

APS Injector Improvements and Research

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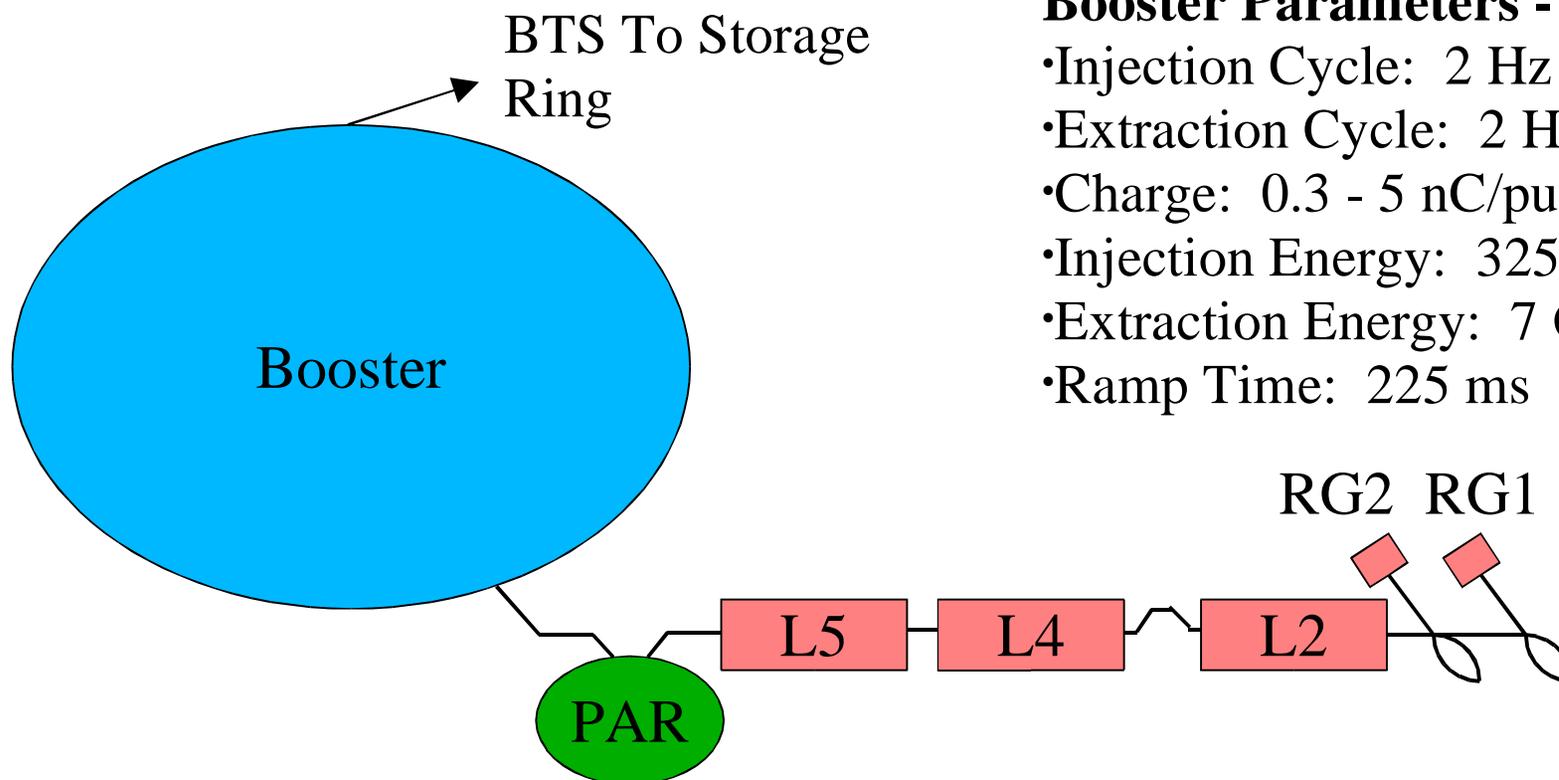
Outline



- 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)

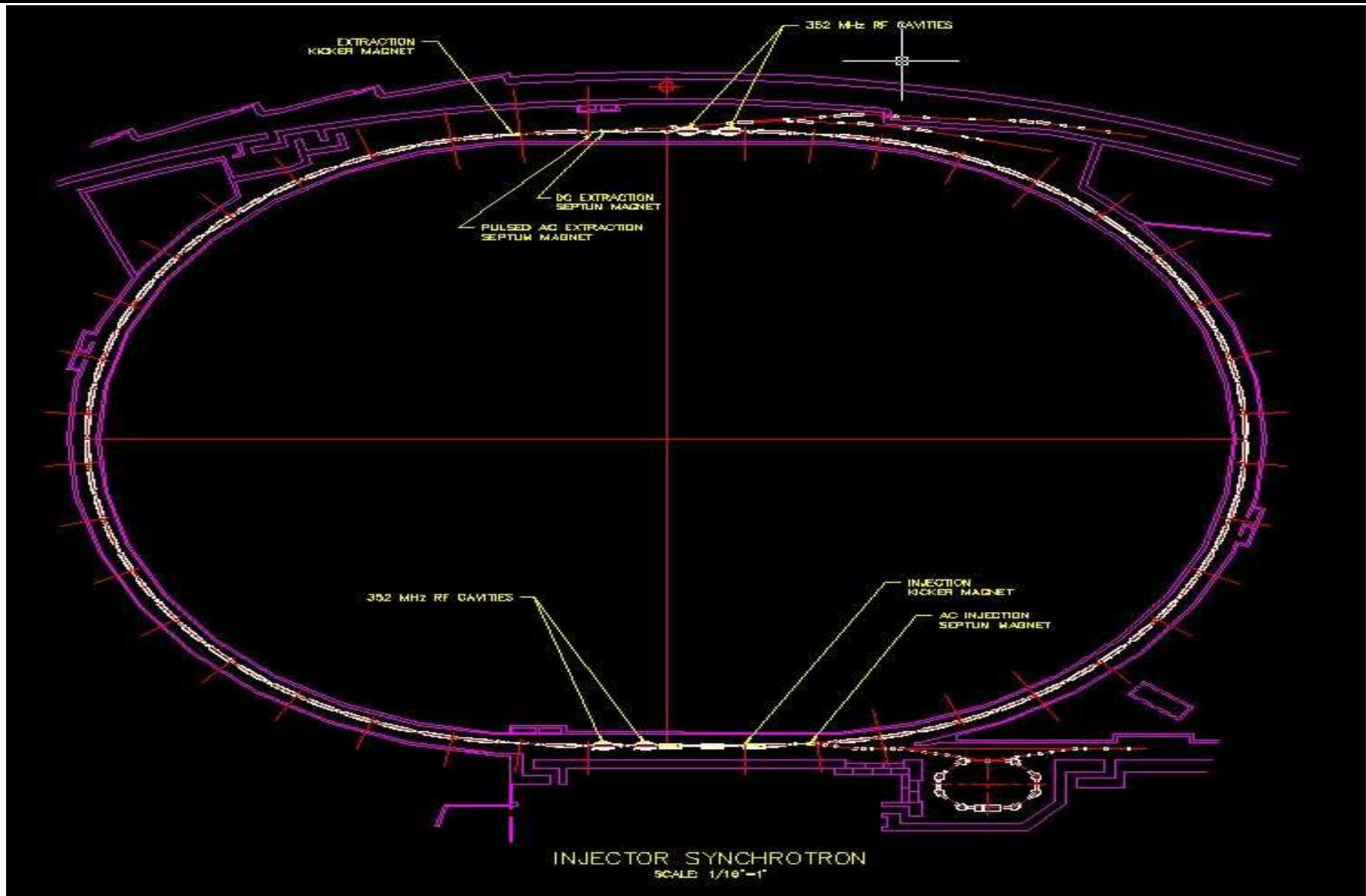


Motivation

- 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





- 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





- 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**





- 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



BoosterOrbitCorrection

File Help

Initializing ...
H Plane selected.

Print Save As... Email...

BoosterOrbitCorrection options

steps	1	averages	30
gain	1	interval in averaging	0.5
interval (s)	5	M:	256
injection turns(N)	0	injection energy(Mev)	325
extraction turns(N)	45768	extraction energy(Mev)	7000
Ramp time points:	5	Auto loading:	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
bpm processing	<input checked="" type="checkbox"/> ms <input type="checkbox"/> scdu	lattice	Get x13.75-y5.80
Plot data:	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No		

Configuration

Horizontal \ Vertical \

Configuration h.default

Ramp Table:

Ramp time points file: /home/helios/SERENO/daily/0305/01/2/nfile

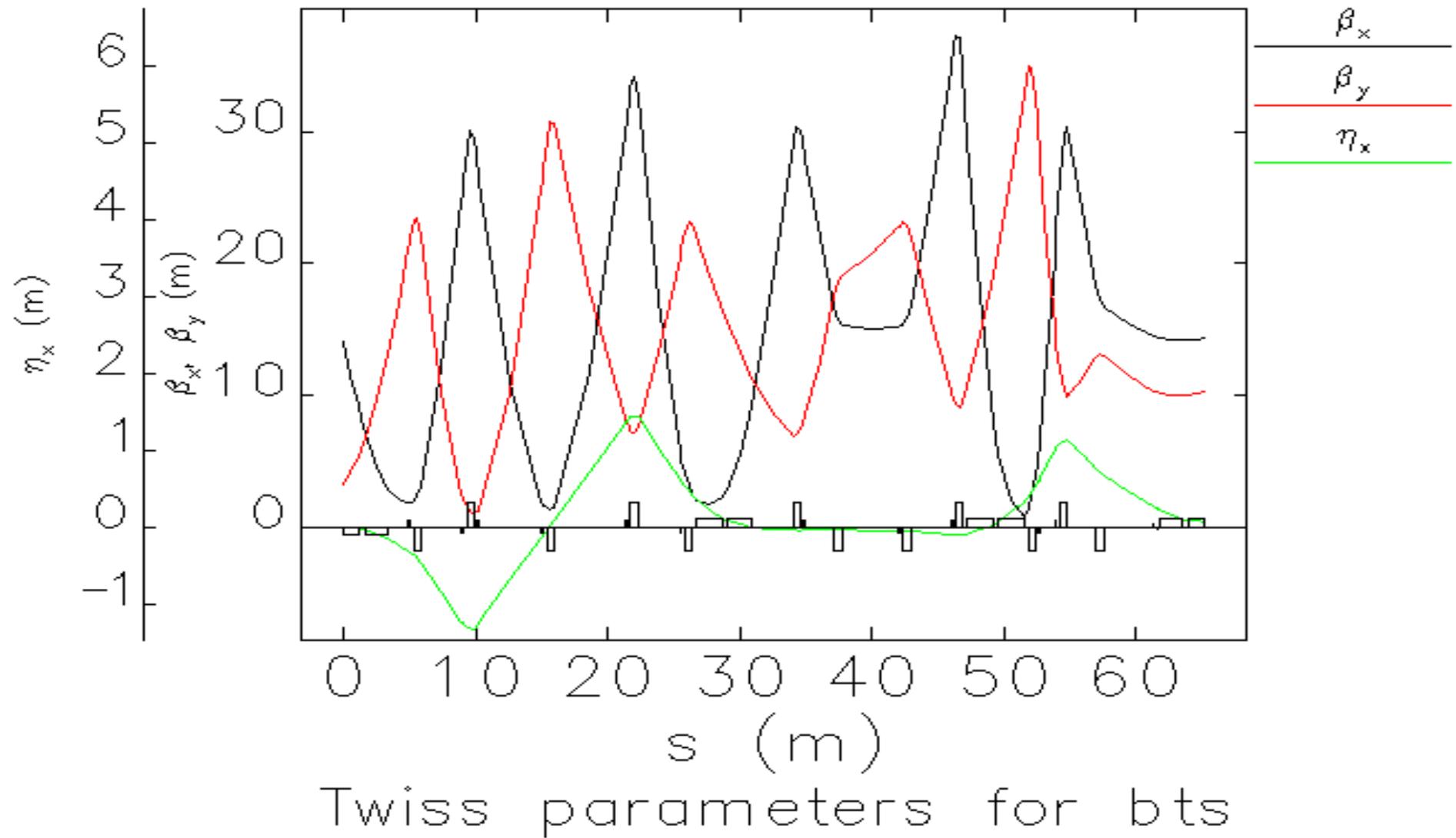
Ramp Table for cal. orbit:



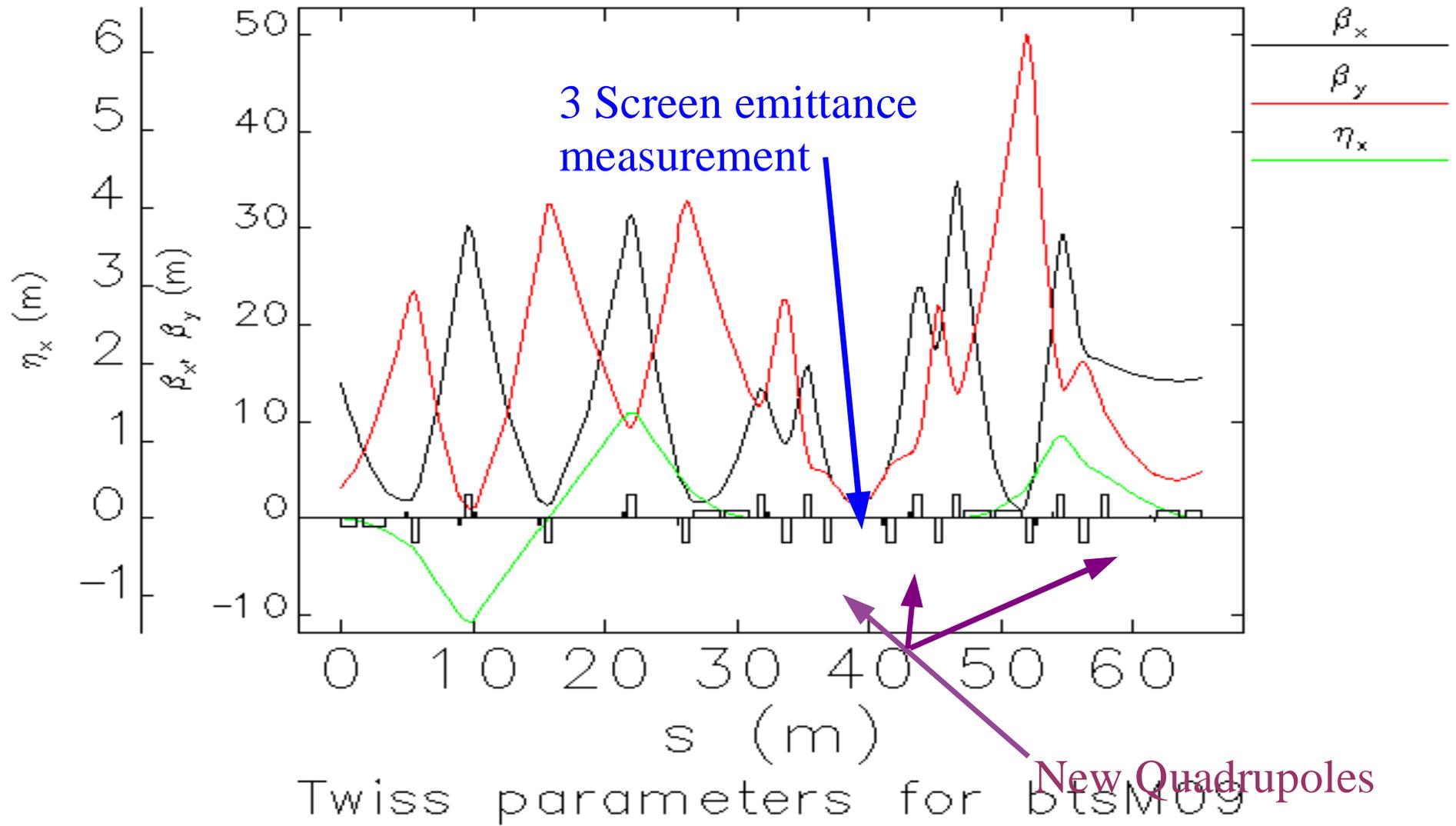
- Goal is to improve SR injection efficiency by experimentally matching the booster beam to the ring.
- Existing diagnostics and optics are not adequate for this task.
- Add five quadrupoles for optical flexibility.
- Add "3 screen" emittance measurement for rapid beam parameter measurement and matching.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



BTS Transport Line Redesign



BTS Transport Line Redesign





- 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



tuneupbooster.adl

JB 07-01-96 / Update 05/27/02 dlw

Check BM, QF, QD Ramps
Prior To Changing Setpoints!!

SR RF Stations
HP 8508 B-A Phase

30.360 Ctl-Law

Injection

B4C8FL1 Act: Lamp
out: OFF in: ON
Cam Sel

Beam Position on Flag 1
(Approximate)

PTB HV CONTROL

PTB:H4 -0.2879
-2.0000 -0.2900 2.0000

PTB:V2 0.2776
-2.0000 0.2773 2.0000

PTB:V3 0.1849
-2.0000 0.1844 2.0000

B4C9FL2 Act: Lamp
out: OFF in: ON
Cam Sel

Beam Position on Flag 2
(Approximate)

Inj Septum 2718.3507
0.0000 443.9828 784.0000

B4C9FL3 Act: Lamp
out: OFF in: ON
Cam Sel

Beam Position on Flag 3
(Approximate)

Inj Kicker 0.0835
0.0000 6.2840 15.0000

Optimization

First Dozen Turns Optimization
(Recall Setup 1 on Scope)
Maximize Beam Current Amplitude
...Using...

StartRamp 26.747
0.000 26.747 33.000

Inj Septum 2718.3507
0.0000 443.9828 784.0000

Inj Kicker 0.0835
0.0000 6.2840 15.0000

Also adjust PTB Correctors
Mainly, PTB:H4

BTS:BX **0.7759** | **317.4960** | BTS:AB

RF Adjustments

Maximize Beam Capture
(Recall Setup 3 on Scope)

Atten. **17**

Offset **-0.000**

Phase **144.307**

Min. RF Capture
Kly_Fwd_Pwr_ < 10 KW
At Injection?
RF Phase?

Low RF Power (End of Ramp)
Klystron

Phase Det 1-0 0.1
Power Phase
Phase Det 1-1 0.2

Kly. Output Fwd Pwr(kw) **426.5**

BEAM Voltage **68020**
Current **12.810**
Power KW **871.336**

RF RLY HUPS PHR MON COL PHR RF DRV

Pulsed Supply Readbacks

B:IK	DAC 6.2840	PFN 0.0835
B:IS	DAC 443.9855	Current 2718.3507
B:EK	DAC 23.0002	PFN 0.0014
B:ES1	DAC 616.5289	Current -0.0877
B:ES2	DAC 622.0559	Current -0.0153

Booster Extraction

Ext Turn Num 61195
0 61195 250000

Ext Kicker 0.0014
0.0000 23.0000 30.0000

Ext Septum 1 -0.0877
0.0000 616.5270 784.0000

Ext Septum 2 -0.0153
0.0000 621.5000 784.0000

- Triple Stop -

Open

0.035 PTB | 0.178 BTS

BTS Storage Ring Zone F

Ext:Thin Septum

THICK SEP. 1 2

CURRENT MON.

BEAM DUMP

BTS:FS1 Act: Lamp
OUT: OFF IN: ON
Cam Sel

BTS:FS2 Act: Lamp
OUT: OFF IN: ON
Cam Sel

BTS:FS3 Act: Lamp
OUT: OFF IN: ON
Cam Sel

BTS:FS4 Act: Lamp
OUT: OFF IN: ON
Cam Sel

BTS:FS5 Act: Lamp
OUT: OFF IN: ON
Cam Sel

BTS:FS6 Act: Lamp
Cam Sel

BTS LENS CONTROLS

Booster Injection Control

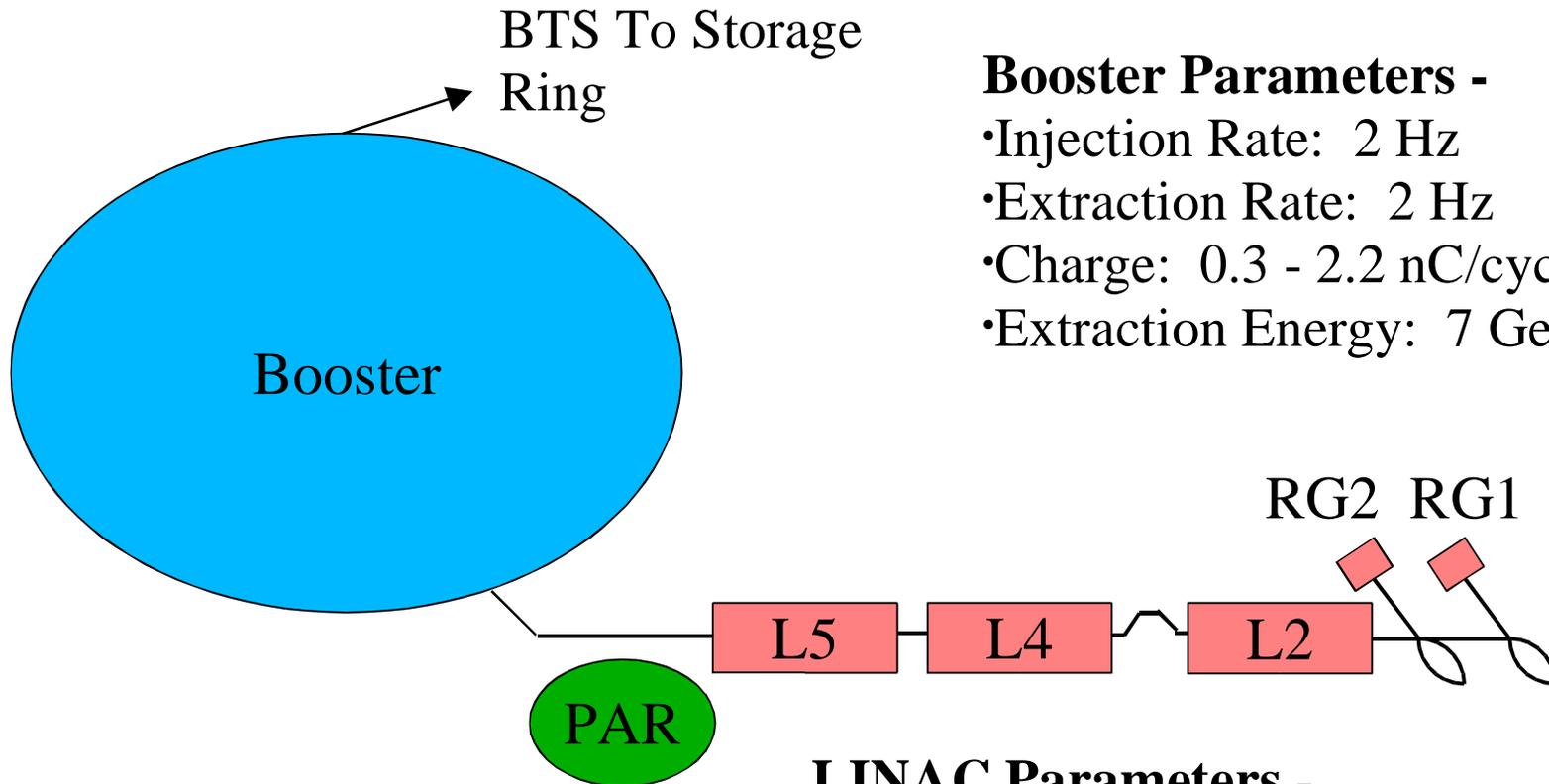




- Short term motivation is to be able to fill the ring if the PAR is down for extended period of time.
- A proposed long term goal is to remove the PAR from the injector chain.
- I led the effort to commission direct injection.
- With S. Pasky, I trained each operations crew to to setup direct injection 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.



BTS To Storage
Ring

Booster Parameters -

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

LINAC Parameters -

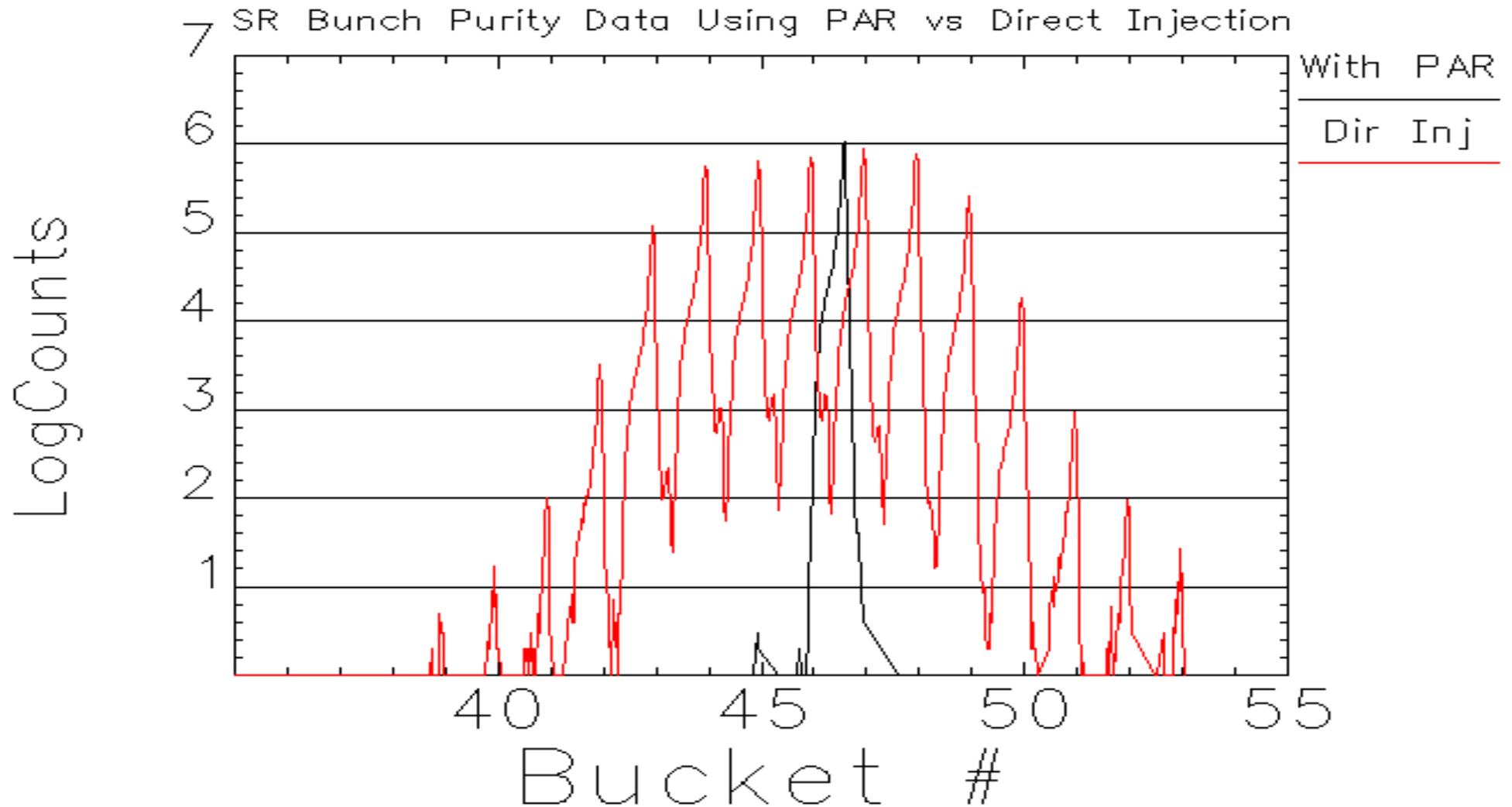
- Injection Rate: 2 Hz
- Extracted Charge: 0.3 - 2.2 nC/cycle
- Extraction Energy: 325 - 450 MeV
- RG2 Macropulse Length: 11-16 ns



- 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





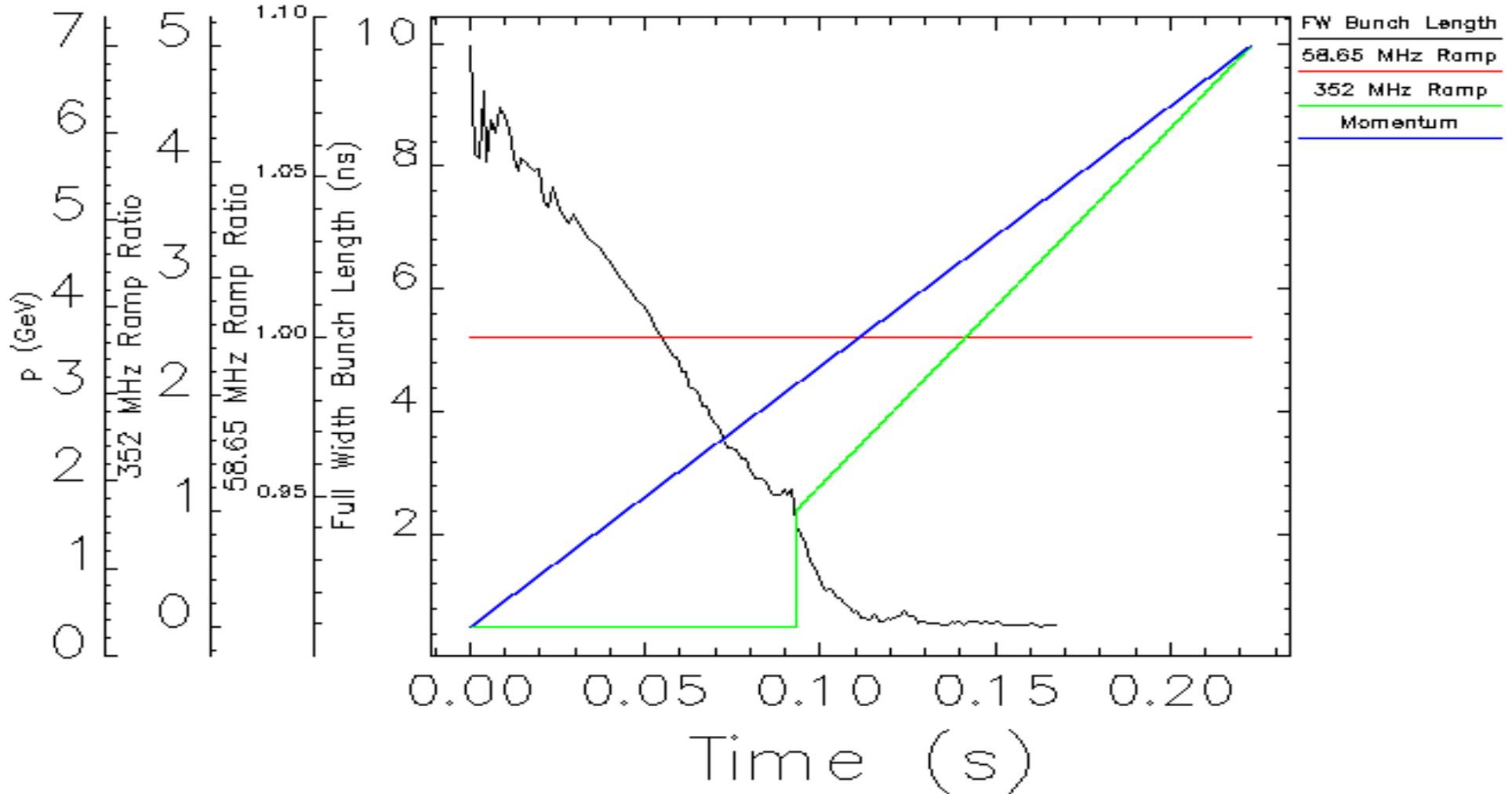
- Will allow capture of the linac macropulse to with good bunch purity and efficiency.
- Idea is to add another rf cavity in the booster at a subharmonic of 352 MHz.
- Keep the existing booster linear magnet ramps.
- One finds from the simulations a set of tradeoffs.
 - Lower frequency cavity can capture 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 $< \sim 5$ ns (J. Lewellen ITS).



Booster Subharmonic Capture



Full-Width Bunch Length and RF Voltage Ramps vs Time



FW Minimum Bunch Length = 0.508 ns





- 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 occasional problems is important in designing the booster system





- 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





- 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.

