High Power RF Systems for

2-8 GeV Fast Cycling Synchrotron

PROJECT X (ICD-2)

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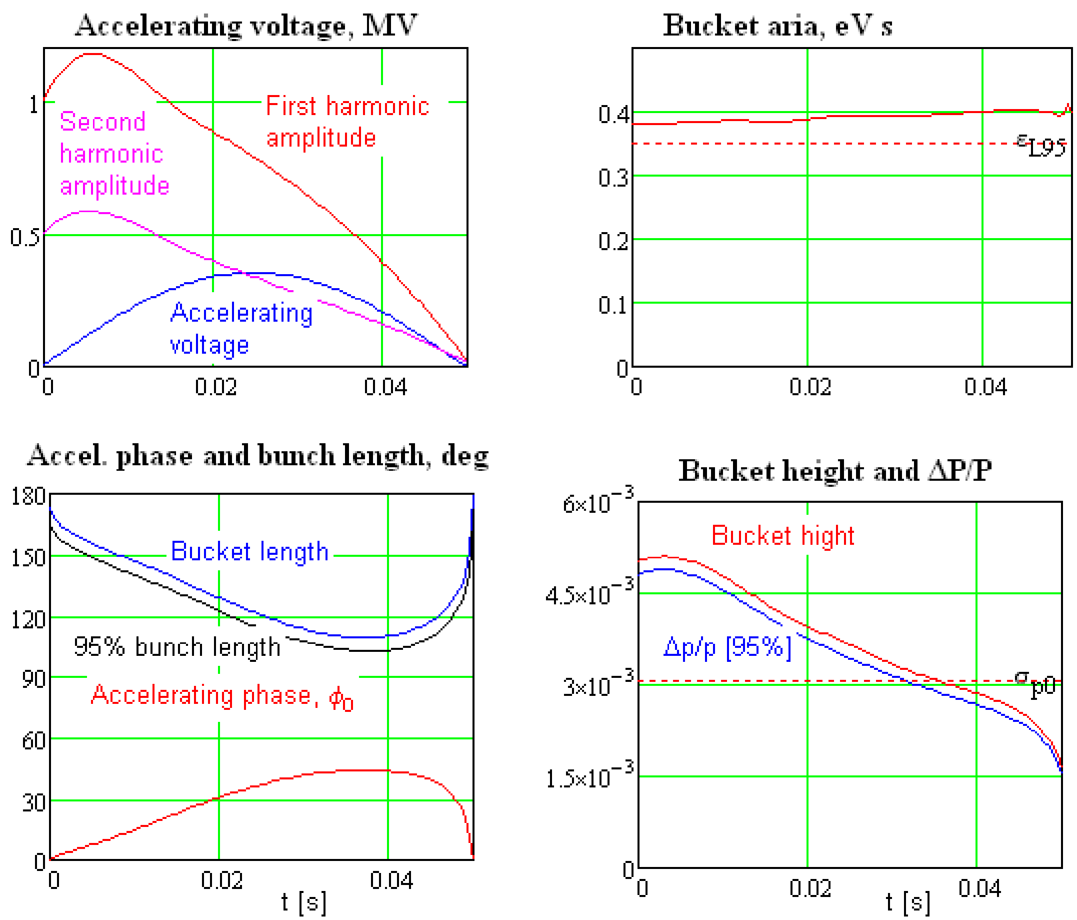
Scope

- **Summary of RF System Parameters**
- **Diagram of proposed RF Cavity -Fundamental**
- **High level components**
- **2^{nd} Harmonic**
- **R&D**
- **Cost**
- **Conclusion**

RF Parameters

Energy	2 to 8	GeV
Transition Energy	13.36	GeV
Number of Particles	2.67×10^{13}	
Beam Current @ injection	2.2	Amps
Repetition rate	10	Hz
Acceleration Ramp Slope	165	GeV/s
Frequency Min	50.33	MHz
Frequency Max	52.81	MHz
Frequency sweep	2.5	MHz
Number of First Harmonic RF stations (h=98)	16	Stations
Peak accelerating voltage	1.6	MV
Cavity peak voltage	100	kV / cavity
Peak Power Dissipation Cavity	50	kW /cavity
Peak Power: beam + cavity	1.5	MW
Peak Power per cavity: beam + cavity	93.75	kW / cavity
Cavity Rs	100	kΩ
Cavity Q	~2857	
Cavity Rs/Q	~35	
Cavity Tuner Geometry		Perpendicular Biased

RF System Parameters



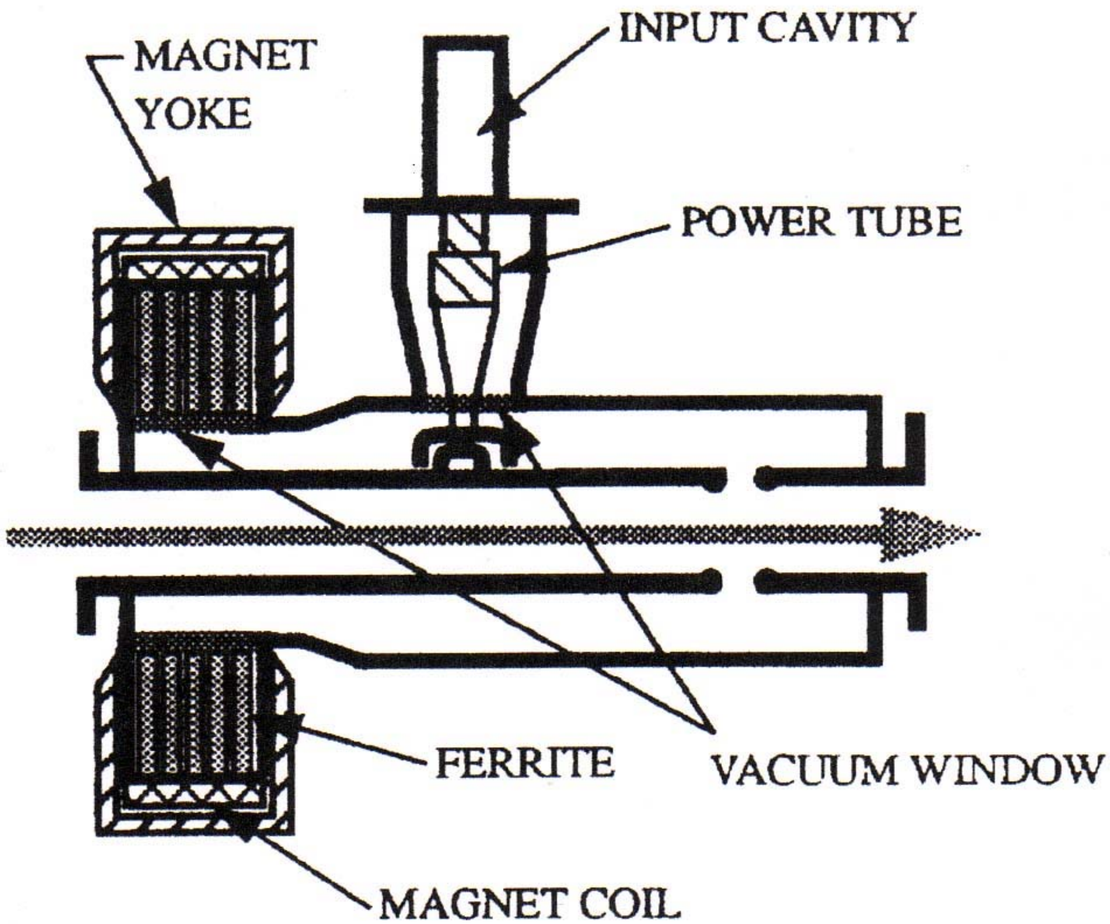
Beam and RF system parameters during acceleration.

Total rf power is presented for the case when 2 of 16 & 1 of 10 cavities are not operating

Cavity Design

- **Cavity is based on the SSC Low Energy Booster cavity which is a quarter wave cavity with low R/Q to reduce the effects of beam loading.**
- **Engineering challenge – to providing adequate cooling to the garnets in this design and have reliable operation at 100KV gradient.**
- **Each cavity is ~ 1.25 meters in length.**

Cavity Design



Prototype Cavity

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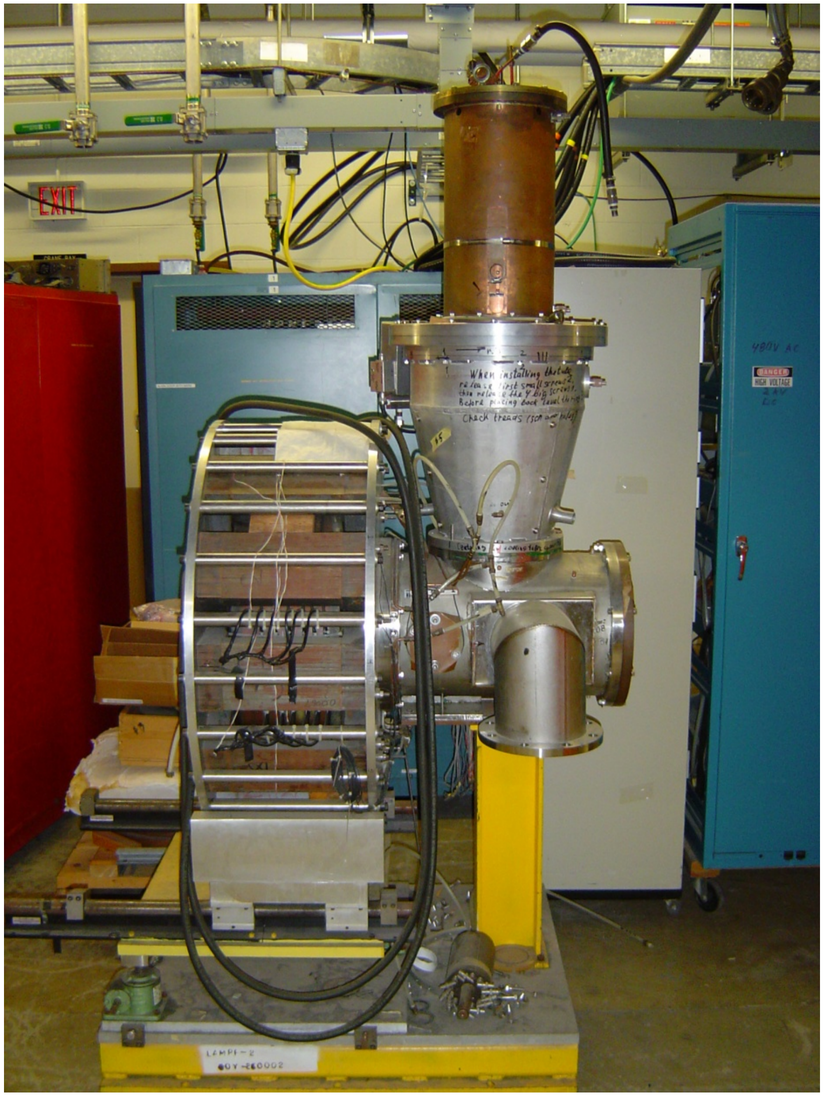
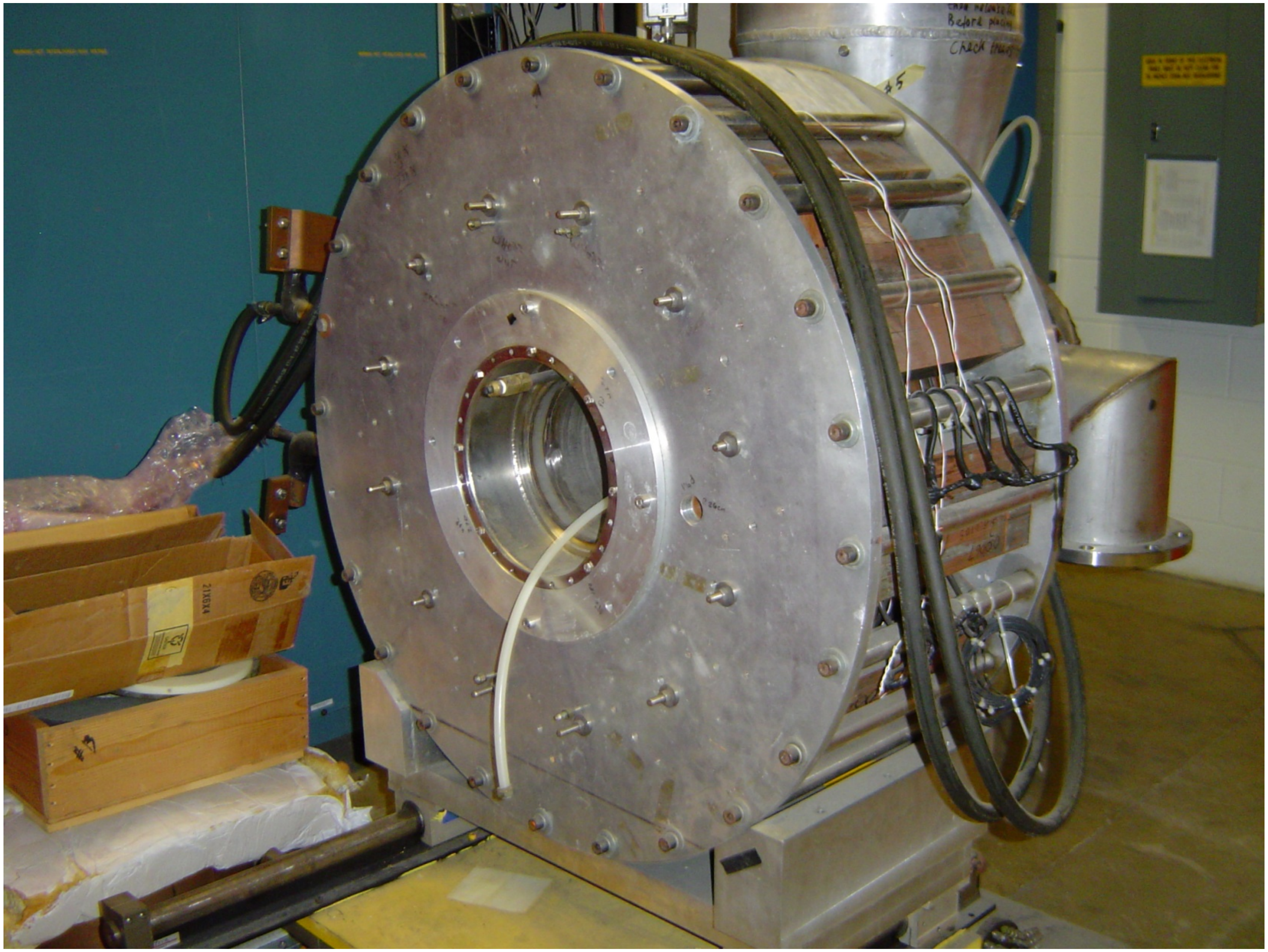
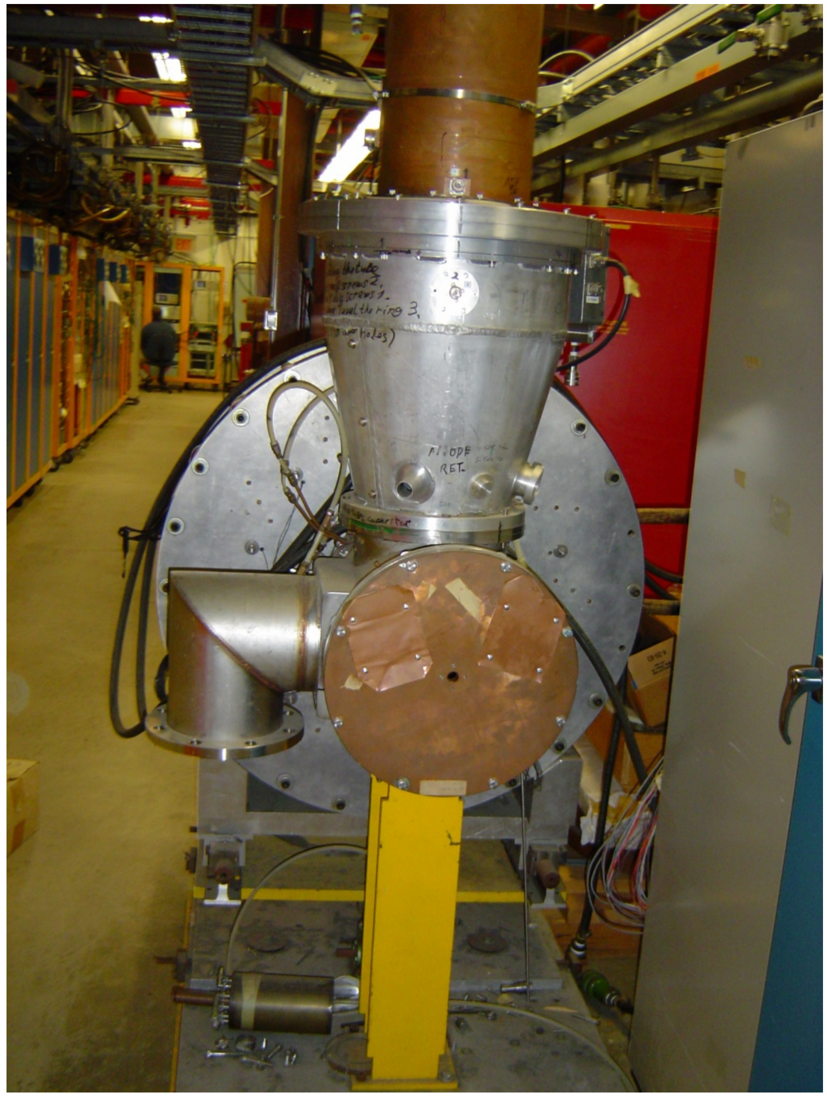


Cavity Prototype



Cavity Prototype



Standard MI RF Cavity

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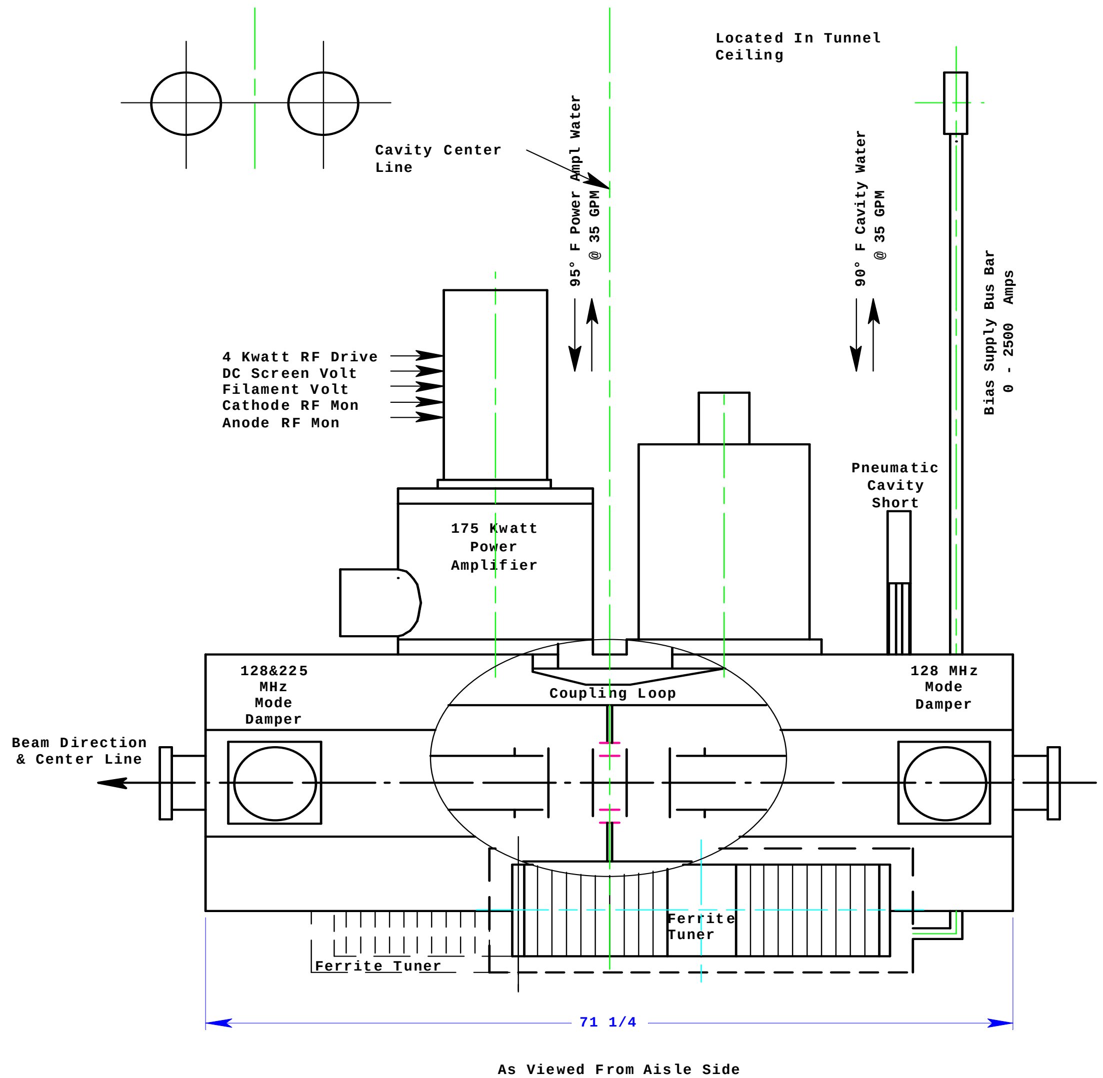
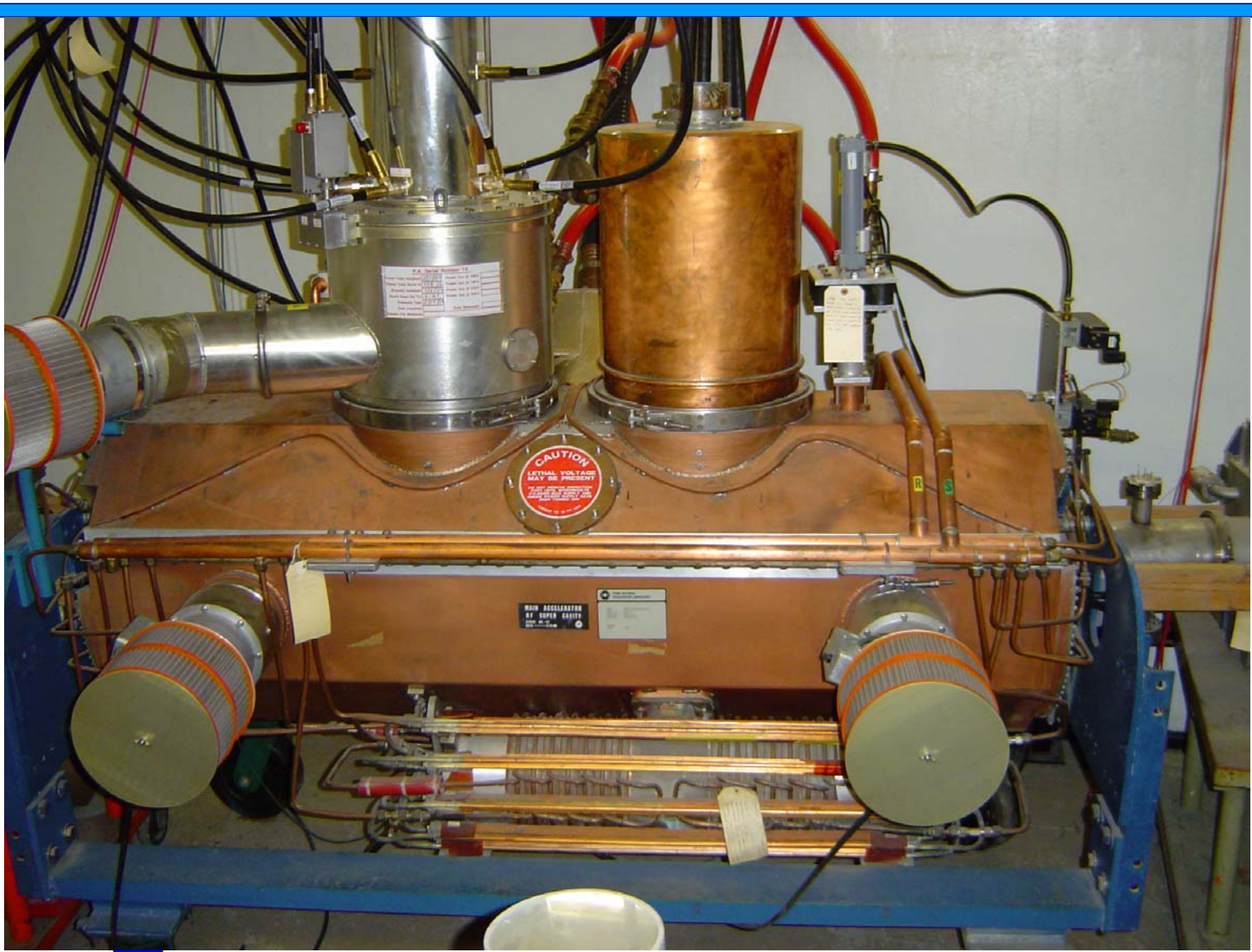
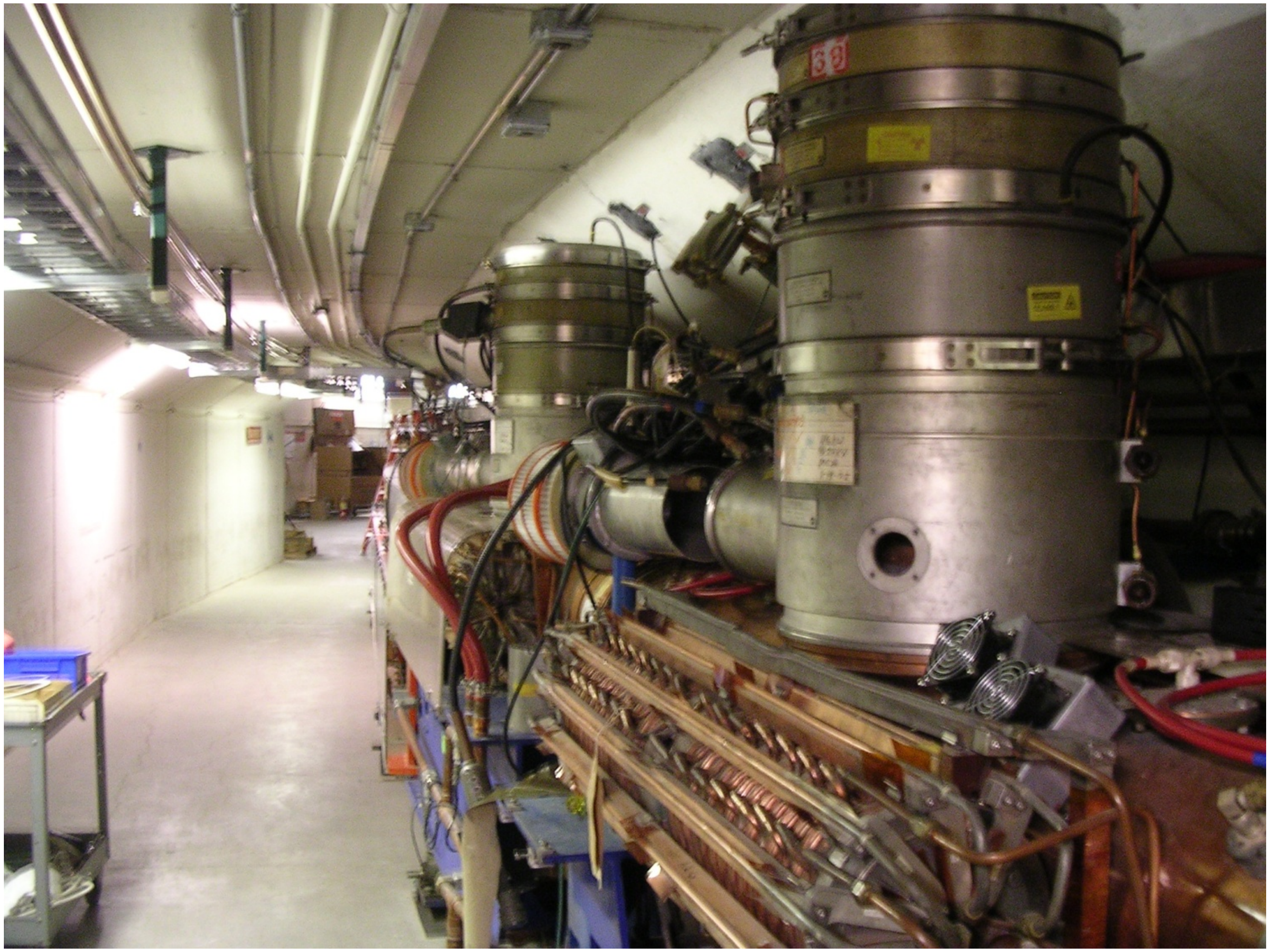


Present Main Injector Cavity

Standard MI RF Cavity



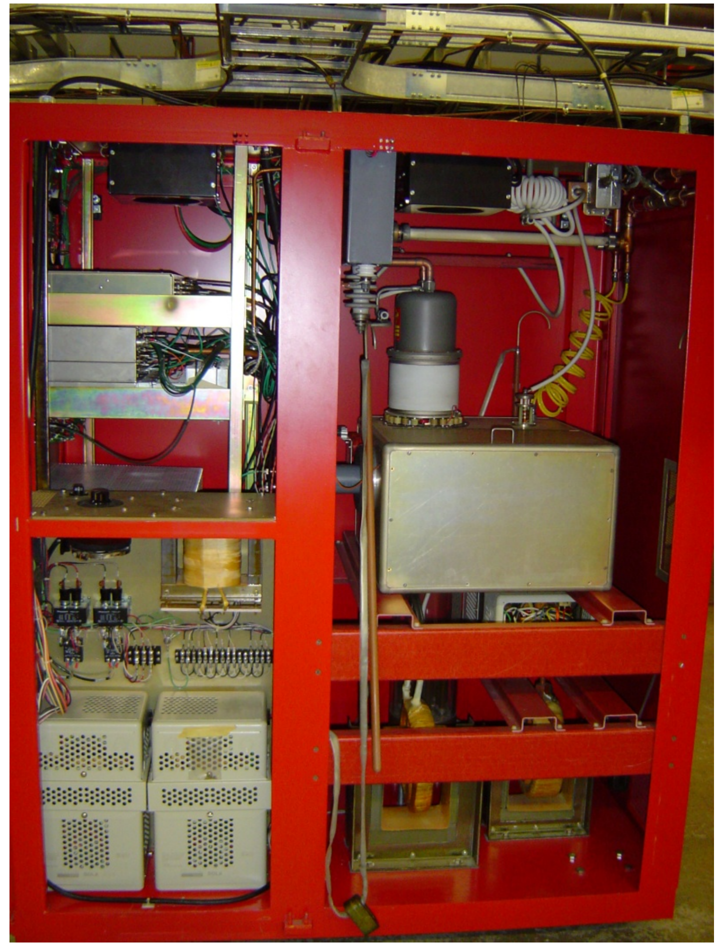
Fermilab Booster Cavity



Typical Station Layout

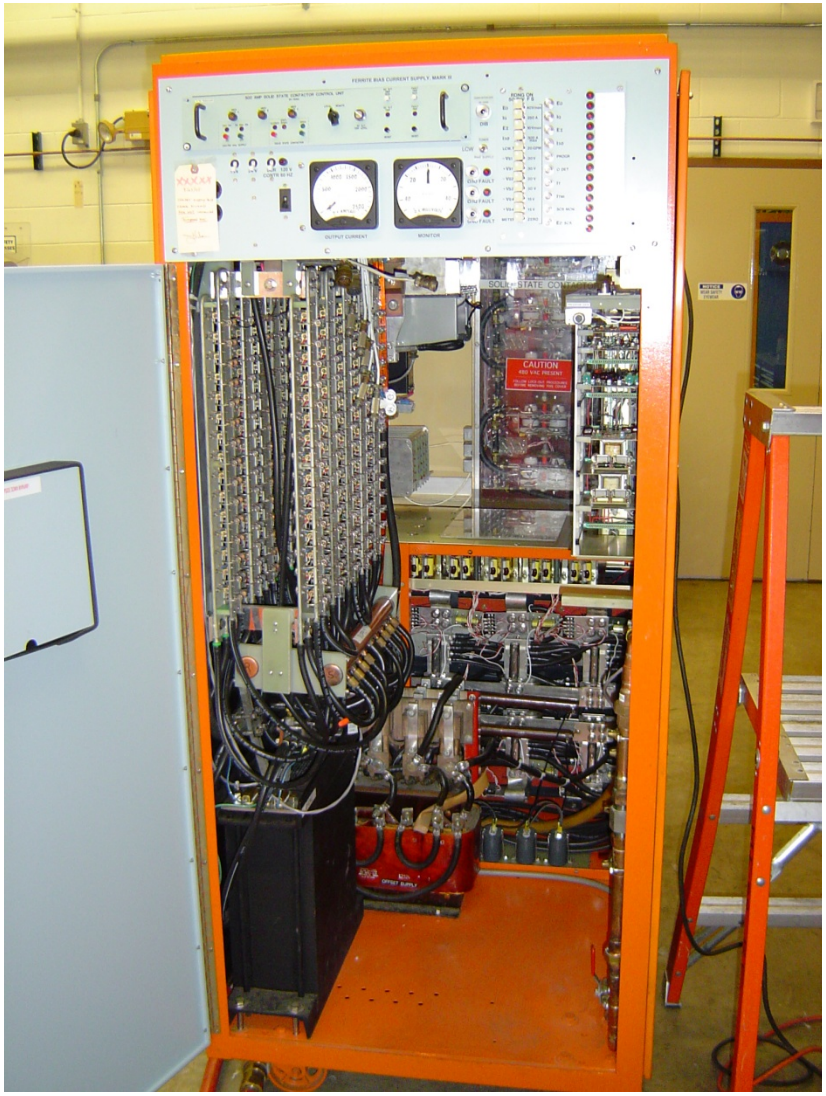
Possible Equipment Gallery Layout

Series Tube Modulator



Standard MI Modulator

Ferrite Bias Supply



- 35V, 2500A fast slewing power supply used for tuning the present Fermilab Booster rf cavity.
- Can operate at 15 Hz

8 KW Solid State Driver Amp

Present MI Solid State
Driver Amplifier

Power Amplifier

- Power Amp will be a modified version of our standard 150KW power amplifier.
- It will be cathode driven from a solid state amp located in the surface building
- Grid grounded for rf but biased to allow dynamic programming throughout the cycle.
- Grid, screen, filament supplies located in surface building

Anode Power Supplies

- **Two large anode supplies will be required to power the fundamental rf system.**
- **Divided into two groups of 8 stations.**
- **Supplies will be very similar to the existing MI-60 anode supplies that presently power the MI's rf system.**
- **Each supply will consist of :**
  - Fused disconnect to the 13.8KV line
  - Fast step start vacuum circuit breaker,
  - 2MW main rectifying transformer,
  - Rectifier stack,
  - Interphase reactor,
  - Capacitor bank,
  - Crowbar,
  - Individual dc vacuum switches connecting each modulator to the anode supplies dc bus (8 station per supply).

Anode Supplies at MI-60

RF Controls

- **Much of the rf controls would be very similar to that of the present Main Injector's 53MHz system.**
- **This would include:**
  - Cavity tuning controller
  - Direct rf feedback
  - Feed forward
  - Possible comb filter

Second Harmonic System

Frequency Min	100.66	MHz
Frequency Max	105.62	MHz
Frequency sweep	5.0	MHz
Number of second Harmonic RF stations (h=196)	10	Stations
Peak accelerating voltage	0.7	MV
Cavity peak voltage	70	kV / cavity
Peak Power Dissipation Cavity	24.5	kW /cavity
Peak Power: beam + cavity	0.43	MW
Peak Power per cavity: beam + cavity	43	kW / cavity
Cavity Rs	100	kΩ
Cavity Q	2850	
Cavity Rs/Q	~35	
Cavity Tuner Geometry		Perpendicular Biased

Second Harmonic

- **Cavity design could be similar to the fundamental including the use of perpendicular biased tuner arrangement.**
- **Specification calls for 2nd harmonic to track the fundamental through out the whole cycle.**
- **Frequency sweep = 5 MHz.**
- **If 2nd harmonic only needed at injection, cavity design would be much cheaper to fabricate.**

R&D Program

- **Start R&D program with existing prototype cavity and tuner.**
- **Complete low level measurements to determine required modifications for our application.**
- **Implement design changes, especially cooling and power amplifier layout.**
- **Run in MI-60 test station to measure high power performance.**
- **Cost ~ $ 5,000,000**

Fundamental System Cost

DRAFT September 2009	Each			FTE	FTE	FTE	FTE	FTE
				Labor	Labor	Labor	Labor	Labor
Fundamental 50.3-52.81MHz	**M&S**	**Quantity**	**31,061,000**	**16.98**	**1.69**	**25.15**	**7.15**	**1.78**
				EE	ME	ET	MT	DR
Series Tube Modulator	155,000	16	2,480,000	1.8	0	3.7	1	0.2
			-					
Ferrite Bias Power Supply	165,000	16	2,640,000	1.9	0.1	3.9	1	0.25
			-					
150 KW Power Amplifier	100,000	16	1,600,000	0.31	0.1	2.6	0.25	0
			-					
Anode Supplies	417,000	2	834,000	0.5	0.1	0.75	0.25	0.2
			-					
RF Cavity with Perpendicular Bias Tuner	650,000	16	10,400,000	1.5	1	3.7	3.7	0.5
			-					
Solid State Driver Amplifiers	150,000	16	2,400,000	1.2	0.15	3.4	0.25	0.1
			-					
RF Station Controls	35,000	16	560,000	1	0	2	0	0.1
			-					
Installation			-					
Cabling materials + termination	12,000	16	192,000					
Cable installation cost	5,000	16	80,000					
Cable Tray	55,000	1	55,000	0.05	0.05	0.1	0	0.05
High Current Ferrite Bias Tuner Bus	20,000	16	320,000	0.2	0.1	0.3	0.3	0.1
			-					
Utilities			-					
AC Power Distribution	250,000	1	250,000					
LCW Water System Local for Rf System	1,000,000	1	1,000,000					
Low Level RF								
Local Station VXI	500,000	1	500,000	4	0	2	0	0.1
Global LL Control System in control roor	100,000	1	100,000	3	0	1	0	0.1
Long. Beam/ RF Diag	150,000	1	150,000	1	0	0.5	0	0
			-					
Test Station	1,500,000	1	1,500,000	0.52	0.09	1.2	0.4	0.08
			-					
Spare Parts	1,500,000	4	6,000,000					

2nd Harmonic System Cost

DRAFT September 2009	Each			FTE Labor	FTE Labor	FTE Labor	FTE Labor	FTE Labor
Second Harmonic100.6-105.62MHz	**M&S**	**Quantity**	**18,009,000**	**5.72**	**1.06**	**13.84**	**4.5**	**0.95**
Series Tube Modulator	155,000	10	1,550,000	1.1	0	2.3	0.6	0.1
			-					
Ferrite Bias Power Supply	165,000	10	1,650,000	1.2	0.06	2.4	0.6	0.15
			-					
150 KW Power Amplifier	100,000	10	1,000,000	0.2	0.06	1.6	0.15	0
			-					
Anode Supplies	417,000	2	834,000	0.26	0.05	0.4	0.12	0.1
			-					
RF Cavity with Perpendicular Bias Tuner	650,000	10	6,500,000	0.94	0.62	2.3	2.3	0.31
			-					
Solid State Driver Amplifiers	150,000	10	1,500,000	0.75	0.09	2.1	0.15	0.06
			-					
RF Station Controls	35,000	10	350,000	0.6	0	1.3	0	0.06
Utilities			-					
AC Power Distribution	100,000	1	100,000					
LCW Water System Local for Rf System	100,000	1	100,000					
Installation			-					
Cabling	12,000	10	120,000					
Cable installation cost	5,000	10	50,000					
Cable Tray	55,000	1	55,000	0.03	0.03	0.06	0	0.03
High Current Ferrite Bias Tuner Bus	20,000	10	200,000	0.12	0.06	0.18	0.18	0.06
Test Station	1,000,000	1	1,000,000	0.52	0.09	1.2	0.4	0.08
Spare Parts	1,500,000	2	3,000,000					

Conclusions

- **Need help from outside collaborators on design and fabrication of the 2nd harmonic system.**
- **Beam loading compensation techniques same as present system utilizing a combination of direct rf feedback, digital comb filter, and feed forward.**
- **Cavity will require much of the R&D effort to solve tuner and cavity cooling issues, reliable operation at 100KV gradient, and HOM dampers.**
- **If ICD-2 is the route, R&D efforts should start soon there after so prototype cavities (fundamental & 2nd harmonic) can be designed, fabricated, and tested in the present MI enclosure with beam .**