

The Fourth CW and High Average Power RF Workshop

May 1 - 4, 2006

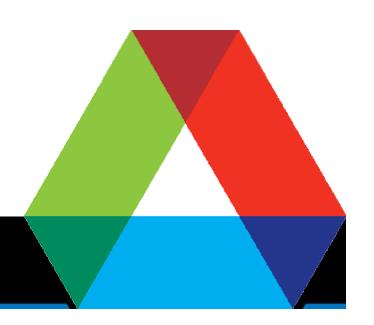
Mark E. Middendorf Intense Pulsed Neutron Source Argonne National Laboratory Argonne, Illinois







A U.S. Department of Energy laboratory managed by The University of Chicago



Acknowledgements

Frank R. Brumwell IPNS, ANL

Roger Blackman IPNS, ANL (Retired)

Jeffrey C. Dooling IPNS, ANL

Quentin Hasse IPNS, ANL

Douglas Horan **APS, ANL**

Robert L. Kustom APS, ANL (Retired)

Marvin K. Lien IPNS, ANL

Gerald McMichael IPNS, ANL

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Ali Nassiri APS, ANL James Spindler **APS, ANL**

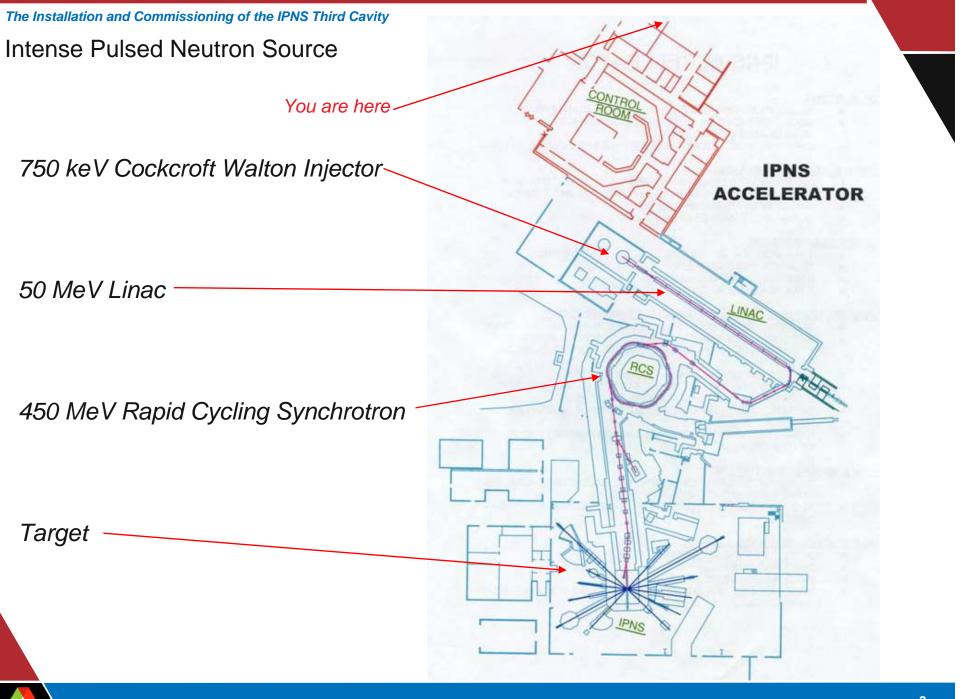
Vernon F. Stipp IPNS, ANL

Charles Whiteford IPNS, ANL

James Zmuda IPNS, ANL

Robert Zolecki IPNS, ANL (Retired)





Outline

- Motivation
- Description of the Original IPNS RCS RF System
- Description of the Third Cavity RF System
- Installation and Commissioning of the Third Cavity RF System
- Plans for Operating Third Cavity at the Second Harmonic



Motivation

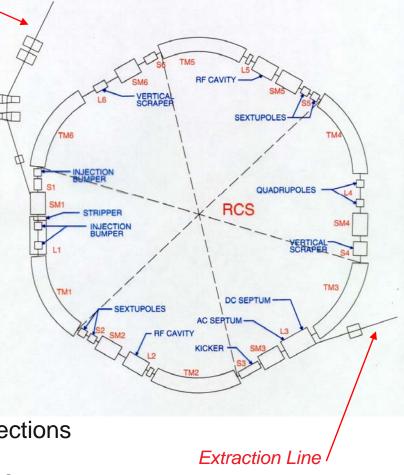
- Early indications suggested that the RF system was voltage limited.
- A third cavity would provide operational flexibility and possibly contribute to increased reliability.
- A third cavity would provide a platform for 2nd harmonic studies.



Original RCS RF System: RCS Machine Parameters

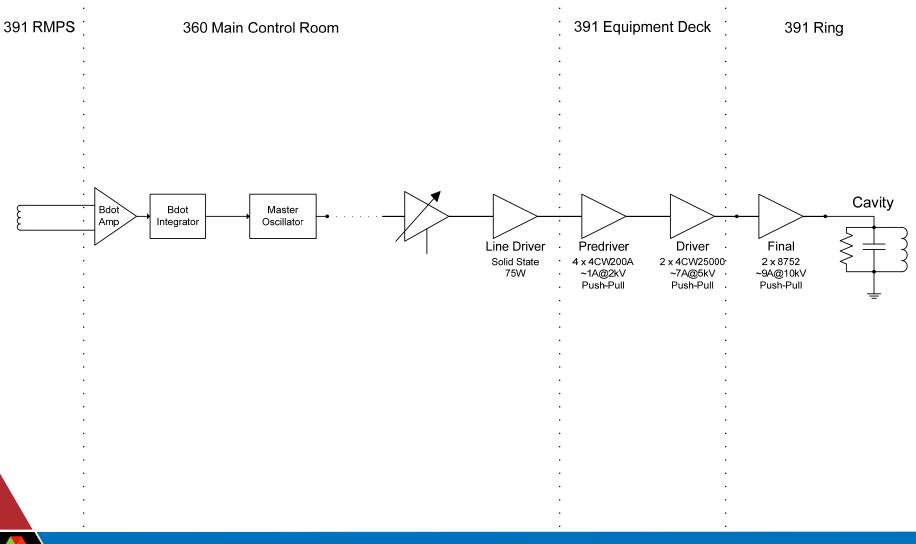
Injection Line 🥆

- Circumference = 42.9 m
- $f_{inj} \sim 2.21 \text{ MHz}, E_{inj} = 50 \text{ MeV}$
- $f_{ext} \sim 5.14$ MHz, $E_{ext} = 450$ MeV
- ~3.7x10¹² protons injected
- ~3.2x10¹² protons extracted
- Harmonic number = 1
- Repetition rate = 30 Hz
- Typical average beam current ~ 15uA
- Cavities located in the L2 and L5 straight sections
- ~21kV total accelerating voltage w/2 cavities



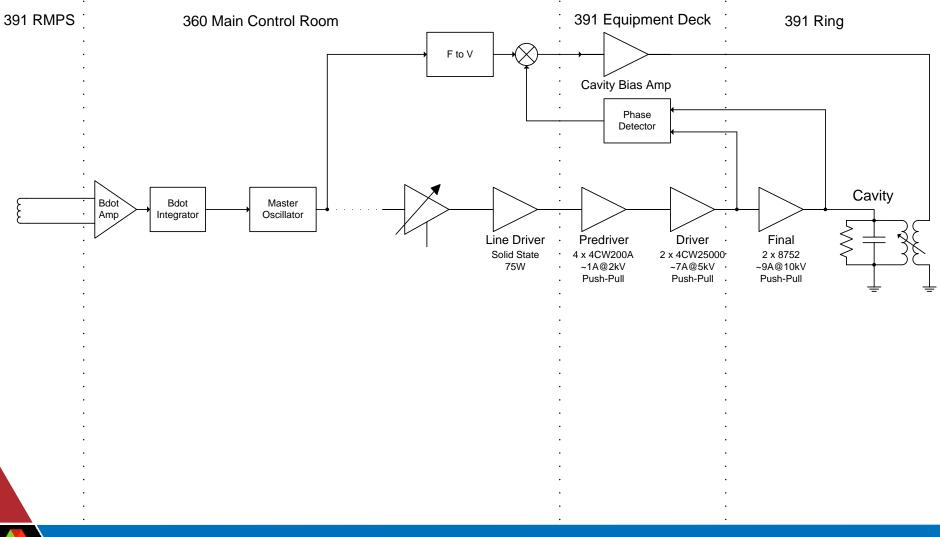
Original RCS RF System: Typical RF System

• Amplifier Chain



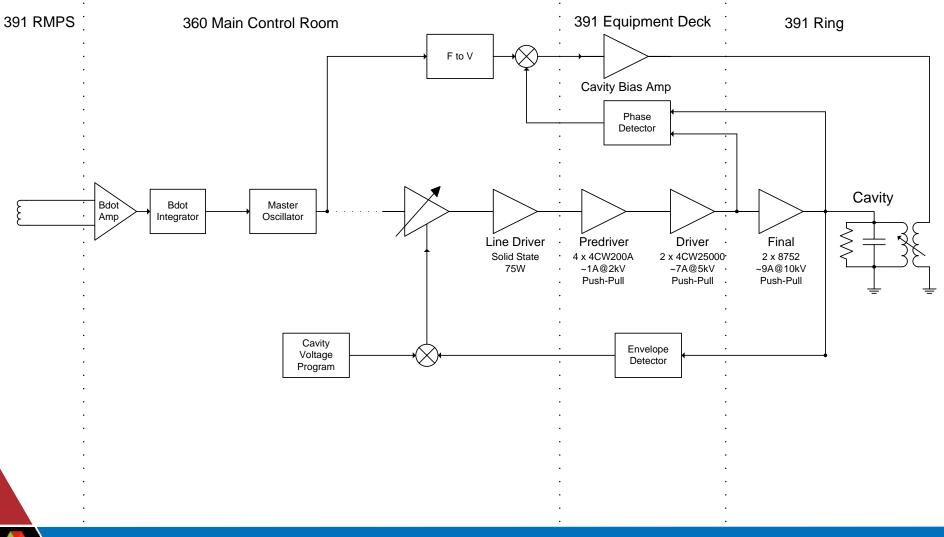
Original RCS RF System: Typical RF System

Cavity Tuning



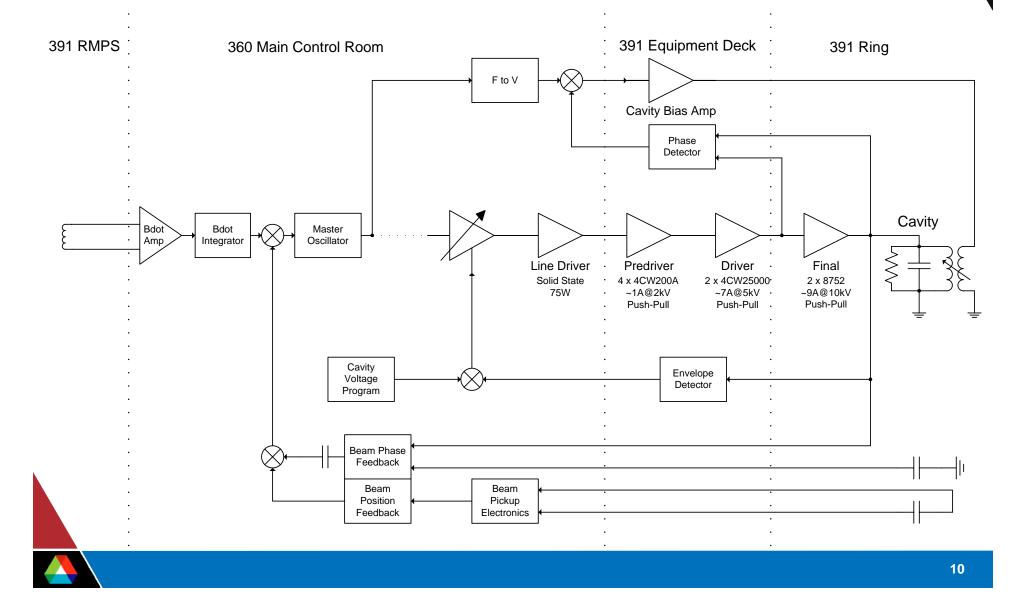
Original RCS RF System: Typical RF System

• Amplitude Control



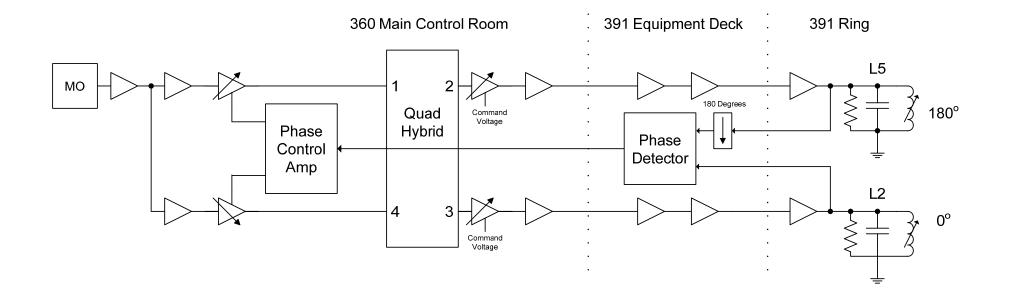
Original RCS RF System: Typical RF System

Beam Position and Phase Control



Original RCS RF System: Typical RF System

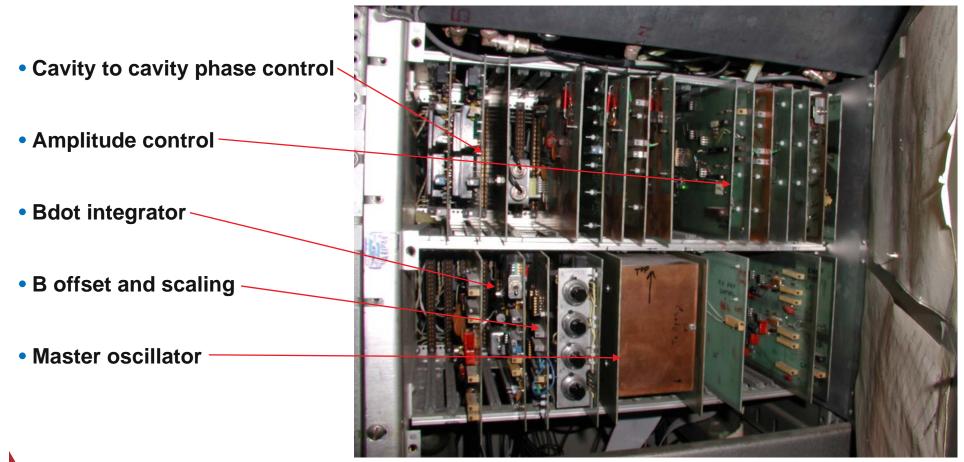
Cavity to Cavity Phase Control





Original RCS RF System: Typical RF System

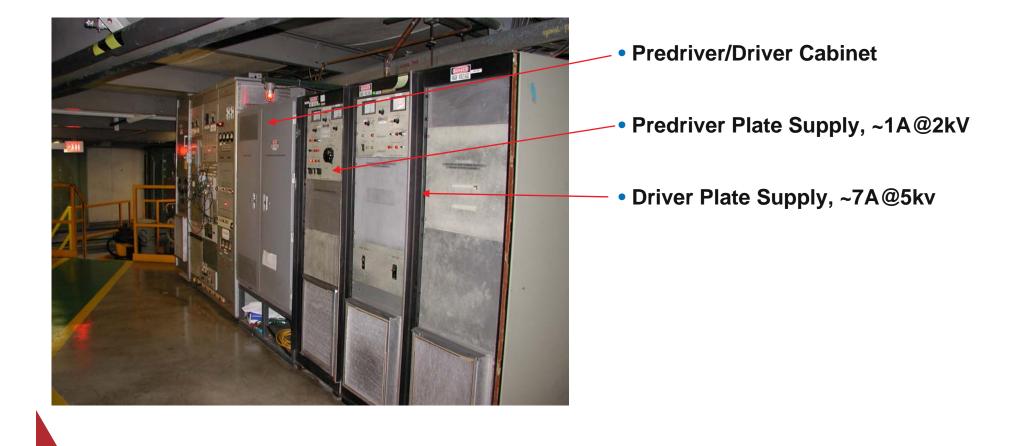
• Low Level RF Electronics





Original RCS RF System: Typical RF System

• Predriver, Driver and Cavity Bias Supply



Original RCS RF System: Typical RF System

• Predriver, Driver and Cavity Bias Supply

- Cavity Bias Supply,
 0 1000A, 30VDC
- Grid and Screen Supplies, Interlock Status and Control
- Predriver/Driver Cabinet





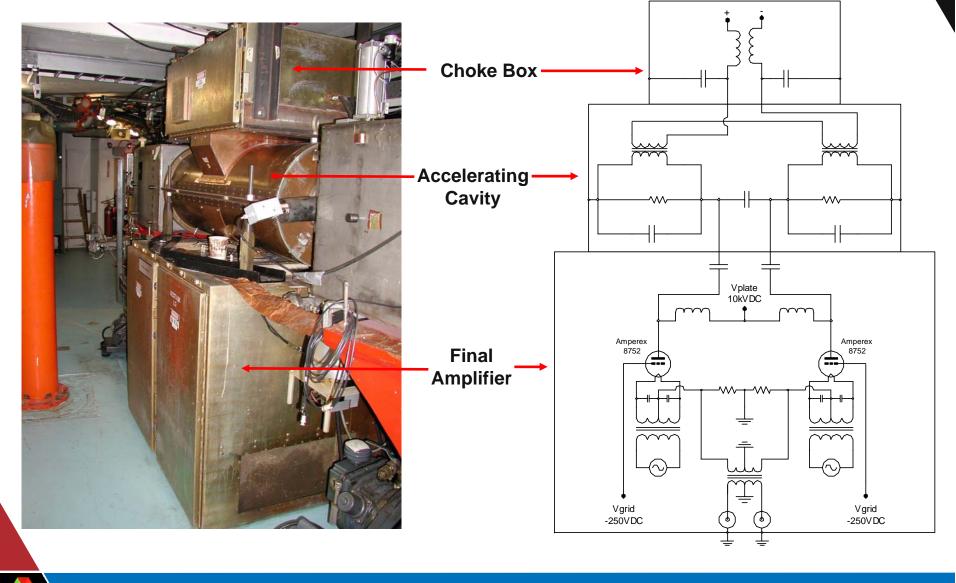
Original RCS RF System: Typical RF System

- Final Plate Supply (the "Reeves")
- Single Supply provide plate voltage to L2 and L5 finals.
- ~18A@10kV total.



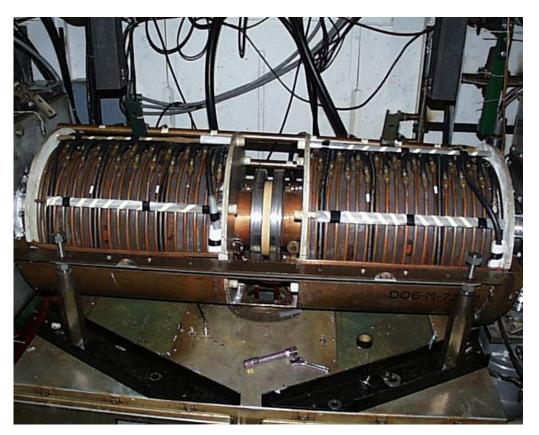
Original RCS RF System: Typical RF System

• Final, Cavity and Cavity Bias Choke Box



Original RCS RF System: Typical RF System

• Ferrite-Loaded, Coaxial Cavity



• Cavities are ferrite-loaded, coaxial structures, with the accelerating gap in the center.

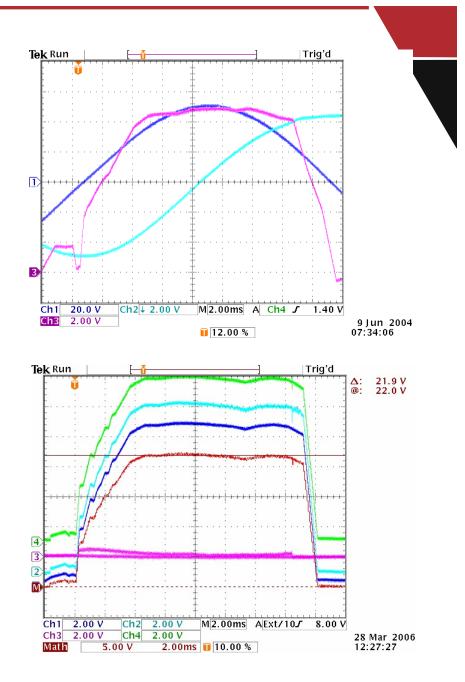
- Cavities are tuned by magnetic biasing of the ferrite.
- Each cavity contains two ferrite stack modules that are each ~20 inches long and ~14 inches in diameter.
- Each stack is made up of 20 Philips type 4H ferrite torroids (mu ~ 350), with edge-cooled copper cooling disks, insulating end pieces.
- Two figure-eight, parallelconnected, water-cooled conductors provide for biasing.
- The gap is formed by a ceramic spacer shunted with glass-vacuum capacitors.
- The cavity is a balanced device and driven push-pull.



Original RCS RF System: Typical RF System

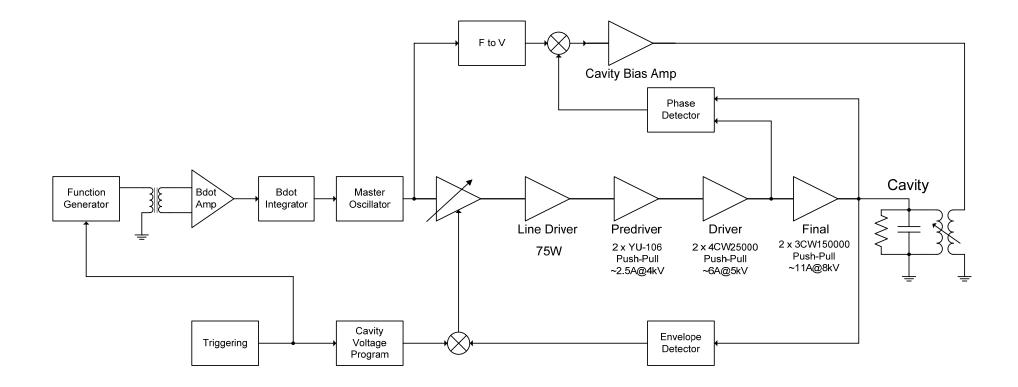
- Typical Two Cavity Operation
 - Cavity gap voltages are driven at RF frequency which is modulated from ~2.21 MHz at injection, to ~5.14 MHz at extraction.

 Cavity gap voltages are amplitude modulated from a few hundred volts at injection, to ~10kV per gap at Bdot max.



The Third Cavity RF System

• Third Cavity Test Stand



The Third Cavity RF System

• Time Line

June 1 – 16, 2005:

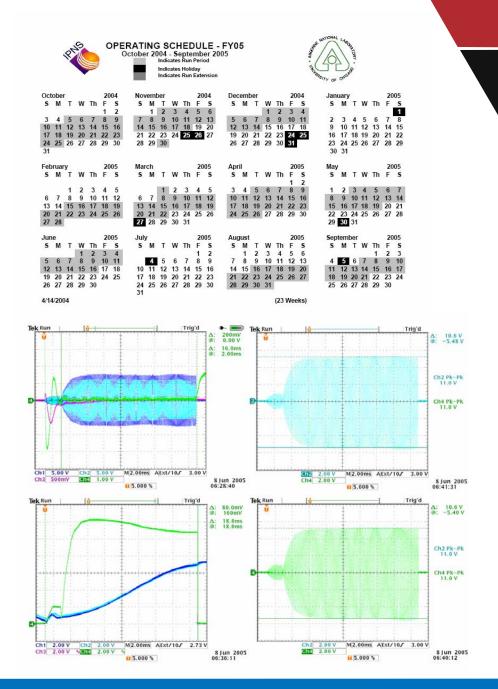
Two week around-the-clock operation in swept-frequency mode at ~11kV gap voltage.

June 17 – August 15, 2005:

Disassembled equipment and moved major components into place.

August 16, 2005:

Typical operating schedule started after summer shutdown, limiting access to working areas.





The Third Cavity RF System





The Third Cavity RF System



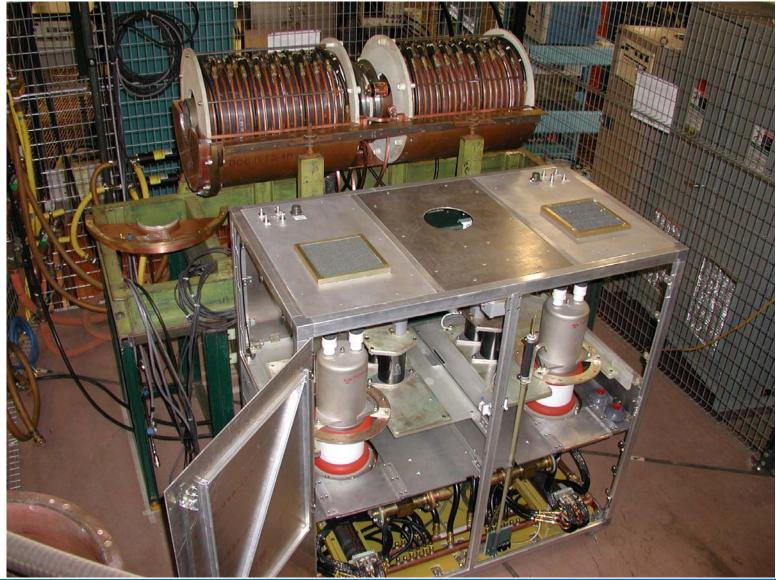


The Third Cavity RF System





The Third Cavity RF System





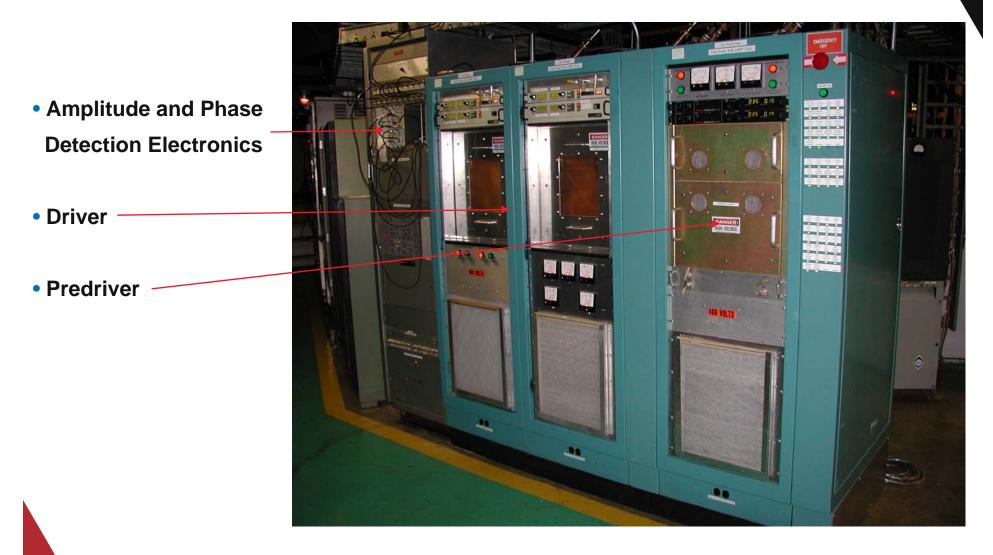
The Third Cavity RF System





The Third Cavity RF System

• Predriver and Driver



The Third Cavity RF System

- Cavity Bias Supply, Final Grid and Filament Supply Cabinet
- Cavity Bias Supply, 0 1000A, 15VDC –
- Final Grid and Filament Supply Cabinet -



The Third Cavity RF System

- "NWL" Final Plate Supply
- 24A@7kV or 12A@14kV T-R Set

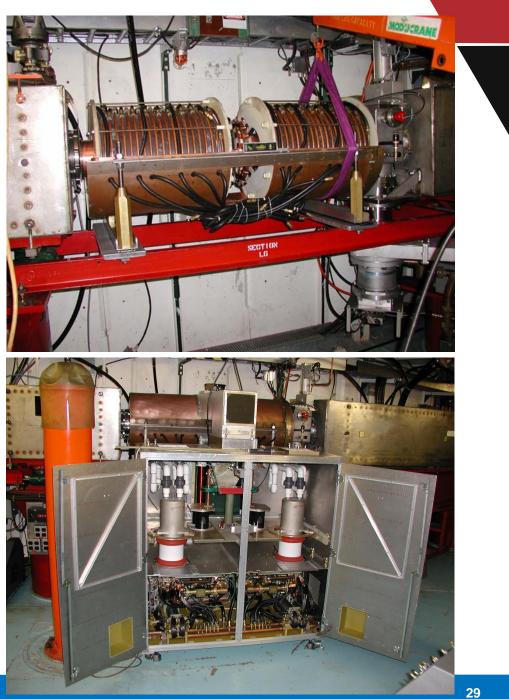
•Modified to include soft start and crowbar



The Third Cavity RF System

Installation





The Third Cavity RF System

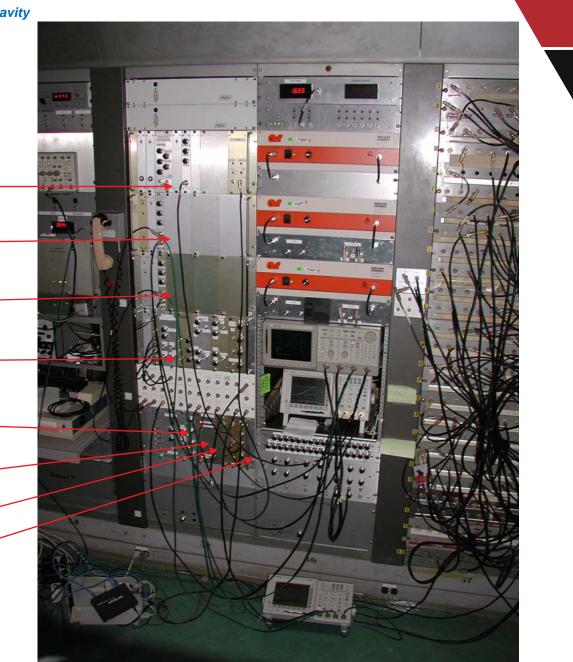
Installation





The Third Cavity RF System

- Low Level Electronics
- L6 Amplitude Control
- L5 Amplitude Control
- L2 Amplitude Control
- Cavity Phase Control
- Bdot Integrator
- B Offset and Scaling
- Master Oscillator
- Cavity Bias -



The Third Cavity RF System

• Time Line (continued)

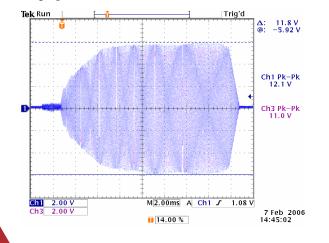
December 14, 2005 – February 3, 2006:

Plumbed in utilities, pulled cables, checke interlocks, performed safety reviews, performed crowbar test, powered on equipment, checked out amplifiers.

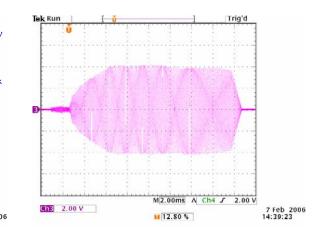
February 7, 2006:

Operated all three cavities in swept frequency mode to full voltage (> 30kV total) without L2-L6 cavity phase control.

Tek Run



A: 11.0 V Ch1 Pk-Pk 10.9 V Ch1 Pk-Pk 10.9 V S Feb 2006 12:40:06



L2 Cavity Upstream Gap Voltage, 1kV/volt

L5 Cavity Upstream Gap Voltage, 1kV/volt

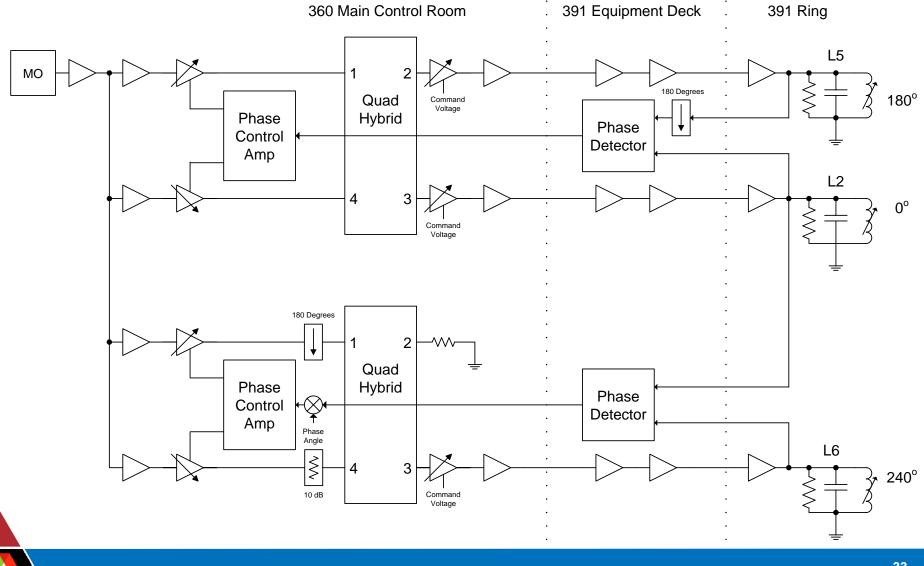
L6 Cavity Gap Voltage

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| 16 | 17 | 18 | 19 | 20 | 21 | 22 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 15 | 16 | 17 | 18 | 19 | 20 | 2 |
| 23 | 24 | 25 | 26 | 27 | 28 | 29 | 27 | 28 | 29 | 30 | | | | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
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FY08-24

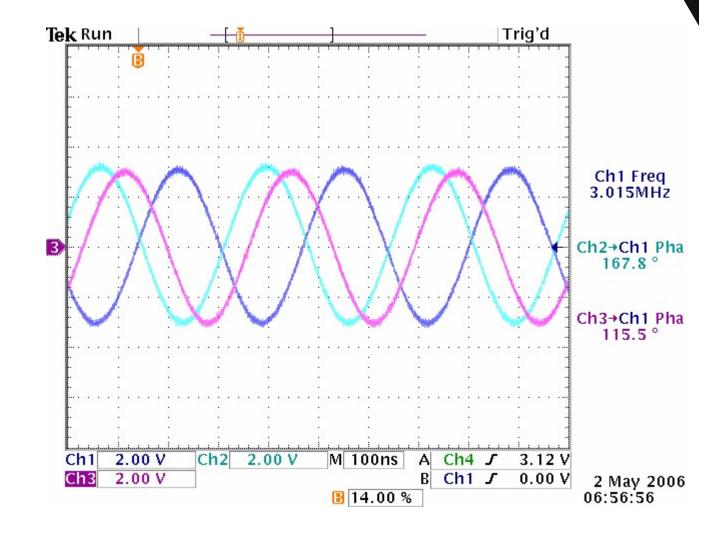
The Third Cavity RF System

Cavity to Cavity Phase Control



The Third Cavity RF System

Cavity to Cavity Phase Control



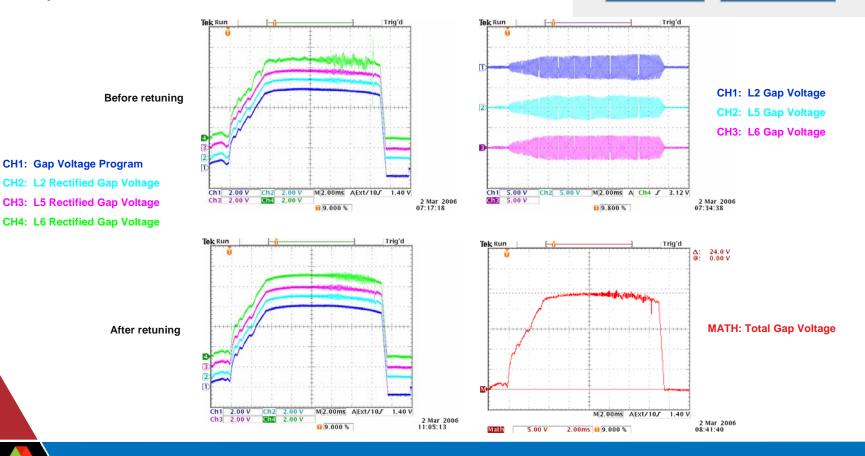
CH1: L2 Gap VoltageCH2: L5 Gap VoltageCH3: L6 Gap Voltage

The Third Cavity RF System

• Time Line (continued)

March 1, 2006:

Implemented L2-L6 cavity phase control and operated all three cavities with beam (> 24kV total).



IPNS_Target_Beam_Curren

13

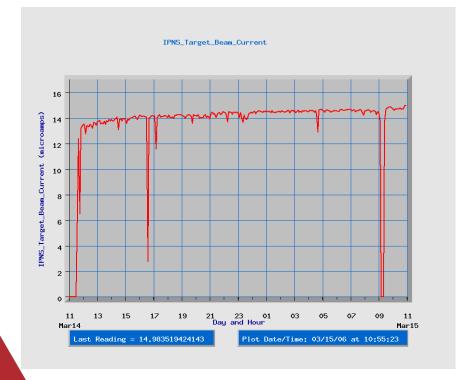
12

The Third Cavity RF System

• Time Line (continued)

March 14 – April 7, 2006:

Three cavity operation.



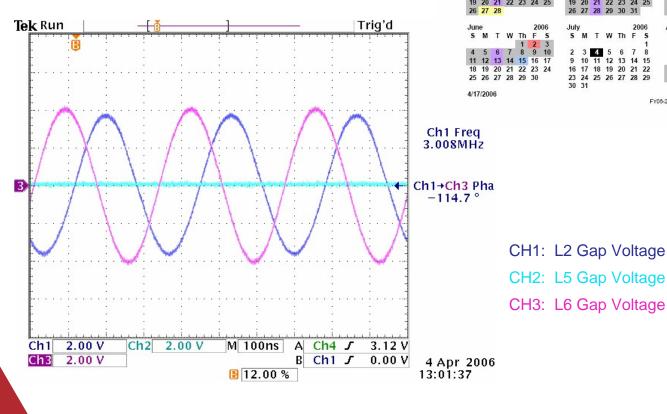
| | | | | | | | India India Start Shut | ates t-up | Run Holi 15:00 | Peri day | | | | - September 2006 Machine Res. 09:00 - 11:00 Machine Res. 09:00 - 15:00 Machine Res. 07:30 - 15:30 | | | | | | | | | | | | | |
|---------------|---------|----|-----|------------|----|------|---------------------------------|--------------|----------------------|-------------|----------|--------|---------|--|------|------|-----|---------|-----------|------|------|------|----|----|------|----|----|
| October 2005 | | | | Nov | om | hor | | | 20 | 05 | December | | | | 2005 | | | January | | | | 2006 | | | | | |
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| 16 | 17 | 18 | 19 | 20 | 21 | 22 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
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| 30 | 31 | | 162 | | | | | | | | | | | | | | | 3333 | | 1993 | 29 | 30 | 31 | | | | |
| February 2006 | | | Mar | March 2006 | | | | | 06 | April | | | | 2006 | | | May | | | | 2006 | | | | | | |
| SMT | | Т | W | Th | F | S | S | M | т | W | Th | F | S | S | М | Т | W | Th | F | S | S | M | Т | W | Th | F | S |
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| 12 | 13 | 14 | 15 | 16 | 17 | 18 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| 19 | 20 | 21 | 22 | 23 | 24 | 25 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 28 | 29 | 30 | 31 | | | |
| 26 | 27 | 28 | | | | | 26 | 27 | 28 | 29 | 30 | 31 | | 30 | | | | | | | | | 28 | | | | |
| Jun | ne 2006 | | | | | July | | 2006 | | | | August | | | | 2006 | | | September | | | | | 20 | 2006 | | |
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The Third Cavity RF System

Time Line (continued)

April 4, 2006:

L2 – L6 operation with beam (~13.5uA).

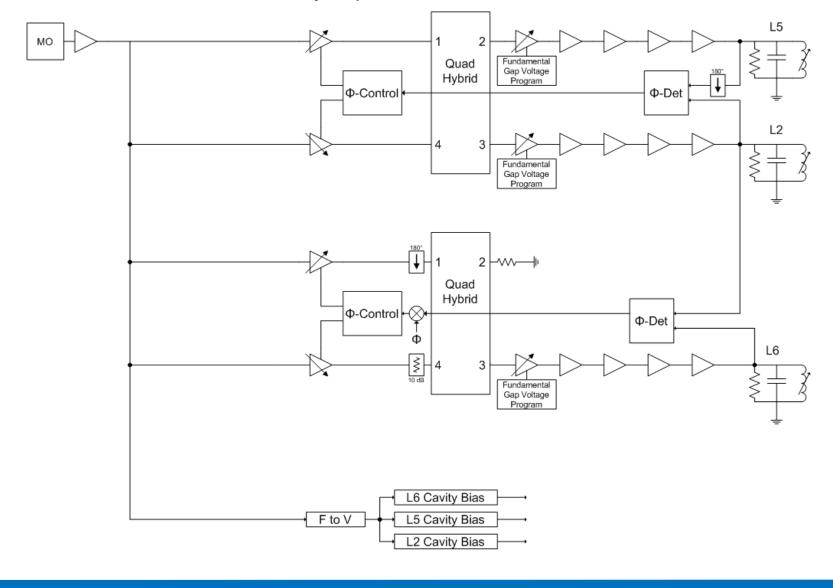




CH2: L5 Gap Voltage

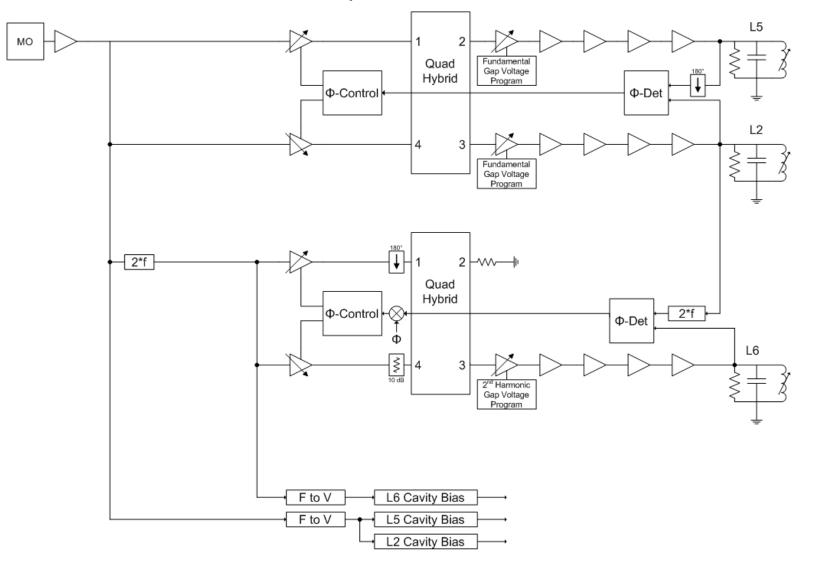
2nd Harmonic

• Fundamental Three Cavity Operation

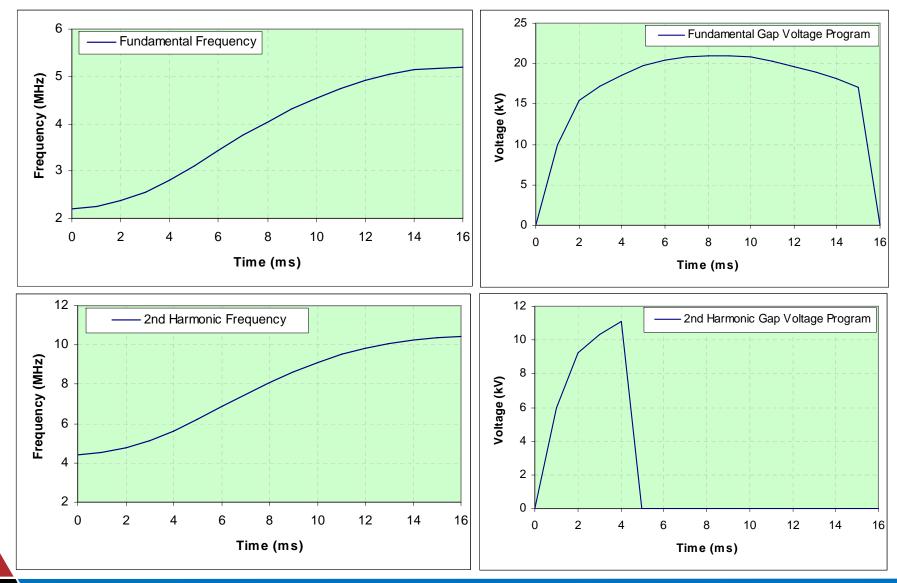


2nd Harmonic

• Minimum Second Harmonic Operation



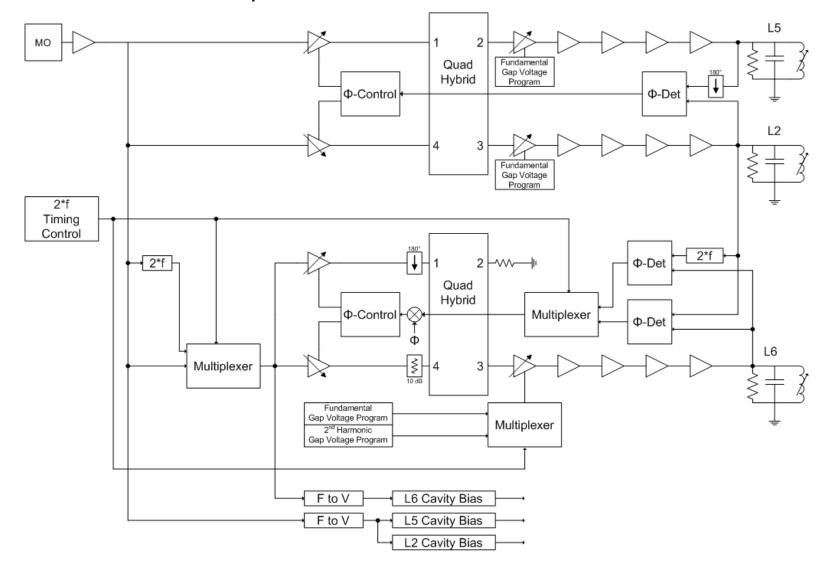
2nd Harmonic



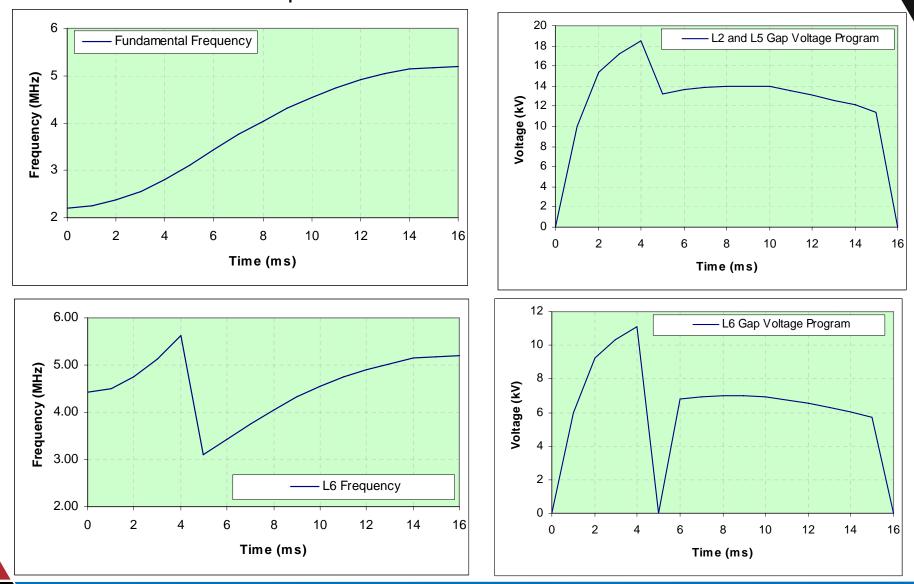
• Minimum Second Harmonic Operation

2nd Harmonic

• Second Harmonic Operation



2nd Harmonic



• Second Harmonic Operation

Summary

- The third cavity has been installed and is operational.
- L2 L6 cavity operation has been demonstrated, although not to satisfactory beam performance levels.
- L5 L6 cavity operation has yet to be demonstrated.
- We have a platform for 2nd harmonic studies and hardware is being built.

