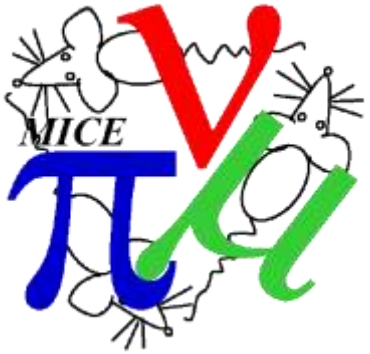


RF Power Test Status

The MICE RF Group

Contributions from Daresbury, RAL, CERN, LANL, Strathclyde University, and Imperial College

Context

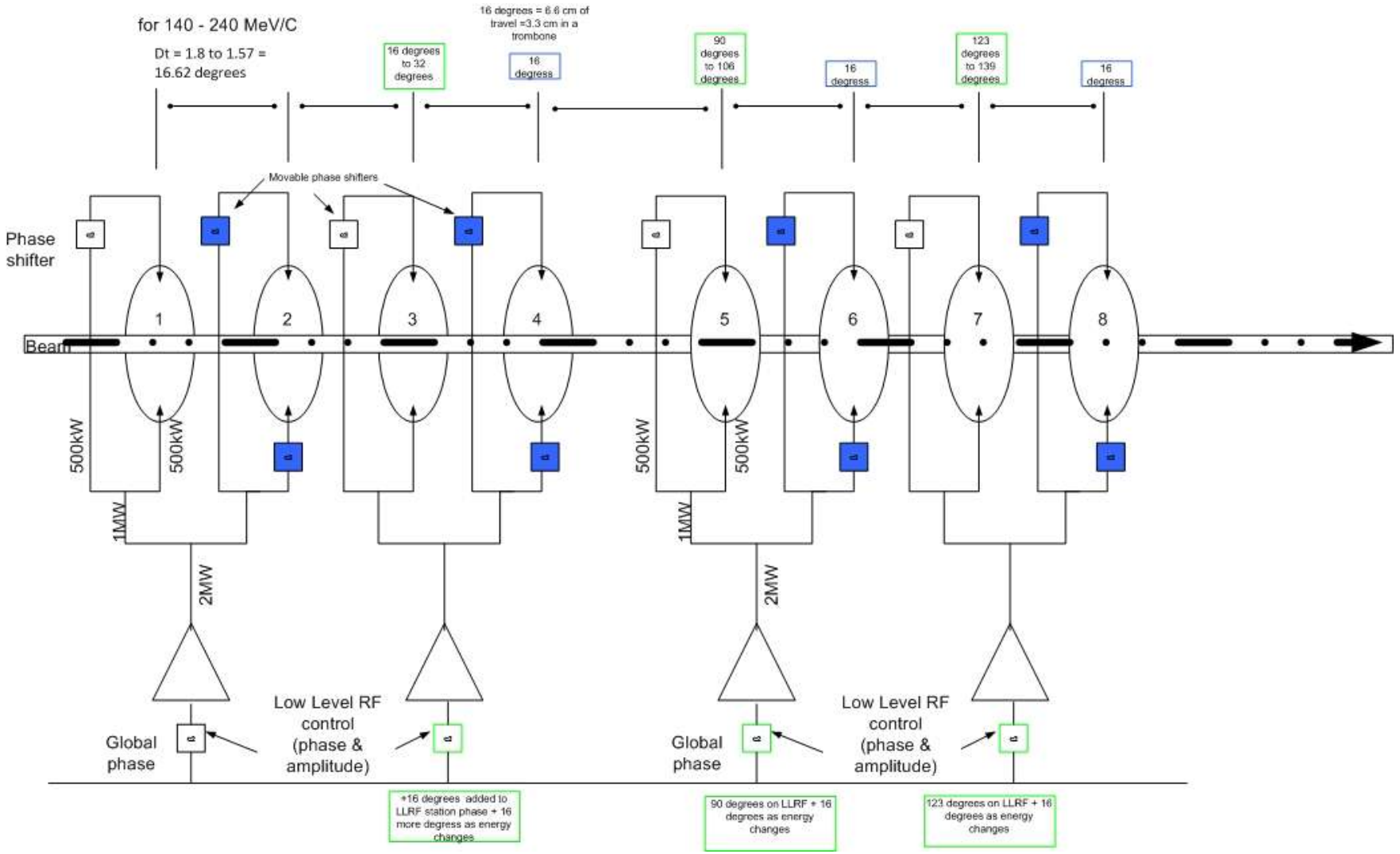
- TIARA project is supporting the development of a prototype Power Amplifier Chain to be used to study Muon Ionisation Cooling
  - Project will demonstrate required peak power at 201MHz for 1ms at 1Hz
    - This will include a fully operational prototype amplifier chain and a power supply system
  - Practical installation and operation of amplifier set will be demonstrated in the MICE Hall
  - The project will also scope out a solution scalable to future accelerators
    - Exploiting developments in new valve technologies- Diacrodes

- Presentation shall first describe the progress in the High Power RF system preparation

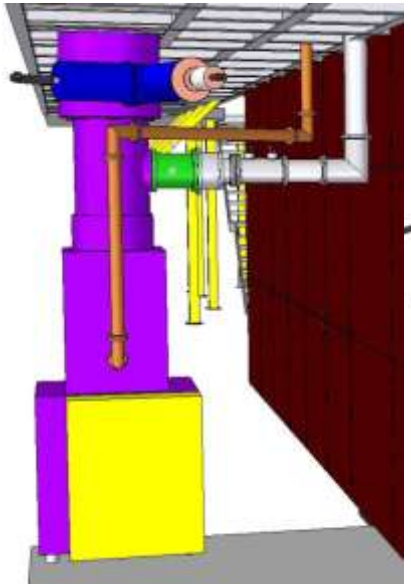
Revised Distribution Network

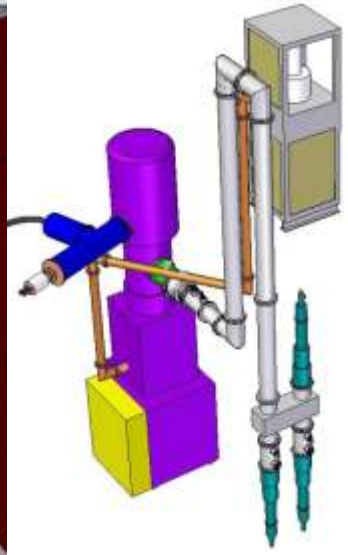
- Elimination of dynamic phase control between cavity pairs
  - Enabled simplification of distribution network
  - Negligible effect on phase control
- Overall layout has been frozen since last meeting
  - Detailed design revisions have been made to accommodate the installation of other equipment
- Procurement underway
  - The network now being procured by University of Mississippi
  - 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

Schematic of Phase Control



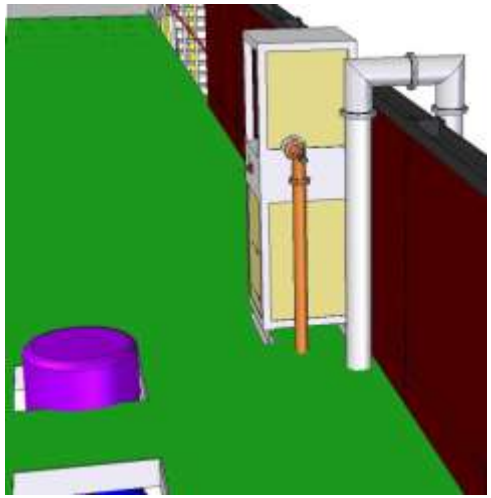
MICE Hall RF system for TIARA Test

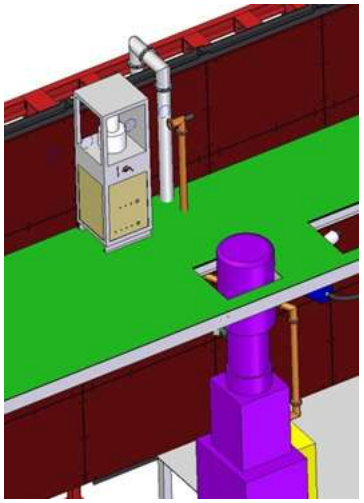


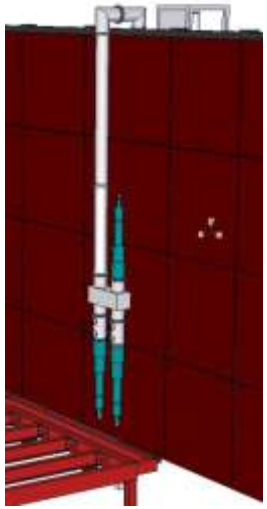


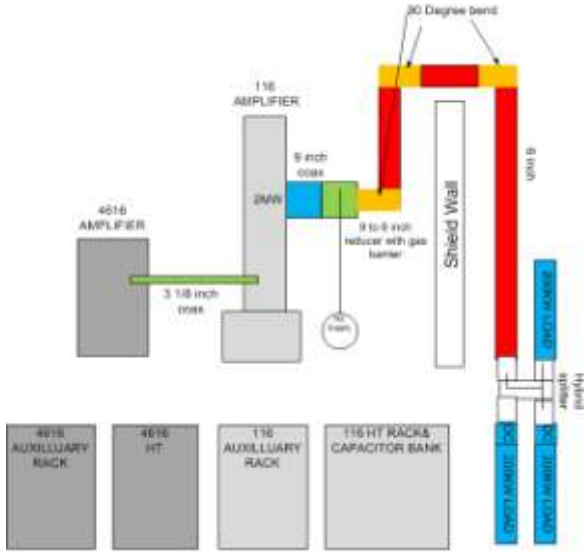
- One amplifier set installed in operational position
  - Installed in the first amplifier station
  - Tetrode on Mezzanine, Triodes deep behind the shield wall
  - Opportunity to test the impact of B-fields during STEP IV
- One hybrid installed on MICE side of shield
- 3 loads, two will share the output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

TIARA Installation Detail



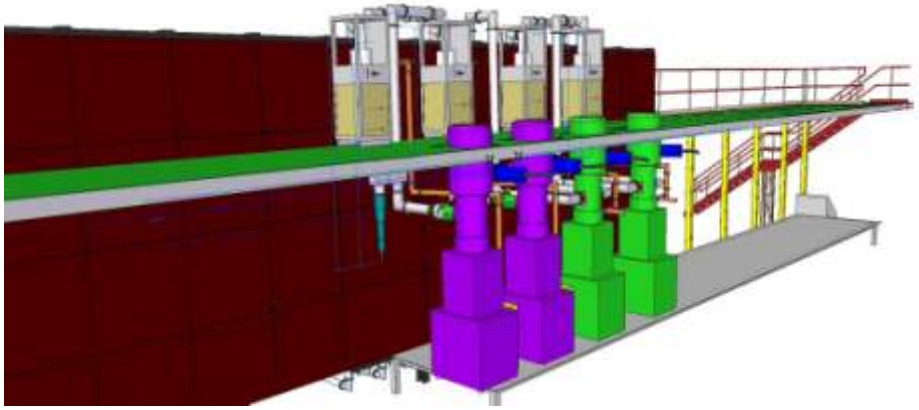




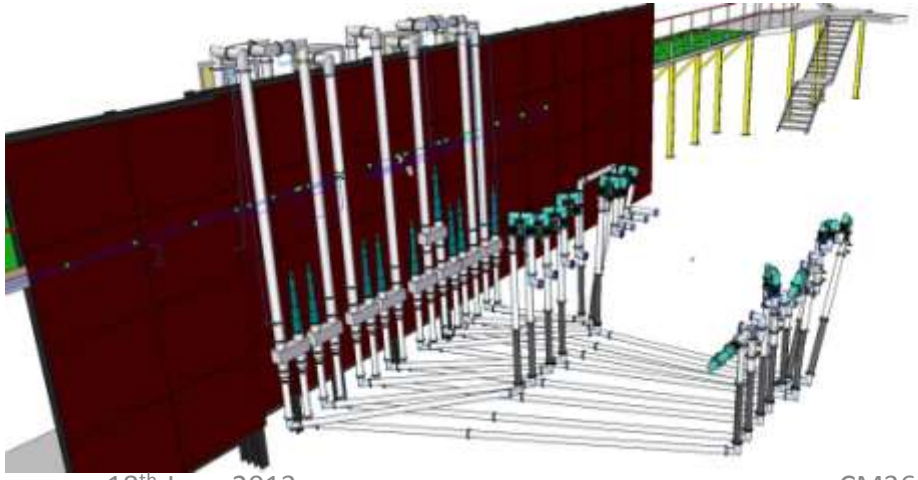


RF Layout – Final Installation

Amplifiers behind Shield Wall



Distribution Network to MICE



- Amplifiers installed behind shield wall
  - Triodes on main floor, Tetrodes on Mezzanine
  - Impact of B-fields currently being analysed
  - Shielding requirements assessed
- High power dynamic phase shifters removed.
- 4 off 6 inch coax lines over wall
  - Pressurised to increase power handling
- Hybrid splitters moved - more accessible
  - Minimises clutter and increases service access to the amplifier stations
- Line lengths matched using 3D CAD
- Manually adjustable line trimmers installed at cavity to take up assembly errors in coax length
- Easier to assemble – introduced flexible coax
  - Allows for small misalignments
- 2 Hybrids split output from the Berkeley Amplifiers on amplifier side of wall
- CERN amplifiers have two outputs
- 4 hybrids on MICE side of shield wall
  - Split power for the opposed couplers of each cavity
- Lines will be pressurised with 2Bar Nitrogen

RF Power Systems

- Medium power valve amplifiers
  - Two of the tetrode amplifiers have operated at nominal required output power (240kW)
  - DL have the refurbishment of 2 other tetrode amplifiers in an advanced state
- High Power Amplifiers
  - High power amplifier No 1 subject to power test using new TH116 Triode valve
  - Connected to input drive and HT taken gradually up to 32kV, (nominal running level for 116 valve)
  - Raising drive, the electrical characteristics of both amplifiers showed high gain and electrical to RF conversion efficiency (see tables)
  - Crowbar events observed at 1.2MW
  - Subsequent operation above 300kW problematic
    - Due to a change in the seating of the valve in its socket
    - Revealed a weakness in one of the resistors in the crowbar
    - Resolved by modification to PSU and triode socket (completed)

Demonstration of required tetrode performance

- New tetrode valve required conditioning
- Input matching re-optimised
- Tube has been operated for > 50-60 hours, with incremental adjustment to amplifier and electrical parameters, system is stable and predictable
- System can be brought to operation after significant down periods immediately

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

Progress towards 2MW output from MICE Triode

- New triode valve installed in DL test set
- Progressive raising of DC bias and RF input drive
  - Using new Tetrode with up to 240kW
- Power raised to 1.2MW- limited by electrical arc fault (air side)
- Resolved by redesigning the valve seats
- Simultaneous upgrade to peak power of crowbar

4616 Tetrode amplifier

High power 116 triode amplifier

4616												TH116						
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 (%)	HT (kV)	Beam current (A)	Electric power in tube (kW)	Forward power (kW)	Efficiency (%)	Gain (dB)	
0	4.12	15	61.8	170	1320	0.65	24.7	3.22	13.0	15.797836	40.0	20	35	700	306	43.7	10.9	HT going up to 20
0	4.12	15	61.8	170	1320	0.65	27.2	5.83	21.4	16.216555	44.0	22	38.4	844.8	333	39.4	10.9	HT going up to 22 4616 powers wandering about
0	4.12	15	61.8	170	1320	0.65	29.3	8.72	29.8	16.539543	47.4	24	39.8	955.2	362	37.9	10.9	HT going up to 24
0.5	4.64	15	69.6	170	1320	0.72	31.2	4.31	13.8	16.368221	44.8	24	42.6	1022.4	405	39.6	11.1	116 effieceny droped, drive up 0.5
1	5.24	15	78.6	170	1320	0.8	39.6	4.4	11.1	16.946052	50.4	24	46.8	1123.2	525	46.7	11.2	match on 116 input
1	5.24	15	78.6	170	1320	0.8	39.4	4.12	10.5	16.924062	50.1	26	48.4	1258.4	557	44.3	11.5	... up to 26
1	5.16	15	77.4	170	1320	0.8	38.5	3.85	10.0	16.823707	49.7	28	50.4	1411.2	593	42.0	11.9	ht up to 28
1	5.16	15	77.4	170	1320	0.8	37.4	3.51	9.4	16.697816	48.3	30	51.6	1548	626	40.4	12.2	ht up to 30 - no x rays, 0.03 mW rf at load
1.5	5.96	15	89.4	170	1320	0.89	49.9	5	10.0	17.511573	55.8	30	57.2	1716	775	45.2	11.9	drive up to 1.5
1.5	5.96	15	89.4	170	1320	0.89	48.9	4.97	10.2	17.423656	54.7	32	59.2	1894.4	814	43.0	12.2	ht to 32
2	6.8	15	102	170	1320	0.99	66	6.66	10.1	18.239087	64.7	32	64	2048	996	48.6	11.8	drive up to 2
2.5	7.88	15	118.2	170	1320	1.1	93.3	9.35	10.0	19.28489	78.9	32	72.4	2316.8	1234	53.3	11.2	BANG

drive

Electric power in tube

Forward RF power

Pre-Amp Gain and efficiency

Electric power in tube

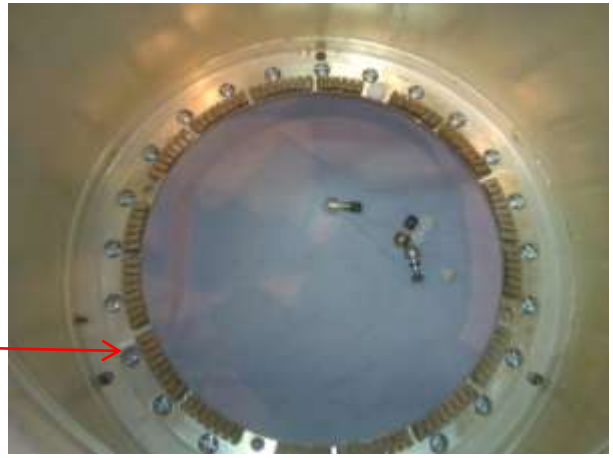
Forward RF power

Gain and efficiency

Resolution of Arcing Problem

Evidence of arcing on HT connection

- The seating of the valve in the HT top box has caused arcing
- The HT box was changed in order to facilitate flow and return cooling of the valve
- Detail dimensional and location differences allowed the valve to sit slightly incorrectly in its socket
- This obviously caused the issues that can be seen when the tube is removed



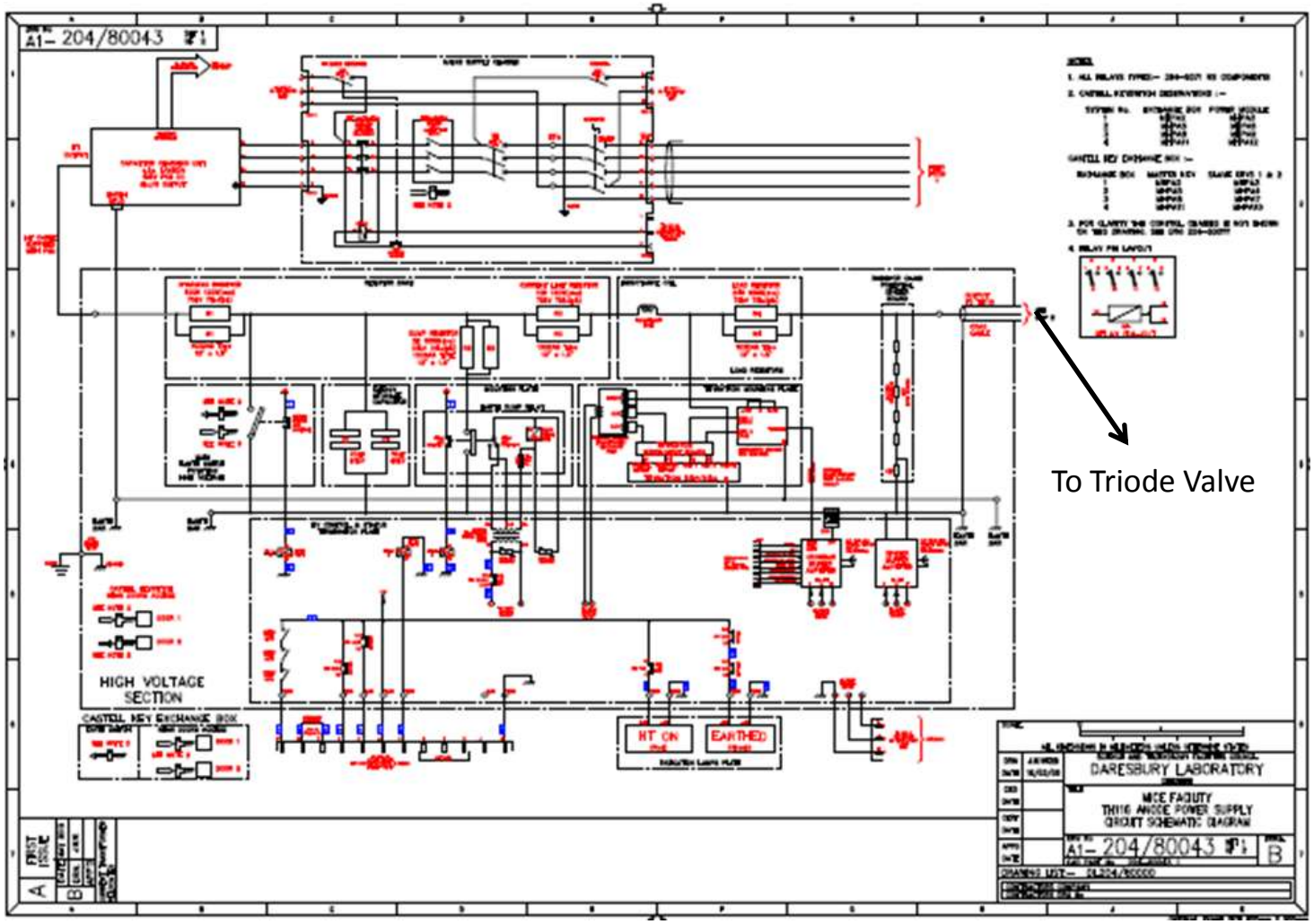
Resumption of High Power Tests

- HT top box redesigned to seat valve more precisely
- Tests have recommenced with old ISIS triode
  - Training by A. Moss, C. White (Daresbury) of new team members
    - T. Stanley, newly appointed MICE RF Engineer (Based at RAL)
    - K. Ronald, C.G. Whyte, A.J. Dick, Strathclyde
  - Builds team for eventual move to MICE hall
- Crowbar misfires have continued to limit maximum voltage between 15-20kV
  - Not limited by DC voltage holdoff
  - Triggering linked to operation of triode grid modulator (either on or off)

Crowbar Resolution

- Extensive investigation by DL electrical team (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



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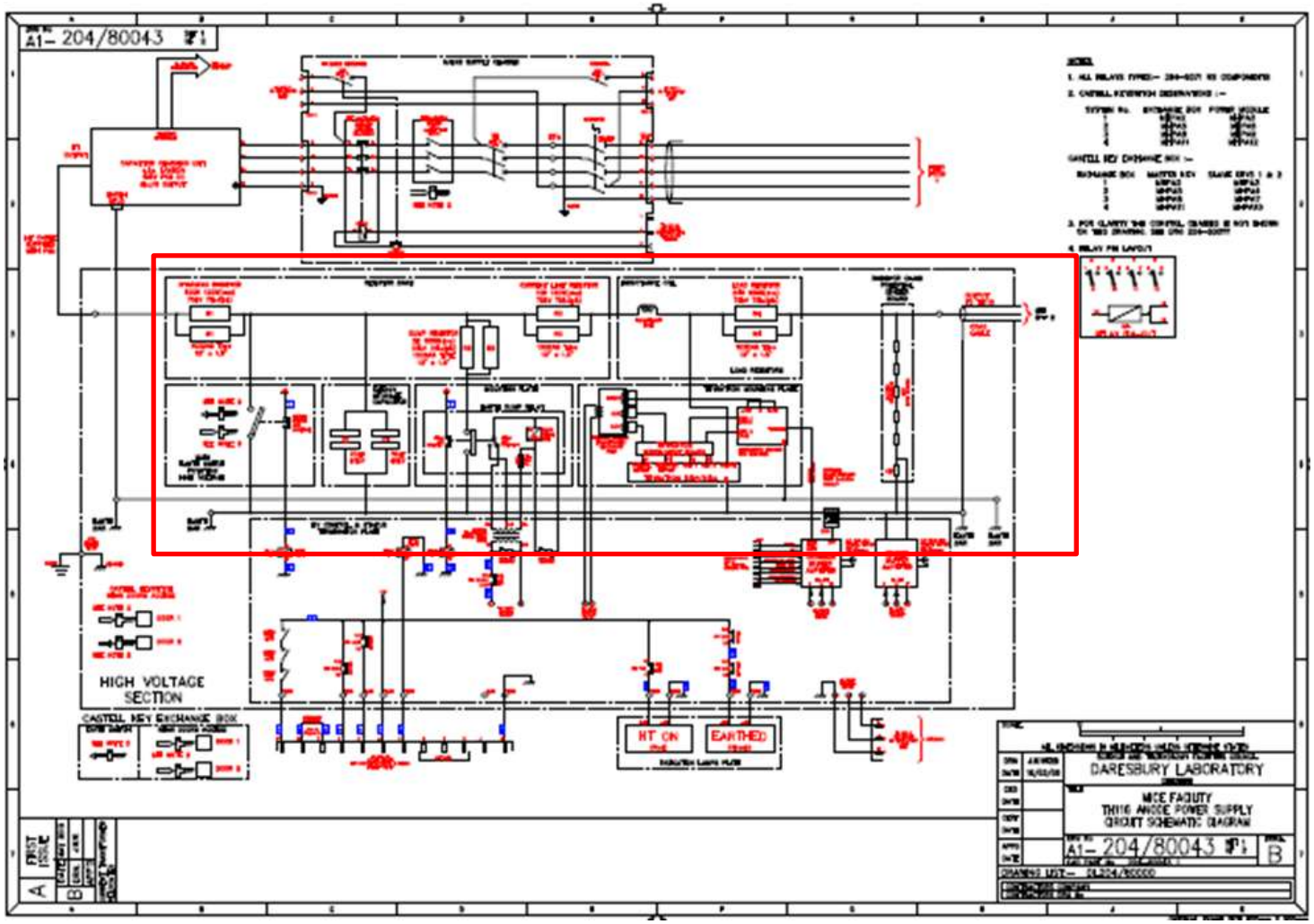
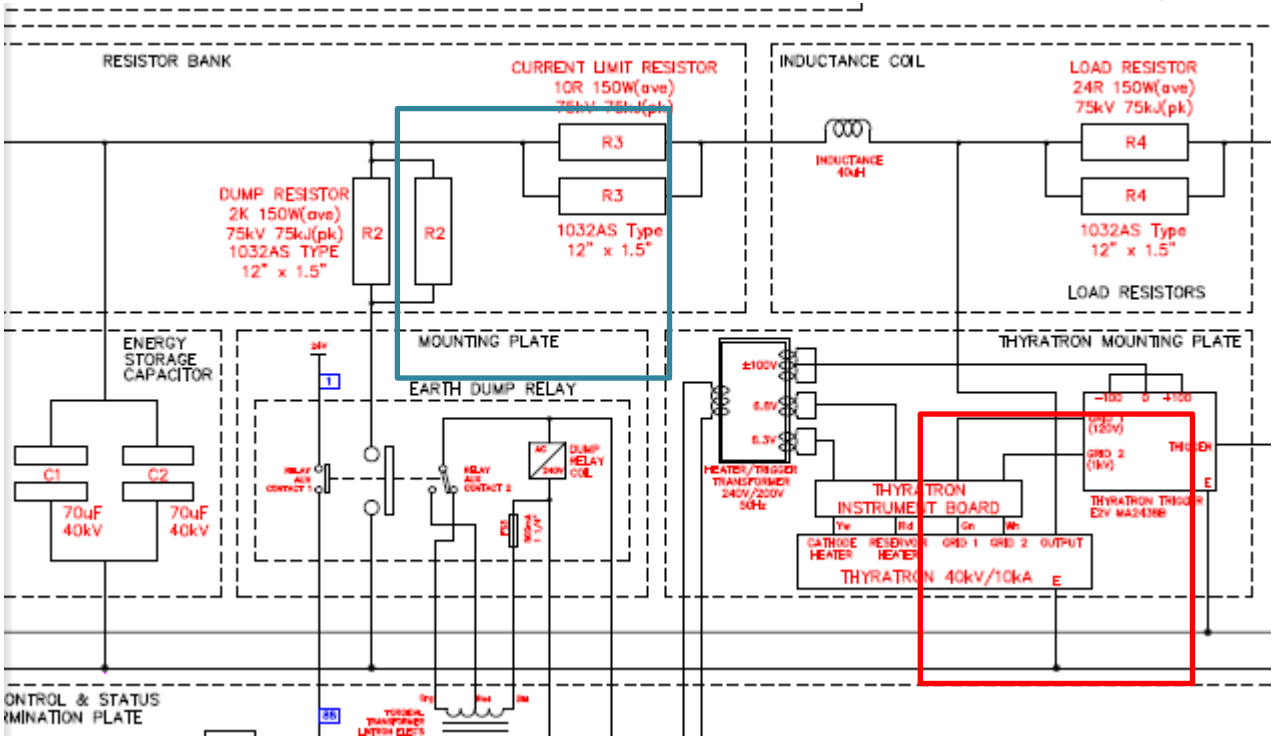
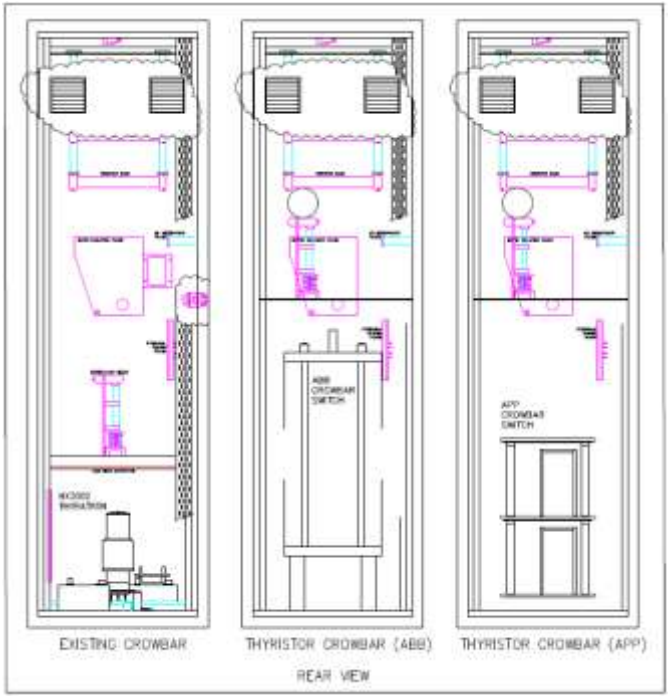


Crowbar Resolution

- Earlier Fault-
- Limiting resistors (blue) Short Circuited
- 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 to resume tomorrow
- 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

MICE Hall infrastructure

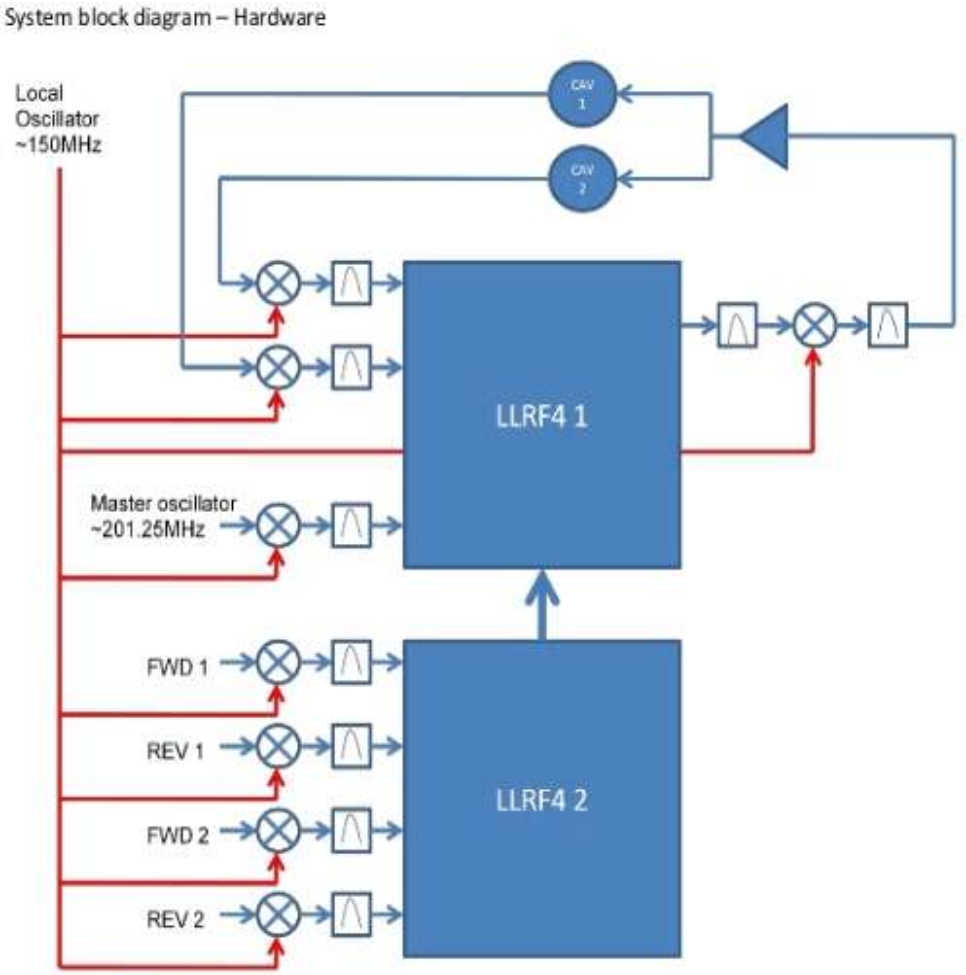
- Hall infrastructure being reviewed
  - Ensure all required services in place for RF system
  - Prime Power, Cooling
- Installation plan for TIARA test network
  - Led by T. Stanley, MICE RF Engineer at RAL
  - Working closely with RAL engineering team
- Draft safety document drawn up to facilitate operation of RF drivers and Cavities in MICE Hall

Summary

- Power Amplifier Progress
  - Required 240kW demonstrated in 2 separate tetrode amplifiers 1.2MW demonstrated in output of Triode with new build valve
    - Constrained by problem with external arcing in the bias circuit caused
    - Resolution by redesign of valve seats completed
    - Upgrades to the prototype power supply crowbar circuit
    - Power tests resumed to attain required 2MW
    - Training opportunity for new people
    - Crowbar limitation being resolved
    - Next phase in tests planned for tomorrow
- Amplifier refurbishment continuing
    - Continuing progress on refurbishment of 2 more tetrodes and 3 triode amplifiers
- 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
- Diacrode tests in progress
  - 1ms demonstrated at 120Hz and 2.75MW

LLRF Concept

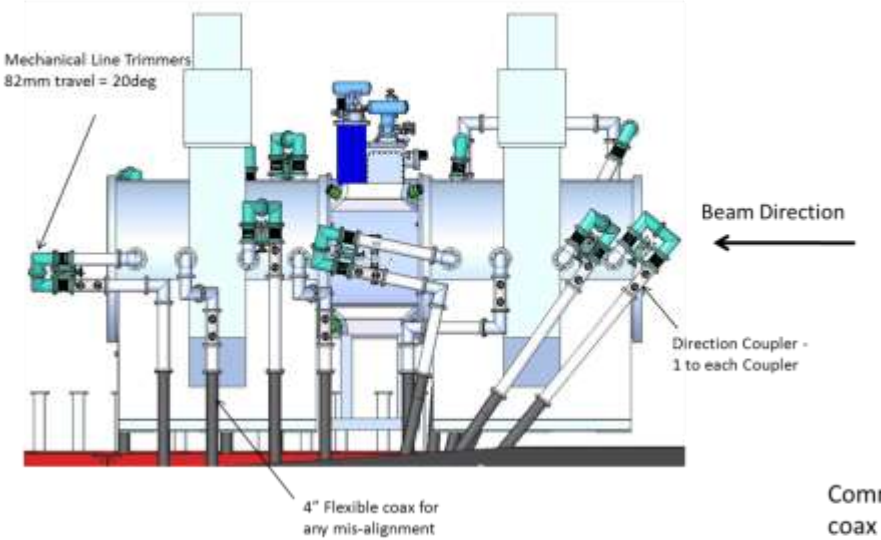
- Digital LLRF system
  - Controls high power amplifier chain
  - Compensates for variation in electrical length of amplifiers and line segments
  - Compensates for droop in amplifier PSU's
- LLRF4-1 Analogue front ends
  - Mix to 30-60MHz for ADC
  - Feed forward control- slow fill of cavity
    - Reduce strain on coaxial lines
  - Feedback control
    - Regulates cavities to 1% in amplitude and 0.5° in phase
  - Output Restores 201MHz RF Frequency
- LLRF4-2 Diagnostic board
  - Monitors forward and reflected amplitude of signals
  - Can interrupt amplifiers output in major fault in the transmission lines
  - Will confirm if RF system has provided the required amplitude and phase

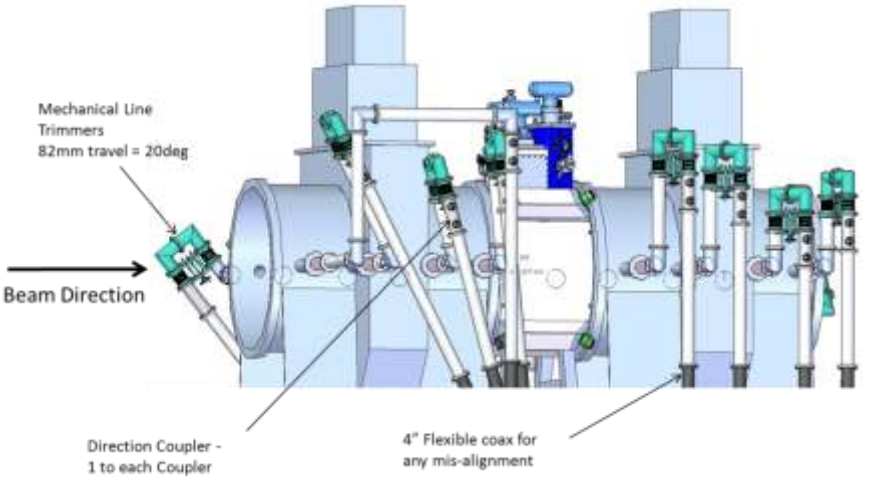


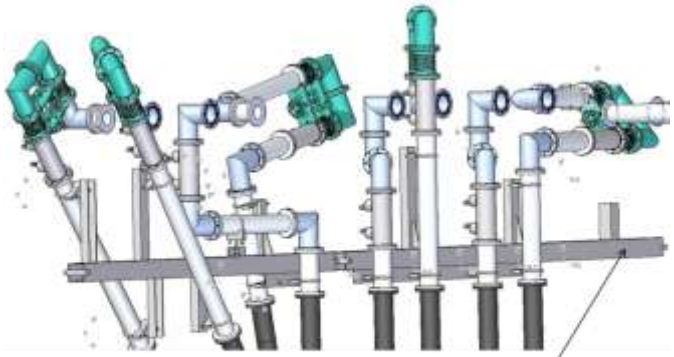
Revised Co-Axial Distribution Network

- Co-axial line length calculated: orders placed
- Hanger and Mounting designs completed and testing in hand

Line Trimmer Arrangement to South Side RF Couplers

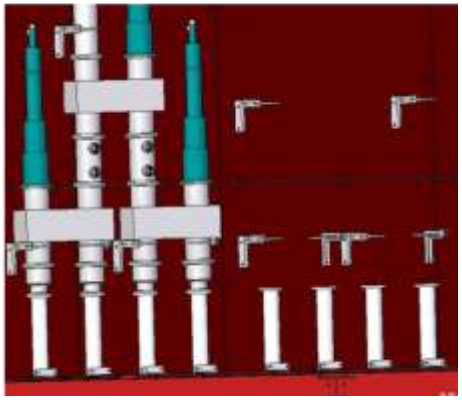






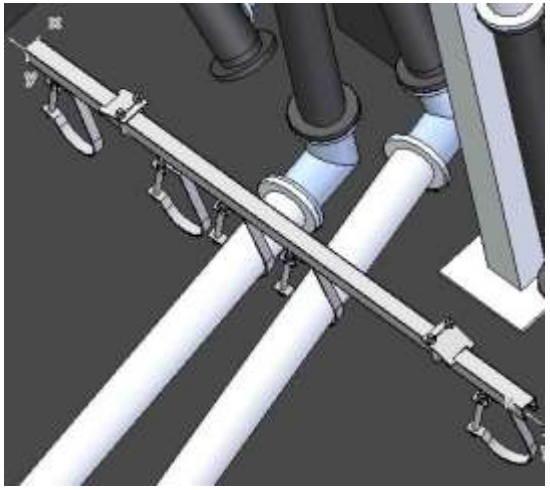
Support frame fixed to South Mezzanine support structure
Coax fixed (2 positions) to relieve stress on cavity couplers

Common bracket & clamp design for
coax and hybrid splitter support
On shield wall



2 off Unistrut frames for coax support
RFCC's - North side

Designs of the RF Coax Support



Coax held in position on ‘hangers’ suspended from floor steelwork.
Flexible system

Hangers suspend on Unistrut fixed to steelwork with adjustable clamps.

No support structure on floor. Clear access for cable trays and water pipes.