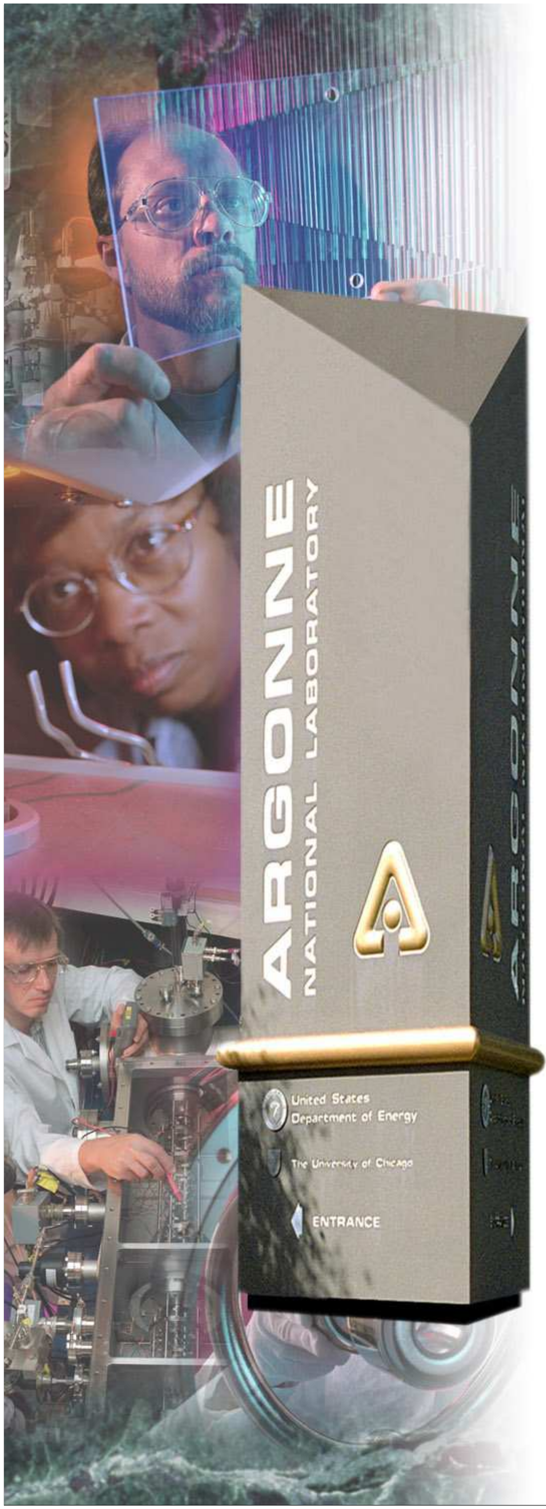

APS Injector Improvements and Research

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Argonne National Laboratory

Office of Science
U.S. Department of Energy

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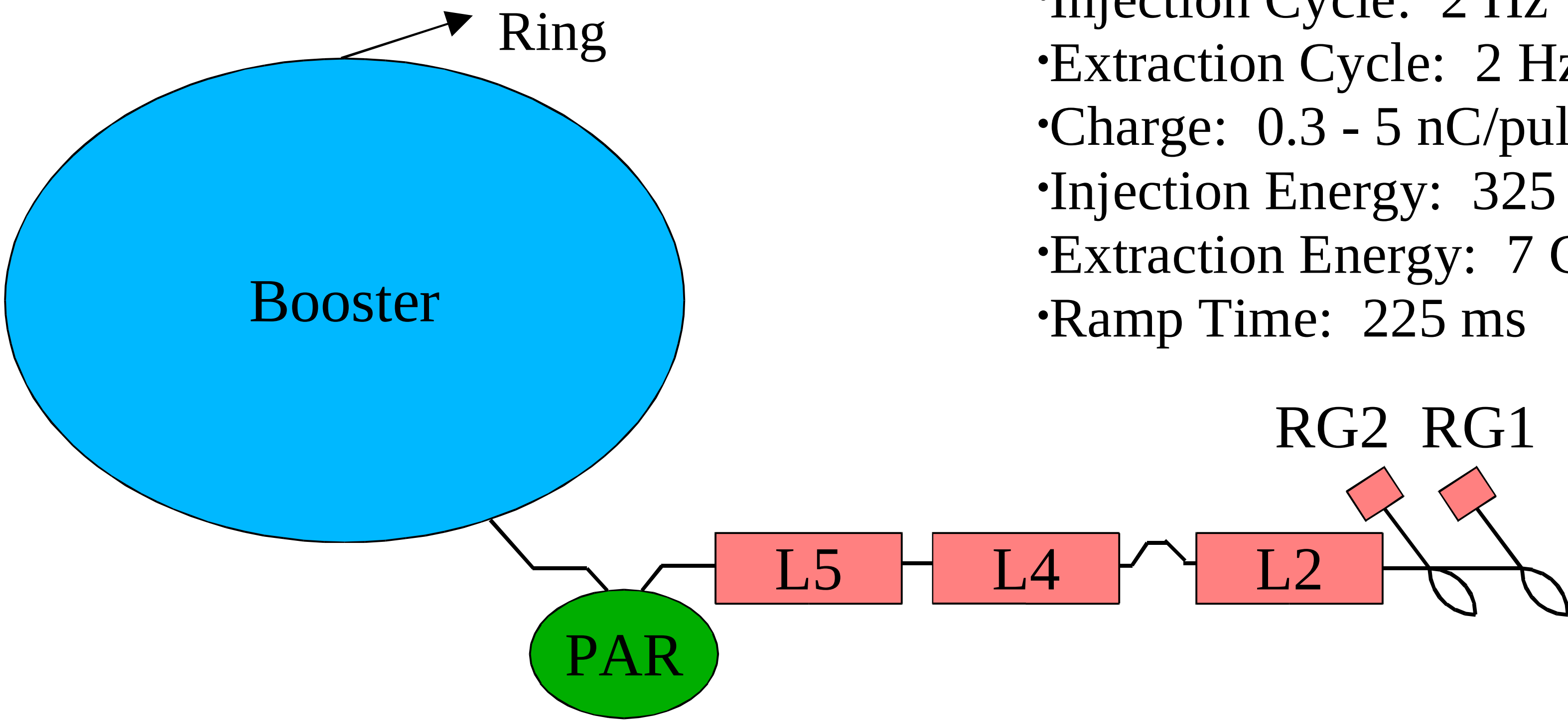
Outline

- Improved injection into the SR
  - Booster low emittance lattice commissioning
  - Booster To Storage Ring (BTS) transport line redesign for quantitative beam matching
- Improved injector reliability and availability
  - Automated booster injection control
  - Direct linac to booster injection commissioning (bypass PAR)
  - Booster subharmonic cavity for direct injection
- Bunch purity investigations

Injector Configuration and Operation for Storage Ring Operations



Booster Parameters -
- Injection Cycle: 2 Hz
- Extraction Cycle: 2 Hz
- Charge: 0.3 - 5 nC/pulse
- Injection Energy: 325 MeV
- Extraction Energy: 7 GeV
- Ramp Time: 225 ms

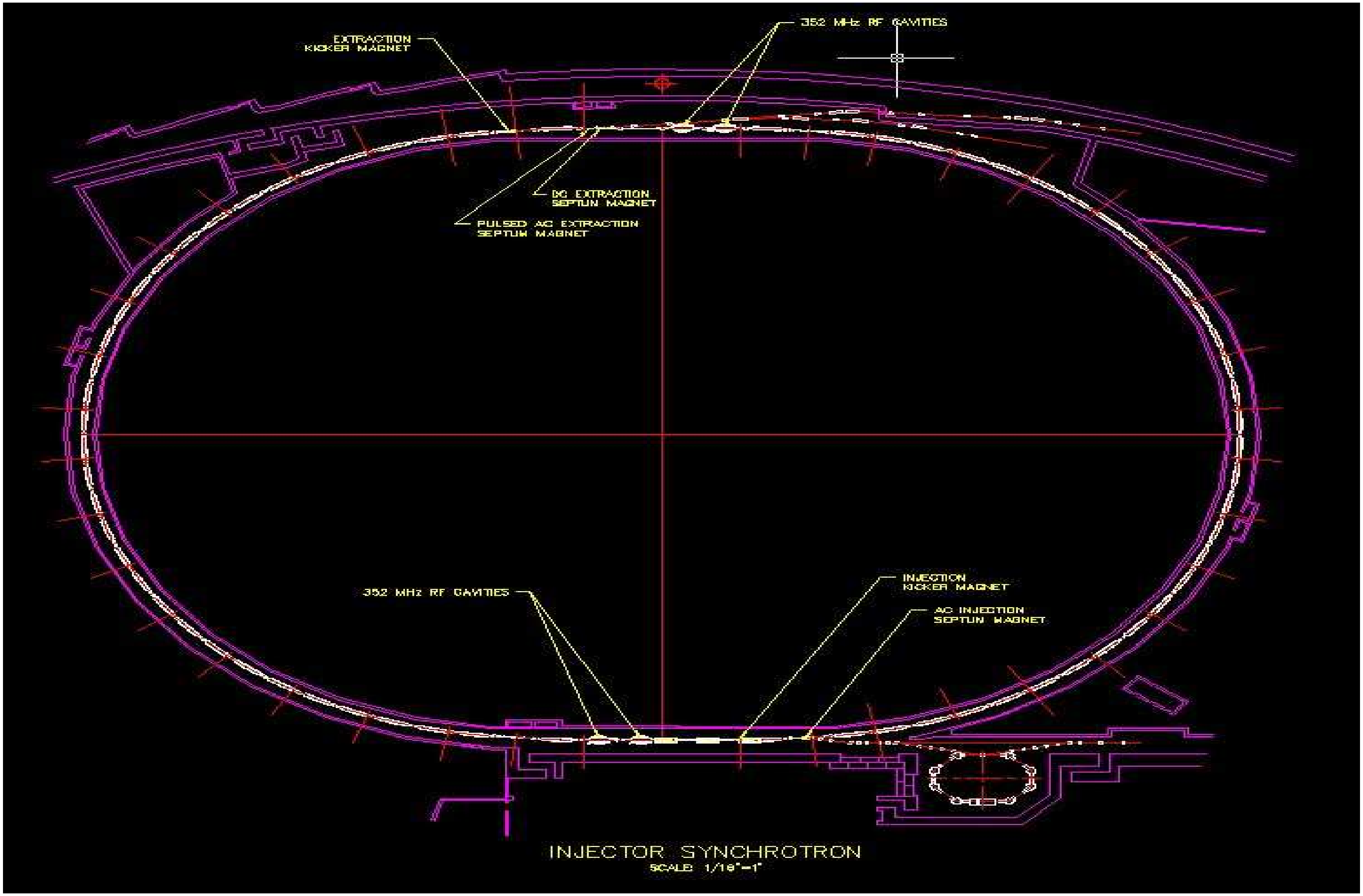
PAR Parameters -
- Injection Rate: 30 Hz
- Injection Pulses: 1-5
- Extraction Cycle: 2 Hz
- Extracted Charge: 0.3-5 nC
- Operating Energy: 325 MeV

LINAC Parameters -
- Pulse Rate: 2 - 30 Hz
- Extracted Charge: 0.3 - 1 nC
- Extraction Energy: 325 MeV
- Linac macropulse length 11-16 ns (RG2)

Motivation

- Improve storage ring (SR) injection efficiency for top-up operation
  - Reduce beam loss at injection
  - Reduce radiation damage to the IDs
- Smaller spot size at the SR injection septum for the same matched injection optics
  - Reduce horizontal betatron oscillation at injection
  - Reduce vertical betatron motion due to coupling (small gap chambers ~5 mm)

Booster Low Emittance Lattice



Booster Low Emittance Lattice

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- Conventional wisdom said the booster emittance could not be reduced.
- With **elegant,** we can optimize the emittance directly
  - We found and explored a matrix of optics options
- We then understood how to decrease the emittance:
  - Increase horizontal focussing using QF
  - Decrease vertical focussing using QD
  - Correct chromatic aberations with SF and SD

Booster Low Emittance Lattice

- Conclusion was we needed to run QF and SD stronger but still well within their limits.
- Asked for controls modifications to the quadrupole magnets.
- Standard Lattice: 132 nm-rad (7 GeV)
- Systematically lowered this
  - Low emittance lattice 1: **109 nm-rad**
  - Low Emittance Lattice 2: **92 nm-rad**

Booster Low Emittance Summary

- Successfully commissioned two new lower emittance lattices for the APS booster.
  - Focusing and chromatic correction
  - Orbit correction along the ramp
  - Optics verification measurements
- Used **109 nm** lattice from July 2002 to December 2002.
- Used **92 nm** lattice since January 2003.
- Developed extensive set of software tools to do commissioning.

Booster Low Emittance Summary

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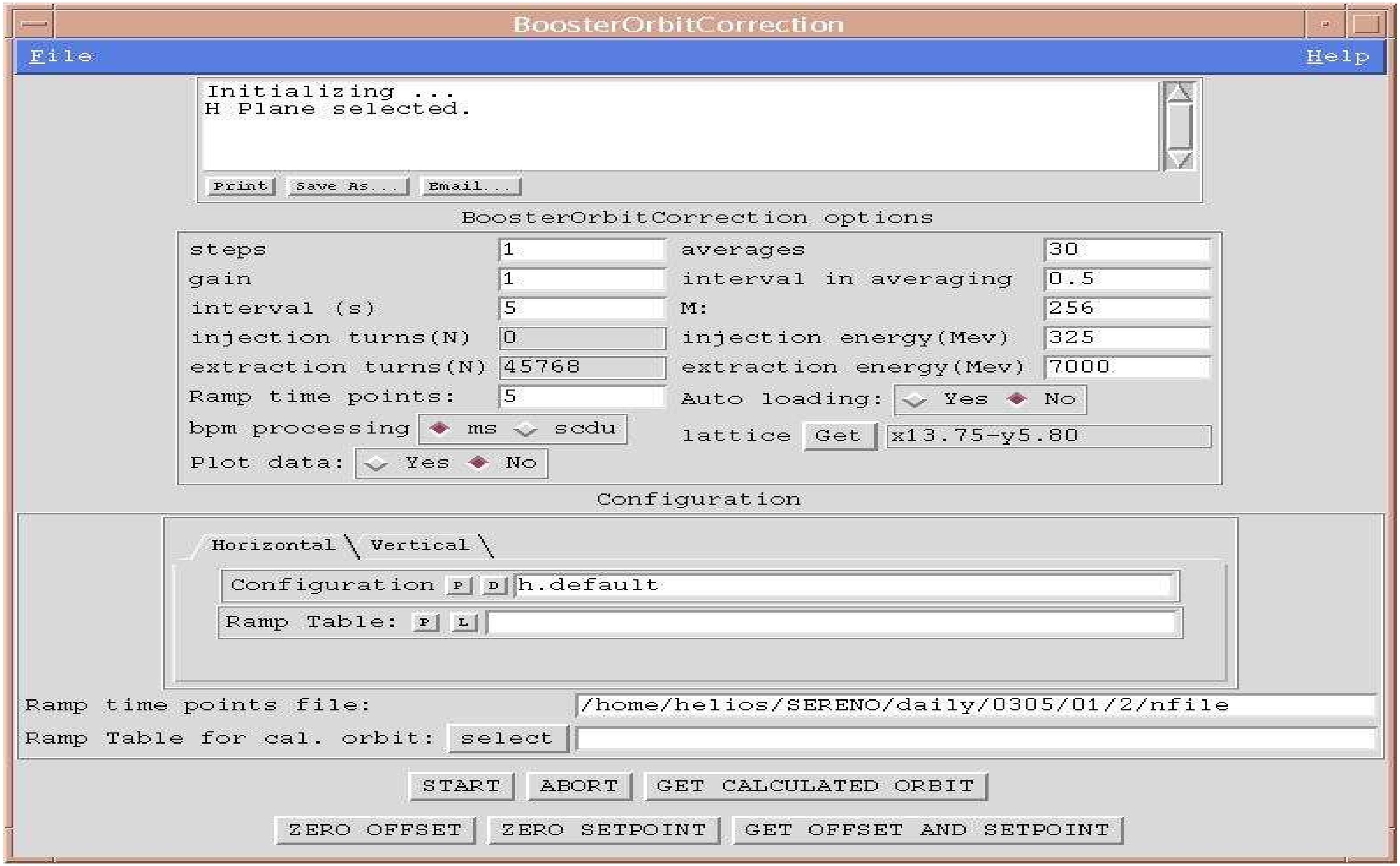
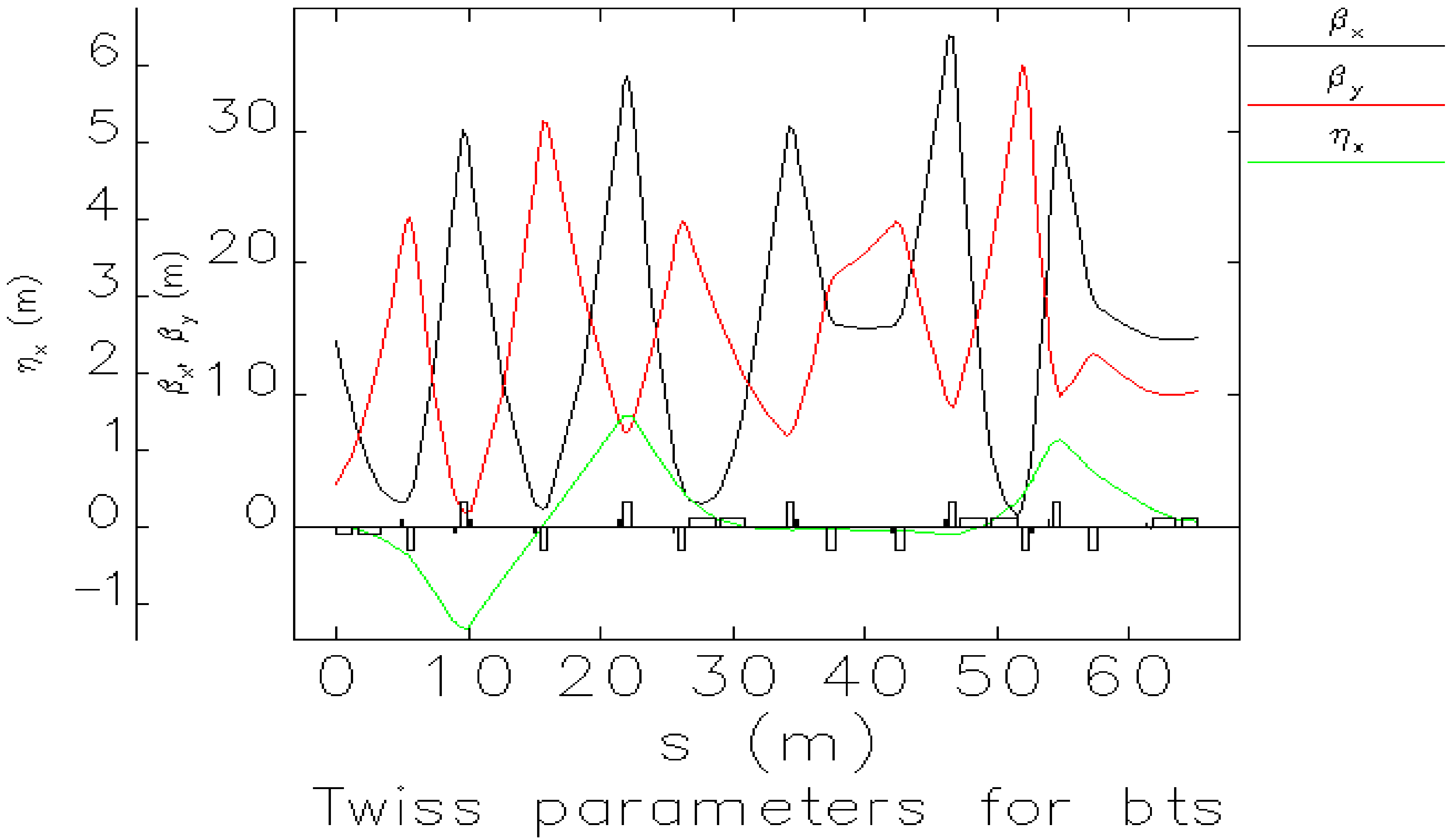


BTS Transport Line Redesign

- Goal is to improve SR injection efficiency by experimentally matching the booster beam to the ring.
- Existing diagnostics and optics are not adequate for this task.
- Add five quadrupoles for optical flexibility.
- Add "3 screen" emittance measurement for rapid beam parameter measurement and matching.
- This design borrows extensively from experience with the linac systems.

BTS Transport Line Redesign



BTS Transport Line Redesign

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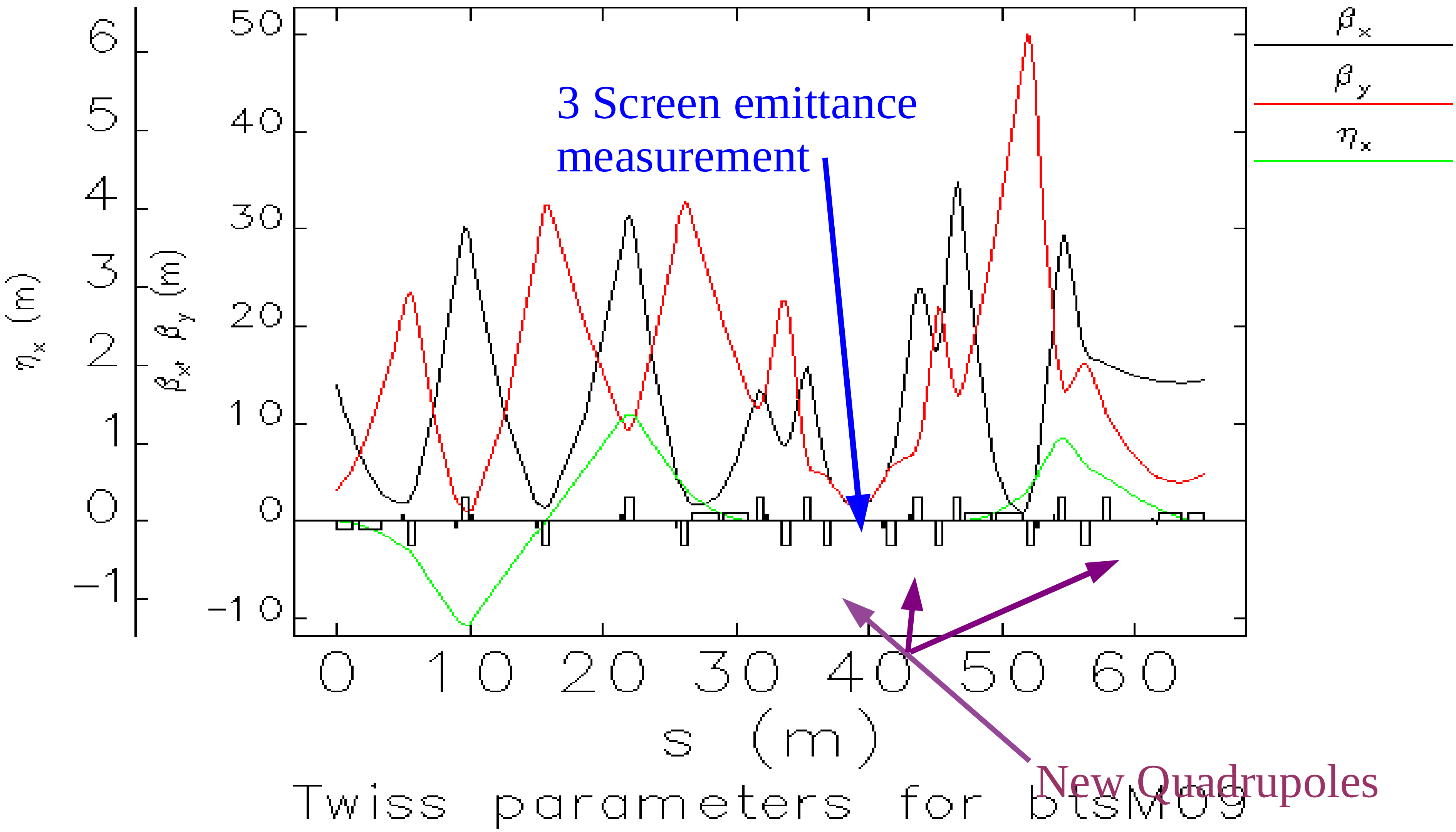

Booster Injection Control

- Top-up requires consistent beam delivery every 2 minutes, 24/7.
- This requires injecting beam into the booster so that it is on the closed orbit for all 6 phase space coordinates (energy,phase, x,x', y,y').
- In the past this was done manually by operators with varying degrees of success and speed.
- I developed an algorithm to automate this
  - Uses IOC software processing of the beam transient. (F. Lenkszus ASD-CTL).
  - Use the processed information to do feedback.

Manual Booster Injection Control

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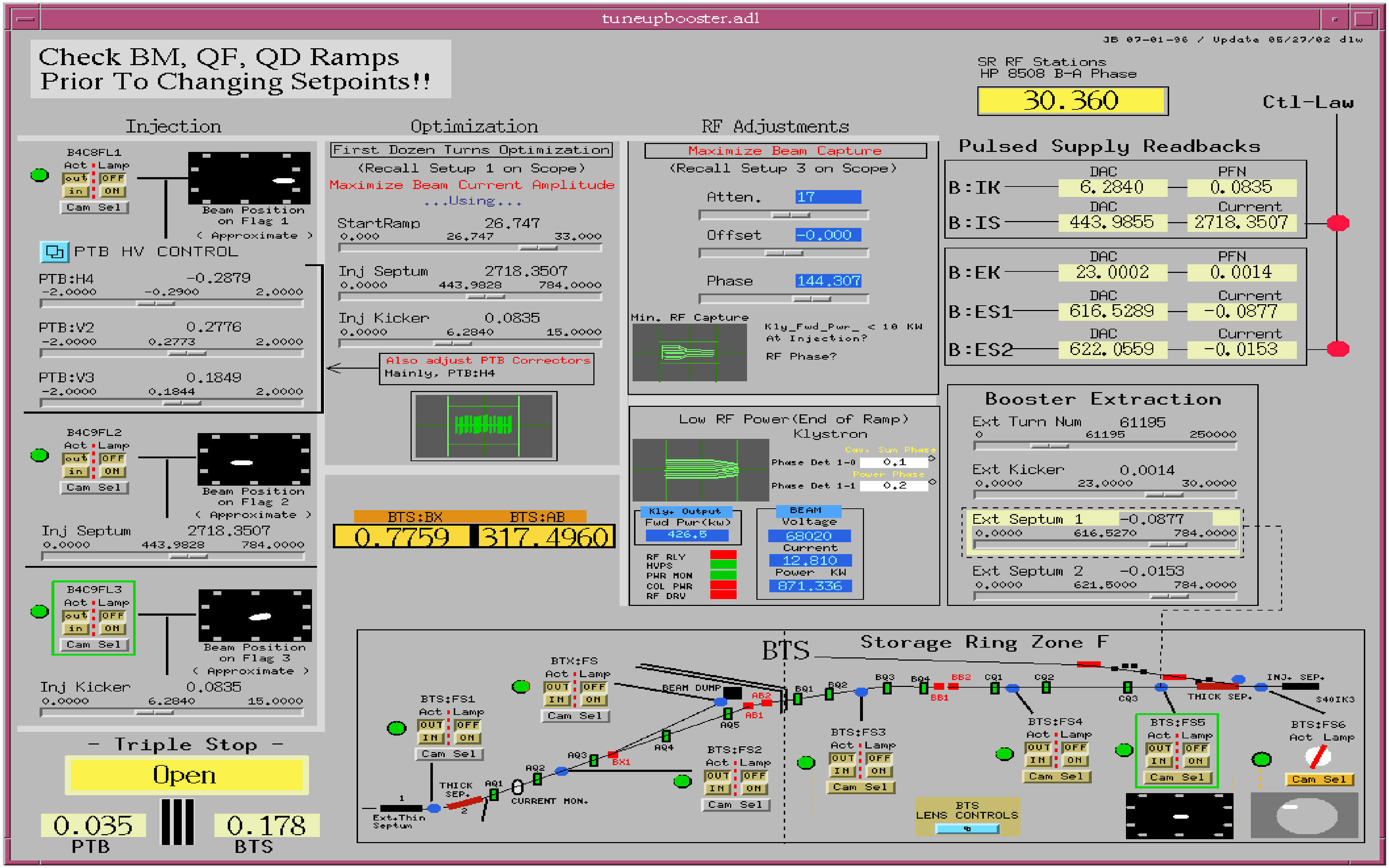

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Booster Injection Control

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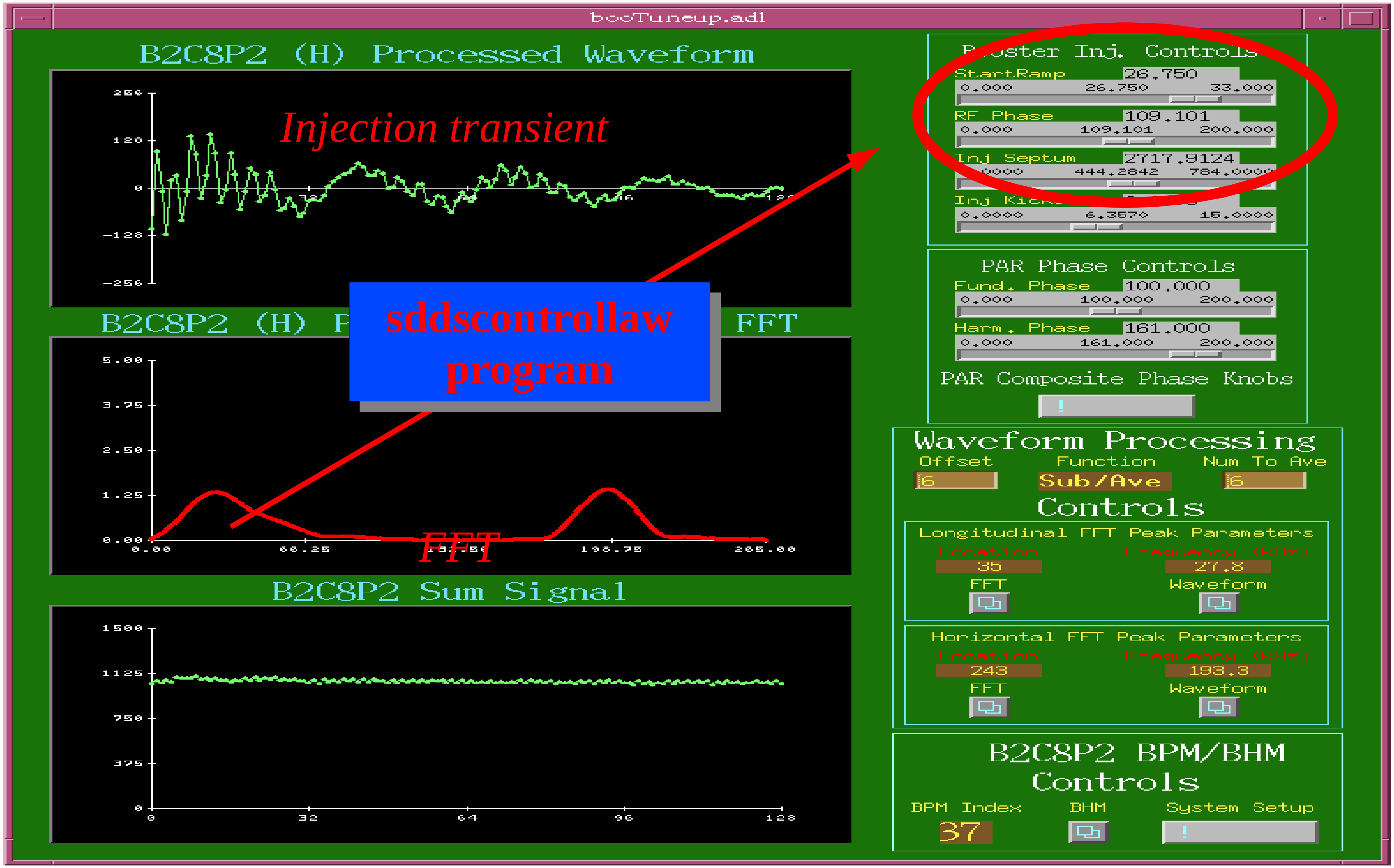
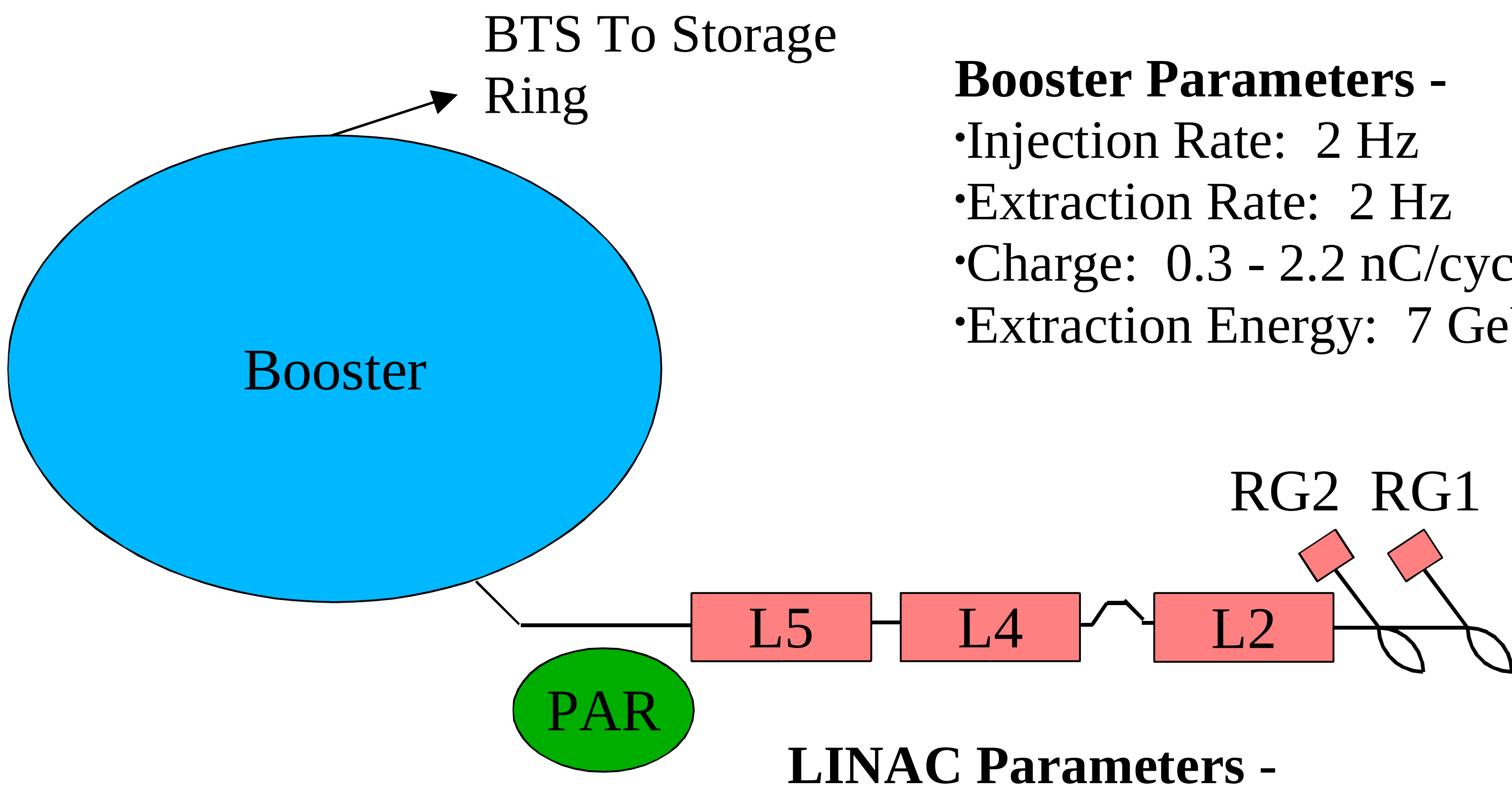


Direct Linac to Booster Injection

- Short term motivation is to be able to fill the ring if the PAR is down for extended period of time.
- A proposed long term goal is to remove the PAR from the injector chain.
- I led the effort to commission direct injection.
- With S. Pasky, I trained each operations crew to to setup direct injection according our written procedure.
- There is now an operations policy in place for using this new capability.

Injector Configuration and Operation for Direct Injection Using rf Gun2.



Booster Parameters -
- Injection Rate: 2 Hz
- Extraction Rate: 2 Hz
- Charge: 0.3 - 2.2 nC/cycle
- Extraction Energy: 7 GeV

LINAC Parameters -
- Injection Rate: 2 Hz
- Extracted Charge: 0.3 - 2.2 nC/cycle
- Extraction Energy: 325 - 450 MeV
- RG2 Macropulse Length: 11-16 ns

Direct Linac to Booster Injection

- Commissioning was straightforward using existing OAG linac software.
- Used existing emittance measurement/matching software to match linac beam to the booster.
- Use PEM to standardize linac magnets, setup linac RF, and set timing.
- Direct injection has a good lifetime (17 to 26 hours depending on coupling) when injecting into the standard 24 singlets fill pattern.
- Price one pays is in bunch purity

Direct Linac to Booster Injection

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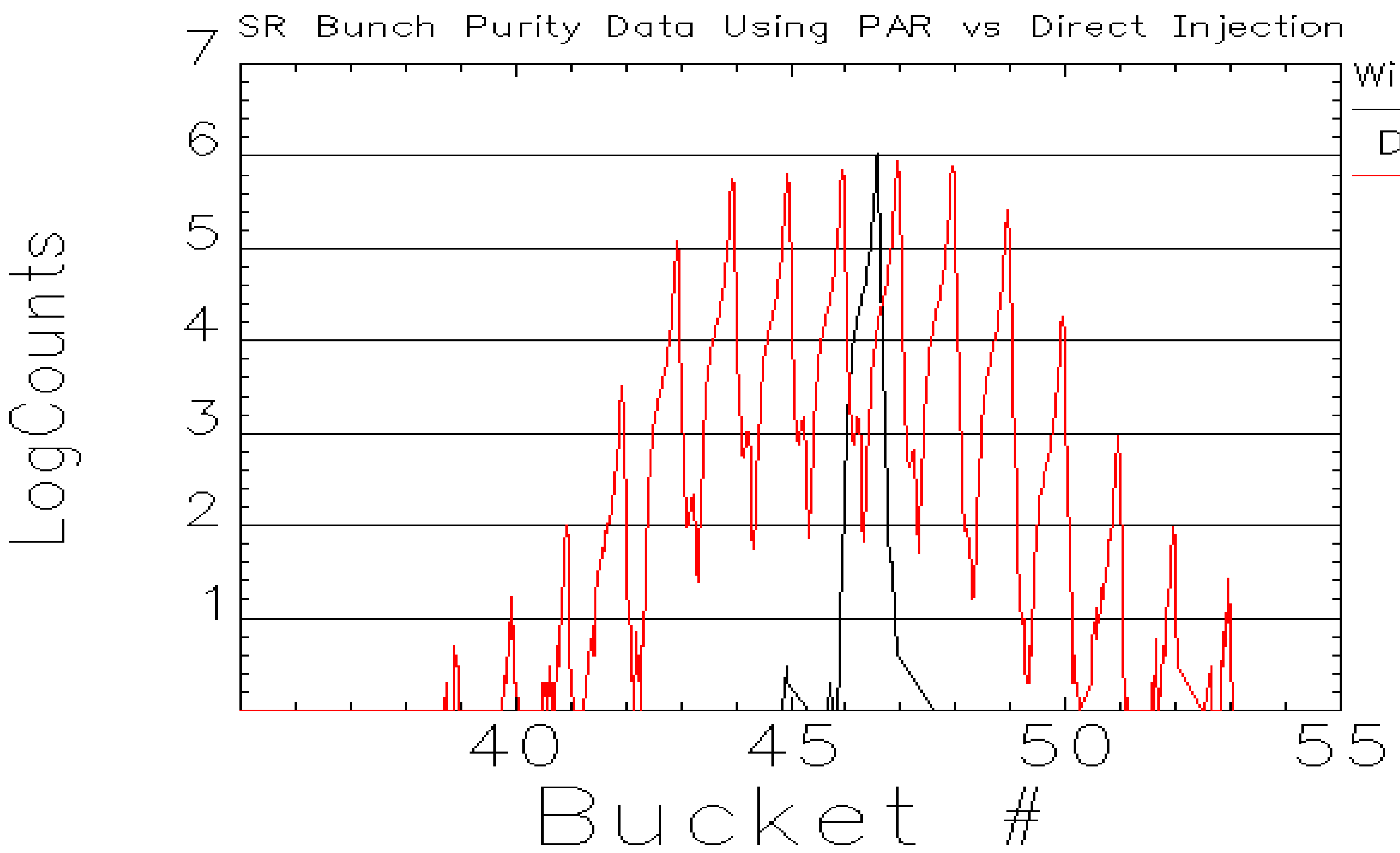

Booster Subharmonic Capture

- Will allow capture of the linac macropulse to with good bunch purity and efficiency.
- Idea is to add another rf cavity in the booster at a subharmonic of 352 MHz.
- Keep the existing booster linear magnet ramps.
- One finds from the simulations a set of tradeoffs.
  - Lower frequency cavity can capture a longer linac macropulse.
  - Price is higher gap voltage and difficulty of construction.
- Shorten gun kicker pulse and test a long drive pulse laser to get <~5 ns (J. Lewellen ITS).

Booster Subharmonic Capture

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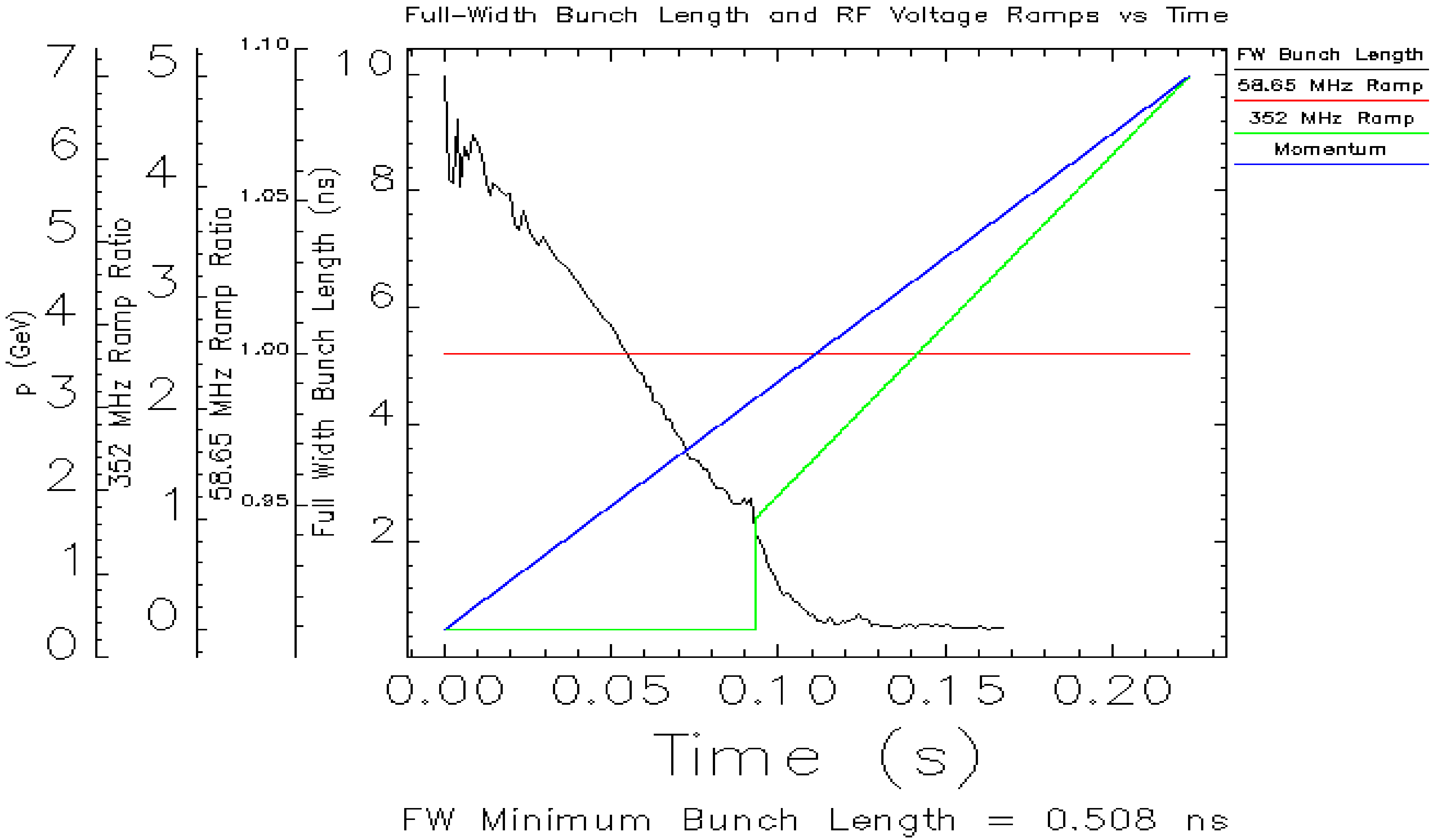

PAR Bunch Purity

- A primary function of the PAR is to provide good bunch purity for timing users
- We are trying to understand why it sometimes doesn't
- The longitudinal dynamics is quite similar to the booster subharmonic capture problem
- Understanding the PAR's occassional problems is important in designing the booster system

PAR Bunch Cleaning

- Another approach to bunch purity is resonant rf knock-out of undesired particles
- The PAR is an ideal place to do this
  - Beam is stored a relatively long time
  - Energy is low
- Working with ASD-CTL and AOD-DIA we recently made a proof-of-principle experiment
- Once implemented, this may largely immunize us against PAR rf problems

Summary

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- OAG tools and techniques are well suited to improving injector performance, reliability, and availability.
  - Booster emittance reduction
  - 6D injection control
- Having a consistent set of tools and techniques greatly aids in design and improvement of all injector machines.
- Physicists and programmers working closely together is one of OAG's great strengths.