Status of the APS RF Systems

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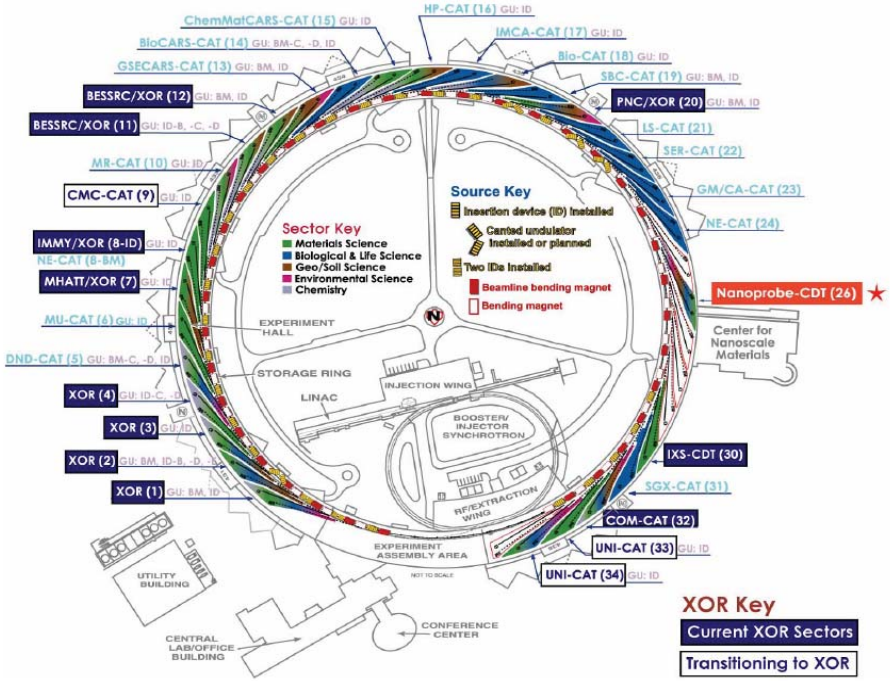
Outline

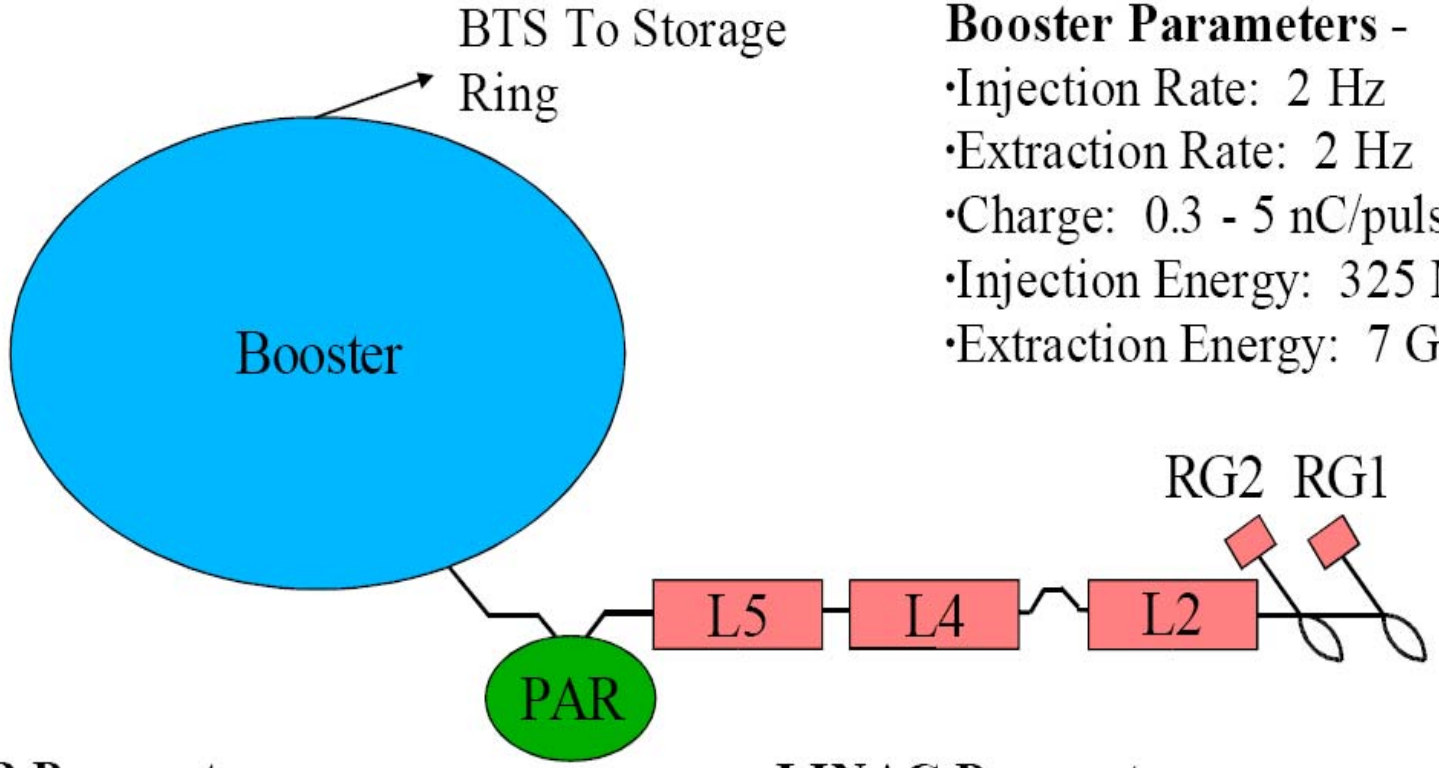
- Introduction
- Technical Systems
- Highlights
- Beam Instability
- RF Operational Statistics
- Summary

Short into to APS



- 7 GeV, 102 mA x-ray synchrotron operating since 1995
- 31 insertion devices (ID) beamlines and 24 bending magnet beamlines
- >3,000 users per year
- >98% availability, 9
- 3.1 nmm eff. emittance, 1%coupling
- Flexible bunch patterns and lattice

Injector Configuration



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 -

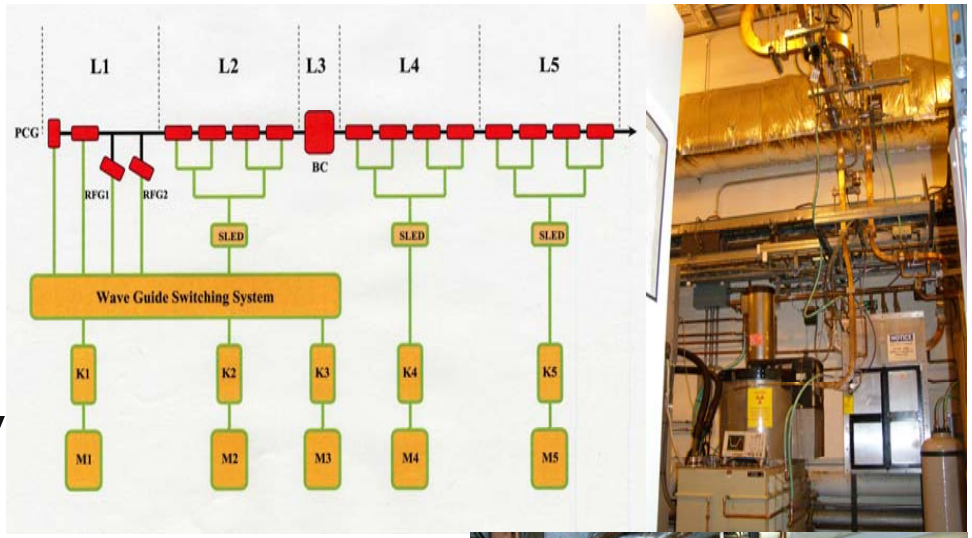
- Injection Rate: <30 Hz
- Injection Pulses: 1-5
- Extraction Rate: 2 Hz
- Extracted Charge: 0.3-5 nC
- Operating Energy: 325 MeV

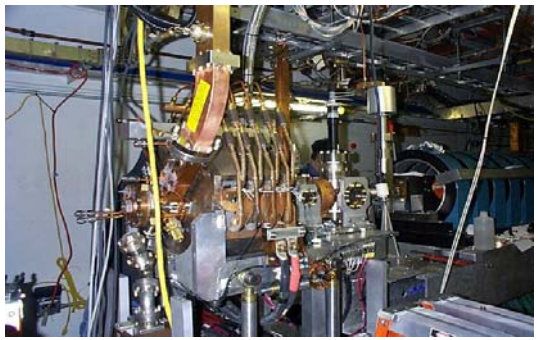
LINAC Parameters -

- 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)

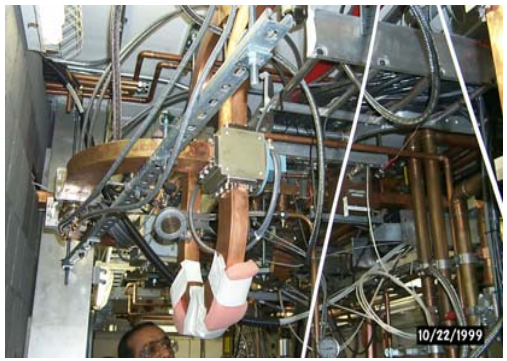
Linac RF

- S-Band Linac
- 450 MeV Linac
- Thermionic rf gun
  - 1.6-cell, π mode
  - Macropulse current 1A, 4.5 MeV
  - Emittance ~ 5 πmm-mrad (rms)



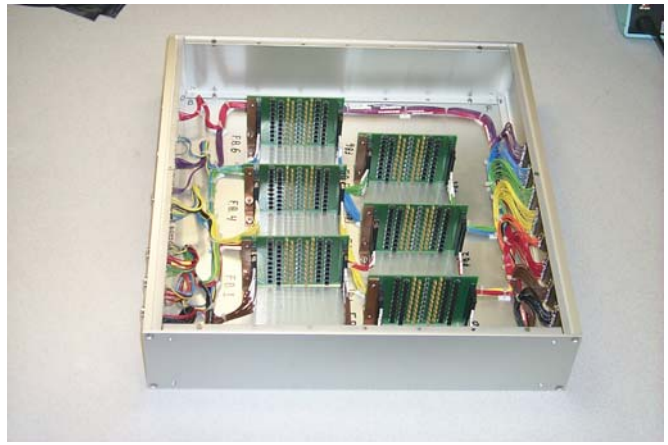


- BNL/ATF photocathode
- ~200 pC/bunch
- 300-A peak
- 3 πmm-mrad (rms)
- 5 MeV
- 119-MHz Nd:Glass laser
- 260 fs Up-conversion IR to UV
- 400 μJ pulse (~1.5 ps FWHM)



Linac RF System Enhancements

- Built and installed a Signal Filtering Chassis (SFC) in all modulators which significantly improved the overall reliability by reducing the amount of unnecessary trips caused by noise.
- Designed, built and installed saturating chokes in series with the thyratrons to delay the thyratron current pulse and reduce switch losses for increased thyratron lifetime.
- Installed new thyratron trigger units with grid pre-pulsing for improved thyratron stability and lifetime.
- Installed new arc detectors viewing the klystron windows, which features increased diameter, radiation resistant, optical fiber and greater circuit gain..



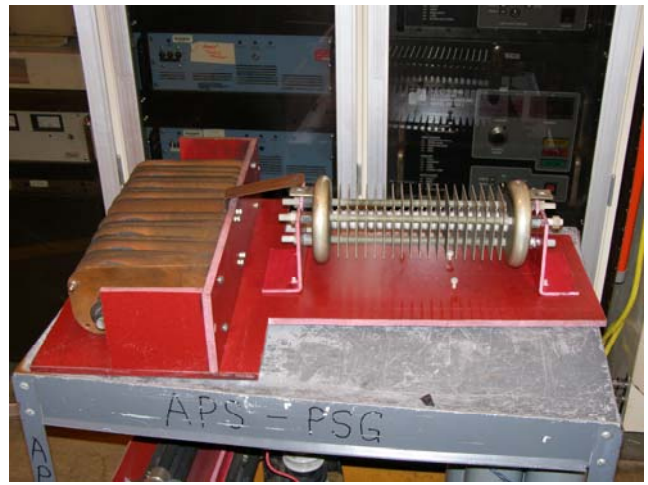
Signal Filtering Chassis

Saturating Choke

Linac RF System Enhancements (2)

- Built a high-voltage “Corona Test Cage” for testing the reliability of high-voltage rf components.
- Implemented new high-voltage cable connectors in all modulators to reduce corona discharge and prevent high-voltage cable failures.
- A “Roll-Around” spare klystron oil tank with klystron was built to reduce operational down-time when a klystron replacement is required.
- Designed, built and installed easy-to-remove “End of Line” clipper assemblies in all modulators for improved downtime.

Spare “Roll-Around” klystron / Tank



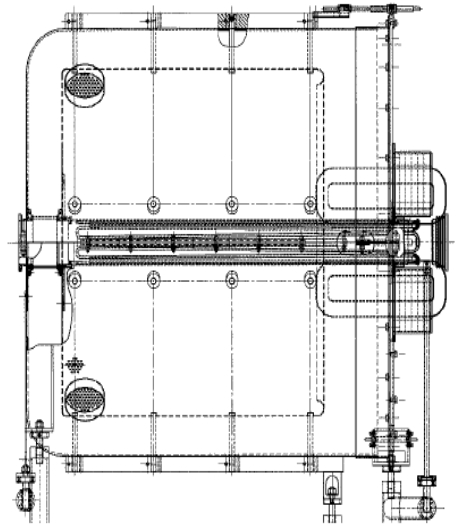
End of Line Clipper Assembly

Particle Accumulator Ring (PAR)

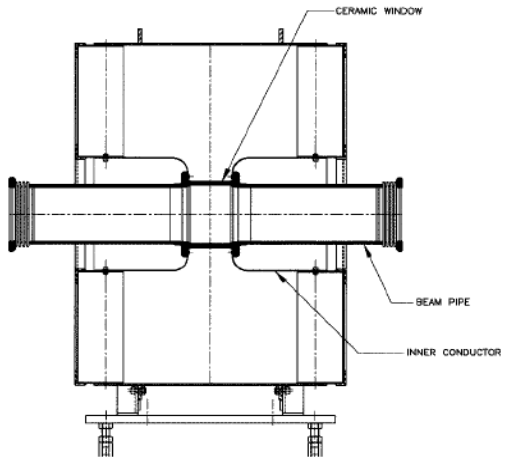
- Accumulates charge from the linac
  - Reduces need for high charge gun (5× reduction)
  - Can routinely provide 5 nC/pulse
  - Can potentially reach operating envelope of 10 nC/pulse
- Compresses bunch from 10-30 ns to 2.8 ns to provide “pure” injection into booster synchrotron
  - Reduces need for short-pulse gun (10×reduction)
- Fundamental RF system @9.8 MHz
  - Design is 40 kV, routinely operates at ~31 kV (325 MeV)
- Harmonic RF system @117 MHz
  - Design is 30 kV, routinely operates at ~27 kV (325 MeV)

PAR RF Cavities

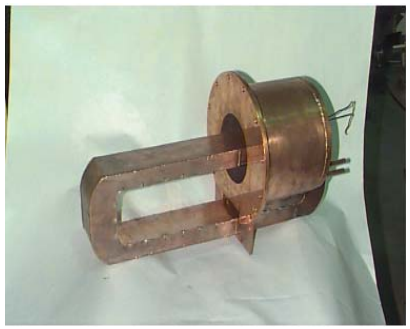
- Plunger-loaded reentrant coaxial structure.
- 1.6 m in length with a radius of 0.72 m and an accelerating gap of 13 cm.



- Reentrant type coaxial cavity.
- 60 cm in length with the outer conductor diameter of 1m and the inner conductor diameter of 30 cm.



- Ferrite tuners are used for both cavities
- Copper housing with toroidal ferrite cores.



	Toshiba M4C21A	Stackpole C/14
O. D. (inches)	8.0	8.0
I. D. (inches)	5.0	5.0
Height (inches)	1.0	1.0
Initial permeability	42	12.5
Magnetic loss tangent	0.0085	
Curie temperature (°C)	340	510
Saturation magnetization (gauss)		2100
Dielectric constant	13.0 @40MHz	10.5
Dielectric loss tangent	0.0003 @40MHz	

PAR RF System Enhancements (2)

- Replaced obsolescent pulse generators driving the harmonic par with VXI based arbitrary function generators, achieving a major improvement in controllability of the generators and stability of the compressed pulse.

- Provided extensive support for the par bunch cleaning design, installation, and commissioning effort, including evaluation of mixers, low and high power amplifiers, and variable phase shifters/ delay lines, arranging packaging, and defining interfaces and spares.

- Ensured equal performance of the back up harmonic par power amplifier by upgrading the high voltage power supply with a new power transformer identical to the one in the alternate triode tube amplifier system.

Original Function Generator

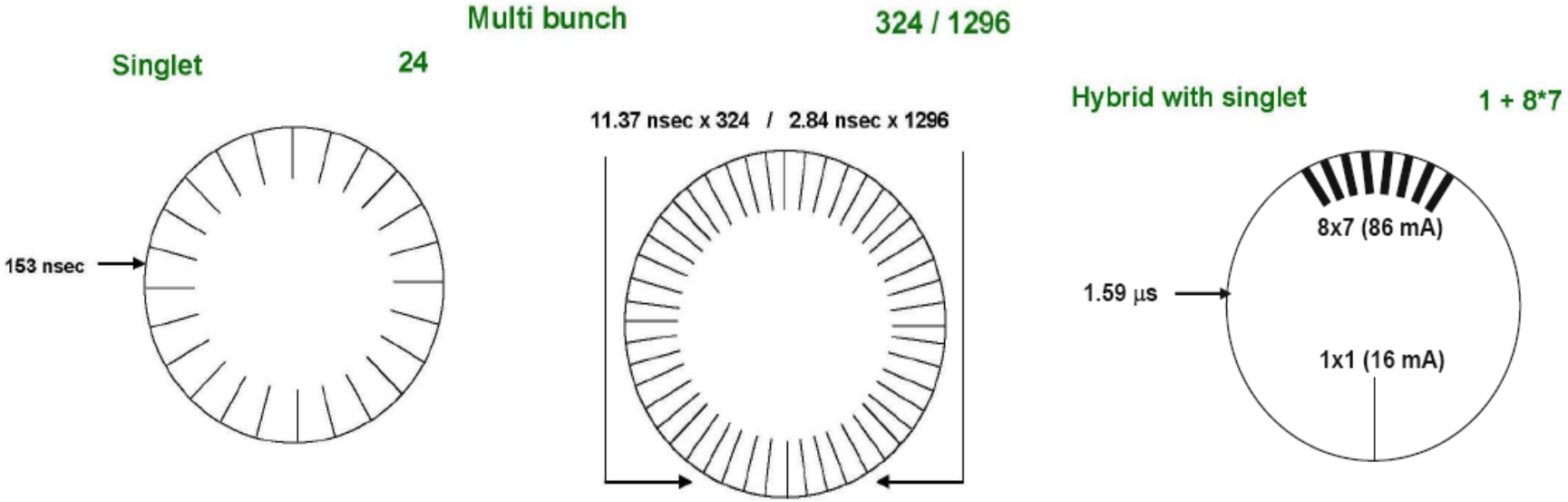
New VXI-based Function Generator

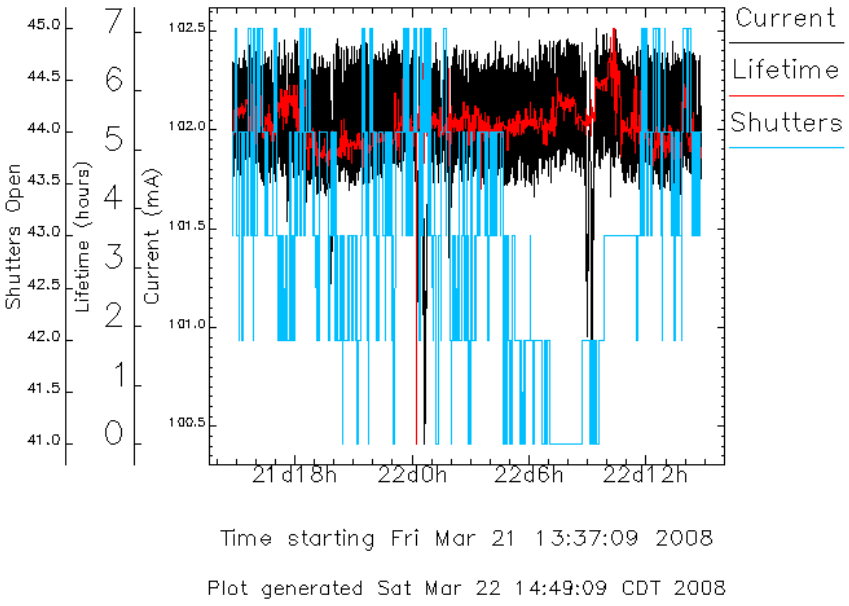
PAR High Power RF Switching Systems

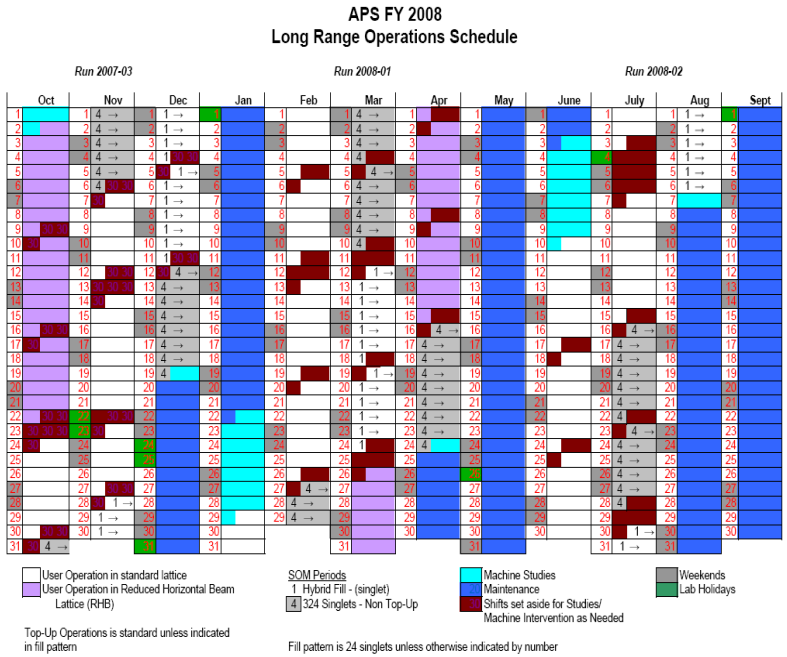
- Switching system controlled by operators using EPICS control screens.
- Both fundamental par and harmonic par uses a high power rf switching system. The LLRF drive to the tube amplifier and the high power rf switch, switch simultaneously.
- Operators can quickly switch high power rf amplifier systems in the event of a failure therefore increasing availability or improving down-time.

Fundamental Par High Power RF Switching

APS Operating Modes, 102 mA





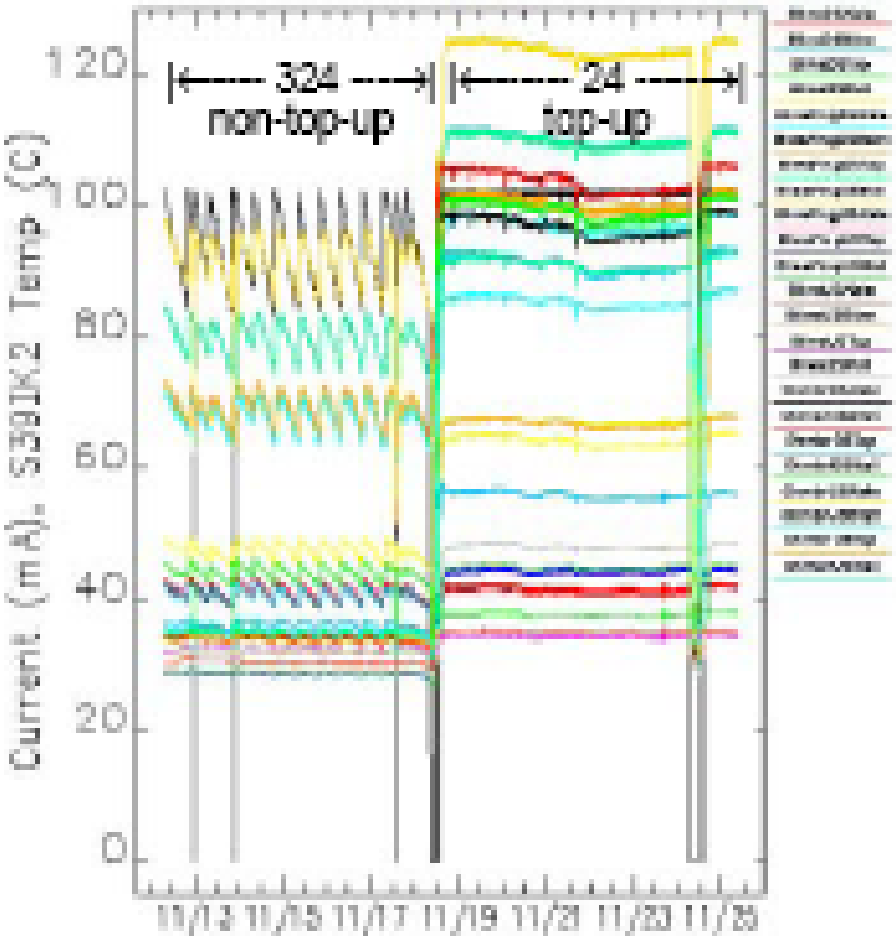


Multibunch Instability at high current

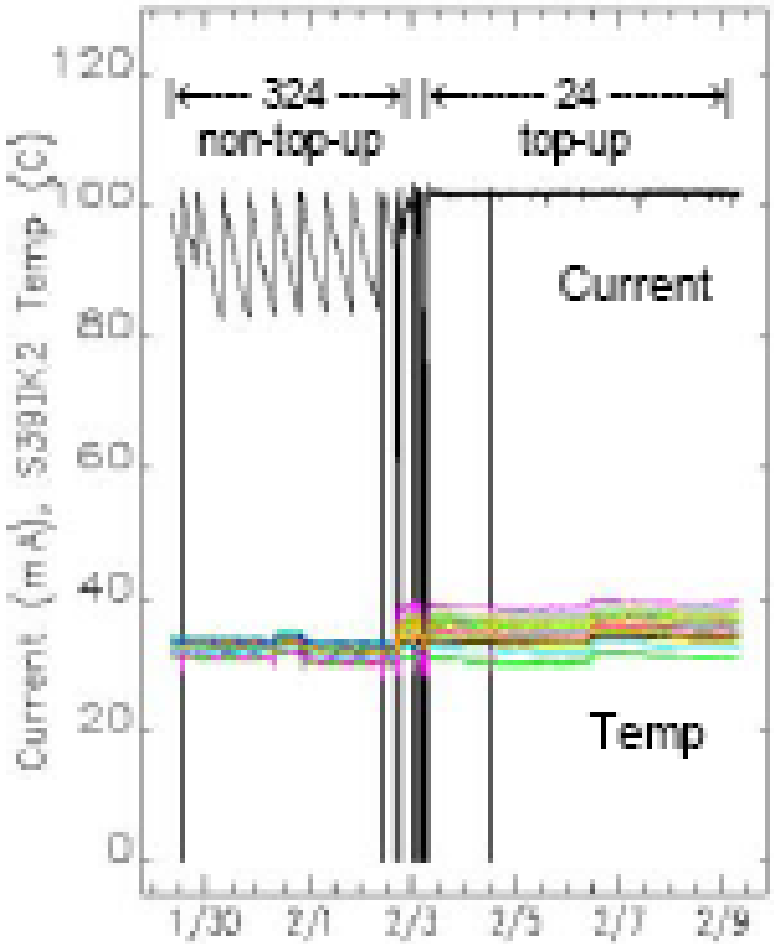
- APS storage ring is normally operated with 102 mA
- A number of high-current studies were carried out to determine MBI limits.
- The longitudinal MB instability is dominated by the rf cavity HOMs and the CBI threshold.
- Beam stable with 324 bunches (200 mA)
- CBI threshold is 245 mA
- With 24 bunches (above 160 mA)
  - Several components approaching temperature limits
    - *Ceramic kicker chambers*
    - *HOM dampers*
  - No CBI observed at this current
- Transverse MBI are mostly driven by the resistive wall impedance
  - Cure: rely on the chromaticity to stabilize the transverse MBI.

Multibunch Instability at high current (2)

- Kicker chamber redesign
  - Mitigate excessive heating



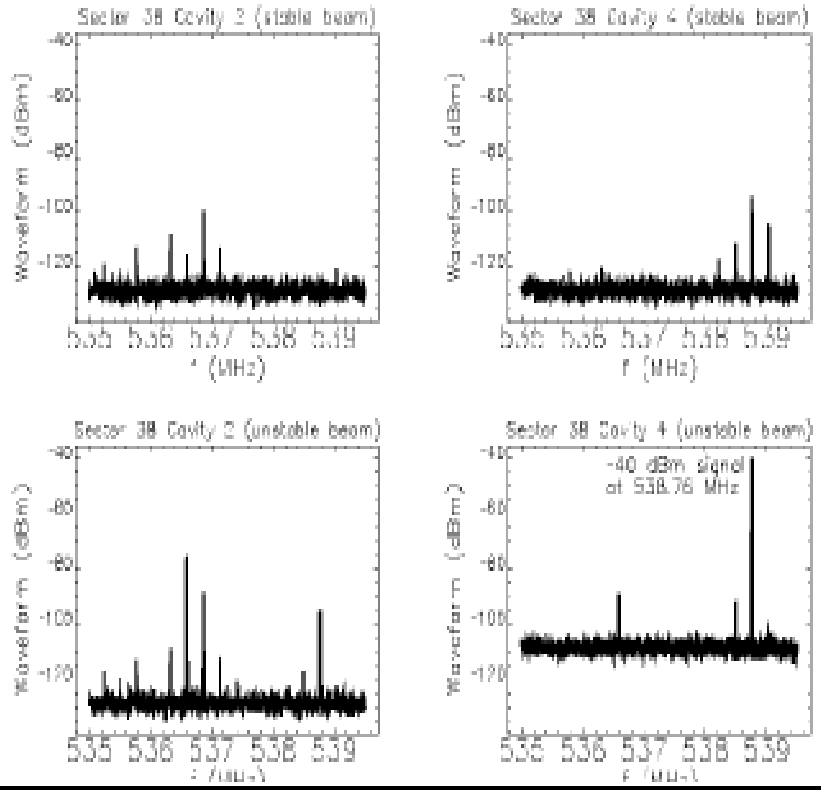
Before redesign



After redesign

Multibunch Instability at high current (3)

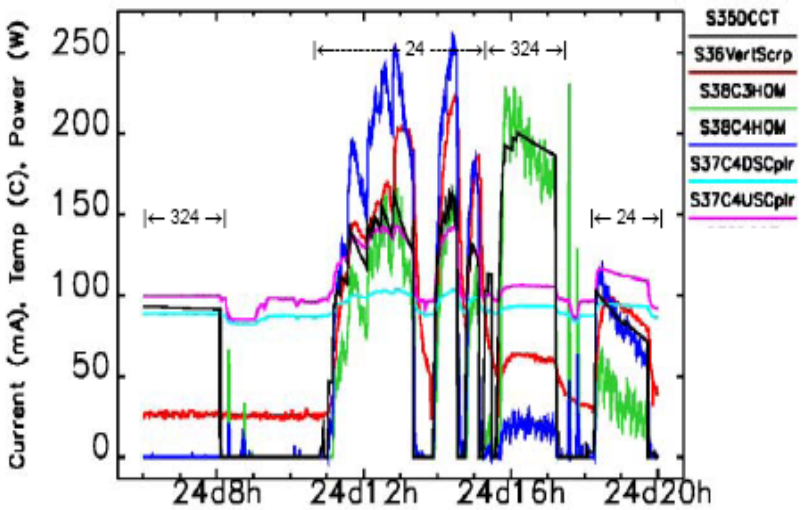
- HOM Dampers
  - Rf cavity HOMs have been long known to potentially drive longitudinal CBIs in the APS
  - Instability is stongly bunch-pattern dependent
  - In 24-bunch operation, the lowest monopole 540-MHz HOM was found to drive CBI at a threshold of about 85 mA
    - *Typical cure*
      - Detuning the offending cavities
      - Adjusting the cooling water temperature
    - *However, it became more difficult to find stable operating points for all cavities.*
    - *HOM dampers were designed and installed in one sector (38)*
    - *It provide a de-Qing factor of about 8*

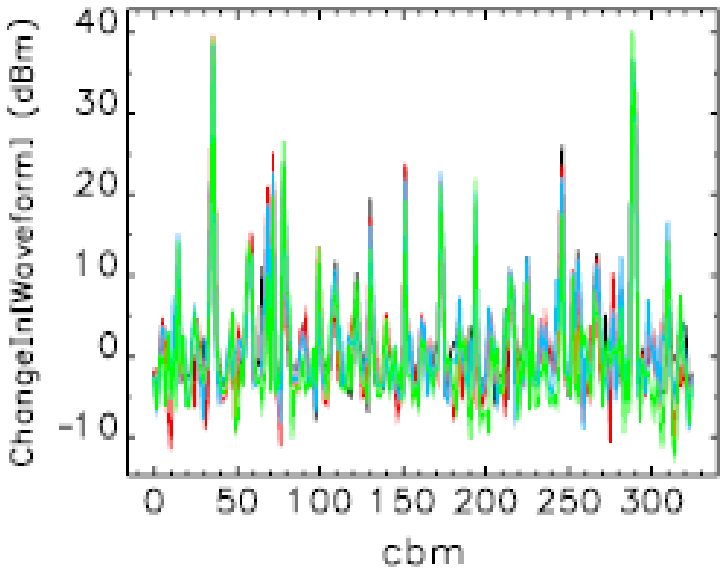


Longitudinal Limits

- We can stably store 164 mA in 24 bunches. No CBIs.
- We concluded that the HOM dampers have raised the threshold by at least 60%
- However, several SR components are approaching temperature limits above ~160 mA.

- With 324 bunches, the beam is stable up to a CBI threshold of ~245 mA
- The dominate mode numbers are 36, 78, and 151
  - 538 MHz, 1211 MHz, 915 MHz





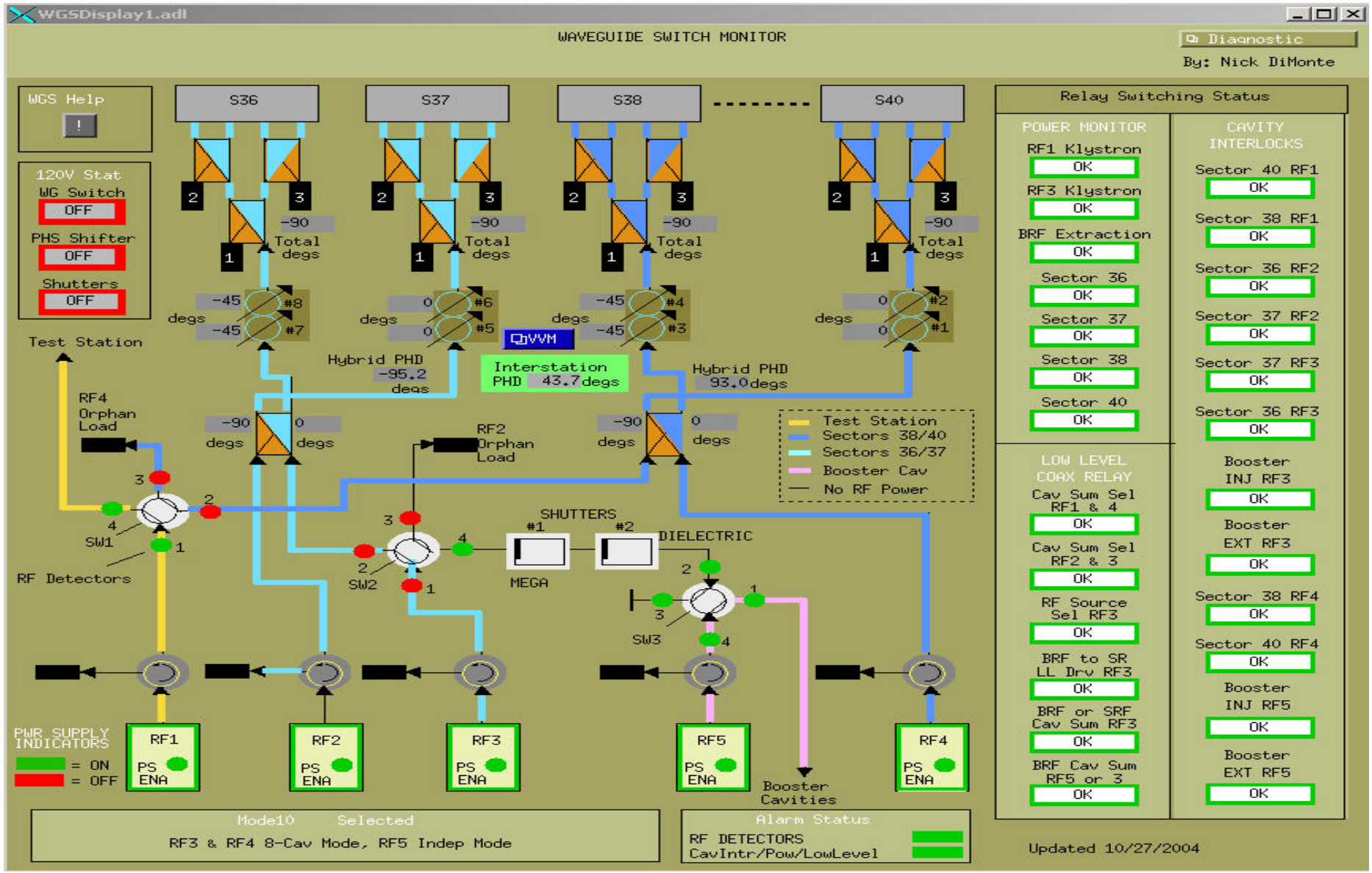
352 MHz RF System Layout

- **Five 352-MHz/1MW**
  - RF1-RF4 for storage ring (CW)
  - RF5 for booster (ramped)

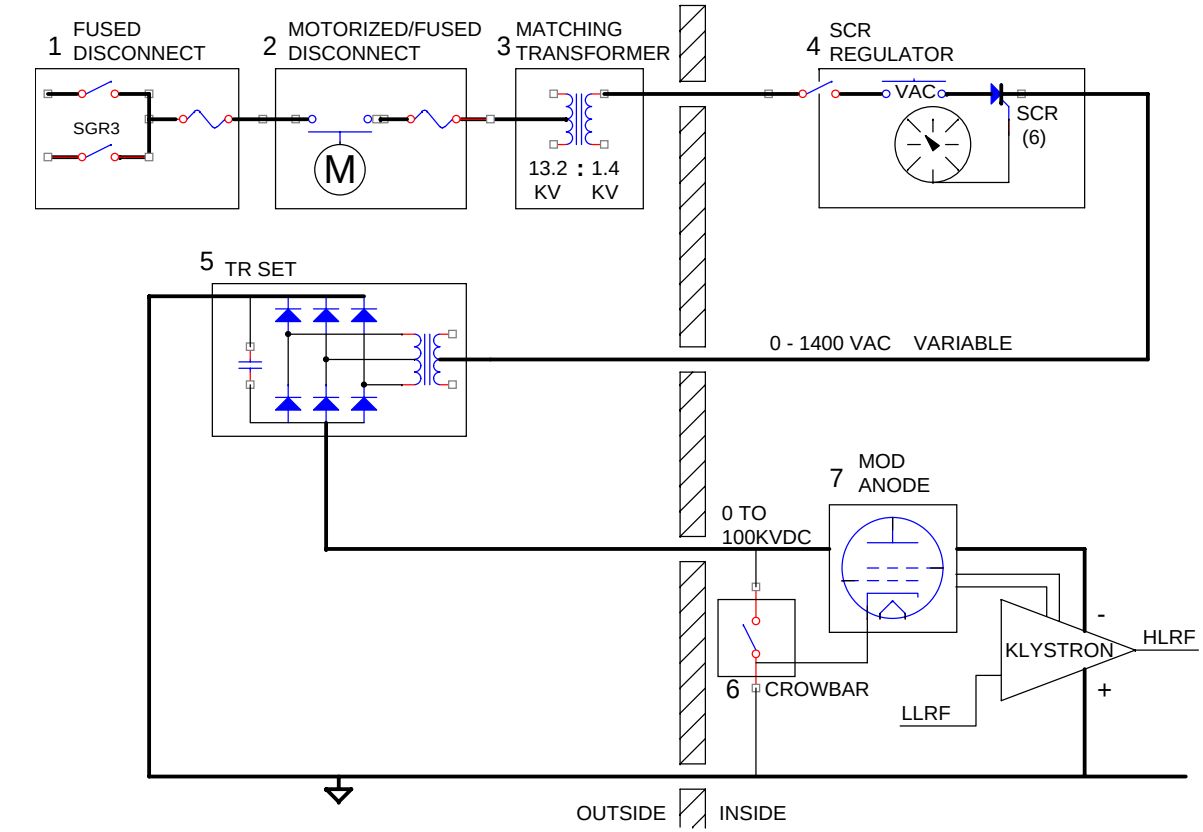
- **Waveguide Switching System provides:**
  - Easy switch to hot standby system
  - RF3 backup for RF5 in Booster service
  - Parallel-klystron mode for storage ring operation greater than 150mA
  - RF1 feeding power to 350-MHz RF Test Stand

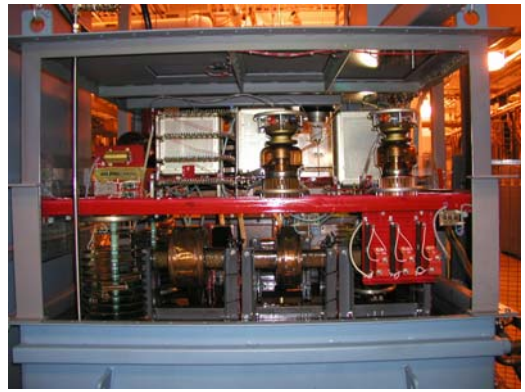
- **Waveguide shutters provide personnel safety isolation in waveguide.**

352 MHz RF Switching Scheme



2MW POWER SYSTEM FOR SR & BOOSTER





RF System Components

Waveguide Switching System

Waveguide Switch

PLC Control

Waveguide Shutters

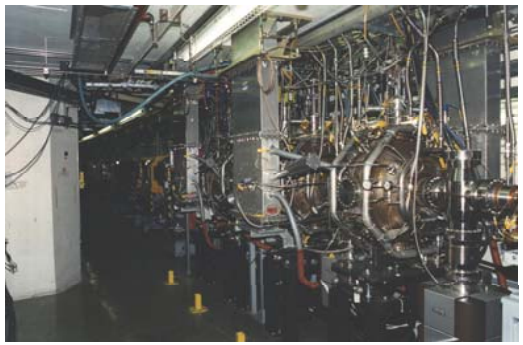
Waveguide Phase Shifter

Klystrons and Power Supplies

352-MHz/1MW CW Klystron

2 MW DC Klystron Power Supply

One Sector of Storage Ring RF Cavities



VXI Analog Low-Level RF Electronics

Highlights

- **Mar 2002 :** 130mA storage ring operation demonstrated.
- aa
- **Apr 2002:** Successful user run at 130mA.
- **Sept 2003:** Successful demonstration of parallel-klystron operation involving all four storage-ring rf systems – 115mA stored.
- **Dec 2003:** 225mA storage ring operation demonstrated utilizing parallel-klystron operation.
- **Apr 2005:** 150mA storage ring operation after Sector 38 HOM damper installation.
- **Apr 2005:** Demonstrated storage-ring bunch shortening utilizing rf phase modulation technique.
- **Aug 2005** 250mA storage ring operation
- **Oct 2006:** Successful use of RF3 in Booster-mode for one week while repairs on RF5 were completed.
- **Oct 2007:** 200 kW operation of a single-cell cavity with dual coupler

352 MHz RF System Enhancements

- **Installed 60Hz ripple-rejection boards to reduce noise on storage ring rf.**
  - Reduce beam motion
- **Installed WR2300 waveguide shutters.**
  - Enhanced personnel safety at test stand, and allowed smoother transition to RF3-Booster operating mode
- **Upgraded RF Source equipment rack.**
  - Improved overall reliability and mean-time-to-repair
- **Designed and implemented new feedback card design.**
  - Improved overall reliability
- **Upgraded computers in rf system power supplies.**

352 MHz RF System Enhancements (2)

- **Installed E-Probe HOM dampers in Sector 38 rf cavities**
- **Upgrade storage ring rf cavity blower controls**
  - Improved overall reliability
- **Installed PLC interlock system upgrades at three storage ring rf system**
  - Improved overall reliability
- **Matching Transformer 1400V:13.2kV:**
  - Installed cooling fan and control system
  - Added proper winding support and blocking material
  - Removed multiple core grounds.
- **SCR Regulator:**
  - Installed water metering and interlocks
  - Installed additional ground bus
  - Modified phase isolation barriers
  - Installed “star” distribution ground system
  - Manufactured spare Gun Anode Regulator cards.
- **Crowbar:**
  - Installed VESDA smoke detectors
  - Added smoke detection interlock system
  - Installed Crowbar Stack video monitoring and distribution
  - Enhanced the di/dt circuitry.

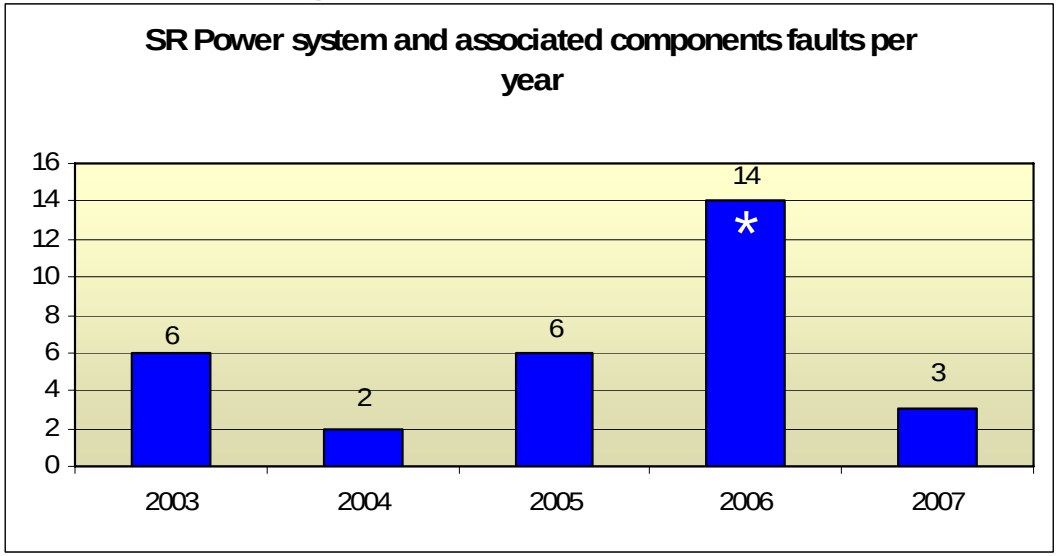
Operational Statistics

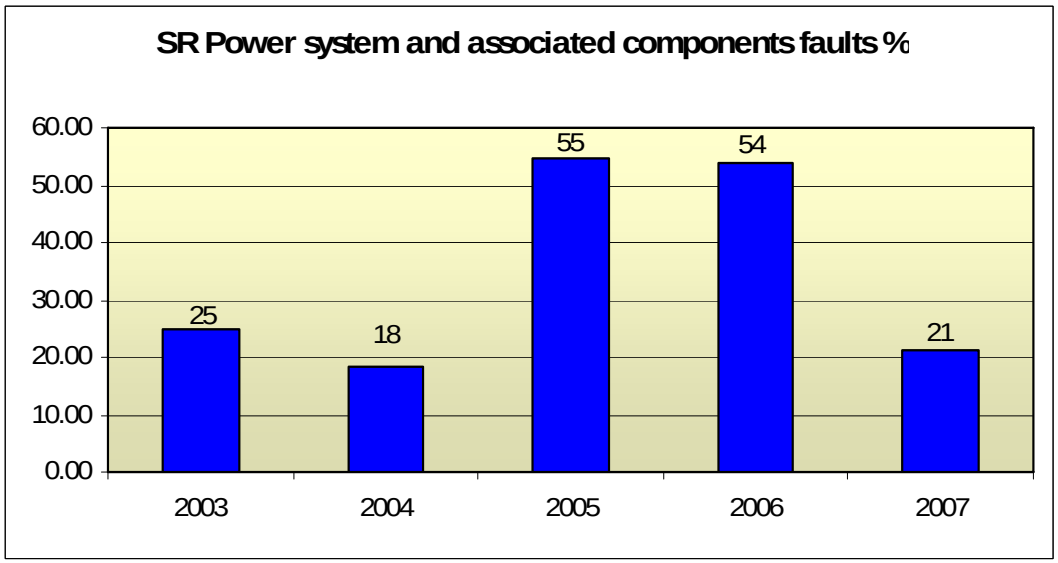
Booster and SR RF

	% Downtime	MTBF
FY 2002	0.58%	98.4hr
FY 2003	0.44%	198.9hr
FY 2004	0.13%	464.8hr
FY 2005	0.27%	493.3hr
FY 2006	0.84%	195.0hr
FY 2007	0.39%	339.3hr

Operational Statistics (2)

SR Power System





* Faults

Faulty circuit breaker: 1

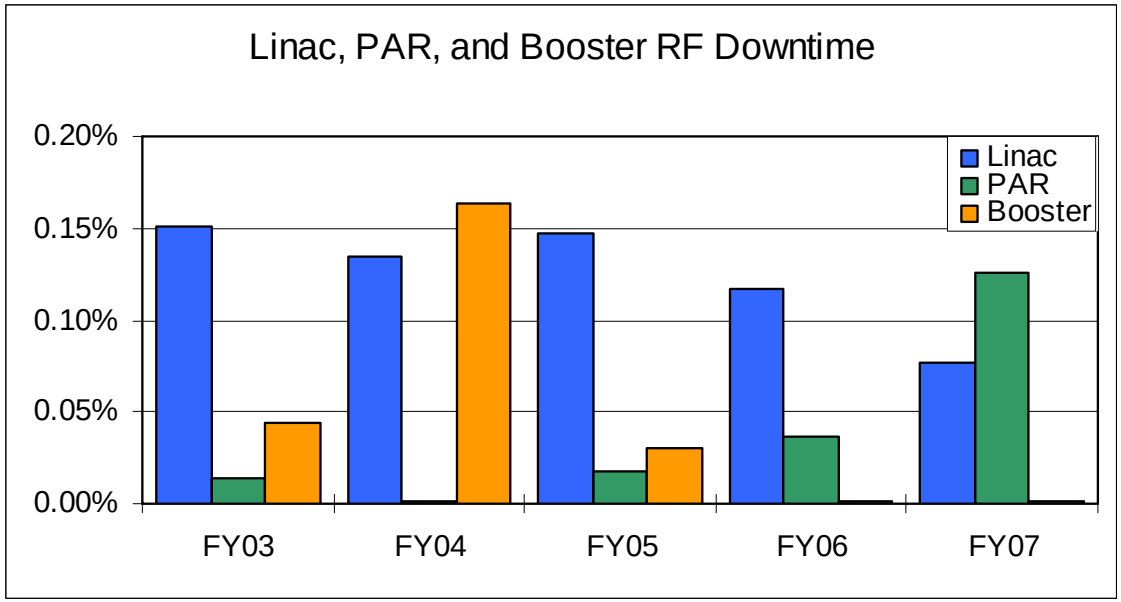
Water load wiring: 1

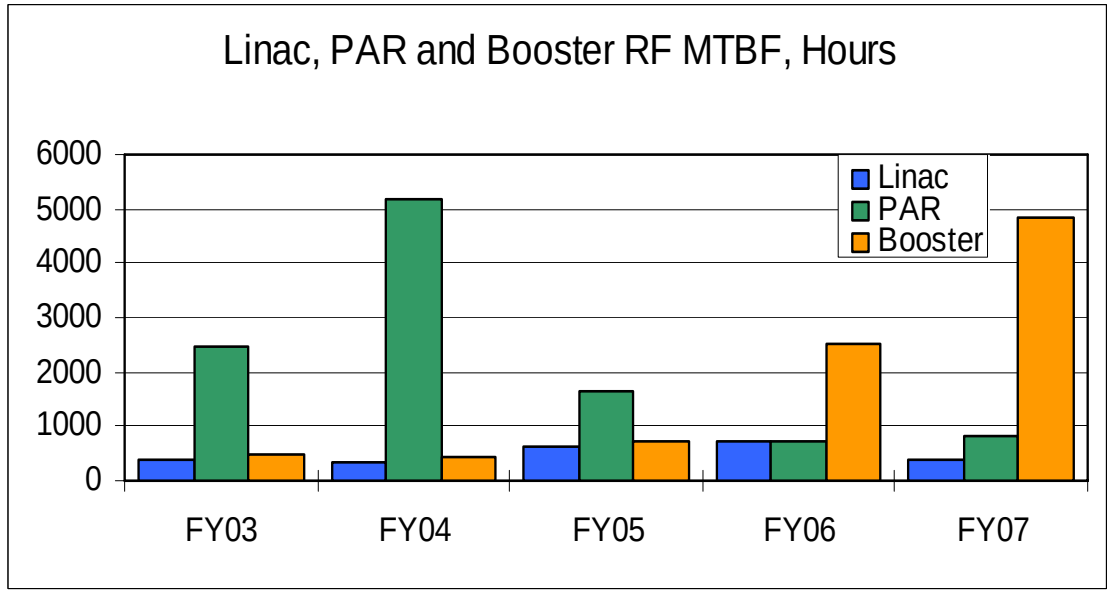
Crowbar fired: 3

klystron ma instability: 4

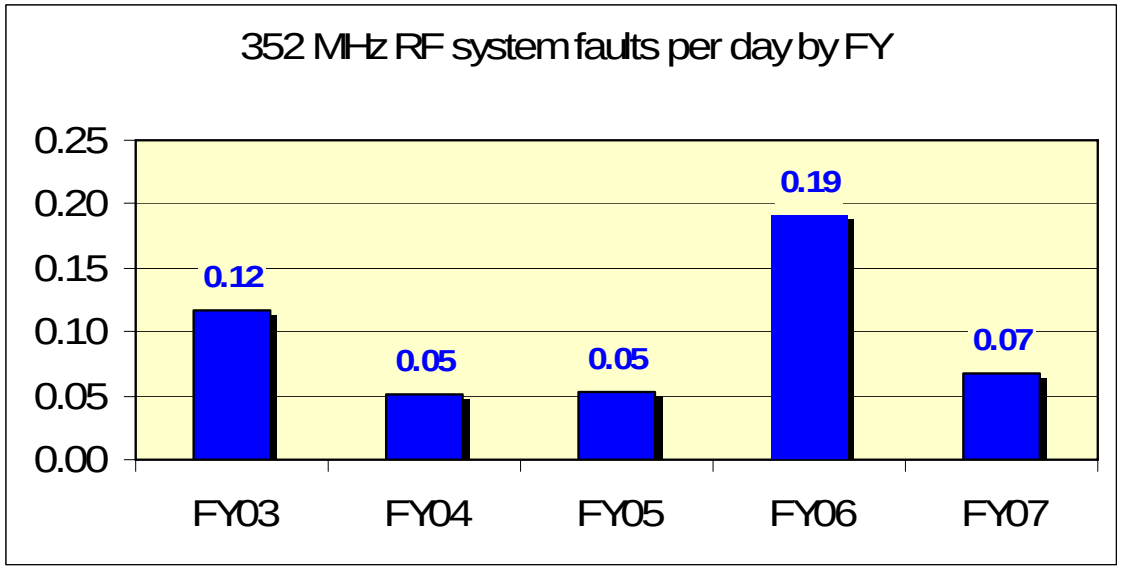
RF4 intermittent opto-coupler 5

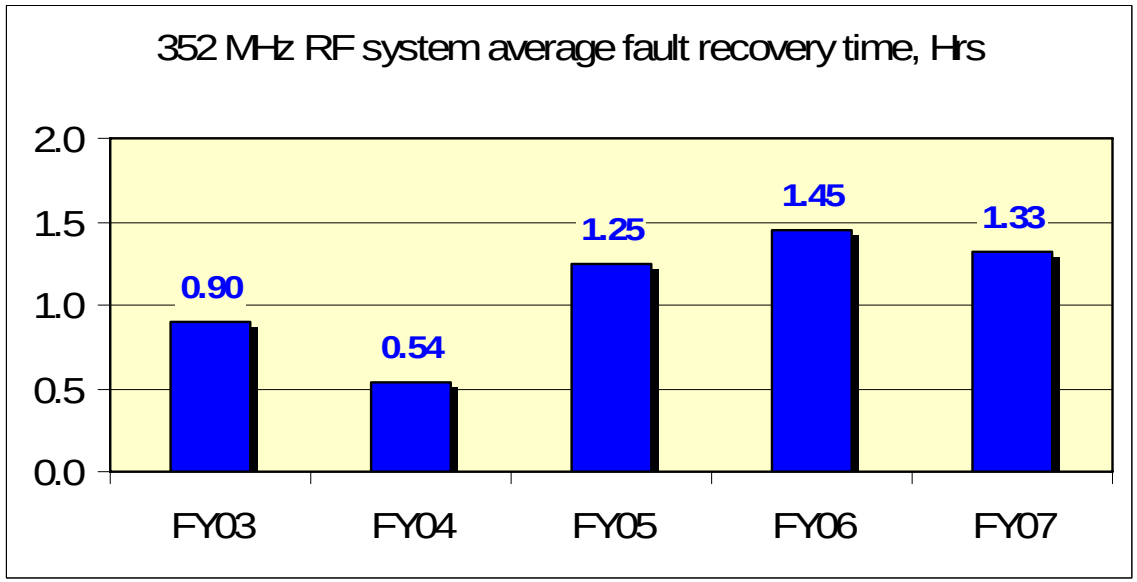
Operational Statistics (3)



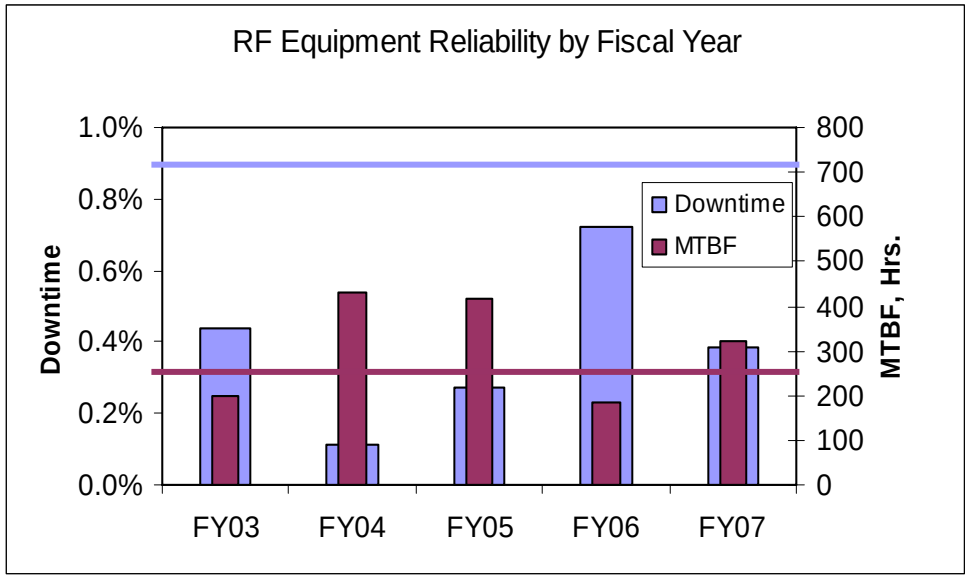


RF Operational Statistics (4)

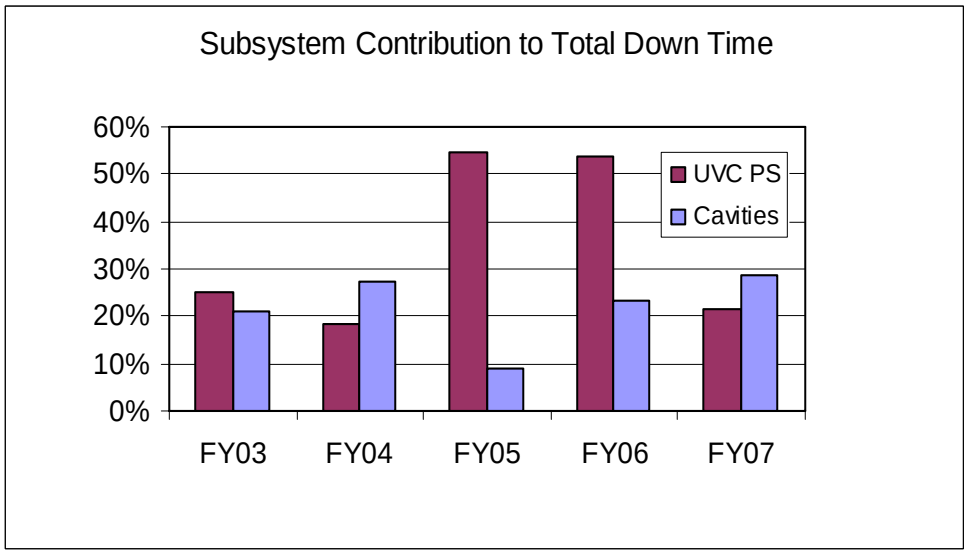




RF Operational Statistics (5)



SR RF down time statistics.



Major contributors to the SR down time.

Summary

- **The APS RF system reliability is world-class and perform equally well compared to 3rd generation light sources worldwide.**
- **Proactive approach to maintenance to minimize rf downtime.**
- **Incremental improvements, enhancement, and upgrades to maintain a steady reliability to meet operational demand.**
- **Systems degradation, components aging and obsolescence makes it difficult to maintain long-term high operational reliability, over 200 hrs MTBF, and higher beam uptime.**
- **Significant investment is needed to address long term rf systems aging and obsolescence issues. We are addressing this in the context of the APS upgrade. Smart investment.**
- **We will focus our efforts on:**
  - Maintain a highly reliable rf systems in support of the APS operation.
  - Develop in-house SRF expertise and establish an R&D test facility in support of the APS upgrade and other SRF related applications.
  - Develop in-house expertise in digital LLRF and controls.
  - Exploring collaboration opportunities for the development of rf systems with other light source facilities