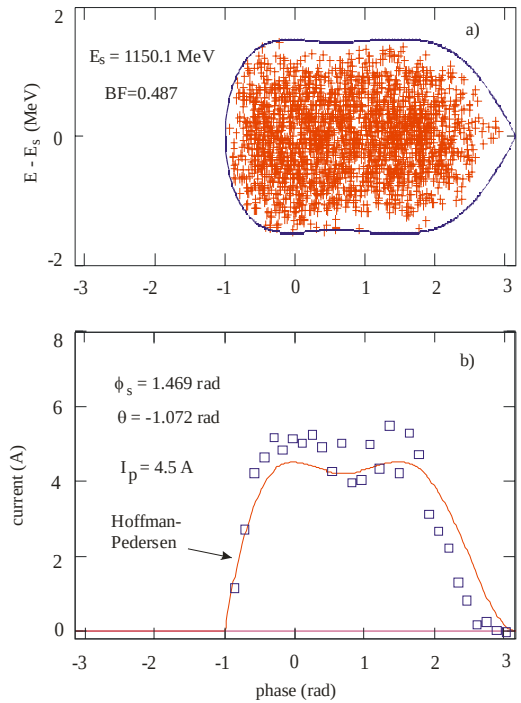
Phase-Space and Current Profile from CAPTURE_SPC

t = 8 ms, SH δ = 0.55, θ = 0



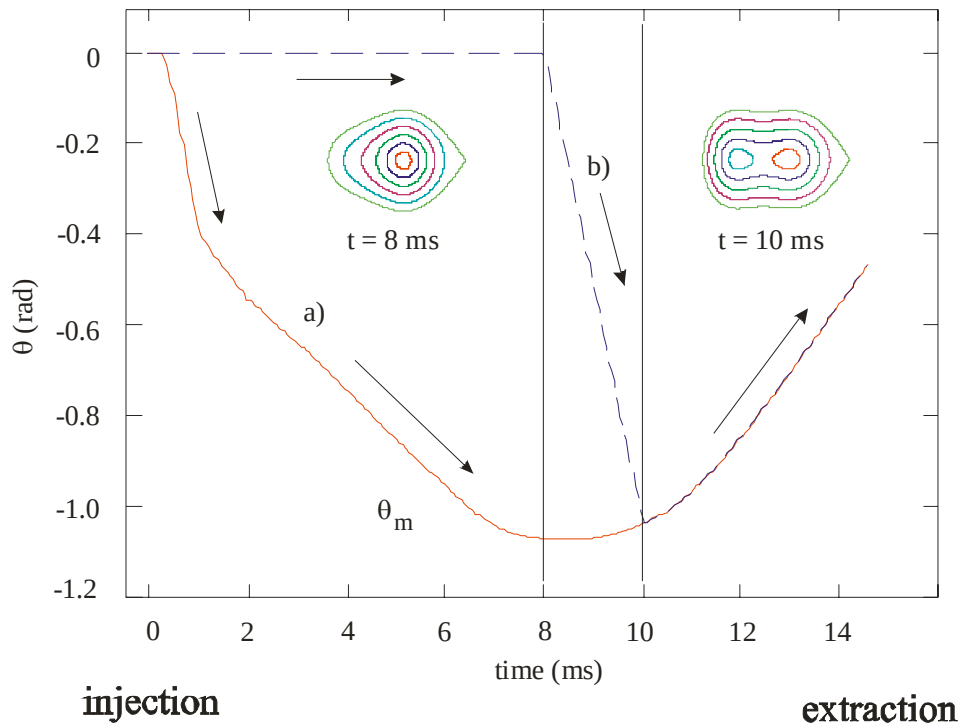
Phase-Space and Current Profile from CAPTURE_SPC

t = 8 ms, SH δ = 0.55, $\theta = \theta_m$

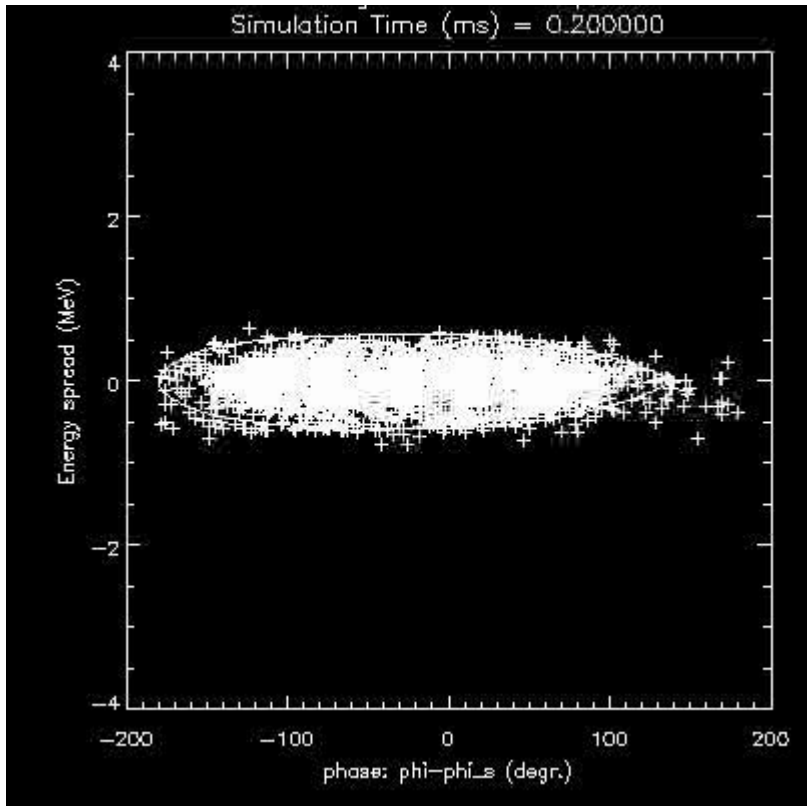


Phase Ramp

SH Phasing Program to Reduce Acceleration Losses

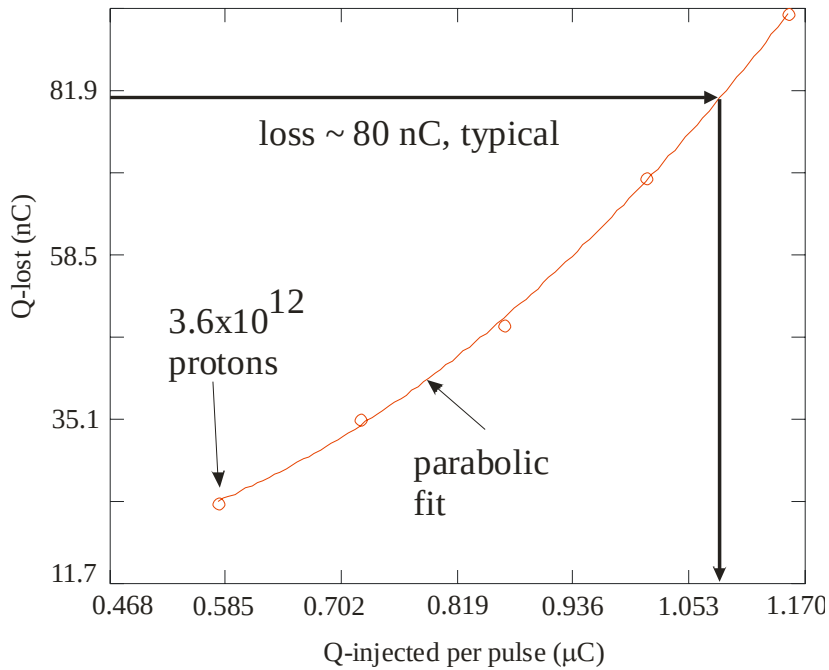


IDL animation of RCS CAPTURE simulation with SH and phase ramp

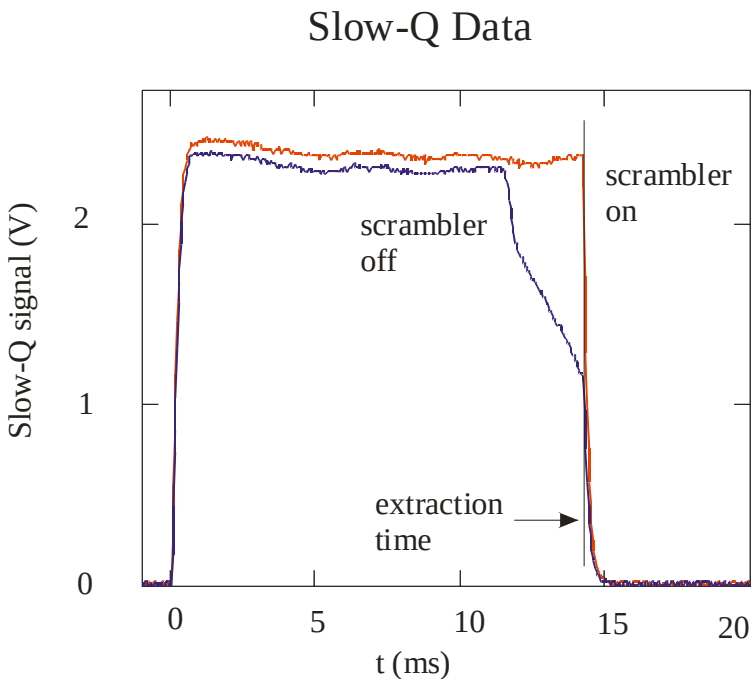


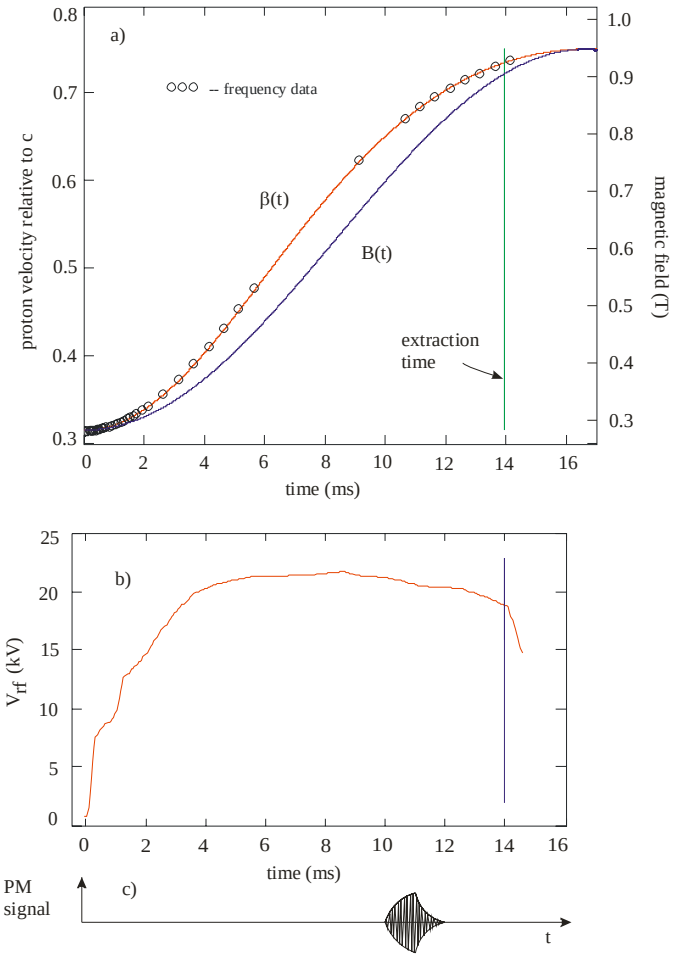
SH rf throughout the entire cycle

Loss limit operation predicted by
CAPTURE_SPC
using θ-ramp from 8-10 ms
(δ=0.55)



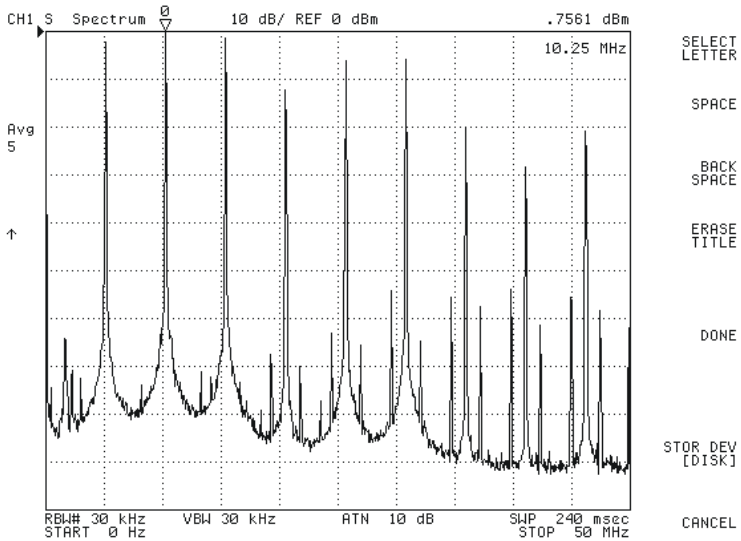
Complication(s)—Instability

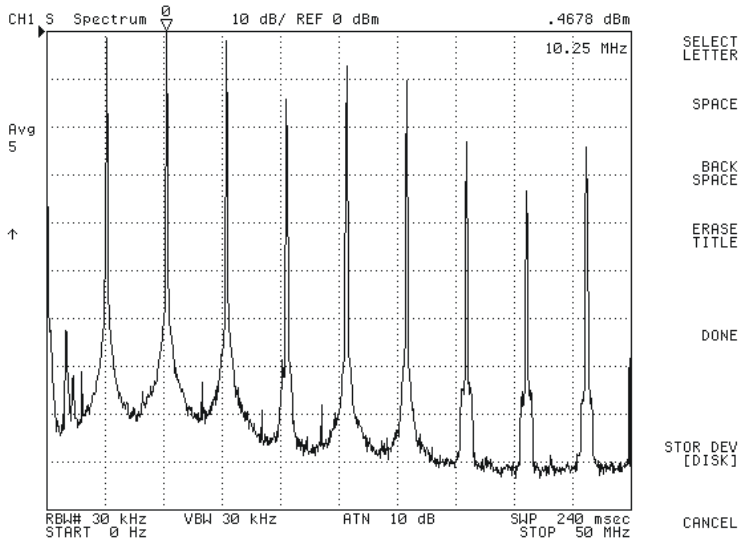




Vertical instability is damped with PM

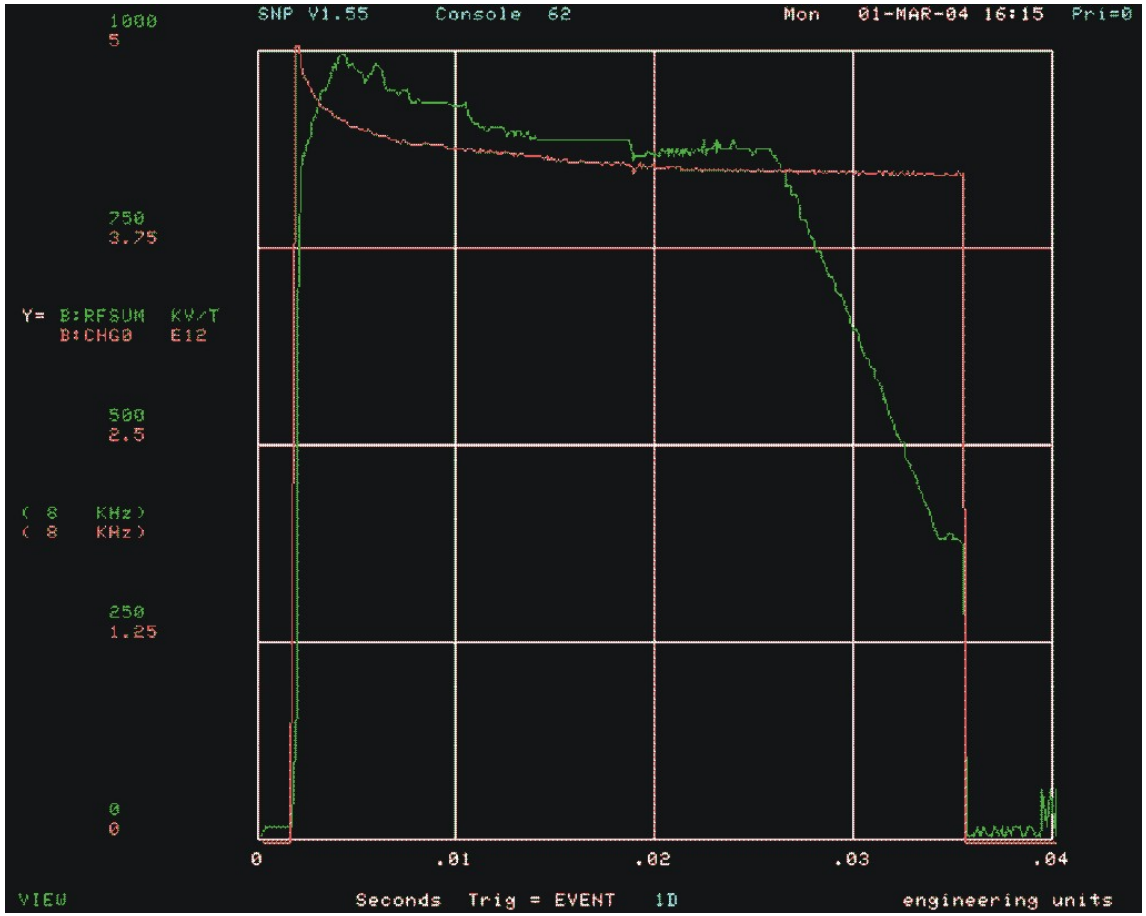
signals from single Pie electrode (H)



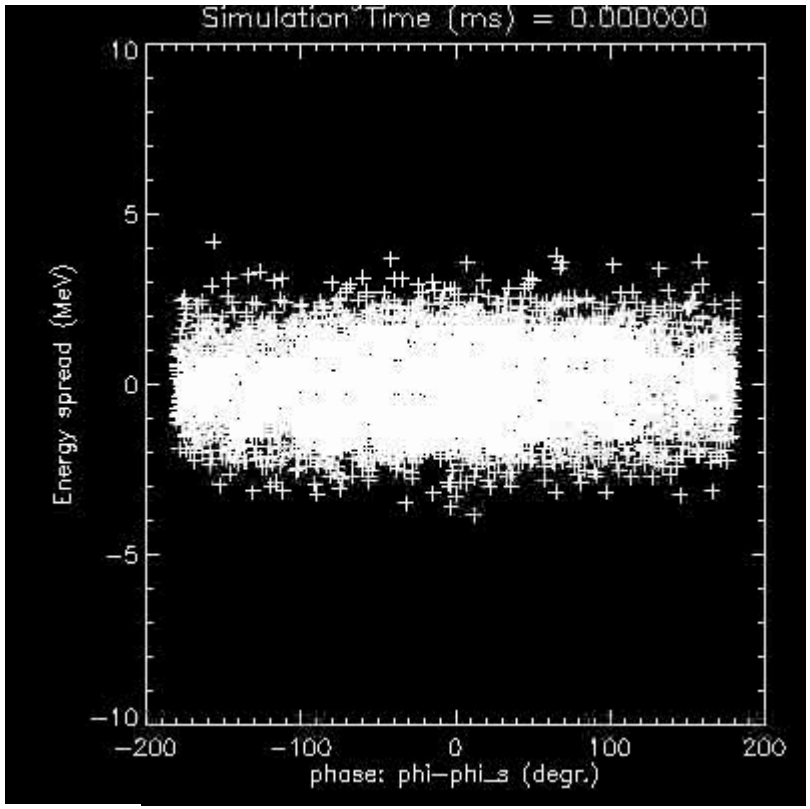


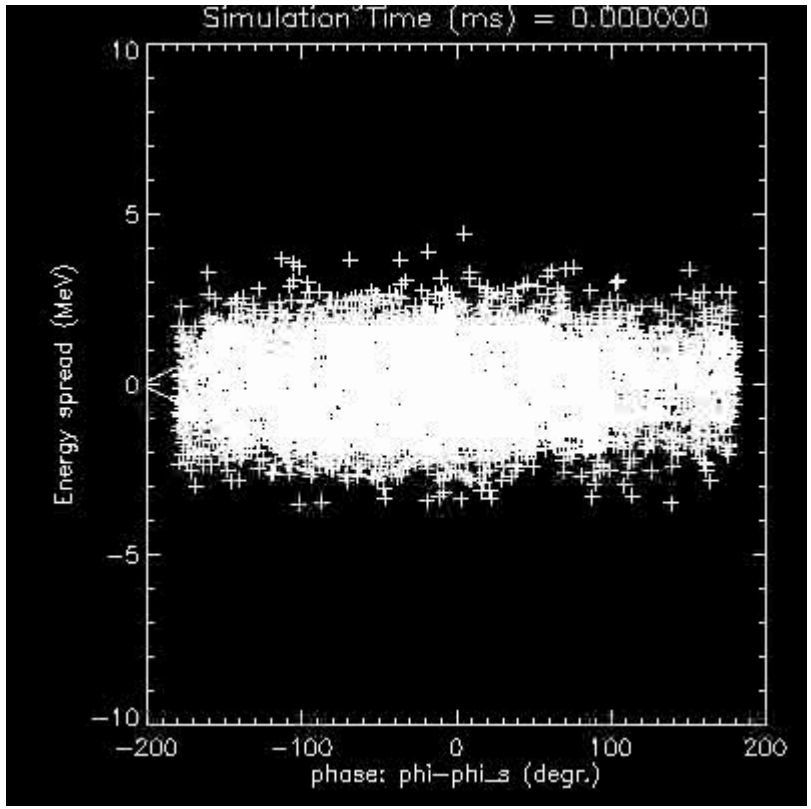
Initial Booster simulation results

Booster V_{rf} and Q data—March 1, 2004



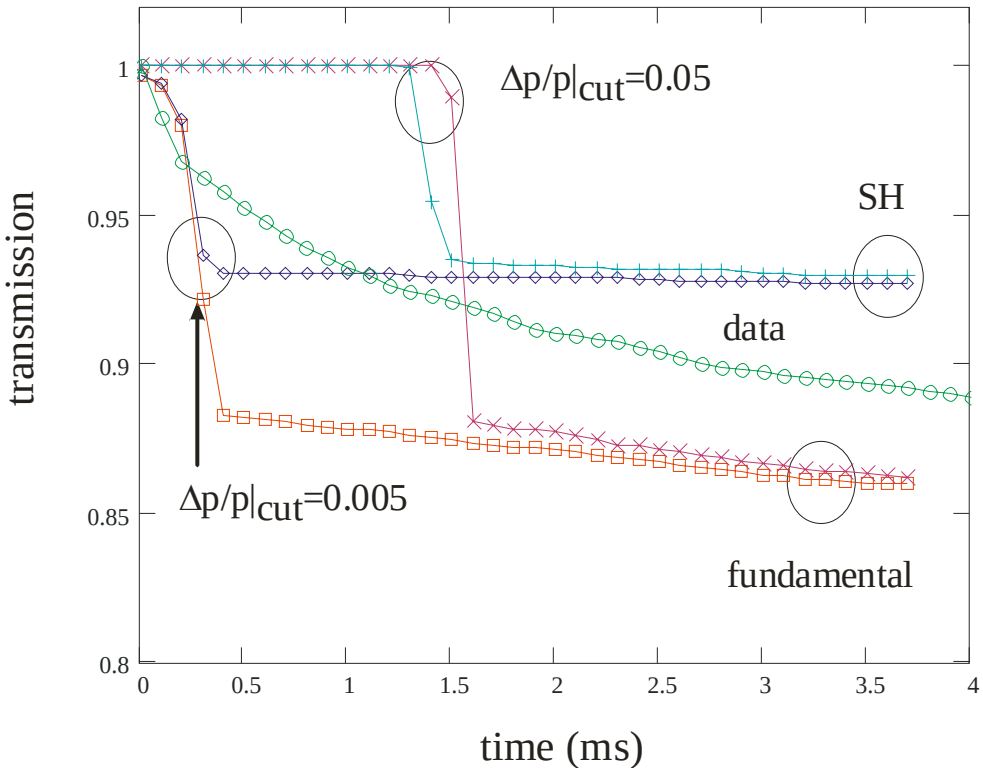
Booster CAPTURE_SPC simulations





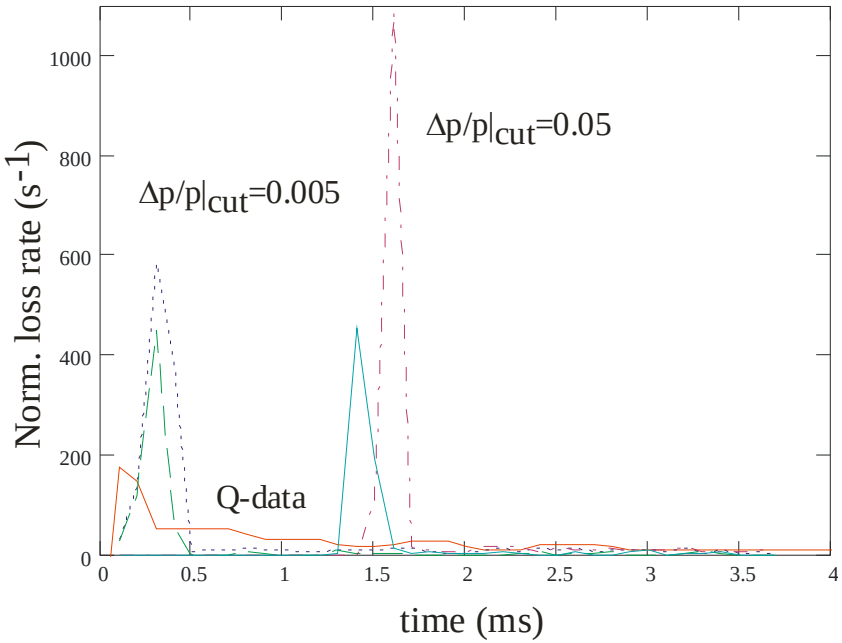
CAPTURE_SPC simulations of the Booster

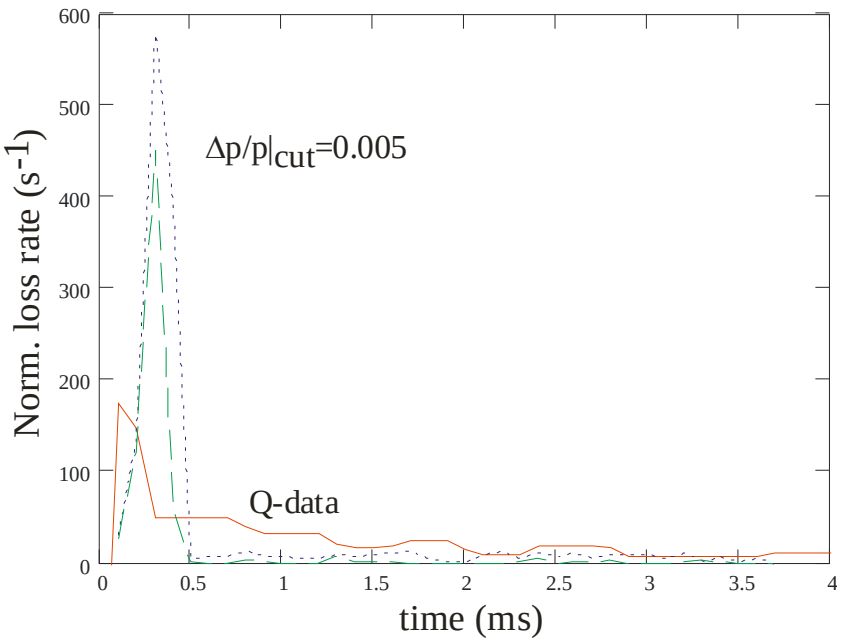
Booster capture loss from simulation and March 1st data



CAPTURE_SPC simulations of the Booster

Normalized Loss Rates from the Booster
CAPTURE simulation and Q-data





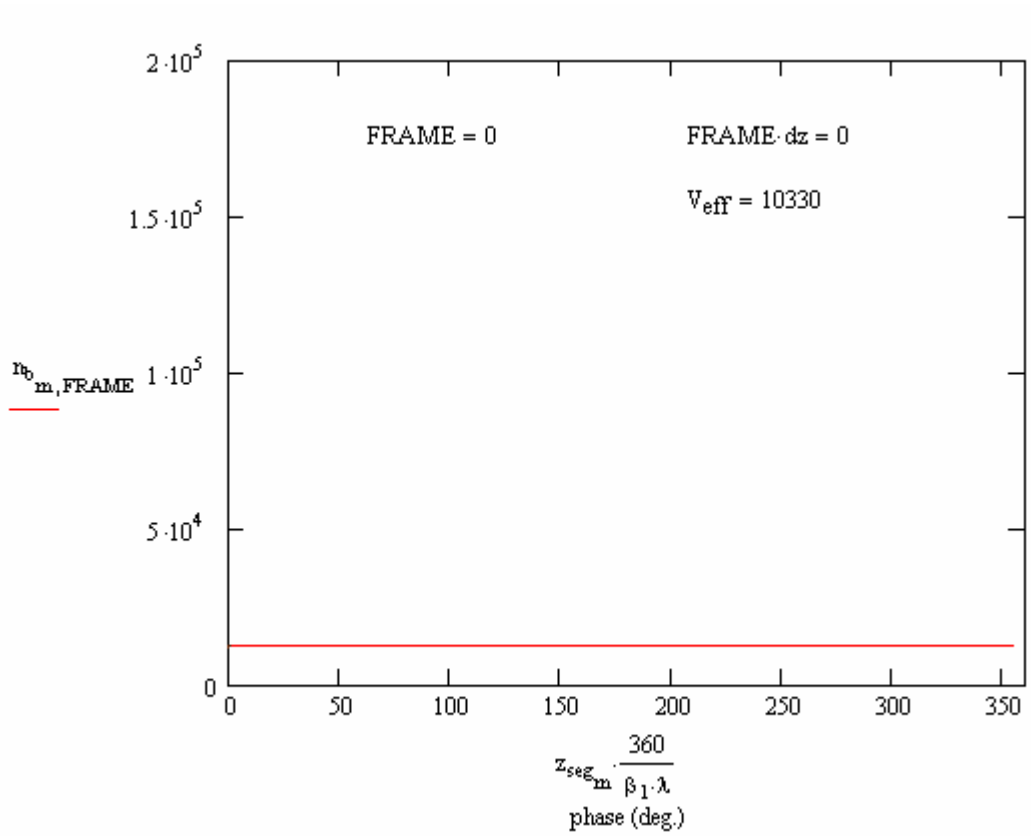
Initial Booster results from CAPTURE

- SH rf (δ=0.55) offers improvement in capture efficiency during the first 4 ms—86 to 93%.
- In the RCS, improvement is 88 to 96%

Further work

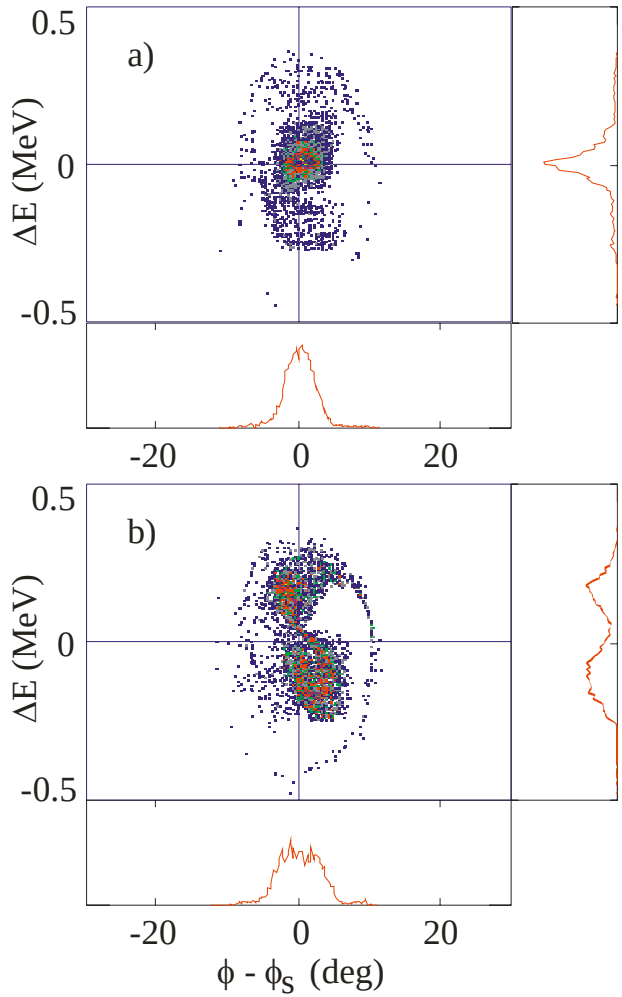
- Effect of turning SH rf off during the cycle
- SH phasing
- PM?
  - Increased energy spread for greater Landau damping
  - Controlled bunch rotation into transition to minimize losses
- Effects of the input distribution from linac

Axial density profile after the buncher



PARMILA modeling of the linac output

PARMILA LINAC final longitudinal phase-space
Buncher voltage of a) 10 kV and b) 13 kV.



Horizontal WS profiles in a high dispersion section of the 50 MeV line