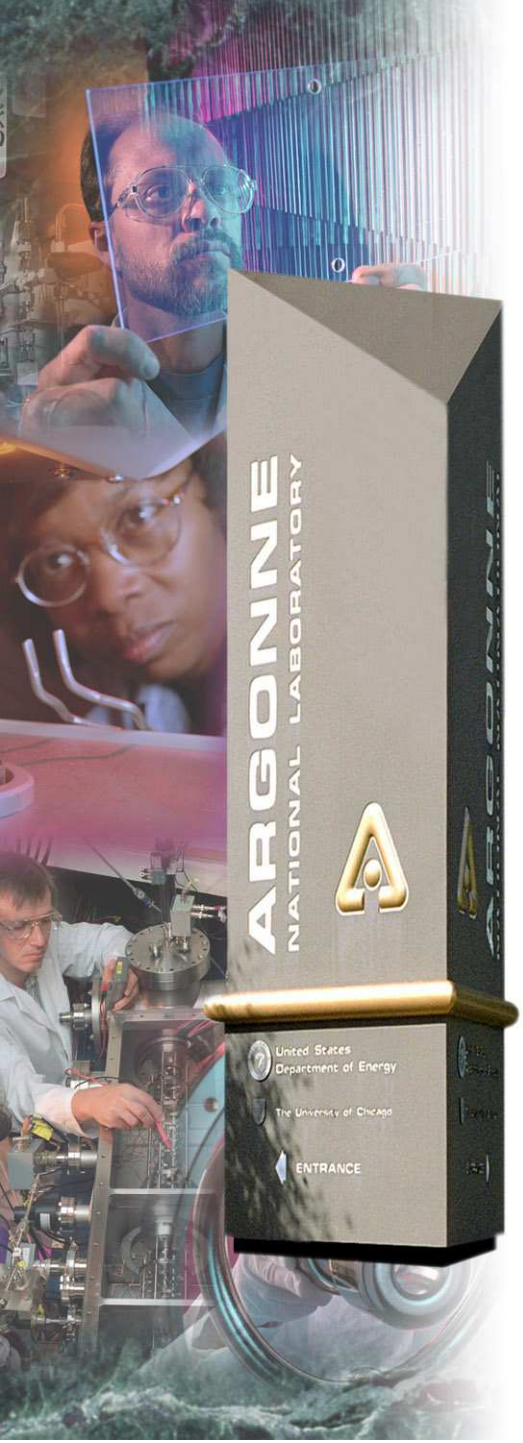


PAR Kicker Upgrade and PAR Retirement Considerations

Nick Sereno

PAR Manager, Booster Manager,
Linac Deputy Manager

Michael Borland

Operations Analysis Group / AOD

Argonne National Laboratory

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Office of Science
U.S. Department of Energy

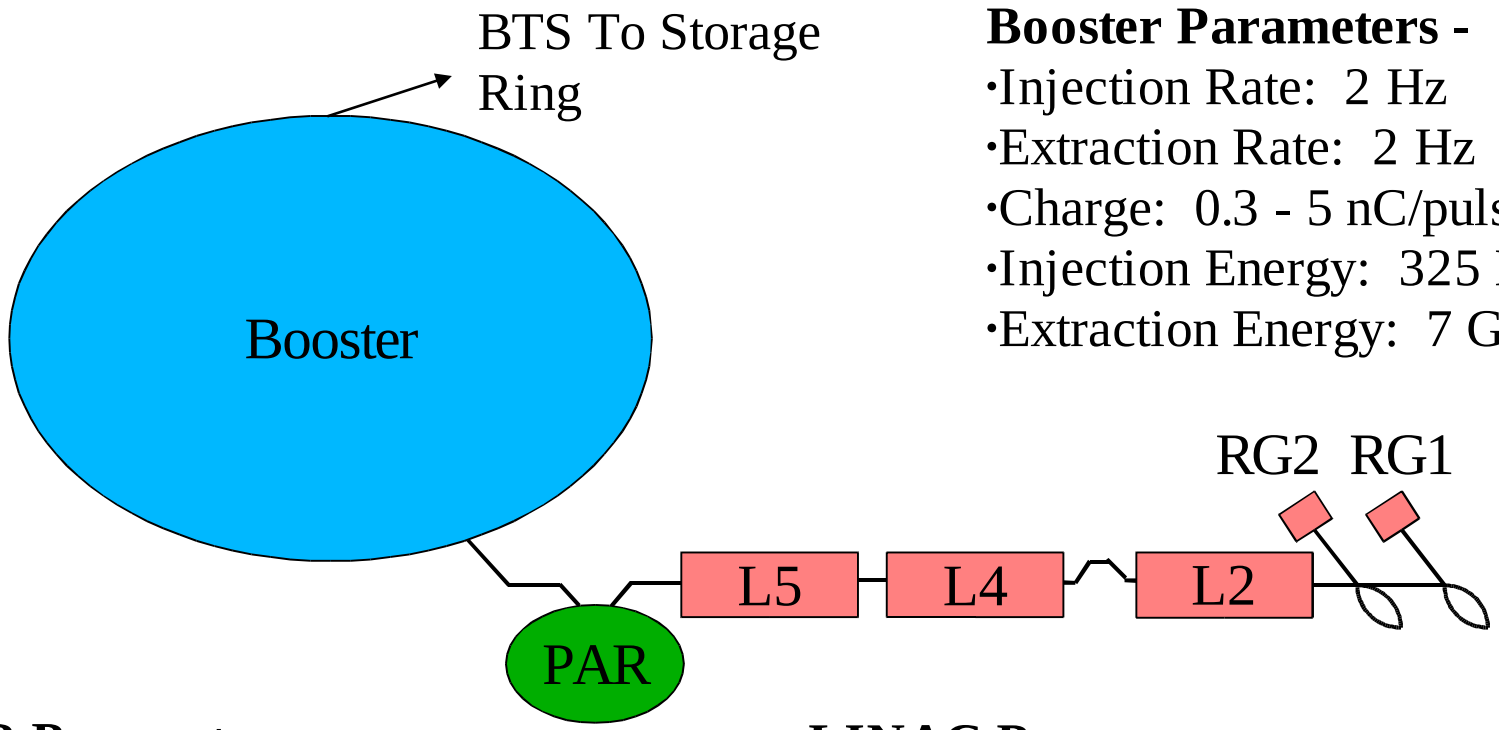
Outline

- APS injector requirements.
- APS injector configuration and operation.
- PAR kicker upgrade advantages and drawbacks.
- PAR retirement options and issues.
- Conclusion.

APS Injector Requirements

- **Top-up and timing mode are the most demanding requirements for the injector**
- **Top-up requires**
  - Single-pulse injection every 2 minutes.
  - 2-3.5 nC/shot
  - Charge requirement will increase if we push the emittance down.
- **Timing (singlets) mode requires good bunch purity: 1 part in 100,000 or better.**

Injector Configuration and Operation for Storage Ring Operations



Booster Parameters -
·Injection Rate: 2 Hz
·Extraction Rate: 2 Hz
·Charge: 0.3 - 5 nC/pulse
·Injection Energy: 325 MeV
·Extraction Energy: 7 GeV

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

LINAC Parameters -
·Beam Rate: 2 - 10 Hz
·Charge: 0.3 - 1 nC/pulse
·Extraction Energy: 325 MeV
·Linac macropulse length 11-16 ns RG2 (30 ns RG1)

PAR Primary Functions

- **Accumulate charge from the linac**
  - Reduces need for high charge gun (5x reduction)
  - Can routinely provide 5nC/pulse
  - Can probably reach operating envelope of 10nC/pulse
- **Compress bunch from 10-30 ns to 2.8 ns to provide "pure" injection into booster**
  - Reduces need for short-pulse gun (10x reduction)

PAR Issues

- **Reliability, maintenance, and time-to-repair for**
  - kicker magnets (>50% of PAR downtime)
  - rf systems (anecdotally the next biggest contributor)
- **We can address this by**
  - Improving troublesome components
  - Finding a way to eliminate the PAR altogether
- **We'll look at benefits of kicker upgrade**
- **We'll also look at difficulties of retiring the PAR**
  - Need to deliver a single pure bunch of up to 10 nC.
  - Do it every two minutes for 6 weeks.

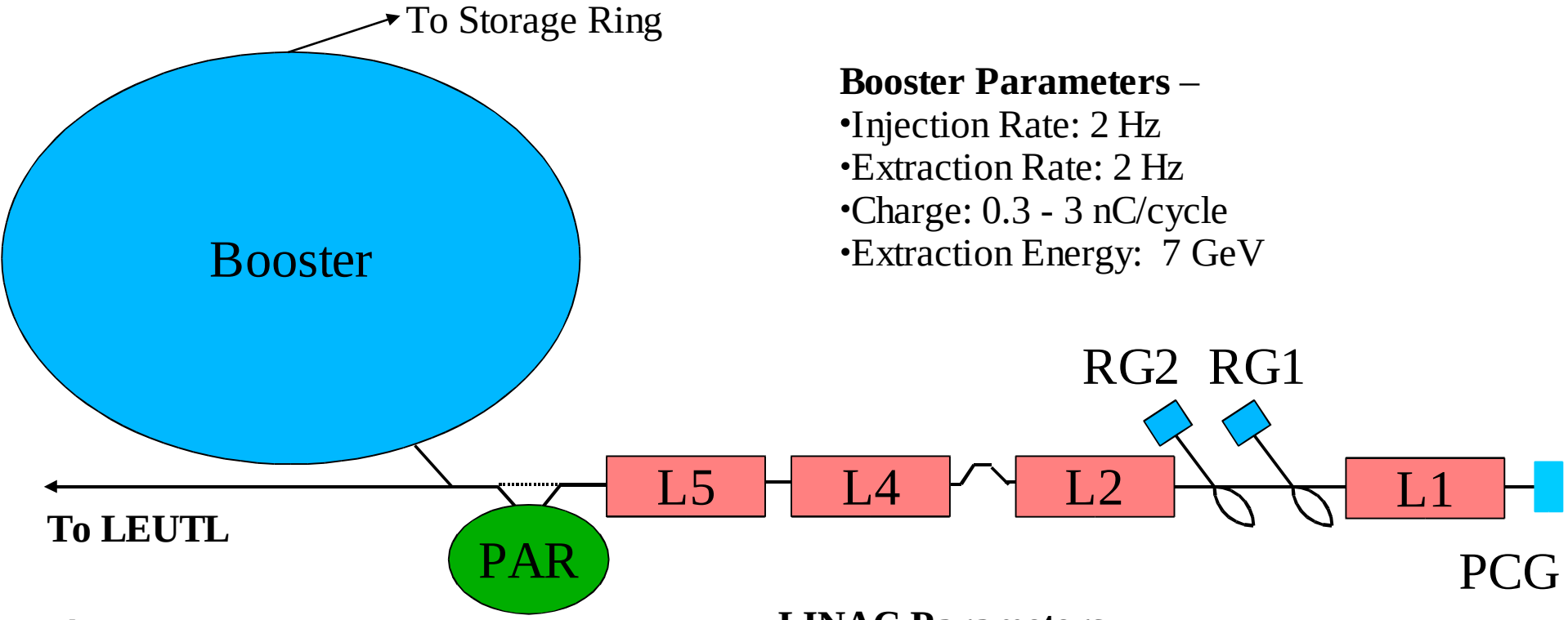
PAR Kicker Upgrade Benefits

- **Primary benefit is reduced downtime for 325 MeV operation.**
- **Present design has 1~2 failures per year**
  - Redesign will reduce this rate
- **Presently, a kicker failure takes as much as 13 hours to repair**
  - Top-up not possible during this time
  - Refills possible if beam lost, but
    - *Bunch purity is beyond horrible*
    - *Takes about 30 minutes to remove locks, close tunnel, bring up linac, and fill*
    - *About 1 hour required to shut down and resume repairs*
- **Present design requires significant maintenance at each shut down**
  - New kicker system would be easier to maintain.

PAR Kicker Upgrade Benefits

- **New design will operate at higher voltage than present design**
- **Will allow the PAR to operate at design energy (450 MeV).**
  - Improved booster reliability: more consistent injection due to injection into booster when magnet currents are higher.
  - Improved PAR reliability: lower fractional energy spread from the linac will give higher, more stable capture efficiency in the PAR (particularly for RG1).
  - May allow top-up/LEUTL interleaving at nearly the highest linac energy (~500 MeV).
- **Optionally, we *might* be able to eliminate the EK kicker altogether.**

Interleaving Injector Configuration With PC Gun and PAR for top-up



Booster Parameters –
- Injection Rate: 2 Hz
- Extraction Rate: 2 Hz
- Charge: 0.3 - 3 nC/cycle
- Extraction Energy: 7 GeV

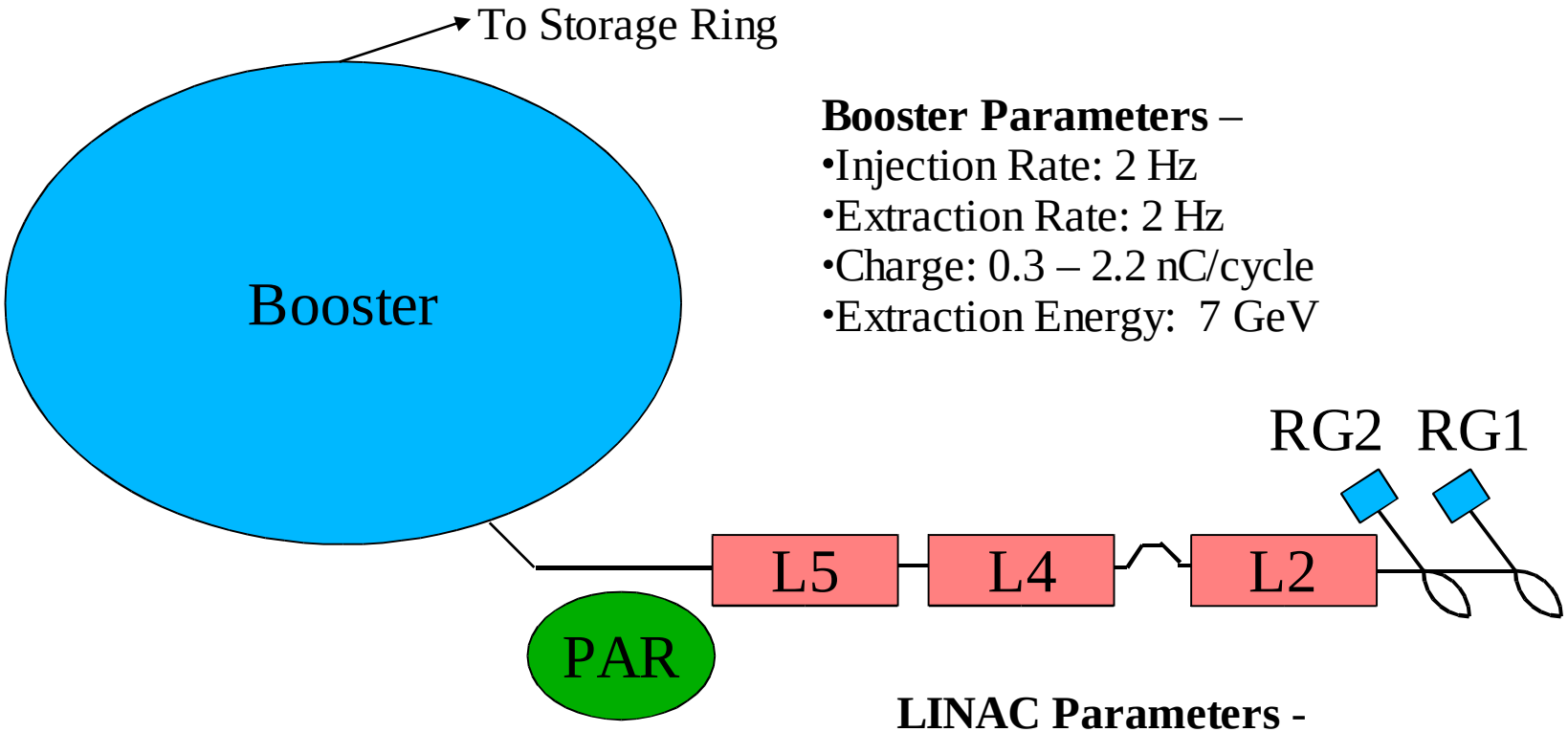
PAR Parameters -
- Injection Rate: 6 Hz
- Extraction Rate: 2 Hz
- Injection Pulses: 1-3
- Extracted Charge: 0.3 – 3 nC/cycle
- Injection Energy: 325 – 450 MeV

LINAC Parameters -
- Pulse Rate: 6 Hz
- Injection Pulses: 1-3
- Extracted Charge: 0.3 – 1 nC
- Extraction Energy: 325 - 450 MeV

Impact of PAR Operation Above 325 MeV

- **PAR fundamental and harmonic RF systems must not have reduced reliability.**
  - Design is 40 kV for fundamental and 30 kV harmonic gap voltage at 450 MeV.
  - Presently operate the fundamental at 31 kV and the harmonic at 27 kV for 325 MeV**.**
- **Somewhere between 325 MeV and 400 MeV the linac loses "redundancy" (ability to fill the PAR without L4 or L5).**
  - Presently, operators simply drive the working system harder to get 325 MeV (~5 minutes).
  - Above the redundancy energy, PAR and linac need to be standardized to down to 325 MeV (~10 minutes).
- **The interleaving benefit may require additional pulsed quadrupoles in LTP to match the transverse optics of the PC gun beam into the PAR.**

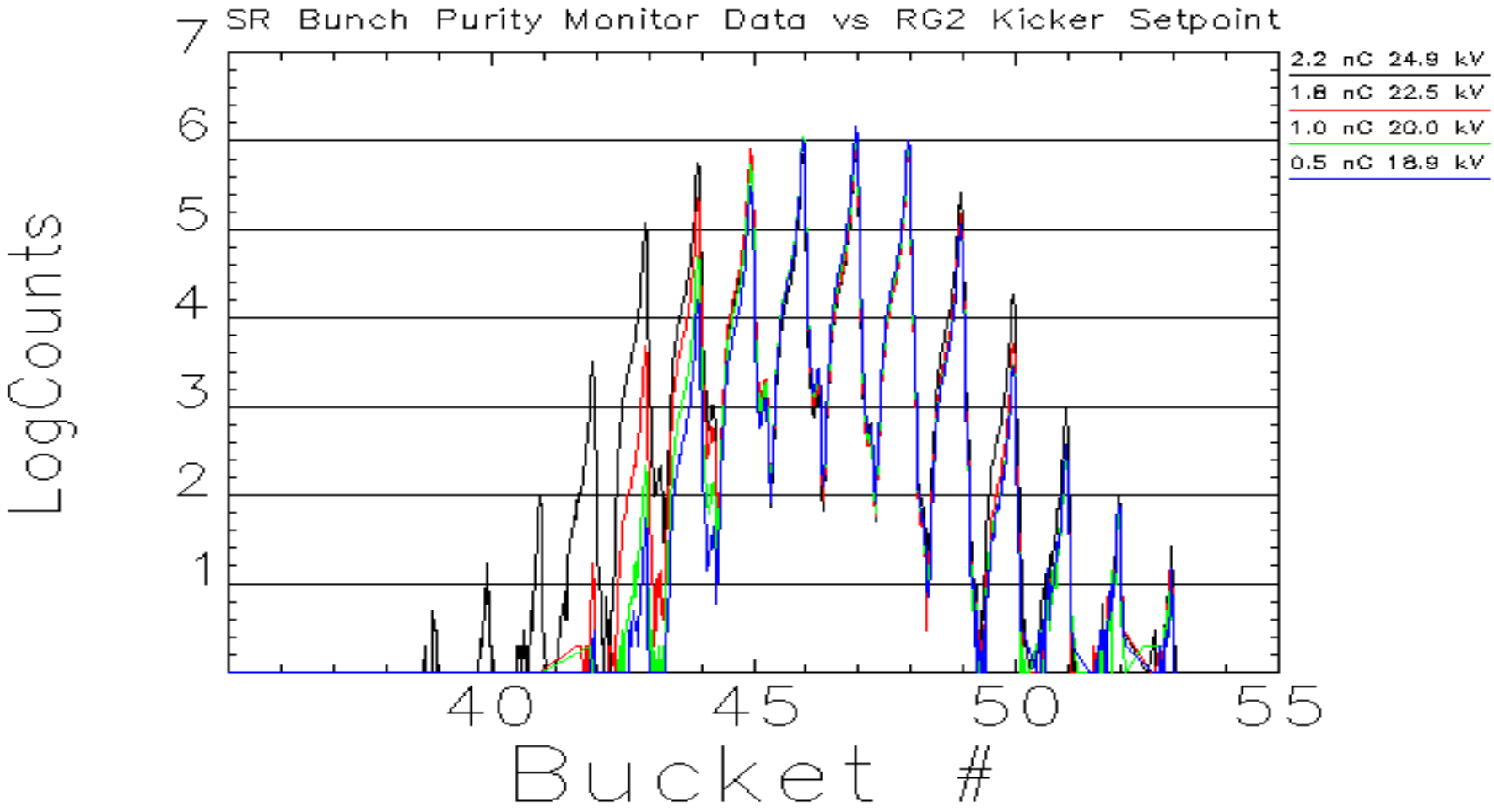
Injector Configuration for Direct Injection



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
- RG1 Macropulse Length – 30 ns

"Impure" Direct Injection – Storage Ring Bucket Pattern



"Pure" Direct Injection Options

- **Bunch cleaning in the booster (transverse knock-out)**
  - By itself, this throws away too much charge to be practical
  - Booster power supply regulation is a problem
    - *Injection at 400-450 MeV helps*
  - May be useful in combination with another scheme
- **Use a subharmonic capture cavity in the booster**
  - Not straight-forward due to low rf-frequency (~30 MHz) and high voltage (~650 kV)
  - Can be made easier by
    - *Shortening the gun pulse*
    - *Combining with bunch cleaning*

Pure Direct Injection Options

- **Replace the rf gun kickers with faster kickers**
  - Recent attempt to speed up existing kickers didn't succeed
  - SSRL rf guns use a swept kicker that delivers a ~2ns pulse
    - *Could explore this with a ~5ns design*
    - *Requires running the gun very hard (~10-20x present level)*
    - *Cathode lifetime would be shortened*
- **Use a short-pulse DC gun**
  - Can provide high charge
  - Difficult to do reliably (Nassiri)
  - Can still have multiple guns using alpha magnets (SLAC does)
  - Requires changes to the front end that might require removal of the PC gun

Pure Direct Injection Options

- **Use a laser-driven rf gun that delivers high charge in a short pulse**
  - LEUTL's PC gun is not suitable in spite of 5-ps pulse length
    - *There is still no solution to the booster-to-laser timing issue*
    - *The system is not reliable or robust enough for operations*
    - *Not clear that it can deliver 5~10 nC/pulse without damaging cathode*
  - Use of a "long-pulse" (~5 ns) drive laser is an option
    - *Duke University does this for their injector*
    - *The bunch purity may not be adequate (O'Shea)*
      - Combine with bunch cleaning or subharmonic capture

Pure Direction Injection

- **Our best non-PAR option seems to be**
  - Long-pulse-laser-driven gun delivering
    - *<=5ns pulse length*
    - *Up to 10 nC per pulse*
  - If needed, provide high bunch purity with
    - *Bunch cleaning and 450 MeV injection, and/or*
    - *117 MHz rf system in booster*
- **We need considerable R&D to ensure that this will work**
- **We need to have some assurance that the new system will be more reliable than the old one!**

Issues with Long-Pulse-Laser-Driven Gun

- **Main issue: does it work reliably?**
  - A laser-drive system with 5-ns macropulse implies 2-Amp pulse off the cathode.
  - We now run at 100-200 mA in a 2-us pulse.
    - *The guns as presently run are* very *reliable*
    - *Cathodes last for years*
  - Does cathode get damaged/degraded over time?
  - What is laser lifetime and reliability?
  - High peak current will impact
    - *Emittance*
    - *Bunch compression and energy spread*
    - *Wakefields*
    - *Transport efficiency*

Thorough Testing Required

- **We'll require significant time both for experiments and simulated long-term running.**
- **Use ITS to investigate as many issues as possible using a *standard APS rf gun*.**
  - Standard guns are easy to operate and familiar to operators
  - With standard gun, can do rapid laser vs. thermionic comparisons that are directly relevant to operations
  - We know what to expect from a standard gun in terms of
    - *Beam quality*
    - *Cathode damage (none)*
    - *Reliability (very high)*
- **After ITS testing, try on installed RG1 or RG2 gun.**
  - Use for a full run as the primary gun
  - Unmodified gun used as backup

Pure Direct Injection Will Require Time to Implement

- **Gun testing: ~6-12 months.**
  - Install standard gun
  - Benchmark diagnostics and measurement techniques
  - Characterize beams (thermionic- and laser-derived)
  - Determine operating parameters
  - Long-term test (1 month of simulated top-up)
  - Inspection of cathode surface
  - Operational test using RG1 or RG2 (1 run)
    - *Inject directly into booster and measure SR bunch purity*
- **Following gun testing, decide if subharmonic system and/or bunch cleaning is needed.**
  - If so, develop and deliver operations-ready system.
    - *Guesstimate about a year needed for this*

Conclusion

- **APS requires high-charge, high-purity injector to support user operations, particularly top-up.**
- **Existing rf guns + PAR meet requirements.**
- **PAR kicker upgrade would**
  - Improve operational reliability.
  - Make the system easier to maintain.
  - Possibly allow higher energy, more reliable injection.
- **“Impure” direct injection has been demonstrated using RG2 and can be used to fill the SR in the event the PAR is down.**
- **Significant effort required to realize “pure” direct injection and retire the PAR.**
  - Long-pulse-laser-driven rf gun.
  - Construction of bunch cleaning or subharmonic capture system.
- **PAR retirement is probably at least 2 years away.**