Fermilab

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Injection from 8 GeV linac Proton Driver into the Main Injector

There are two injection modes to compare:

- synchronous injection into waiting buckets
- slow capture from coasting beam

Each mode needs some new hardware; it will be shown that slow capture needs less. There are two principal figures of merit:

- bunch area
- beam loss

It will be shown that loss can be negegible for either mode. Attempt to get emittance approaching the best attainable in slow capture, may cause some loss in the synchronous mode. Just before the workshop I learned that the linac may deliver $\Delta p/p \sim \pm 10$ MeV, larger than my working number of $\Delta p/p \sim \pm 3$ MeV. Fig. 16 from the design concept report TM-2169 Part II is shown in the next slide. Interpretation is not completely clear, but the implication of much wider momentum spread has led to last minute revisions of my presentation.

halving the number of SCRF klystrons by cutting the beam current by half and doubling the pulse length (see sect. 23.4). This scenario narrows the cavity bandwith and doubles the synchrotron phase advance across a group of cavities, both of which will reduce the performance of Vector Sum Regulation.

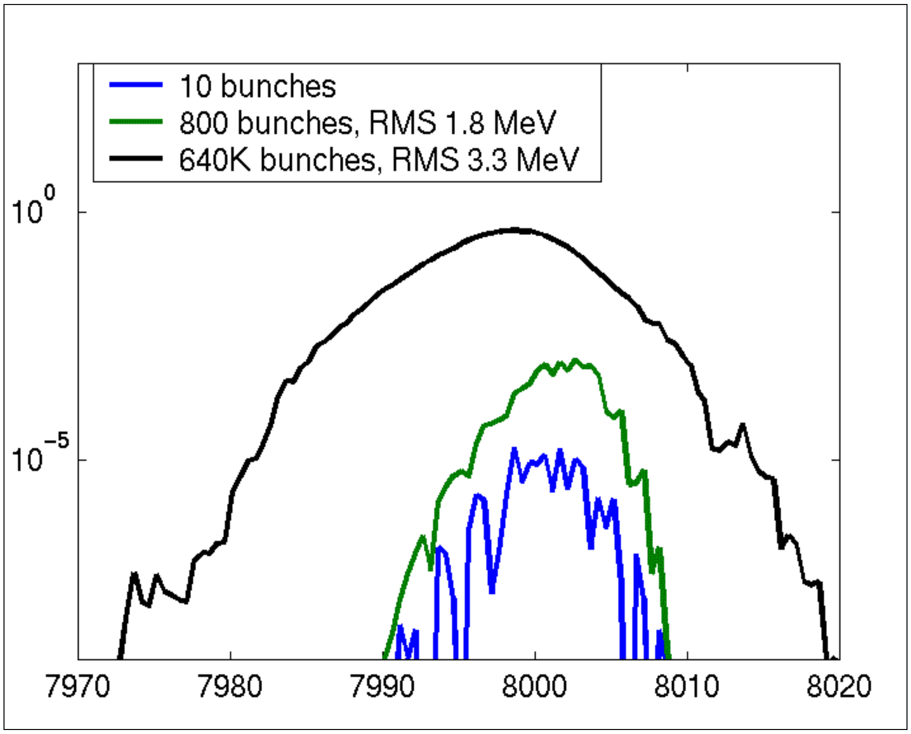


Figure 16 – Simulation of Vector-Sum Regulation with Microphonics in the 1207.5 MHz (β = 1.00) section of the 8 GeV Linac. One klystron drives 12 cavities. Microphonic resonance shifts of σ = 10 Hz were assumed, approximately 3x worse than recent measurements of SNS cavities (Figure 15). Beam was injected into the 1207.5 MHz section at 1.3 GeV with an initial emittance of 2.2π eV-s and zero energy jitter. Bottom trace: energy spread of 10 representative bunches, with a typical emittance of 2.8π eV-s (i.e. dominated by the incoming emittance). Middle trace: energy spread of 1 "macropulse" of 800 bunches. Top trace: energy spread of 800 macropulses, with an energy spread including the pulse-to-pulse fluctuations due to cavity microphonics. The output energy jitter was dominated by microphonics effects as expected, but the output energy spread was limited to σ(E)/E = 0.04% by vector sum regulation.

5.9 Resonance control in the 805 MHz (β< 1) Linac

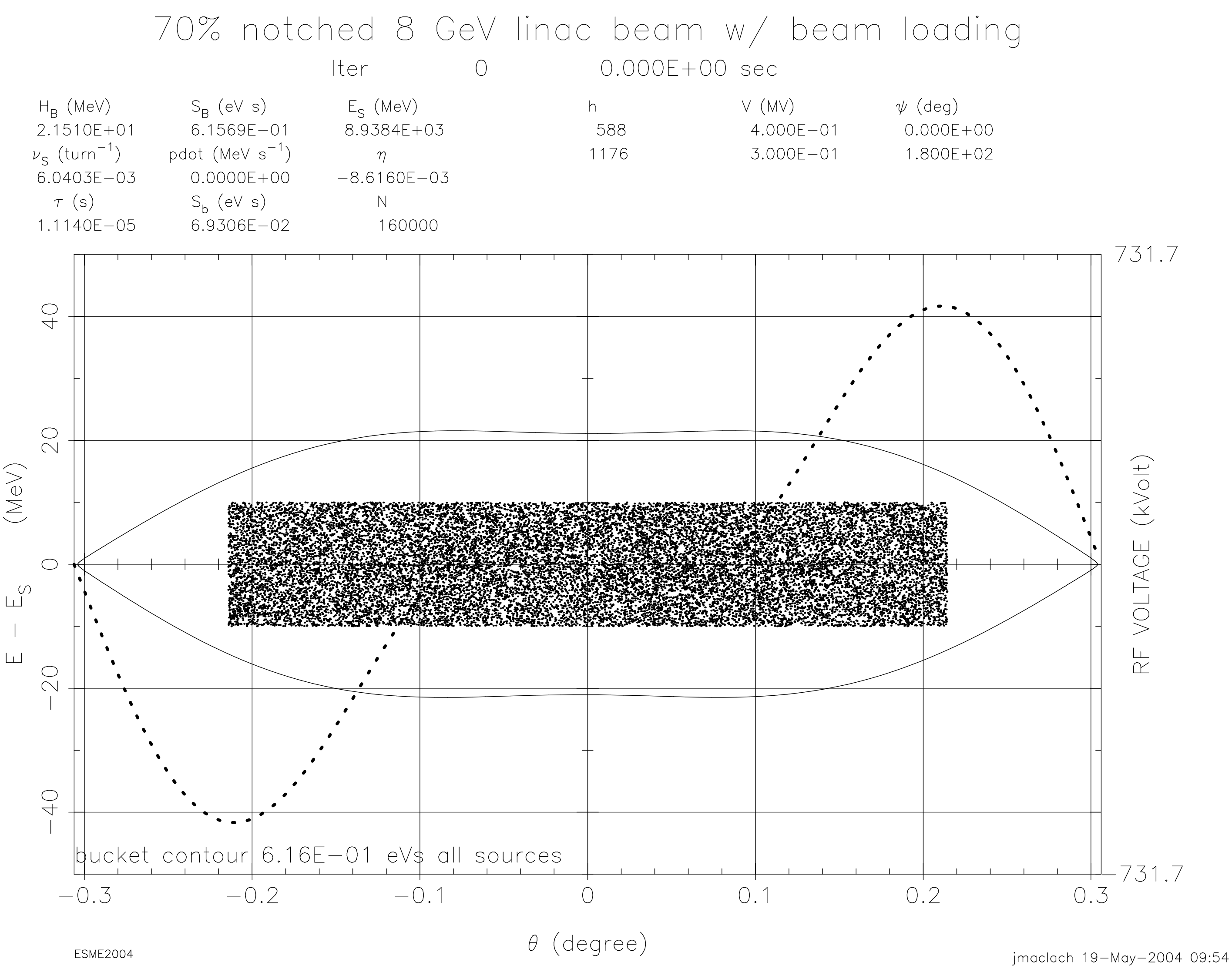
In the β <1 (805 MHz) section of the linac, the stringent resonance control requirements for non-relativistic protons will be met by high-power, fast ferrite tuners (sect. 13.6) on the RF drive to each cavity. These provide fast modulation of phase and amplitude of the RF drive to each of the 96 cavities, while preserving the economics of the TESLA-style RF fan out.

Page 33 of TM-2169, the current draft of the 8 GeV linac concept. The caption paritially explains how the energy spreads shown were generated by various assumptions about the control of phase in the high energy modules. Even without a full understanding of the details, one is warned that the concept as it now stands is not favorable for direct injection into the MI.

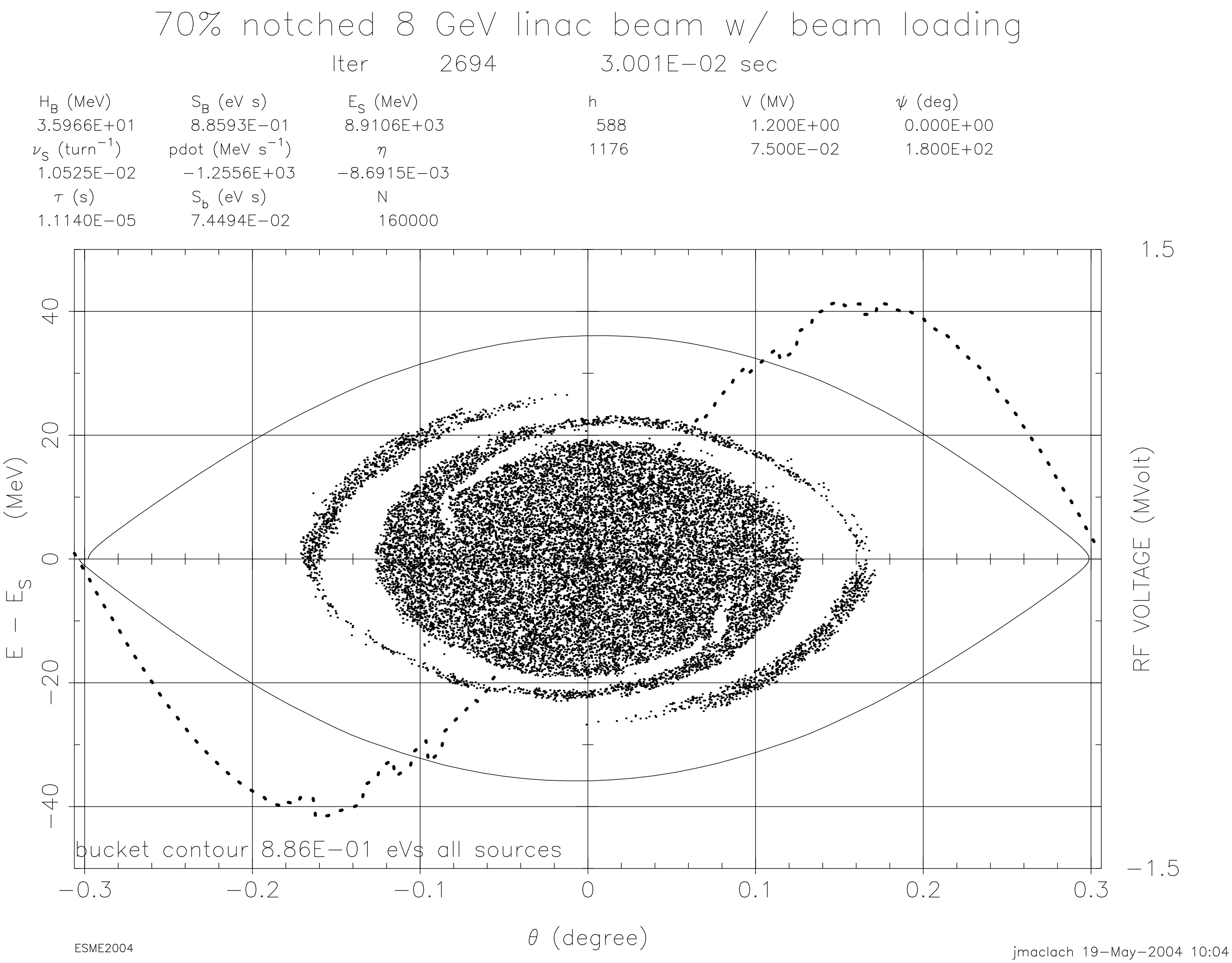
Synchronous Capture

- Synchronous capture requires that the beam have about 6 ns gaps every 19 ns during the 3 ms of injection.
- The beam must also be chopped at 90 kHz to provide the abort or kicker gap of a few hundred ns.
- Because synchronous capture is into existing 53 MHz buckets, it does not reqire a barrier cavity to preserve the kicker gap.
- Momentum painting permits matching into buckets at higher voltage for better stability.
- A second-harmonic cavity with 50% (or even more) of the fundamental capture voltage is valuable to match the flat beam segments onto the normally elliptical trajectories.

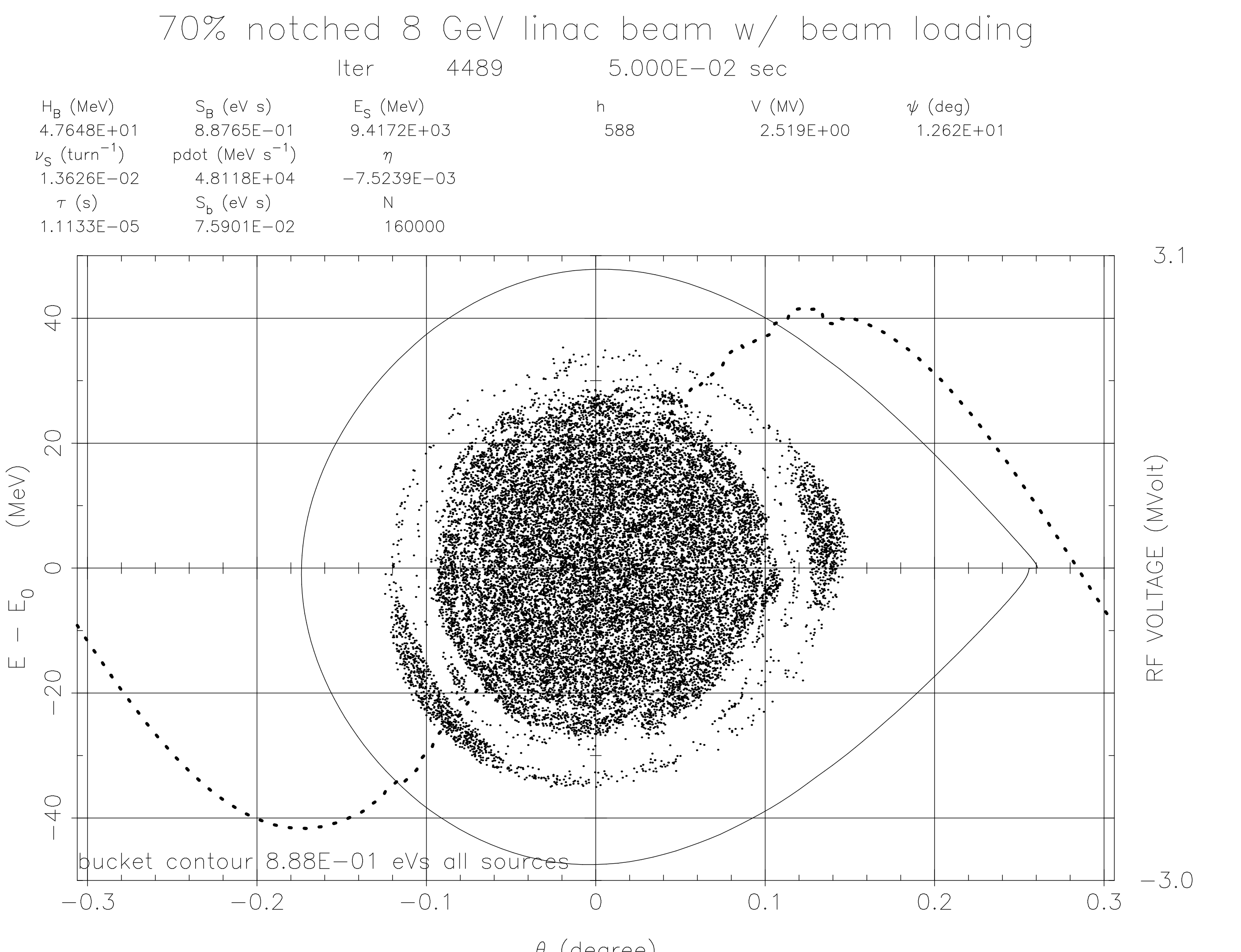
- The emittance optimization involves three sources of dilution.
  - intentional dilution from painting
  - dilution from instability
  - dilution from imperfect matching
- emittance optimization can be improved by accepting small beam loss.
- The matching operation for synchronous capture also needs $\sim$ 30 ms.



A $3 \cdot 10^{11}$ proton chopped segment of 8 GeV beam approximately mactched to .6 eVs bucket created by 53 MHz at 400 kV and 106 MHz at 300 kV.



Same bunch shown in previous slide after .03 s of matching; rf voltatage change is 400 kV $\longrightarrow$ 1.2 MV for 53 MHz and 300 kV $\longrightarrow$ 75 kV for 106 MHz.

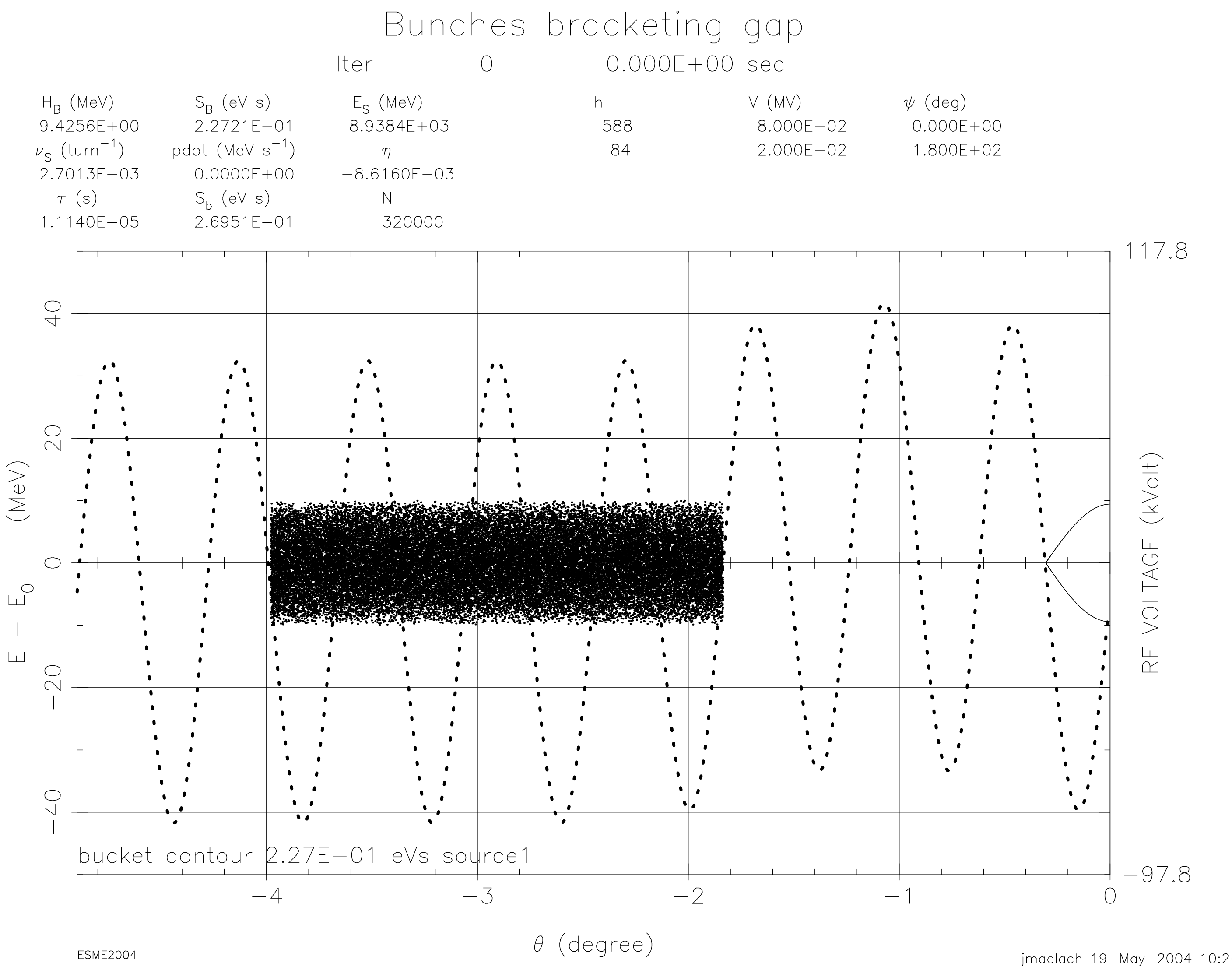


Same bunch shown in previous slide after acceleration to nearly 9 GeV. The bunch areas are about 0.38 eVs, excluding some very tenuous halo.

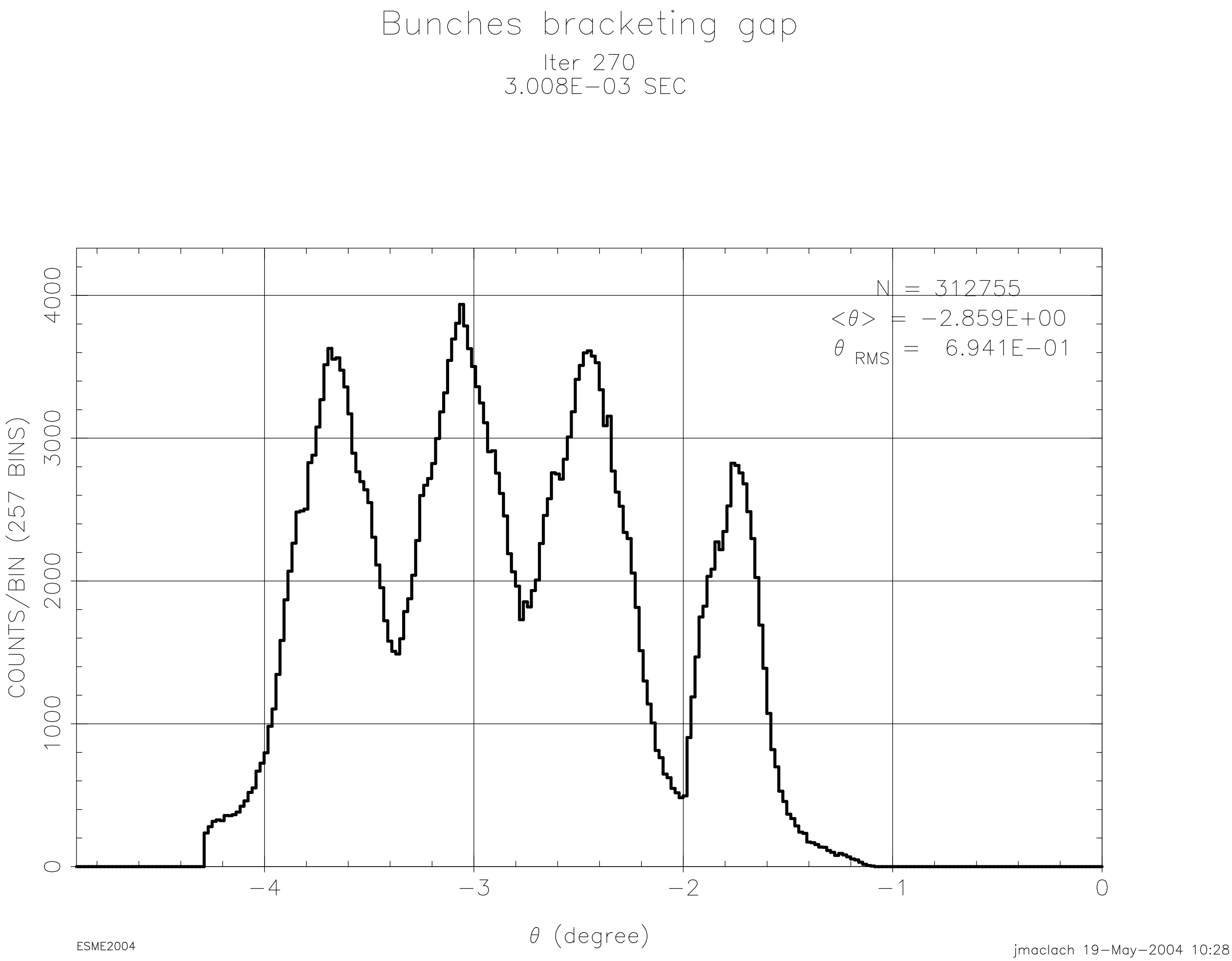
Slow Capture — Abort Gap Preservation

- Slow capture may require momentum painting to preserve stability while the rf voltage is low if linac delivers $\Delta p/p \sim \pm 3$ MeV.
- Greater momentum spread not only enhances stability but also permits higher initial voltage and faster capture.
- Optimum momentum spread balances emittance dilution by instability vs. intentional emittance dilution by painting.

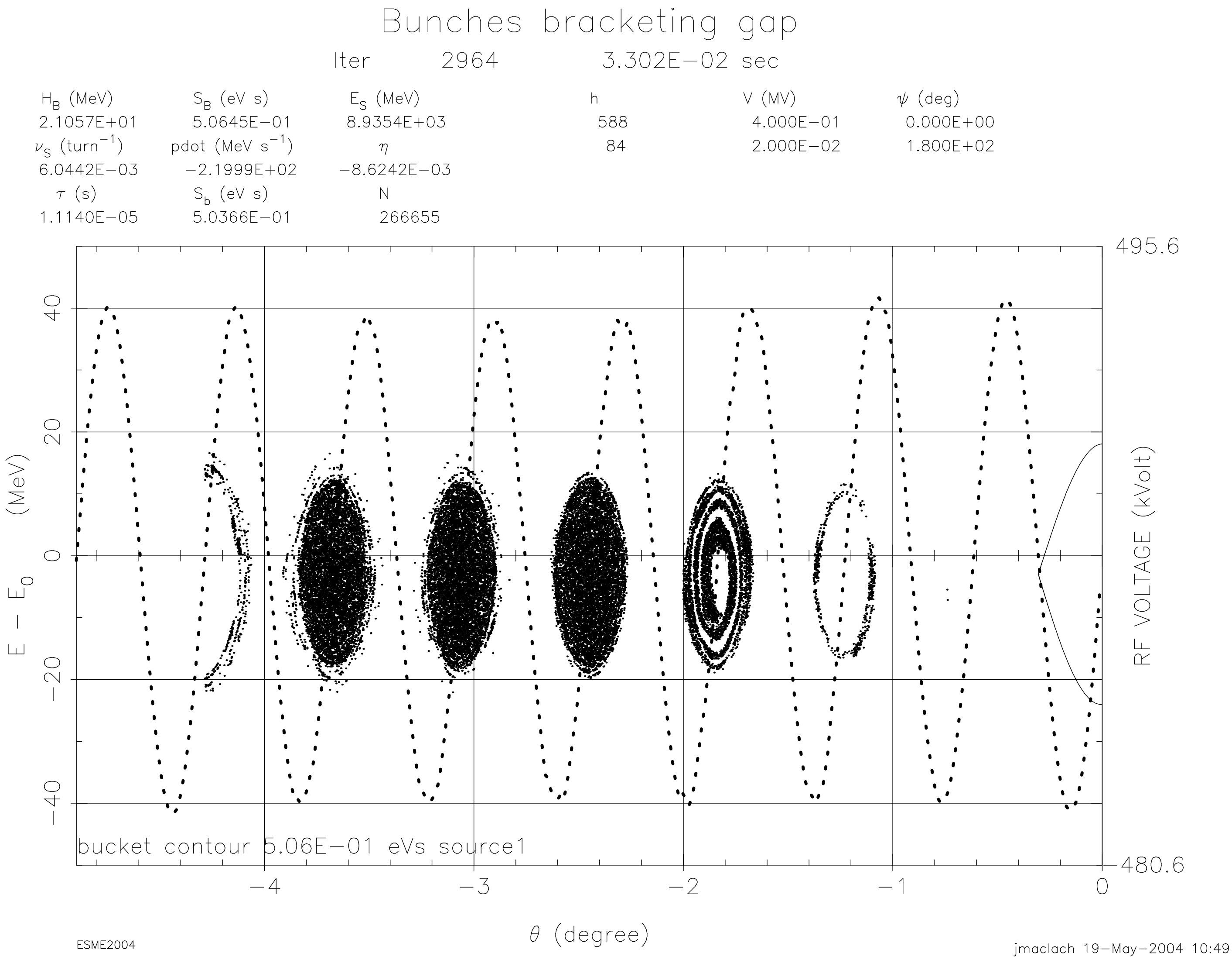
- Beam must be chopped at circulation frequency to leave an abort or kicker gap of a few hundred ns.
- Injection time for $\sim 10^{14}$ protons is 3 ms.
- The capture time is ~ 30 ms or longer.
- An rf barrier created by the existing or simillar finemet cavity can maintain a gap in the beam of few hundred ns. Barrier voltage required depends on $\Delta p/p$.
- The 90 kHz chopping is simpler by electric deflection than by laser stripping of H^-.
- The BPM signal should be detectable a few (maybe 1 or 2) hundreds of μs after beginning of injection; there is always some 53 MHz rf present. Problem is probably dynamic range, not maximum feasible sensitivity.



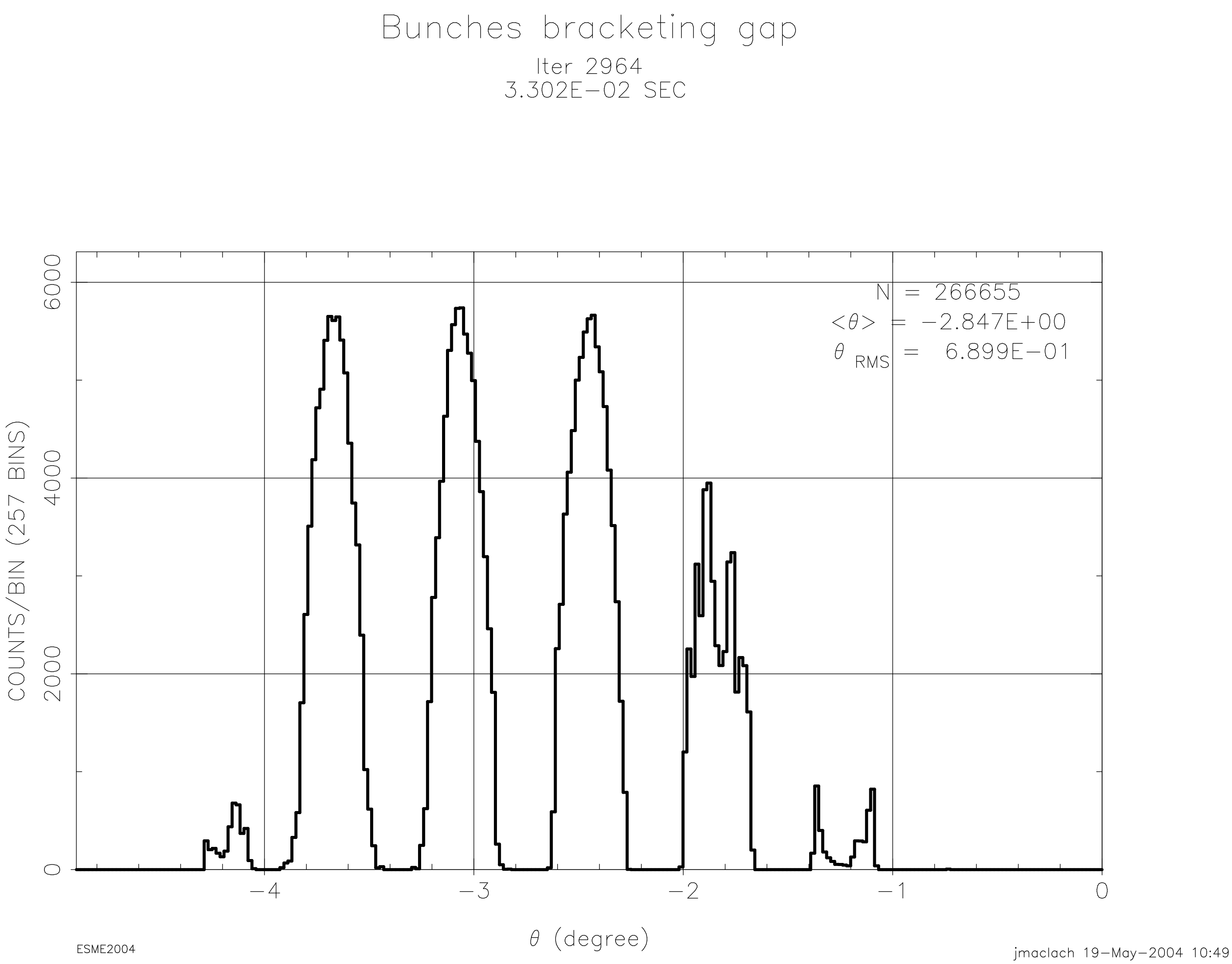
A 66 ns segment of 8 GeV beam of Δ E =$\pm$10 MeV carrying $1\cdot10^{12}$ protons; the dotted curve is the rf waveform of 53 MHz rf at 80 kV plus a 20 kV isolated sinusoidal barrier at 7.5 MHz.



The azimuthal projection of the preceeding distribution after the 3 ms injection period.



The same distribution after 30 ms additional for slow capture. The final 53 MHz voltage is 400 k V; the adiabaticity parameter for the capture is $\alpha_{\rm ad} = 0.08$. The bunch areas are about 0.3 eVs again excluding a few tail particles.



The azimuthal histogram for the preceding distribution; the population for the leftmost bucket reflects transfer of particles to more negative phase not replenished by transfer from more negative phase because that part of distribution was not included initially. The rightmost 2 bunches are inside the 20 kV barrier, but the kicker gap is not filled.

Comments or Conclusions

- It is unclear that there is advantage to synchronous transfer of 53 MHz chopped beam in preference to capture from 90 kHz chopped beam in time, efficiency, or emittance if the available momentum spread from the linac is $\Delta p/p \sim \pm$3 MeV.

- Synchronous capture at higher initial rf voltage is a good fallback if stability difficulties are more severe than anticipated.

- In either case the final longitudinal emittance is within the momentum acceptance of the Main Injector at transition.

- Results shown are not painstakingly optimized; the longitudinal coupling impedance is not well enough known to permit highly accurate quantitative conclusions.