402.5 MHz Debunching in the Ring

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Motivation

- The BPMs in the ring can be operated in either of two modes:
  - Baseband, sensitive to frequencies of at most a few MHz,
  - Linac RF frequency, sensitive to a narrow band around 402.5 MHz.

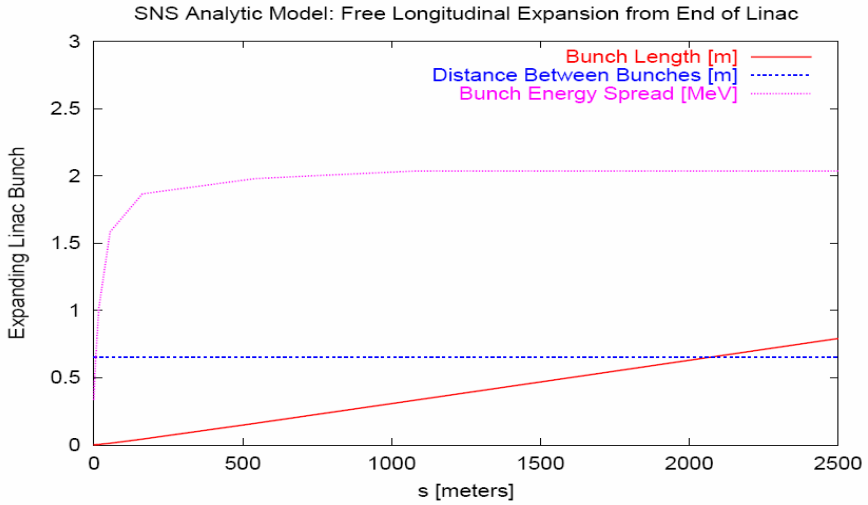
- To assess the possible duration for using the BPMs in the RF frequency mode for diagnosing low intensity injected beams, the following studies of the debunching of the linac time structure in the ring were performed.

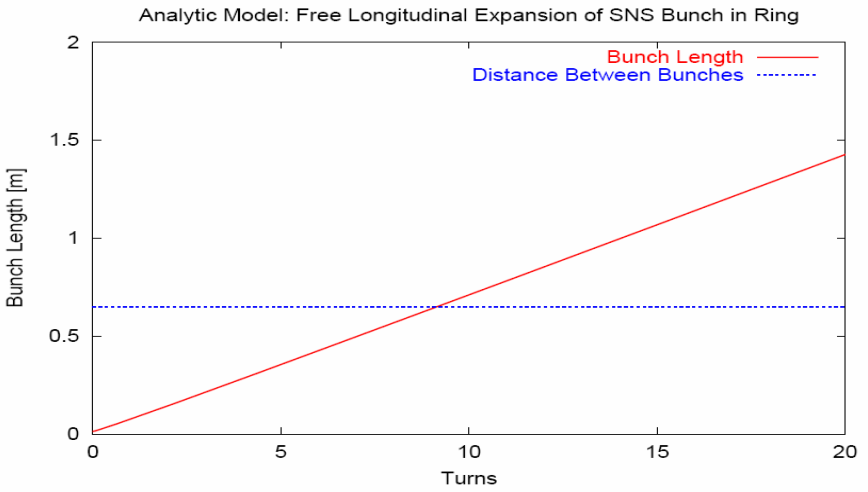
Simple Analytic Model

- We start with a simple analytic model:
- Assume
  - Ellipsoidal bunch of uniform charge density,
  - Bunch is circular in transverse plain,
  - External transverse focusing is just sufficient to maintain constant transverse dimensions,
  - Free expansion in the longitudinal direction.
- Solve for the length of the bunch as a function of time given the
  - Initial charge, dimensions, and expansion rate.
  - Solve in reference frame of bunch and then convert to lab frame.
- Solutions were obtained using Mathcad for SNS and for PSR parameters.

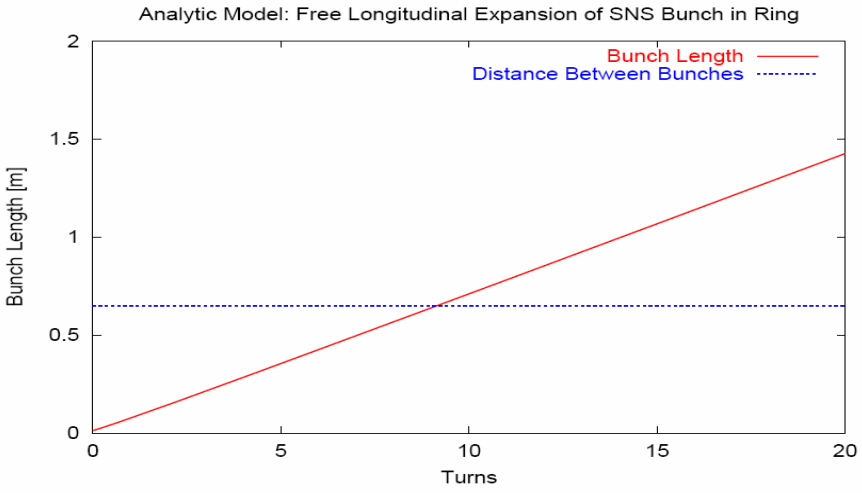
Analytic Model: Expansion of Linac Bunch

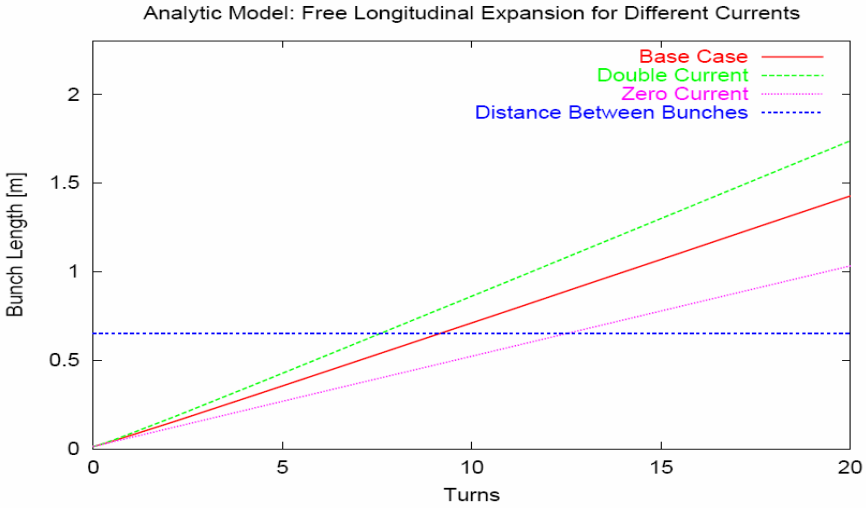
- For SNS parameters at the end of the linac, the bunch expands to
  - dE = ± 2 MeV in about 1000 meters, and is close to the final value in about 200 m
  - A size of 0.65 m (the interbunch spacing) in about 2000 m.
- For parameters taken at the injection foil, the bunch size expands to the interbunch spacing in about 9 turns.

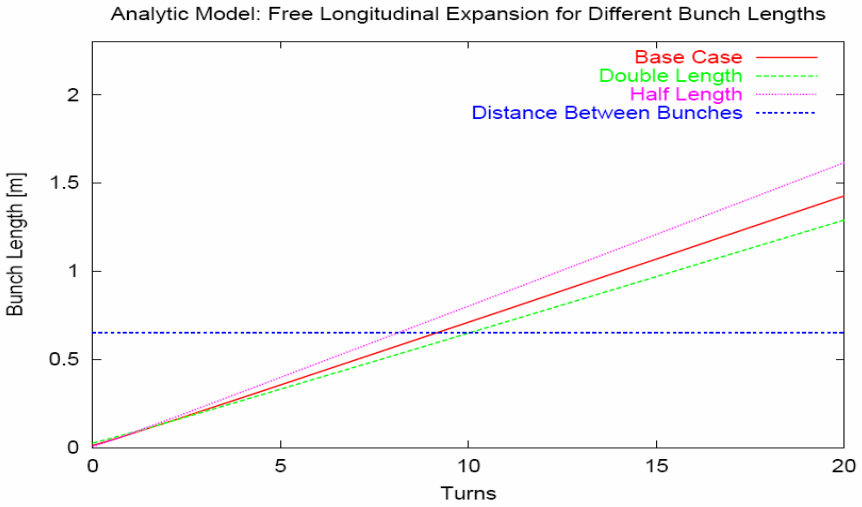


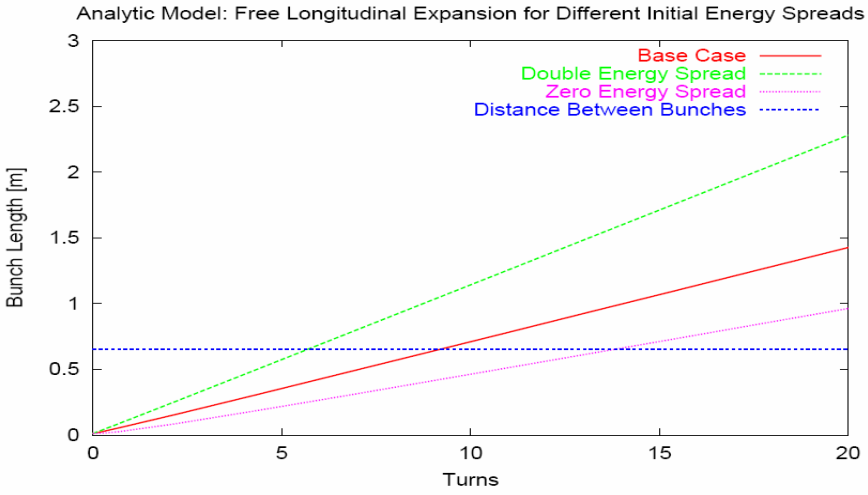


Analytic Model: Sensitivities to Initial Bunch Current, Length, and Expansion Rate



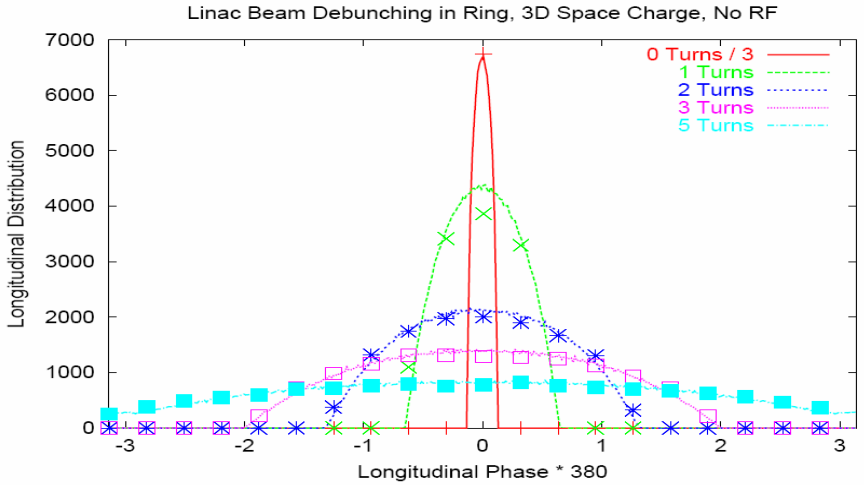


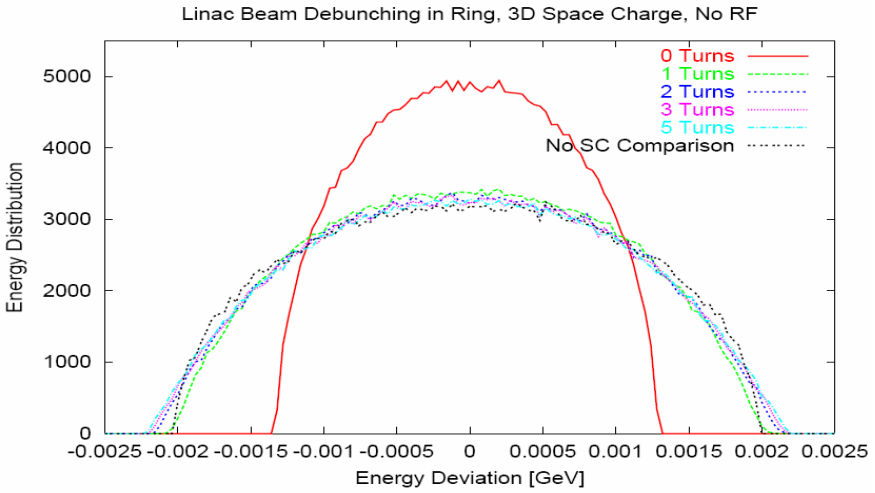




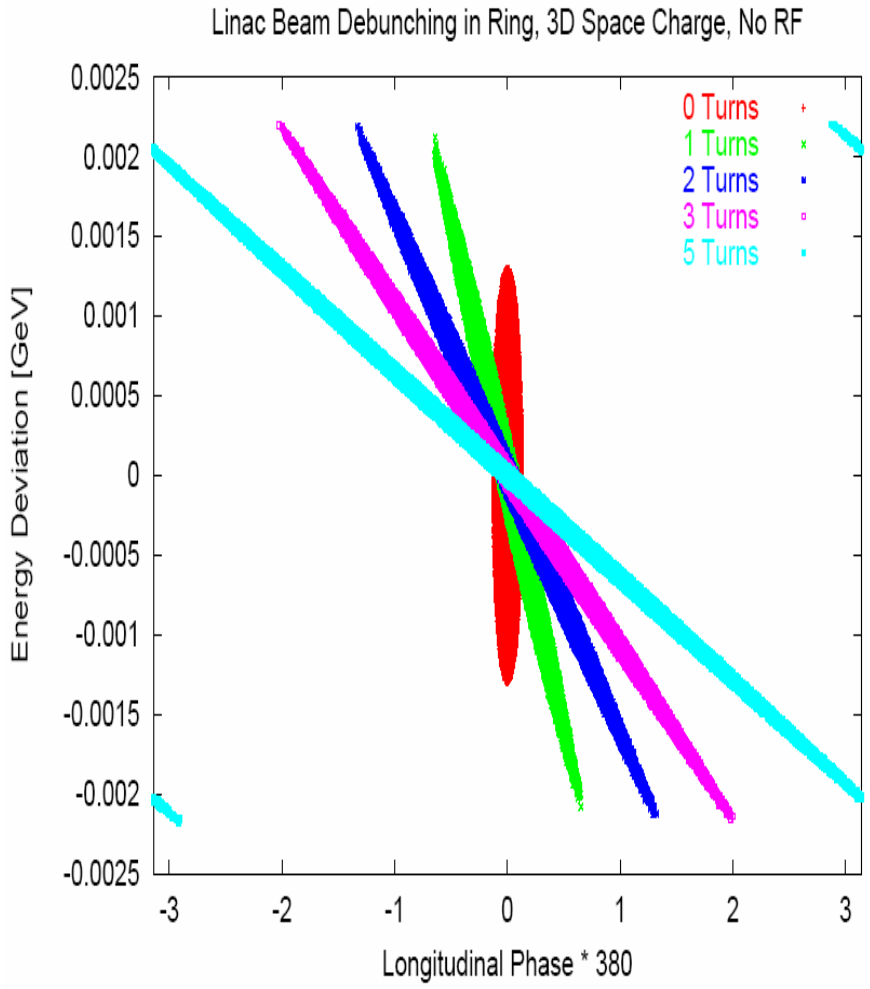
ORBIT Calculations with Full 3D Model: 402.5 MHz Debunching in Ring

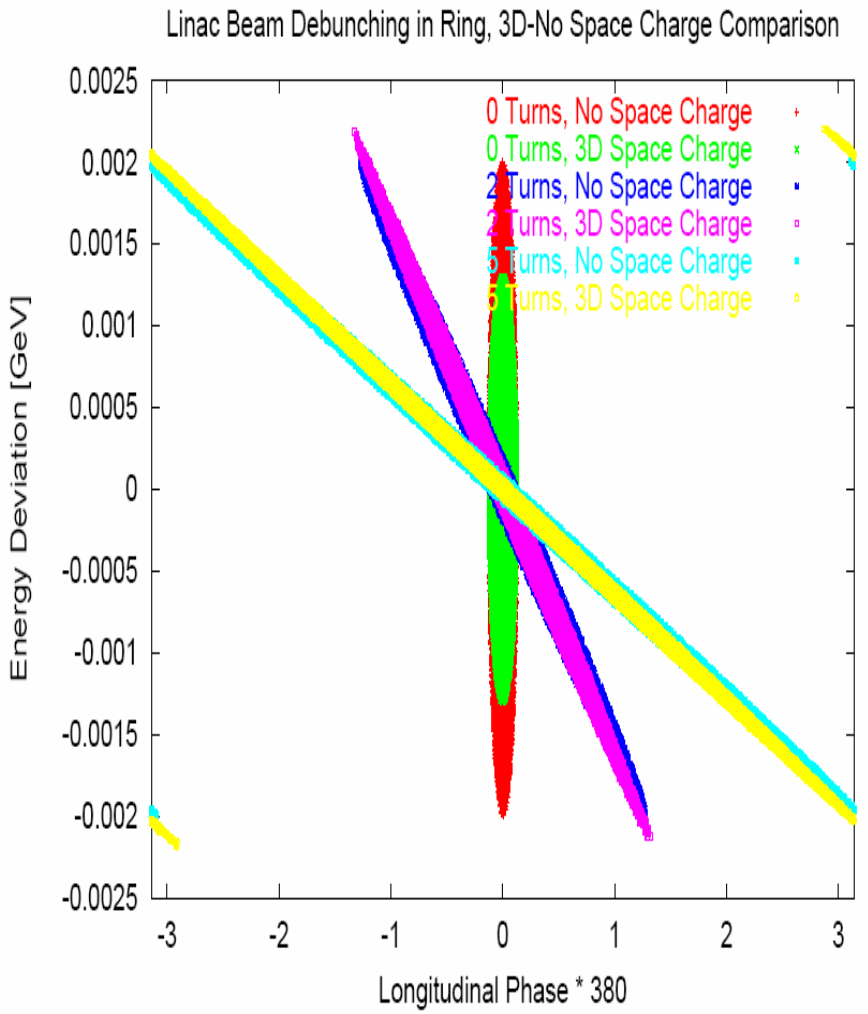
- Taking initial conditions to be the linac bunch at the injection foil:
  - energy distribution reaches steady state in about 1 turn
  - Longitudinal distribution debunches in about 5 turns
- The role of the space charge force is to quickly increase the energy spread to a broad steady state distribution, which then leads to rapid debunching.
- Once the steady state energy spread is achieved (1 turn), space charge can be ignored.





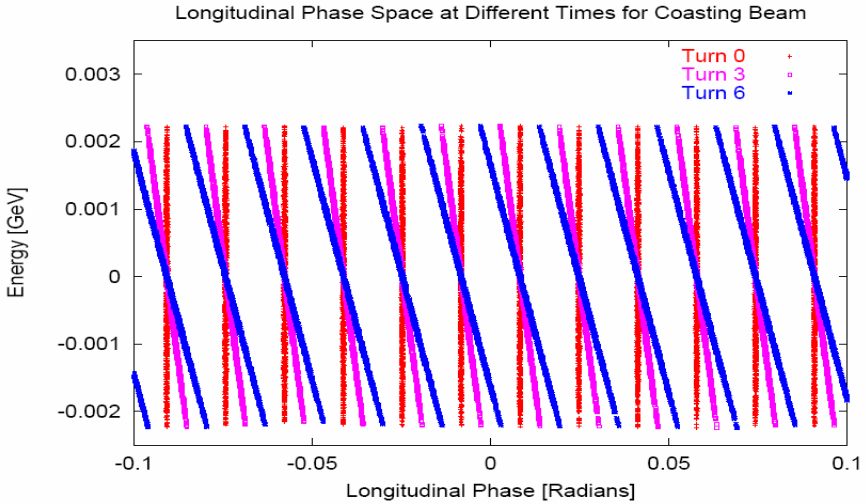
ORBIT 3D Model: Phase Space Debunching and Space Charge Effect

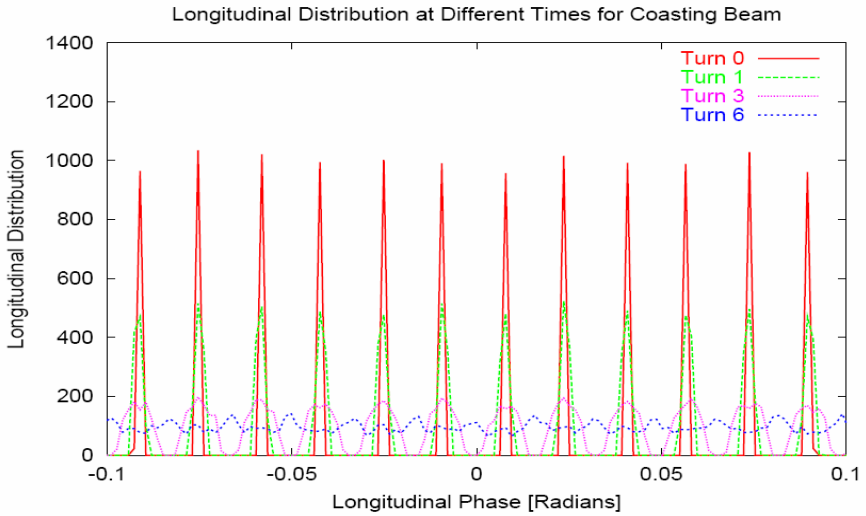




ORBIT Calculations:
Multibunch Evolution and Loss of 402.5 MHz Signal

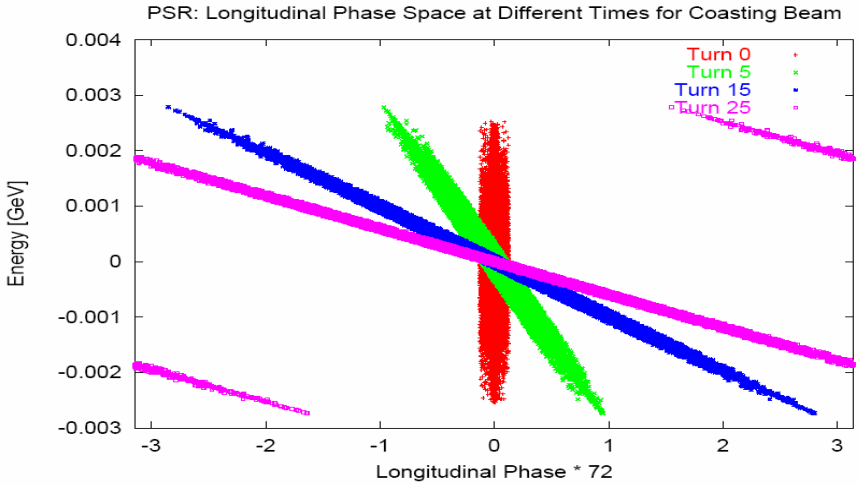
- Multibunch calculations with ORBIT are consistent with the single bunch evaluations when the same energy distributions are used:
  - Debunching occurs in about 5 turns,
  - Because the energy distribution rapidly achieves steady state, space charge is not a big factor in debunching after the first turn.

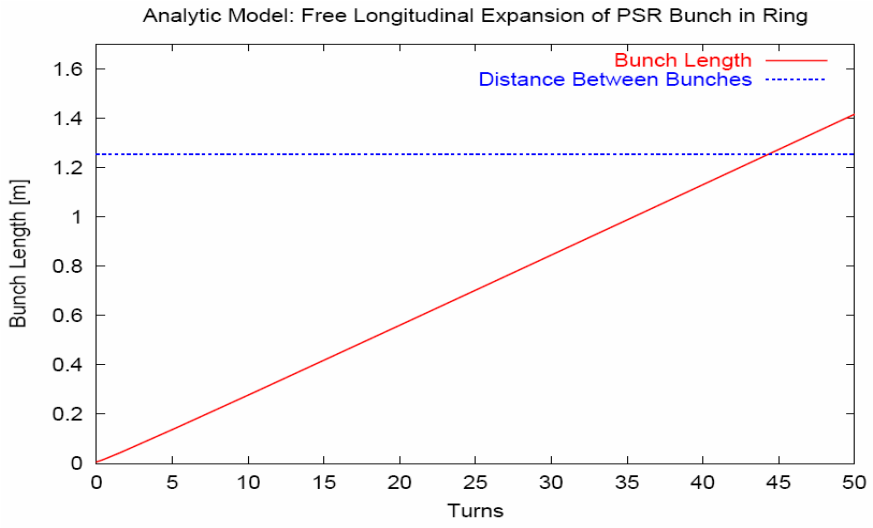


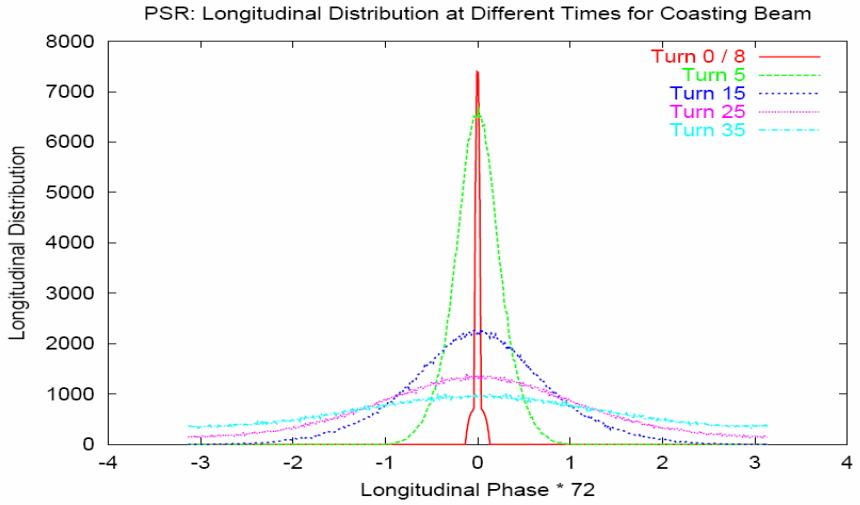


Single Turn Debunching in PSR

- Analytic and ORBIT single bunch calculations agree: debunching in 40-50 turns. More turns than in SNS because
  - PSR turns are 90m and SNS turns are 248m,
  - PSR bunch spacing > 1.2m and SNS bunch spacing = 0.65m.

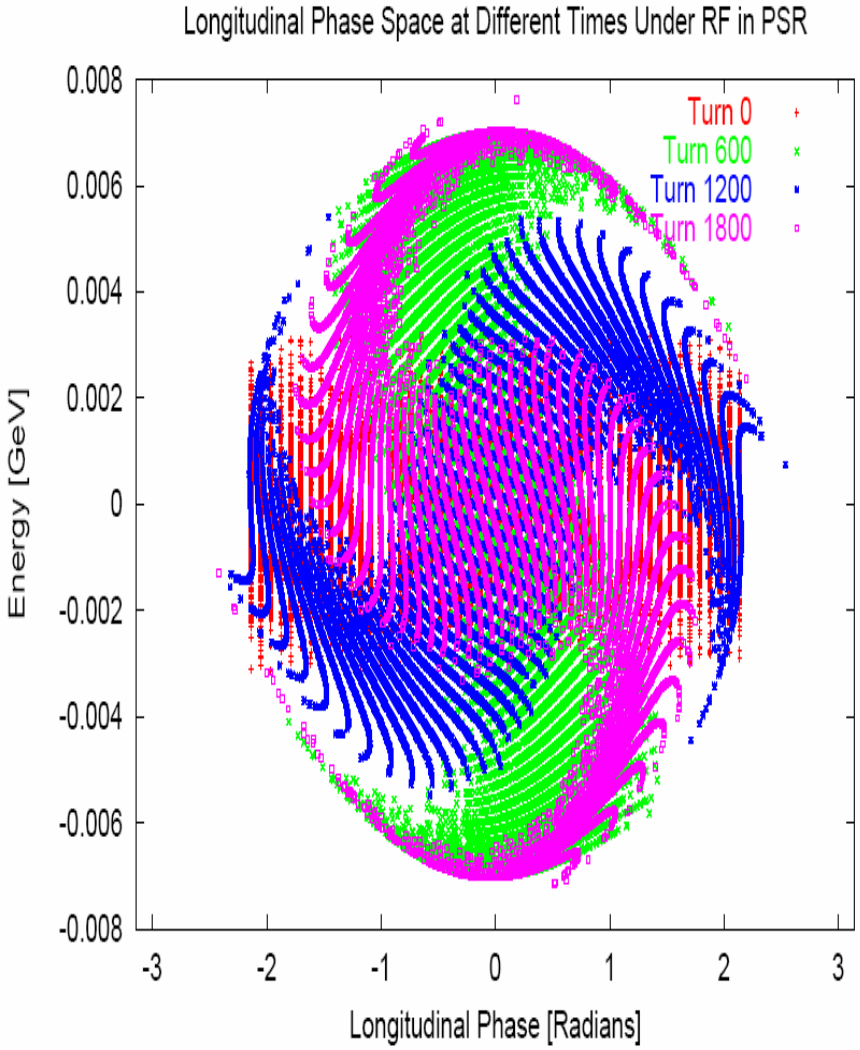






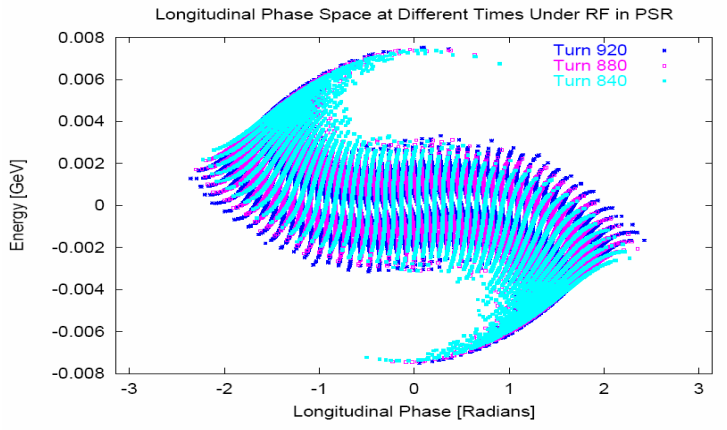
PSR Single Turn Injection with RF: Realignment After Half Synchrotron Periods

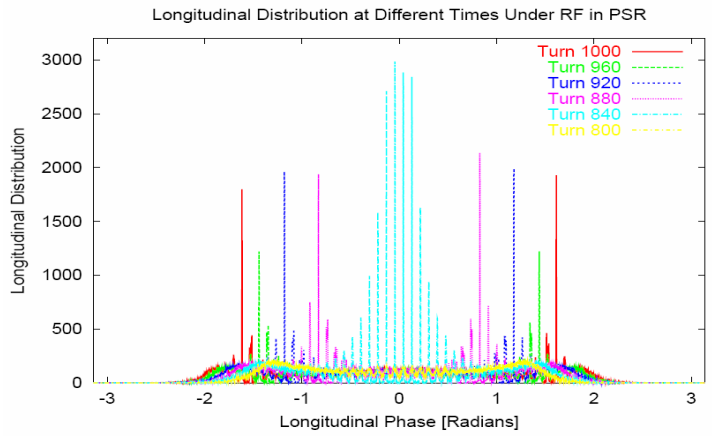
- The injected single turn linac pulse train rotates in the RF bucket.
- After half integer multiples of the synchrotron period, the pulses realign in space.
- At these times, the linac bunch structure is observed.
- This is seen experimentally, and in ORBIT simulations, which agree both in the observed pulse structure and in the details of its timing.



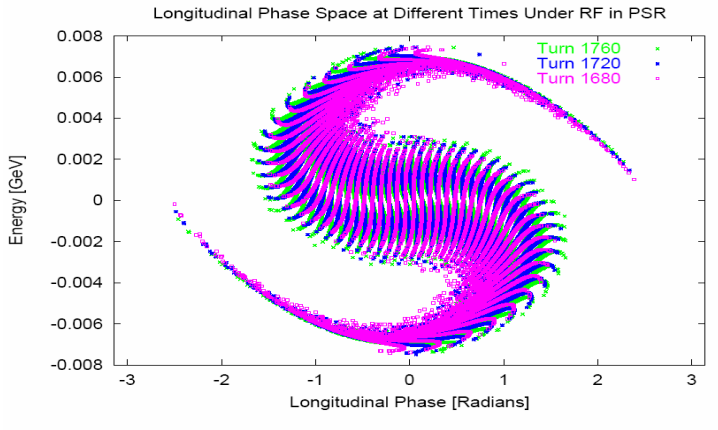
PSR Single Turn Injection with RF: Realignment After Half Synchrotron Periods

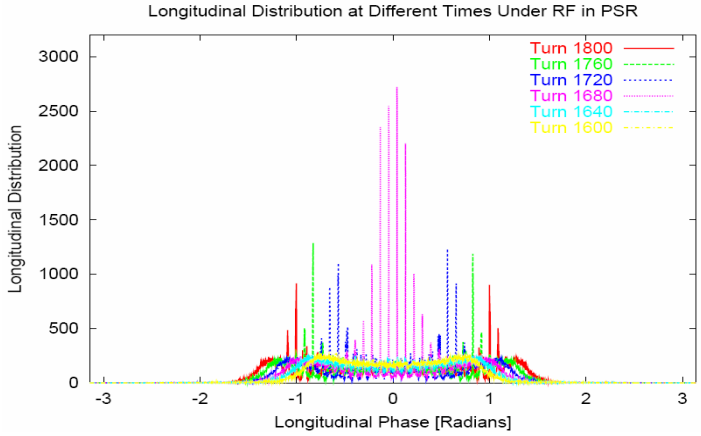
Half Synchrotron Period





Full Synchrotron Period

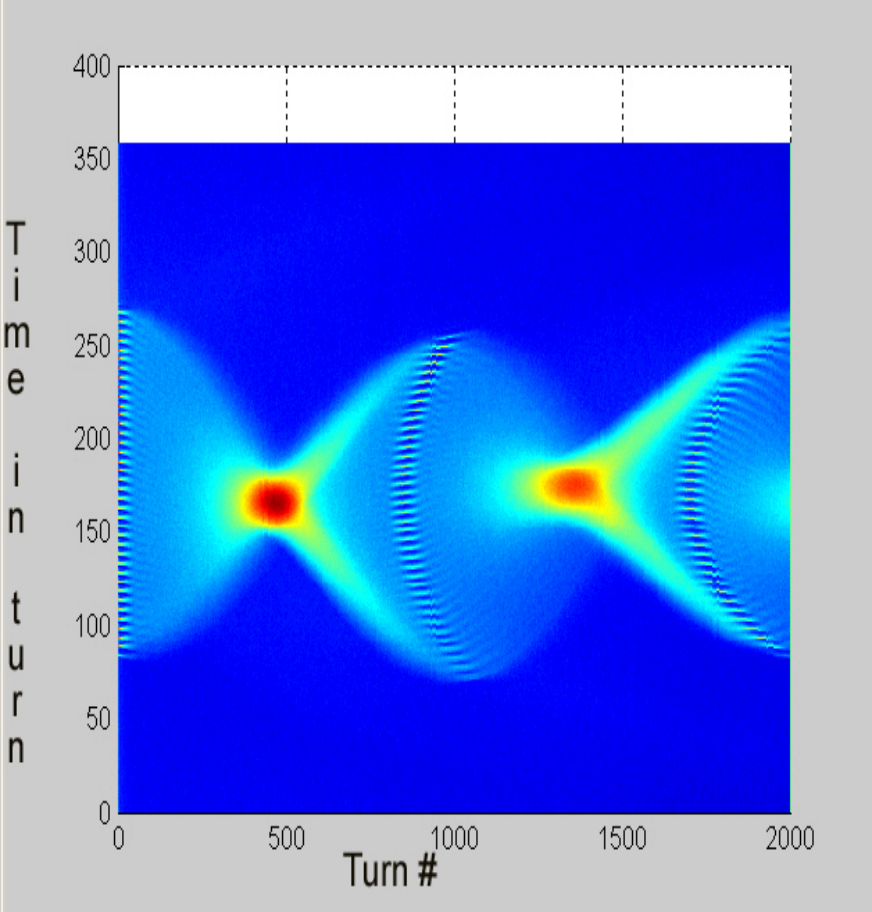




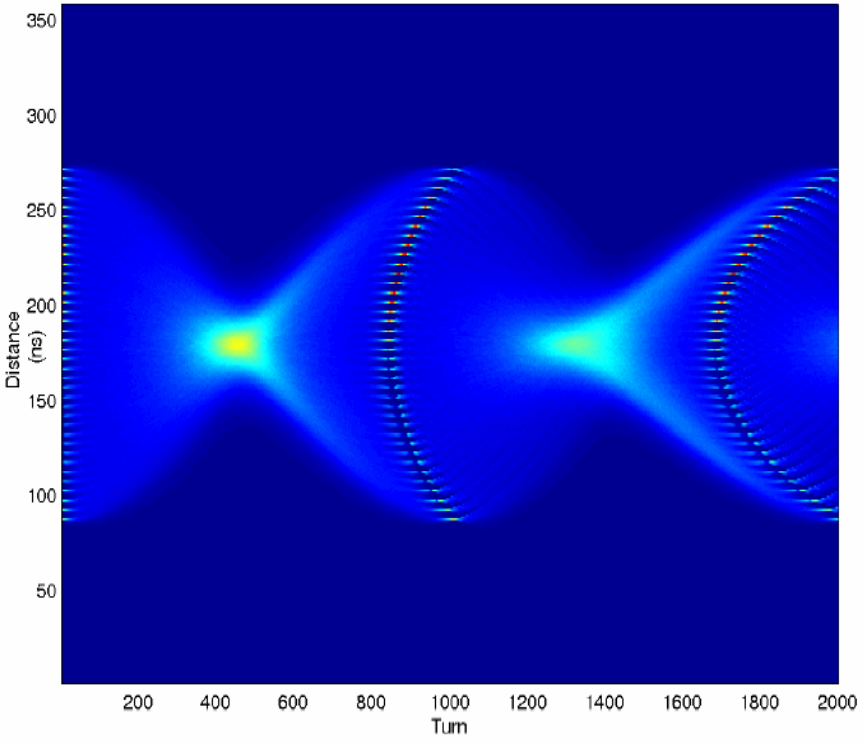
PSR Single Turn Injection with RF: Realignment After Half Synchrotron Periods

Bunch Structure vs Time

Experimental Observation



ORBIT Calculation



Conclusion

- A study of the debunching of the 402.5 MHz linac beam after injection into the ring was carried out
  - Using the ORBIT code, and
  - With an analytic approach.
- The computational and analytic results are in agreement, and they indicate that the intrabunch space charge force acts very quickly (100s of meters or 1-2 turns) to achieve a steady state energy spread, which then determines the subsequent rate of debunching (approximately 10 turns in SNS, 45 turns in PSR).
- The results suggest that, at full linac current, we have no more than 10 turns of 402.5 MHz signal in SNS.
- We also note that ORBIT single turn injection calculations for PSR with RF operating reproduce the experimentally observed reappearance of the linac bunch structure at half integral multiples of the synchrotron period.