RF Parallel Review

Kevin Ronald for the MICE RF Group

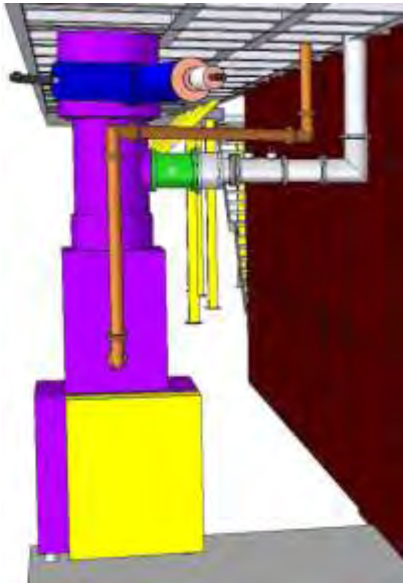
Summary

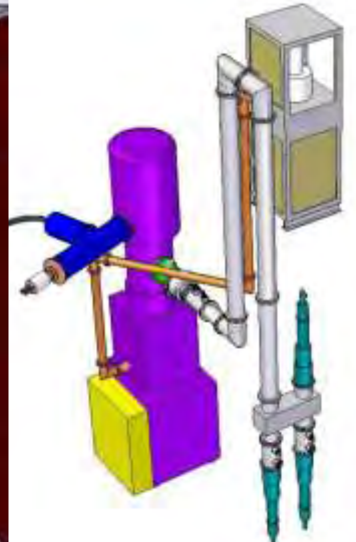
- Five papers:
  - Kevin Ronald & Tim Stanley on the HP test progress at Daresbury
  - Yagmur Torun on the progress towards cavity tests at FNAL
  - Luca Somanchini on the testing of the gas actuators for the cavity tuners
  - Colin Whyte on proposals for the RF timing system
  - Chris Hunt on estimation of cavity electron current and X-ray production

Distribution Network

- Overall layout has been frozen since last meeting
  - Detailed design revisions have been made to accommodate the installation of other equipment
- Procurement underway
  - The network now being procured by University of Mississippi (thanks to Don Summers and the Mississippi team)
  - Orders let for some $500k US in components
  - Components required for TIARA tests in the MICE hall prioritised
  - Encompasses items required to build further amplifier chains
- Progress on installation
  - Hangers and mounts for distribution network designed and prototypes tested
  - Plans in hand for final installation in the MICE Hall (with RAL Engineering team)
  - Support infrastructure being planned for tests in the MICE Hall
- TIARA test plans
  - Plans are advanced for bringing the amplifier chain to RAL once it has demonstrated its peak power requirement at Daresbury
  - Infrastructure is being put in place for the required electrical panels and the cooling circuits.
  - Equipment required is being procured
  - List of priority items defined from the MEGA order

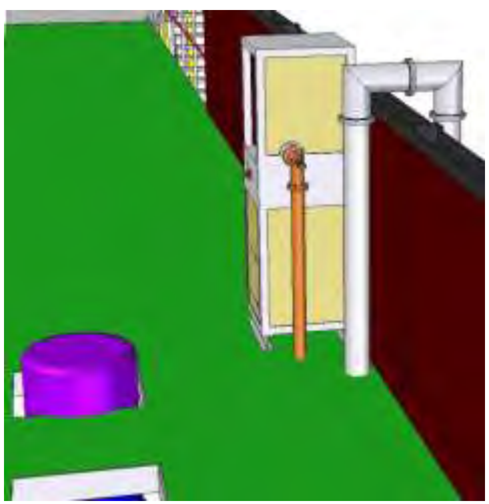
MICE Hall RF system for TIARA Test

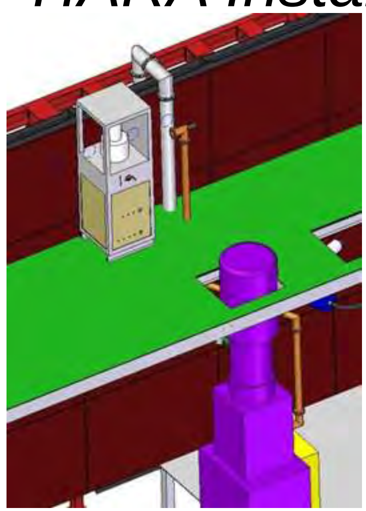


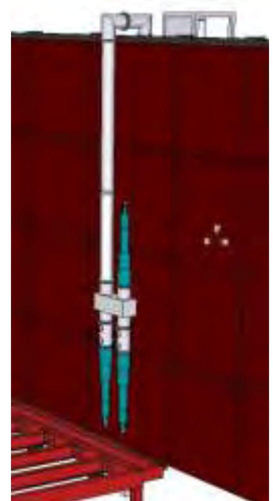


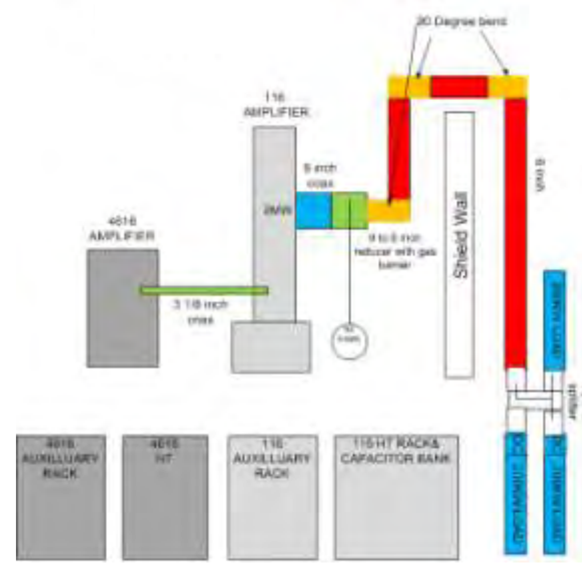
- One amplifier set installed in operational position
  - Installed in the first amplifier station
  - Tetrode on Mezzanine, Triodes deep behind the shield wall
  - Opportunity to test the impact of B-fields during STEP IV
- One hybrid installed on MICE side of shield
- 3 loads, two will share the output power of the amplifier
- TIARA test network components prioritised for delivery

TIARA Installation Detail









RF Power Systems

- Medium power valve amplifiers
  - Two of the tetrode amplifiers have operated at nominal required output power (240kW)
- High Power Amplifiers
  - High power amplifier No 1 subject to power test using new TH116 Triode valve
  - Operated at up to 1.2MW, bias voltage of 32kV
  - Crowbar event revealed a weakness in the crowbar dump resistors
    - Tests halted to rectify
  - During these tests both amplifiers showed high gain and efficiency (see tables)
  - To date the new tetrode valve has been operating for some 100hrs
    - Very stable and dependable, easy to adjust output power
  - Resumption of the HP tests, problematic to operate above 300kW
    - Repeated crowbars observed
    - Extensive investigation identified a number of areas to improve
      - Valve socket modified to improve seating
    - Key fault identified as being a very unusual thyratron failure mode
      - Thyratron is the crowbar switch- used to protect triode from internal arc
      - Thyratron supports DC voltage perfectly well, but triggers independently when triode modulator operates
      - Fault possibly associated with earlier resistor issue

Demonstration of valve performance

Drive (dBm)	ct 100mv per amp	HT (kV)	Electric power in tube (kW)	Grid 1 (V)	Screen Grid (V)	Drive (W)	Forward power (kW)	Reflected power (W)	Reflected Power Percentage (%)	Gain (dB)	Efficiency (%)	Ion Pump Current (μA)
0	8.1	19	153.9	170	1740	1086	48	243	0.5	16.5	31.2	0.11
1	9.9	19	188.1	170	1740	1376	69.2	320	0.5	17.0	36.8	0.17
2	12	19	228	170	1740	1740	102	307	0.3	17.7	44.7	0.3
3	14.9	19	283.1	170	1740	2200	158	311	0.2	18.6	55.8	0.39
3.5	17	19	323	170	1740	2480	208	314	0.2	19.2	64.4	0.55
3.7	17.7	19	336.3	170	1740	2580	236	364	0.2	19.6	70.2	0.98
3.5	17.5	19	332.5	170	1740	2480	234	287	0.1	19.7	70.4	0.64

4616 Tetrode amplifier

4616

Drive (dBm)	ct 100mv per amp	HT (kV)	electric power in tube kW	Grid 1 (V)	Screen Grid (V)	Drive (W)	Forward power (kW)	Reflected power (kW)	Reflected Power Percentage (%)	Gain (dB)	Efficiency (%)
0	4.12	15	61.8	170	1320	0.65	24.7	3.22	13.0	15.797836	40.0
0	4.12	15	61.8	170	1320	0.65	27.2	5.83	21.4	16.216555	44.0
0	4.12	15	61.8	170	1320	0.65	29.3	8.72	29.8	16.539543	47.4
0.5	4.64	15	69.6	170	1320	0.72	31.2	4.31	13.8	16.368221	44.8
1	5.24	15	78.6	170	1320	0.8	39.6	4.4	11.1	16.946052	50.4
1	5.24	15	78.6	170	1320	0.8	39.4	4.12	10.5	16.924062	50.1
1	5.16	15	77.4	170	1320	0.8	38.5	3.85	10.0	16.823707	49.7
1	5.16	15	77.4	170	1320	0.8	37.4	3.51	9.4	16.697816	48.3
1.5	5.96	15	89.4	170	1320	0.89	49.9	5	10.0	17.511573	55.8
1.5	5.96	15	89.4	170	1320	0.89	48.9	4.97	10.2	17.423656	54.7
2	6.8	15	102	170	1320	0.99	66	6.66	10.1	18.239087	64.7
2.5	7.88	15	118.2	170	1320	1.1	93.3	9.35	10.0	19.28489	78.9

High power 116 triode amplifier

TH116

HT (kV)	Beam current (A)	Electric power in tube (kW)	Forward power (kW)	Efficiency (%)	Gain (dB)	
20	35	700	306	43.7	10.9	HT going up to 20
22	38.4	844.8	333	39.4	10.9	HT going up to 22 4616 powers wandering about
24	39.8	955.2	362	37.9	10.9	HT going up to 24
24	42.6	1022.4	405	39.6	11.1	116 effieceny droped, drive up 0.5
24	46.8	1123.2	525	46.7	11.2	better match on 116 input
26	48.4	1258.4	557	44.3	11.5	ht up to 26
28	50.4	1411.2	593	42.0	11.9	ht up to 28
30	51.6	1548	626	40.4	12.2	ht up to 30 - no x rays, 0.03 mW rf at load
30	57.2	1716	775	45.2	11.9	drive up to 1.5
32	59.2	1894.4	814	43.0	12.2	ht to 32
32	64	2048	996	48.6	11.8	drive up to 2
32	72.4	2316.8	1234	53.3	11.2	

drive

Electric power in tube

Forward RF power

Pre-Amp Gain and efficiency

Electric power in tube

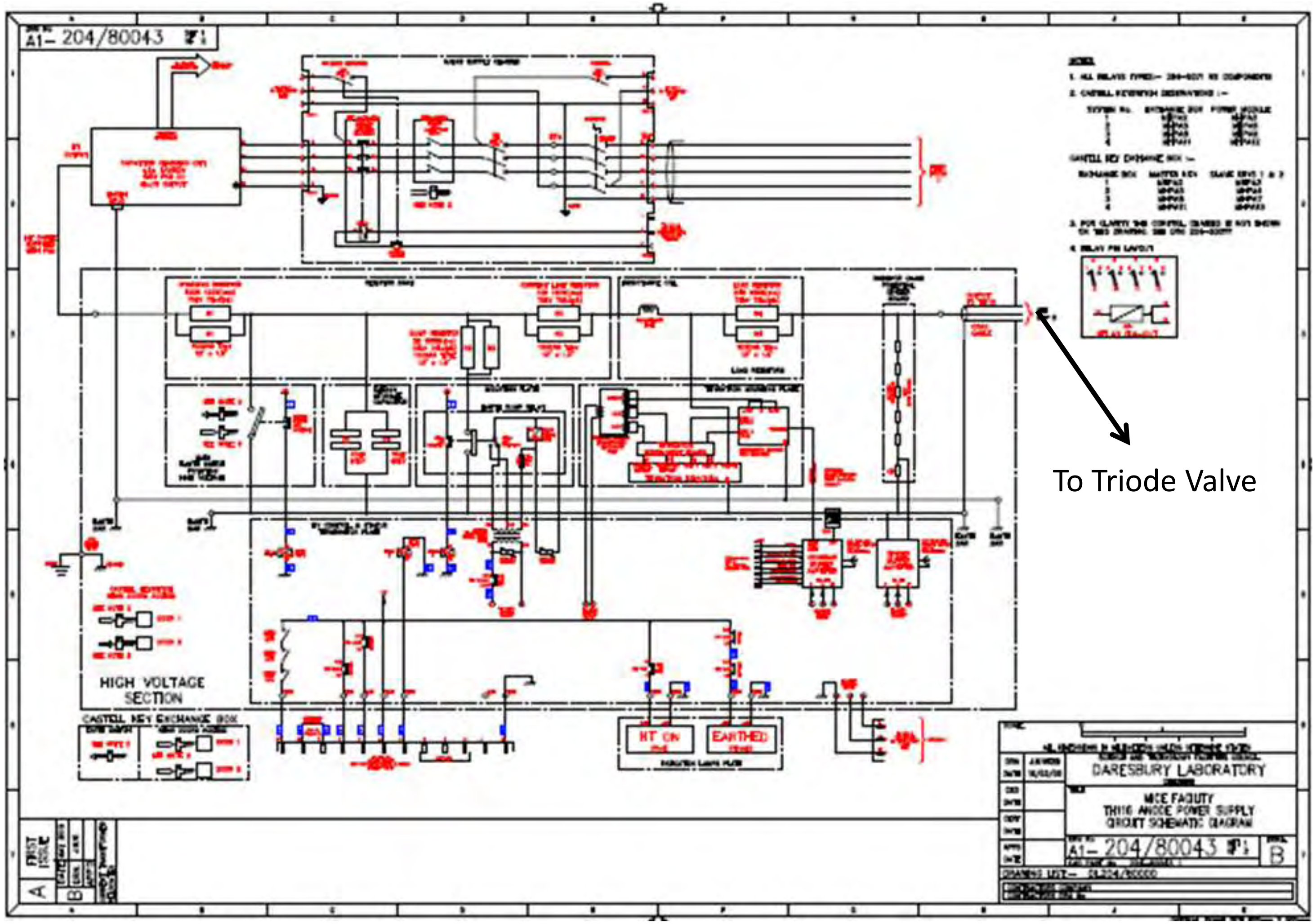
Forward RF power

Gain and efficiency

Crowbar Resolution

- Extensive investigation by DL electrical team (work led by C White and S Griffiths) have identified the source of the false crowbars

- Unusual fault in Thyratron
- Vital component protecting triode
- Became sensitive to modulation of HT circuit



To Triode Valve

Crowbar Resolution

- Extensive investigation by DL electrical team (C White and S Griffiths) have identified the source of the false crowbars

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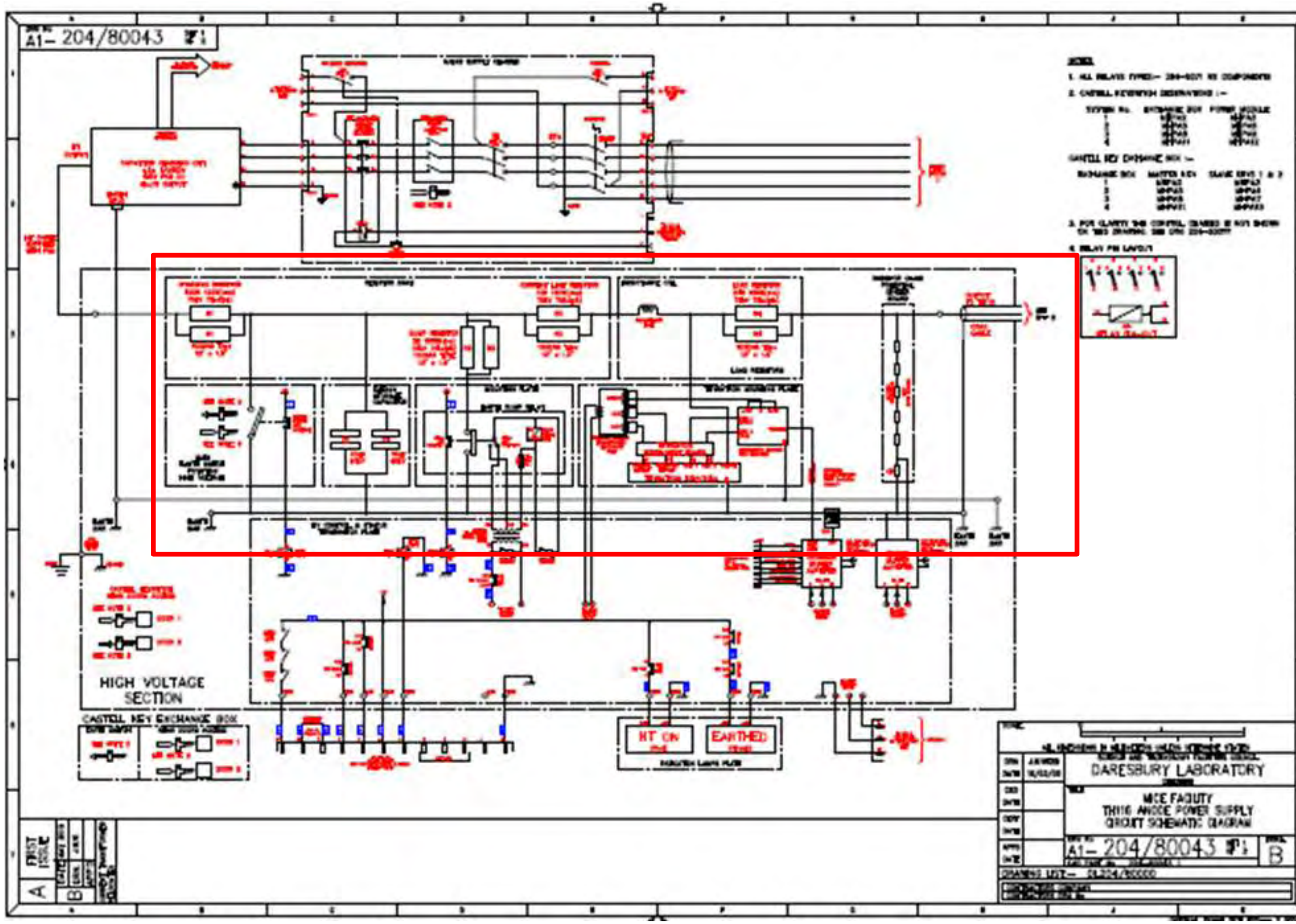
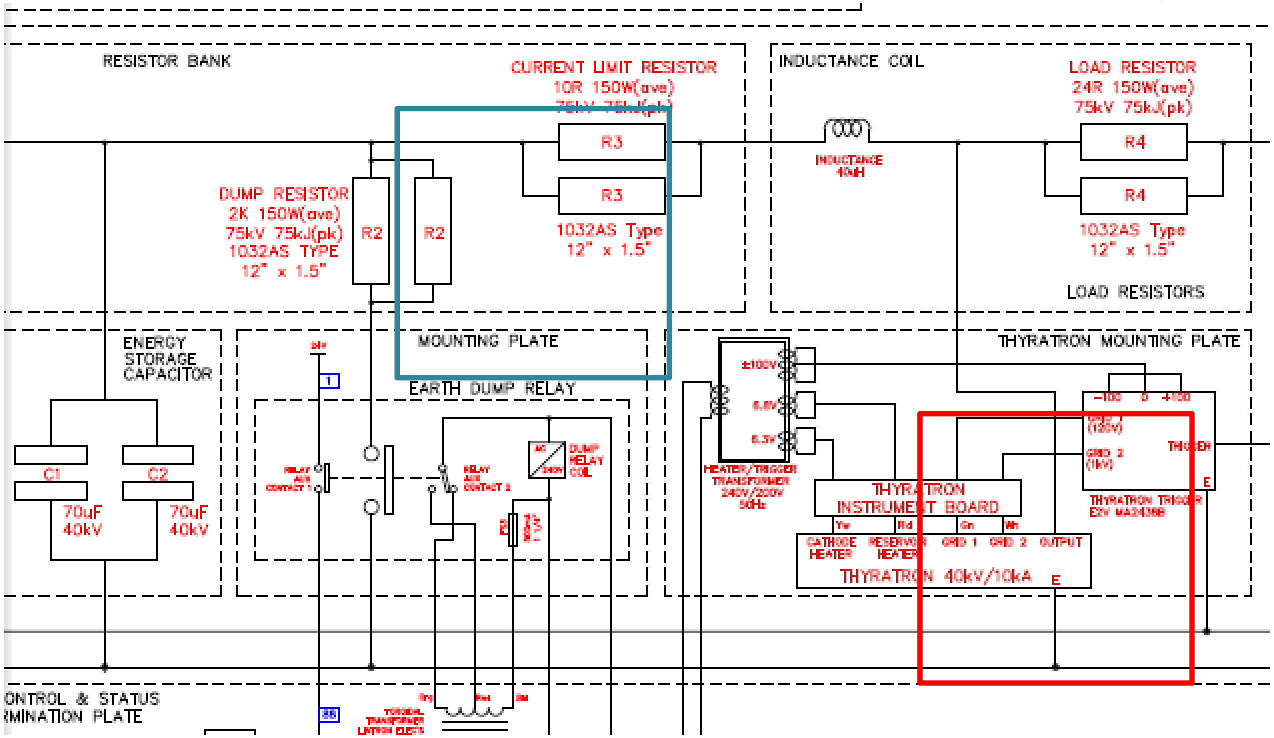
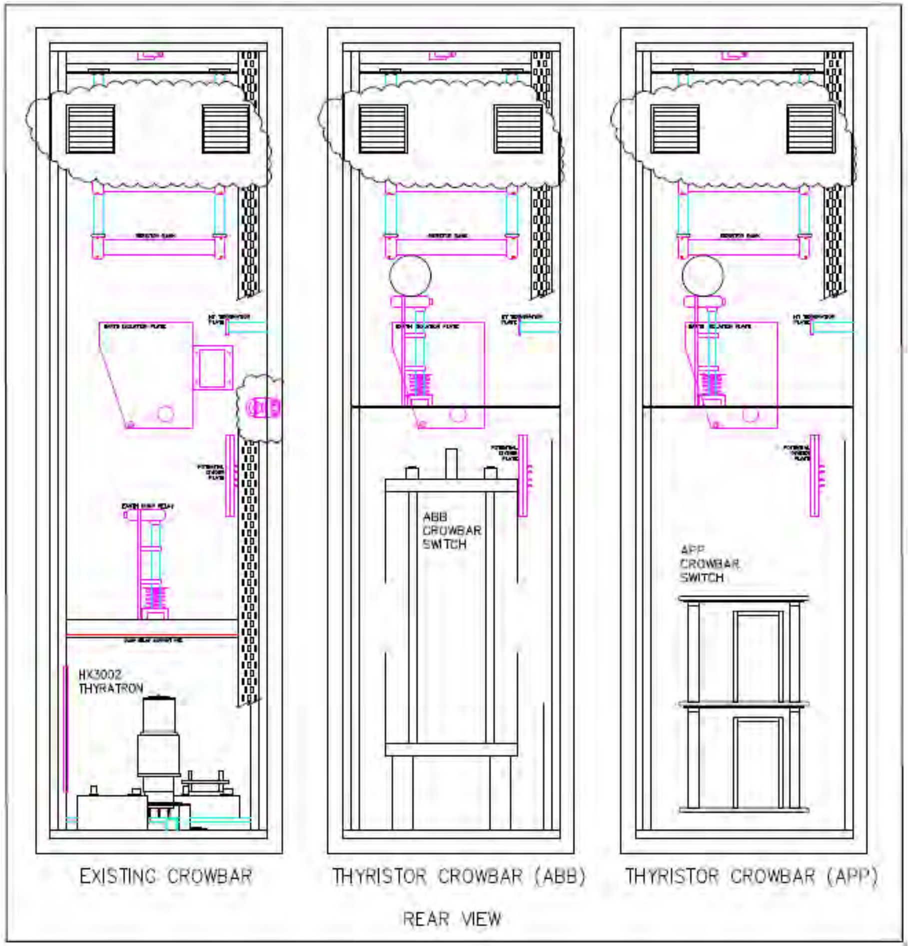


Crowbar Resolution

- Earlier Fault- May have damaged thyratron (red)
- Tests undertaken with old triode
- Thyratron replaced by alternate component
- False Crowbars ceased
- Operation up to 30kV resumed
- > 1MW operation achieved
  - With old valve
- New triode reinstalled
- Tests Resumed today
- Replacement of original thyratron proposed

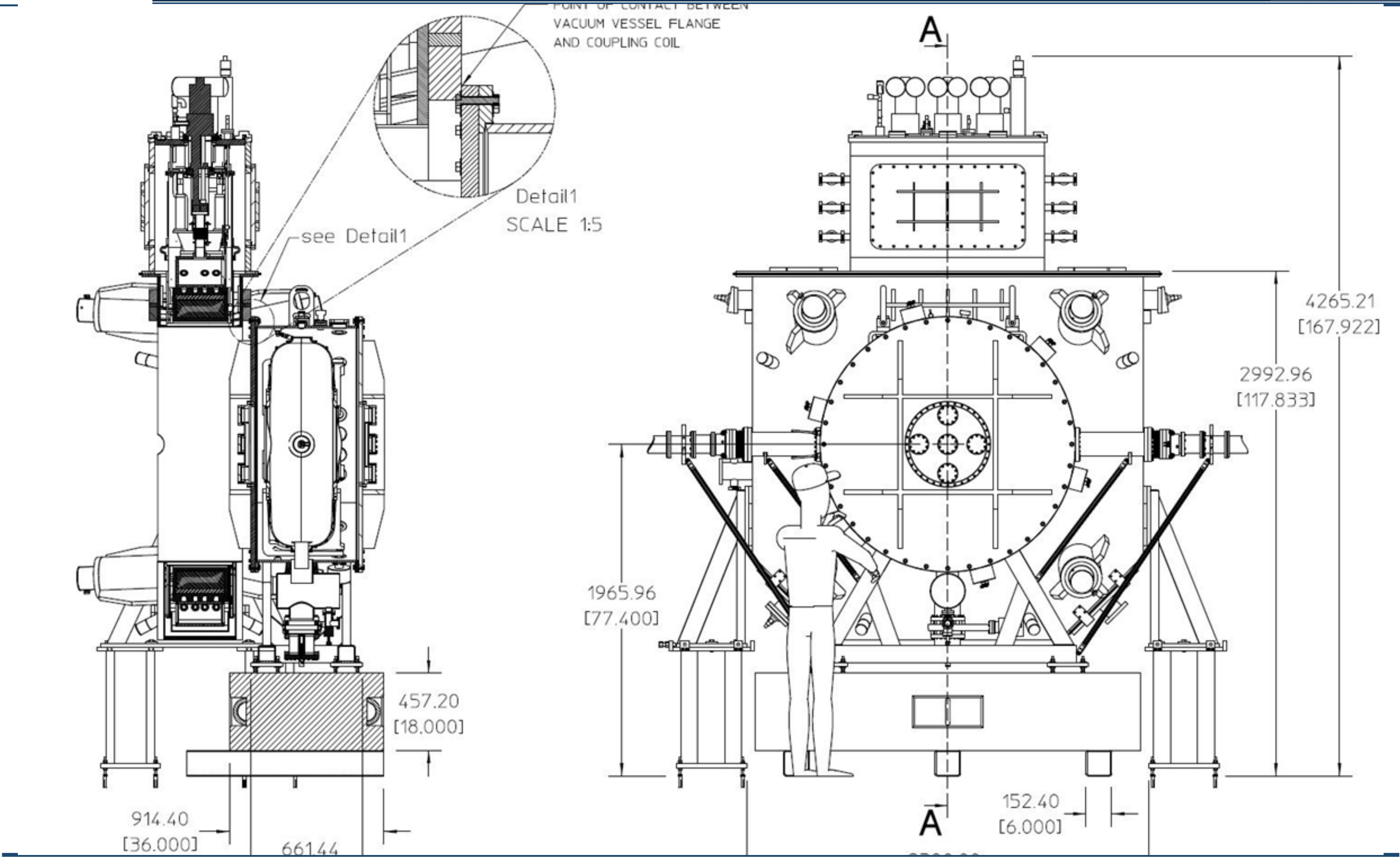


Crowbar Resolution

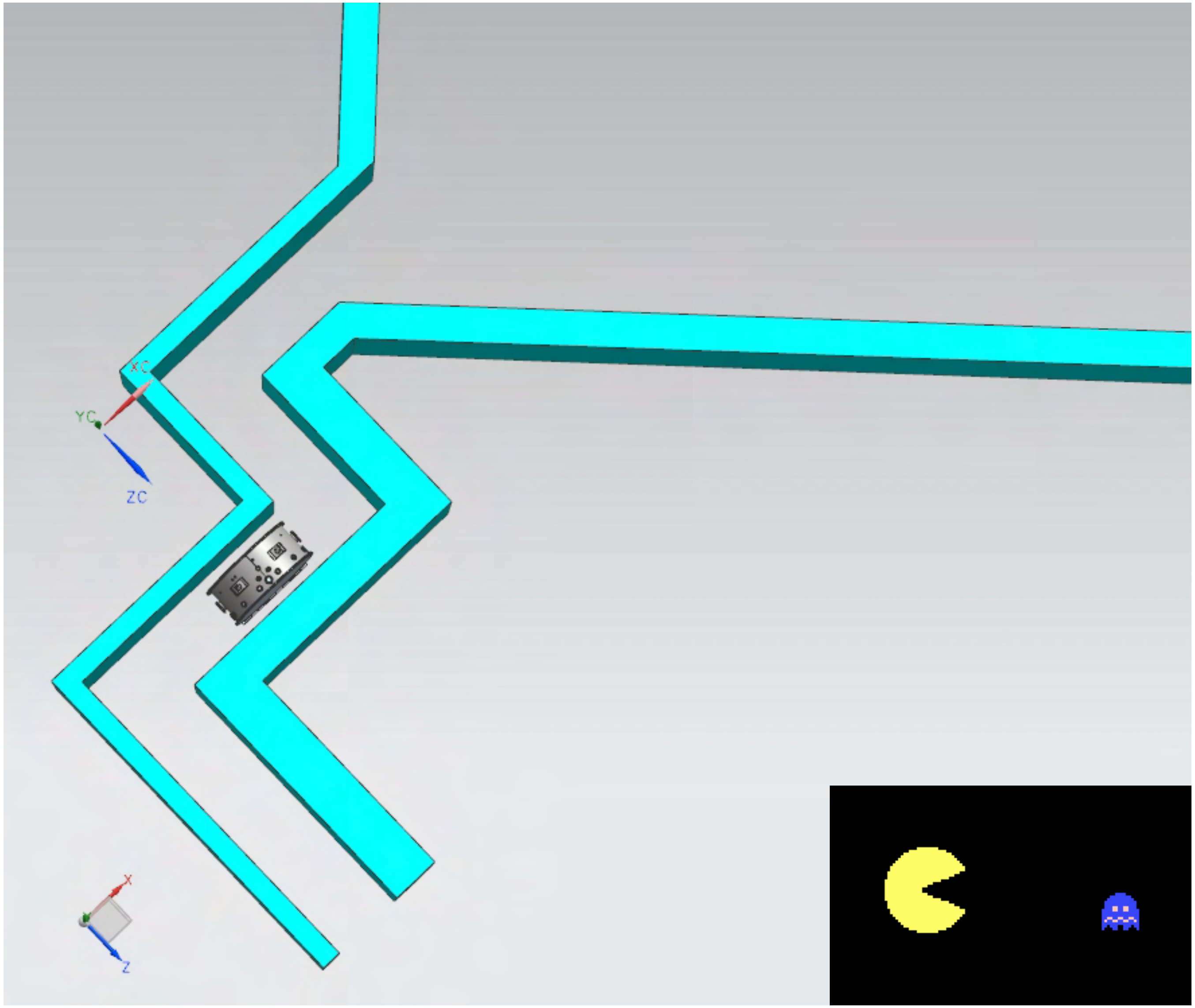


- A replacement Thyratron is proposed to enable operation above 30kV in the short term
- Alternative Crowbars being considered for future circuits (risk mitigation)
- Rear view of 40 kV power supply rack showing
  - existing thyratron crowbar
  - potential solid state replacement options
    - APP switch can be accommodated with a few design changes.
    - ABB switch is large and would be difficult to fit in the existing rack.
    - Diversified Technologies switch is a complete rack
- Compact APP switches cost ~$32k

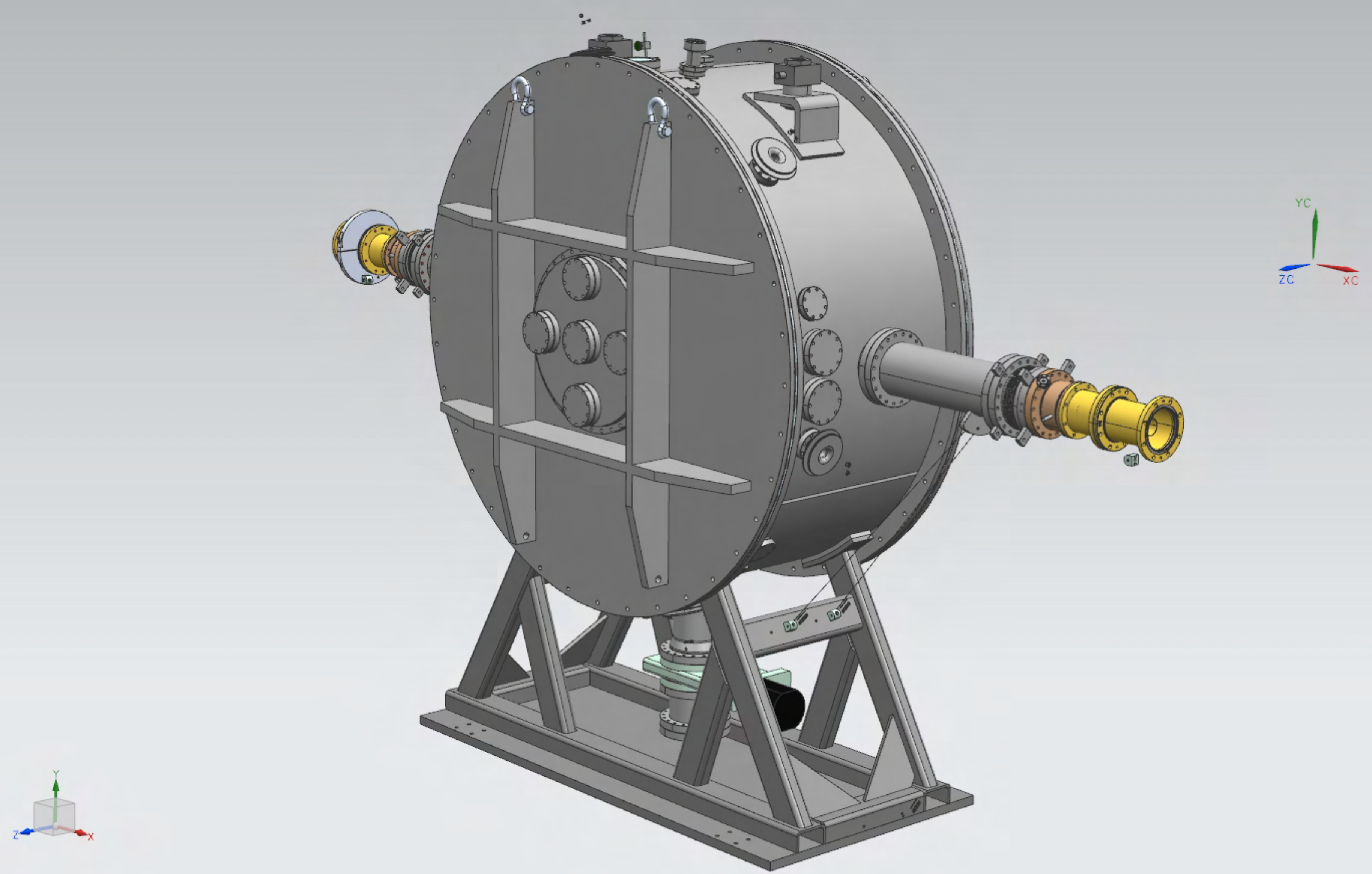
Final layout -- RFCC$_{\text{lite}}$



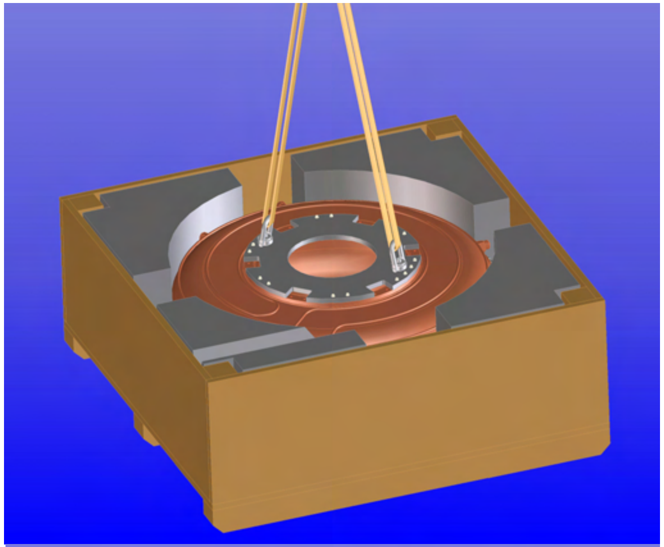
Through the Maze

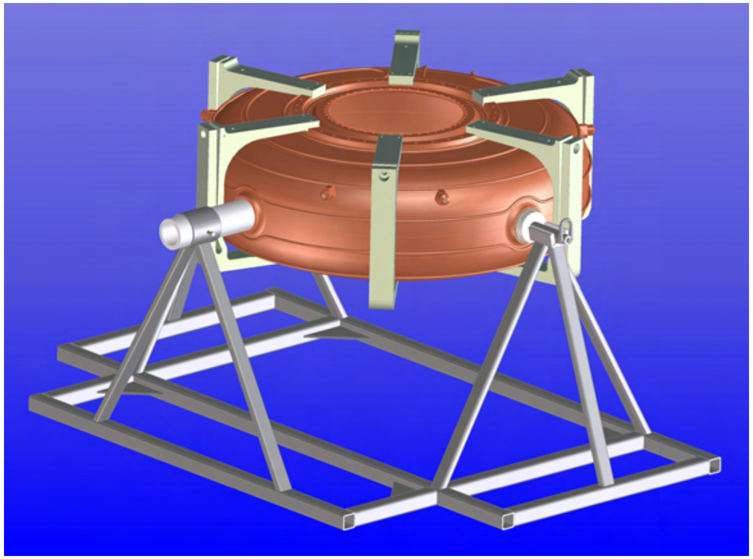


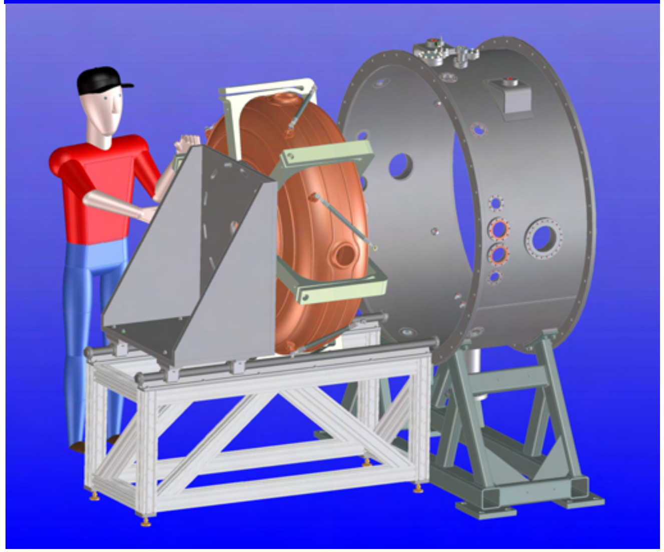
On Operational Stand



Assembly



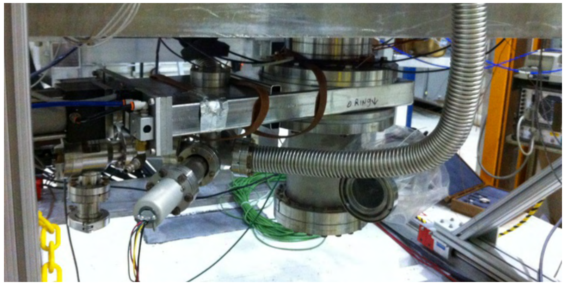


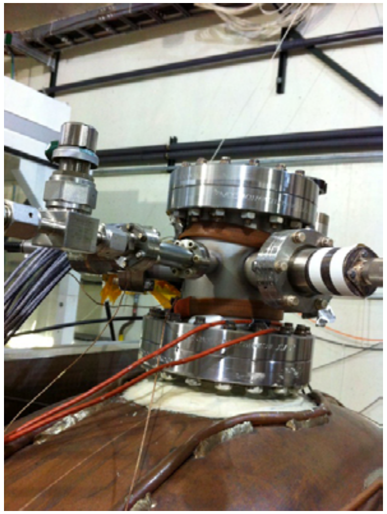


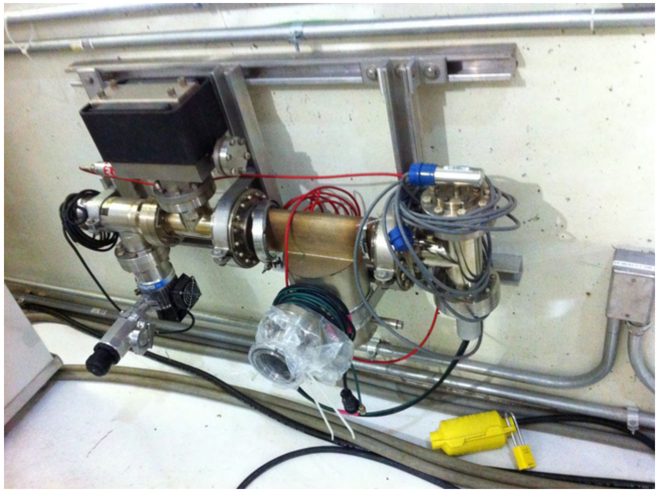
- Horizontal stand for tuner installation
- Vertical stand for cavity insertion
- Similar to MICE RFCC
- But simpler (one-sided)
- Welded designs changed to Al extrusion

Vacuum system

- Vessel arrived under purge
- Pumpdown test
  - Baseline 0.16 uTorr
- No other test planned until installation in hall
- Water feed-thru only concern
- Will reuse existing vacuum system
  - Getter + ion pumps
- Separate gauges for cavity, vessel and coupler vacuum pressure

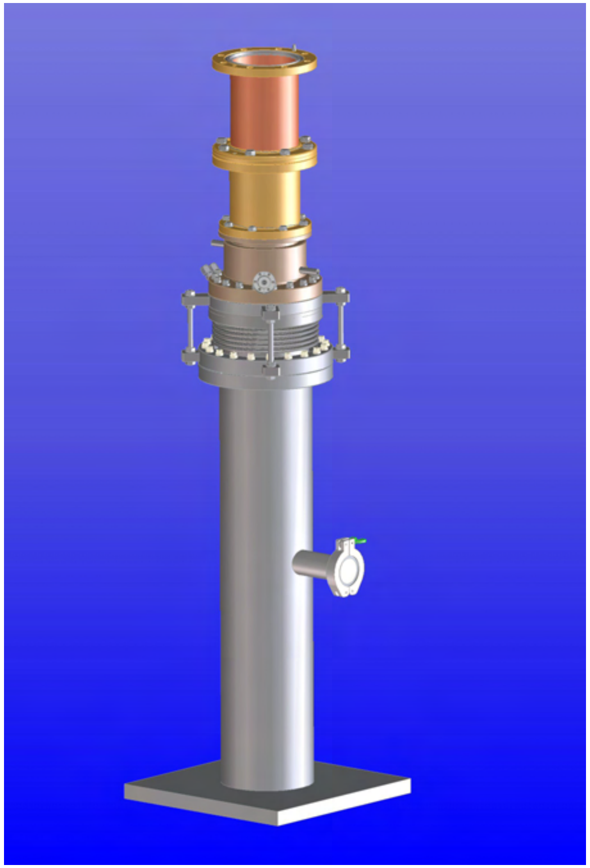






Couplers

- Mechanical interface different from earlier prototype in air
  - Separate conditioning stand not feasible
- Vacuum test stand designed (A. DeMello) for initial certification at LBNL
- Drawings finalized modulo minor tweaks (A. DeMello)
- Materials/parts being purchased by Fermilab this week
- Fabrication at LBNL: 10-12 weeks
- Test-fit and coupling adjustment in Lab-6
- To be removed before transport and reinstalled in MTA clean room

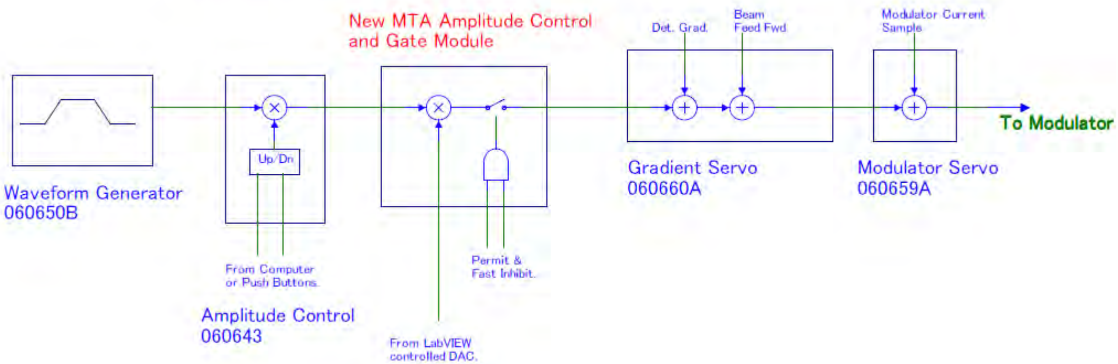


Diagnostics

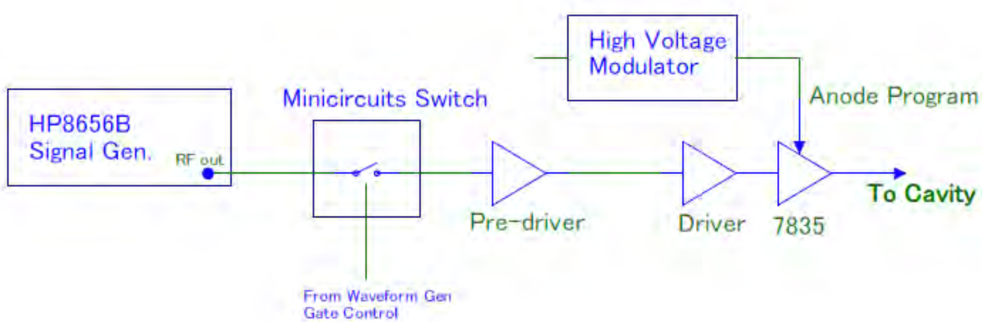
- Vessel
  - Top plate (A. Moretti) for
    - RF pickups
    - cavity vacuum pickup
    - optical fibers
  - acoustic sensors under test on 805-MHz cavities (P. Lane, P. Snopok)
  - vacuum
  - thermocouples
- Couplers
  - directional couplers for forward/reverse power
  - vacuum
- External
  - Air pressure (tuner control)
  - Water temperature/pressure (cooling)

RF Controls
(D. Peterson, R. Pasquinelli)

Linac Station 7
Amplitude Control Block Diagram



Linac Station 7
RF Drive Block Diagram



Linac RF station 7 modifications for MTA 201 MHz cavity testing

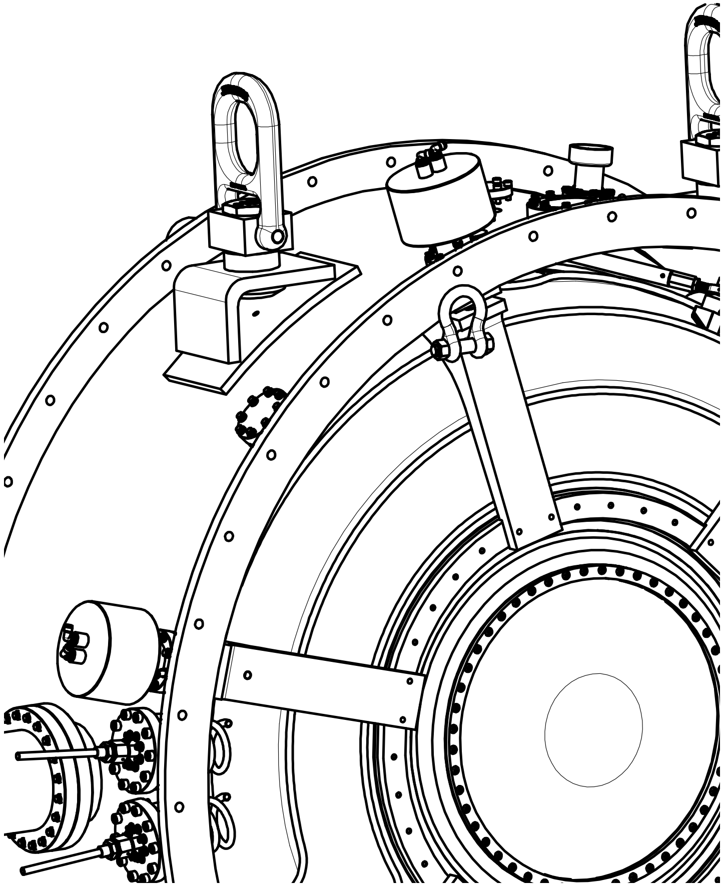
- Short Term (testing in progress)
  - Amplitude Control via modulator ramping
  - Frequency Control via HP8656B.
- Mid Term
  - Tuner Control via RS-485 and pneumatics.
- Long Term
  - New LLRF with phase control and beam sync.

- Frequency control through signal generator
- Driver amplifier driven into saturation
- Overall amplitude control through program curve to the Modulator

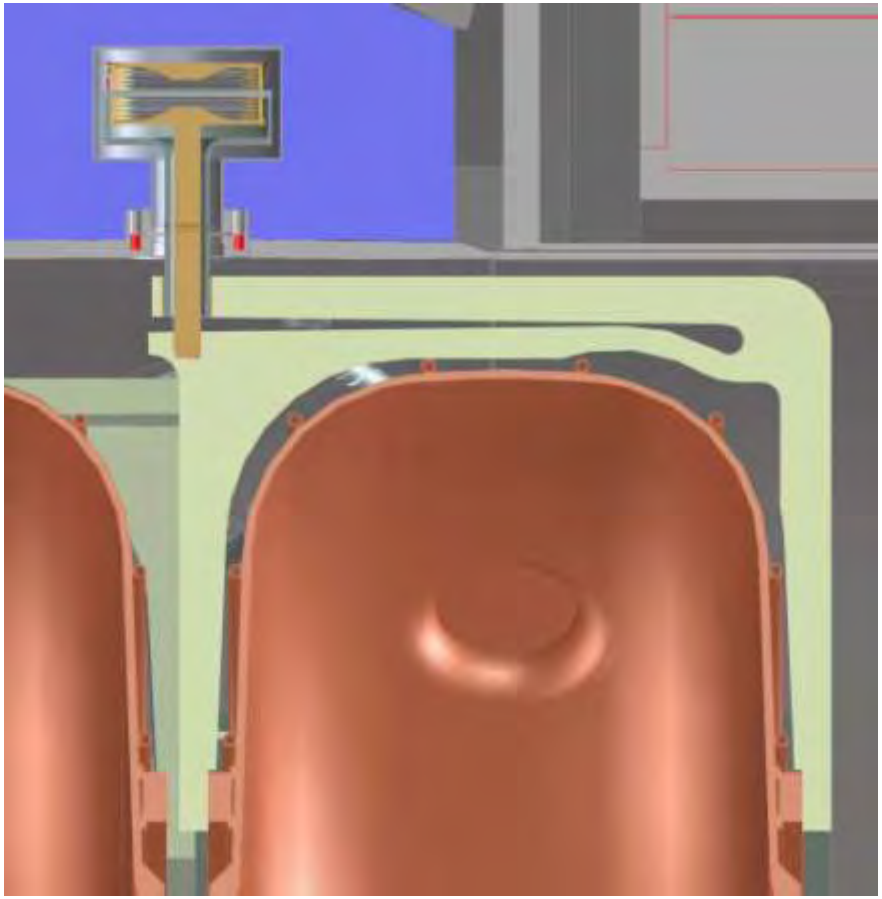
Single Cavity Tuning System

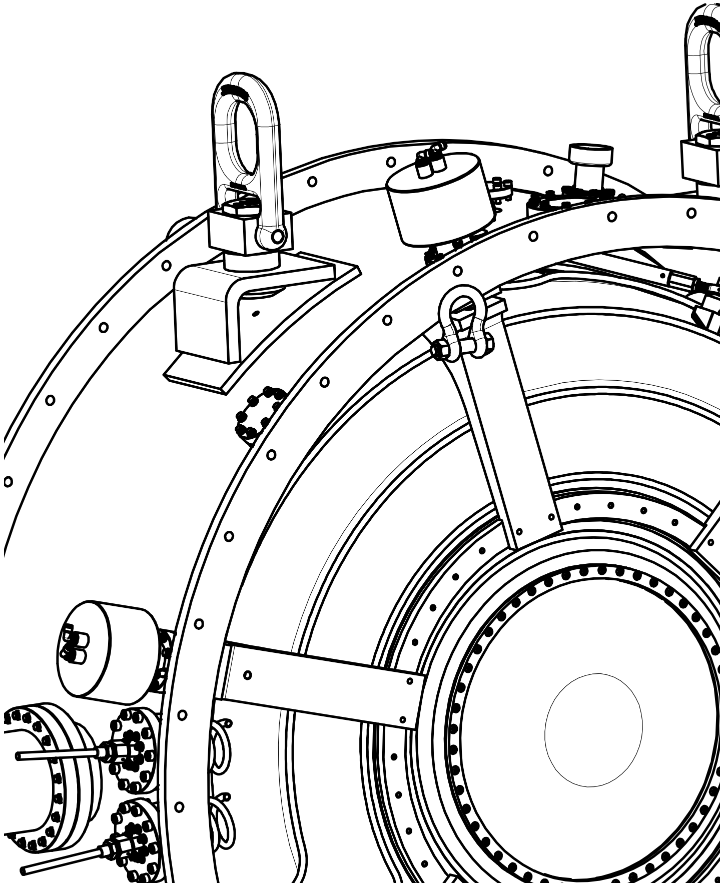
Tuning System:

- Forks will be in vacuum
- Actuators will be outside vacuum vessel

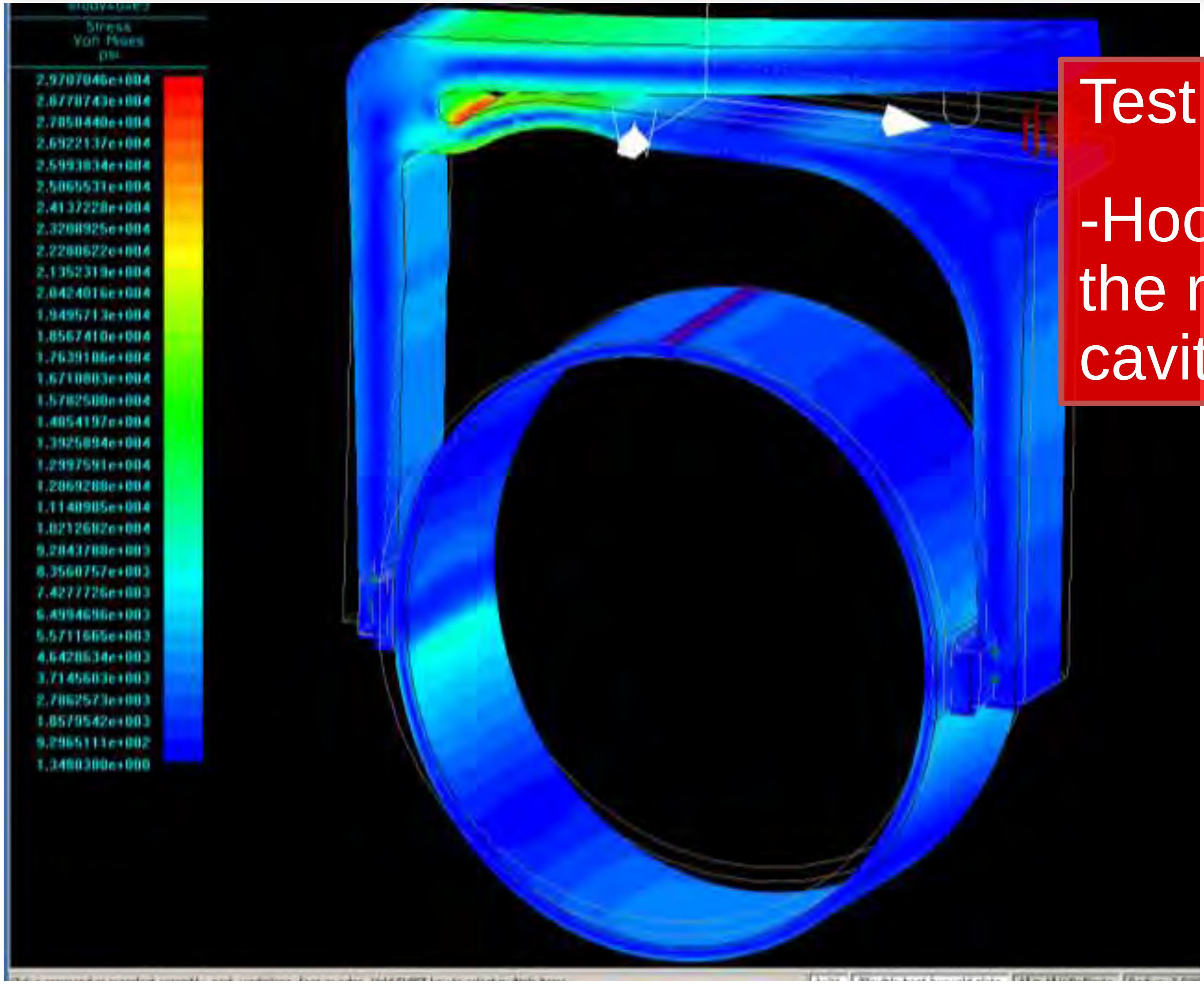


Single Cavity Module





Test Stand



Test Stand:

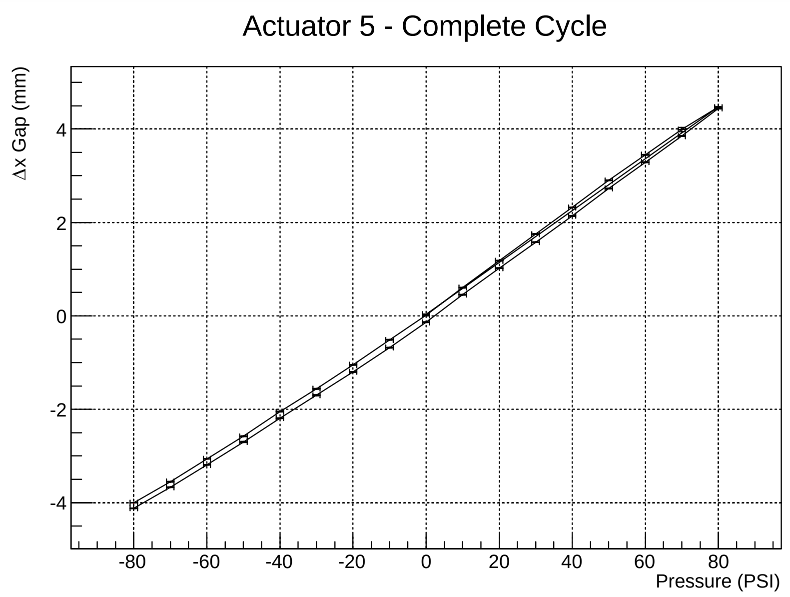
-Hoop to simulate the response of the cavity

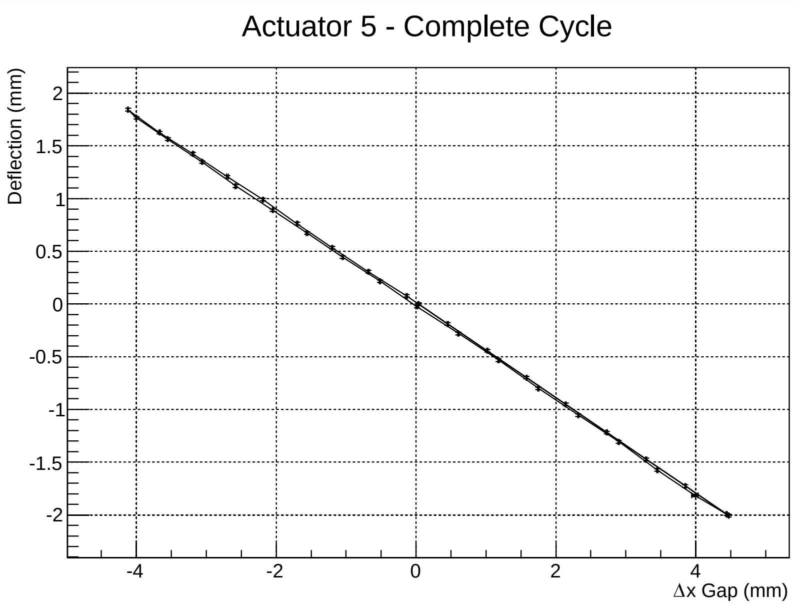
Ranges and Sensitivity

Ranges Results				
	Pressure (PSI)	***Deflection (mm)***	***Transducer (V)***	***Δ Gap (mm)***
Range	± 80	± 1.78	± 0.787	± 4.002
Mean Error	1.5	1.3E-02	4E-03	8E-03

We have a good resolution

Single Actuator Analysis





Analysis of single actuators shows hysteresis to be present, but predictable, associated with the actuators

Group analysis shows reasonably reproducible response of several actuators (six are required in each cavity)

Future analysis will look at cavity S parameters rather than mechanical displacements

Will investigate the resiliernce of the tuning system when one actuator is disable

Muon-RF Phase measurements

Undersampled Signal Analysis

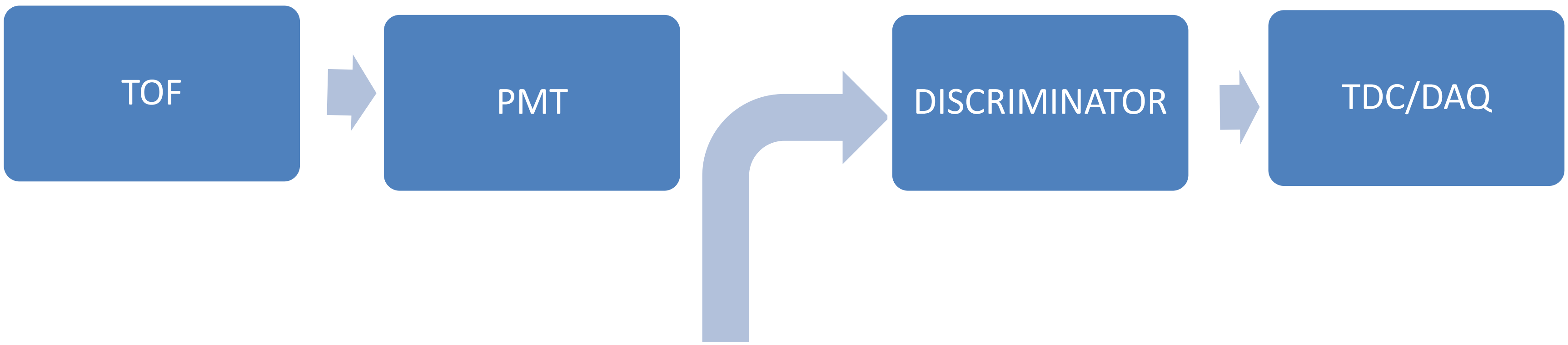
- 201.25GHz, recorded on oscilloscope at 40GS/s.
- Data thinned to give waveforms sampled at 1GS/s and 100MS/s (same as digitisers used elsewhere in MICE system).
- 100MS/s for 1ms = 100k pts/ pulse.
- Fit to data
  - free parameters
    - phase and amplitude
  - frequency restricted +/- 50kHz (+/-1kHz @ limit)
- Yet to be proven.
- Ultimate accuracy limited by pulse length.
  - 1ms pulse implies 1kHz accuracy on frequency.

TOF Timing Circuit

TOF	PMT	DISCRIMINATOR	TDC/DAQ
Particle Arrives at TOF – Scintillator emits Photon(s)	Photon arrives at PMT – Output Voltage Rises	Output Voltage reaches Threshold – Logic Signal output	Logic Signal Received at TDC – Time is noted on DAQ
	Response time ~0.7ns	Variable rise time - Typically 1-2ns	25-40ps

For the TOF measurements the photomultiplier tube response time and electronics delays are not needed as the calibration is performed relative to a reference ‘pixel’ in the TOF

TOF Timing Circuit



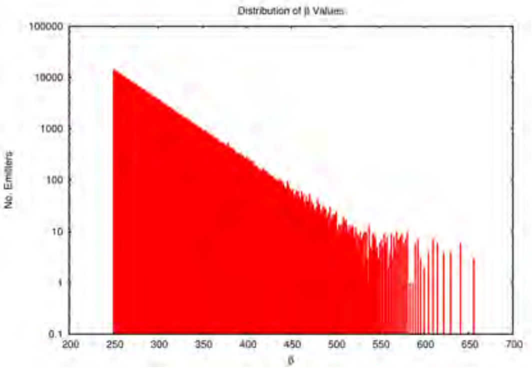
- RF signal into free TOF discriminator channel -> TDC.
- Discriminator max 30MHz repetition rate.
  - Frequency min error 1kHz/200MHz x ~5ns = 0.025ps error per RF period
  - 30MHz acquisition rate max time error = 7 periods x 0.025ps = 0.175ps.
- Continuous measurement of phase at 30MHz sample rate.
- Fit sine wave to TDC data to determine phase of RF at any given time
  - Requires amplitude data from undersampled waveform acquired in ADC system

Assumptions

- Cavity Geometry
  - Ideal pillbox shaped cavities
  - No Be windows
  - Emitters on found on flat faces of cavity
- Field Simulation
  - Perfect field simulation (TM010 Mode)
  - No edge effects at cavity iris
  - Solenoid Fields not currently supported
- Particles
  - Produced at rest
  - Space charge negligible
  - Emitters have identicle area
  - No integrated X-Ray simulation
  - No dE/dx simulated

The Code

Very rough estimate for emitter distributions used (Moretti et al). More data needed to improve emitter distribution.



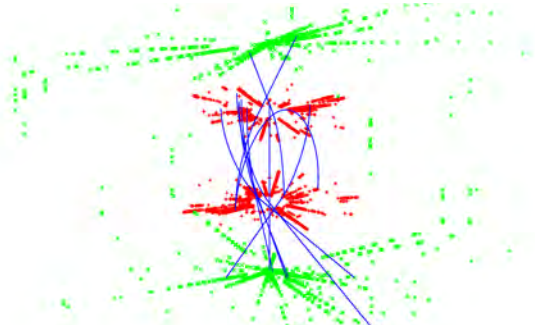
Distribution of β for emitters

$\beta < 250$ neglected. Emitter Current negligible.

Geometry

Simple cavity design used for testing. NOT a MICE Cavity!

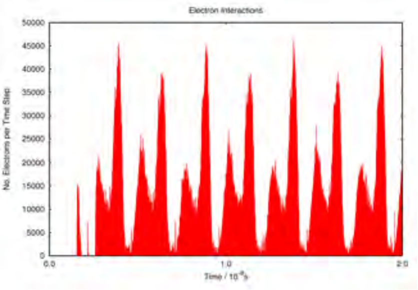
Radius	0.5m
Length	0.4m
Iris Radius	5cm
Mode	TM010
Frequency	201.25 MHz
Gradient	8.0MV/m



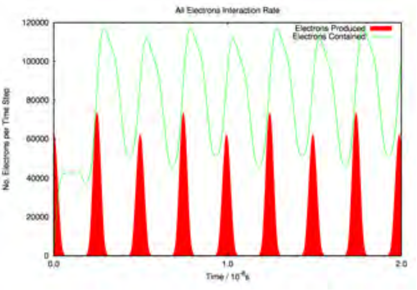
RED: Electron-Cavity Interaction Points
GREEN: Electrons Leaving the Simulation Volume
BLUE: Example Electron Tracks

Rates and Currents

Time dependent results. Interaction and production rates as a function of time.



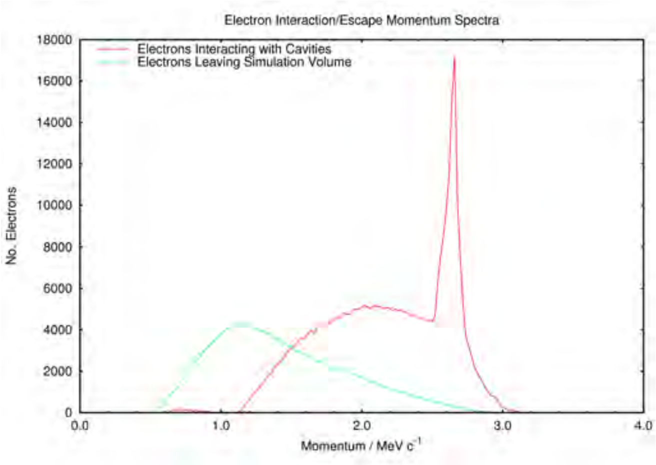
No. Electron-Cavity Interactions per Time Step



RED: No. Electrons Produced per Time Step

GREEN: No. Electrons Contianed with the Simulation

Spectra



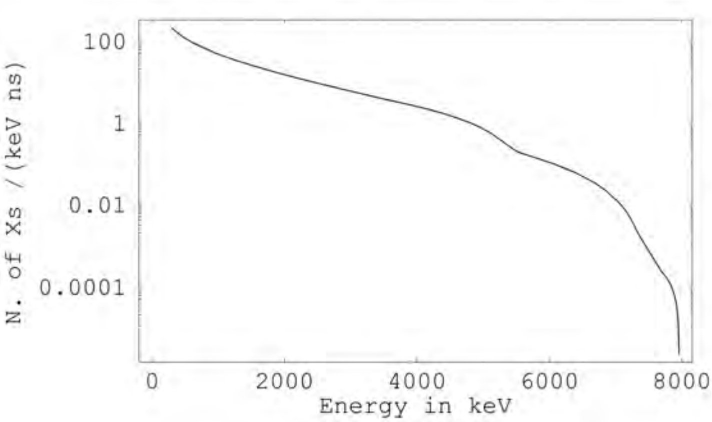
RED: Electron-Cavity Interaction Momenta
GREEN: Electrons Leaving Simulation Momenta

Preliminary X-ray spectrum

- Approximate Kramers formula for thick target was used:

$$\frac{dY}{dk} = \frac{2\times5\times10^{-4} Z}{511}\left(\frac{E_{\max} - k}{k}\right) \quad \text{(photons per keV)}$$

- Only interactions with Cu included so far.
- Work in progress to simulate X-ray spectrum in MARS code.



Summary

- Power Amplifier Progress
    - Fault determined in RF power supply
    - Tests are now back in progress, power above 1MW observed from old triode
  - LLRF design in hand
    - Exploiting a know system with significant expertise in UK and US collaboration members
    - Design concept outlined
    - Slow cavity fill demonstrated on bench at 1.3GHz
- Cavity Test Progress
    - Plan described to assemble first cavity in MTA
    - Using single cavity test stand
    - Assembly through Summer, tests in Autumn
- Gas pressure control system for the actuators described
    - Results from tests of tuner actuators (on test loops) show good, predictable, reproducibility
- Muon Phase determination system discussed
    - Proposal to use existing ToF digitisation systems
    - Include sub sampled recontruction of RF phase and amplitude, based on known frequency
- Electron currents and trajectories
    - Computation based on projected FE current densities from projected tip densities
    - Permits initial assessments of likely electron currents and energies, hence X-ray spectra