MICE
Demonstration of Ionisation Cooling

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On behalf of the MICE collaboration

Outline

- MICE Experiment
- STEP IV
  - Partial Return Yoke
  - Magnets and Alignment
  - Magnet cooling
- Demonstration of Ionisation Cooling
  - RF Modules
  - Temperature
  - RF Power
  - RF distribution

MICE Experiment

- Muon Ionisation Cooling Experiment is an international collaboration aiming to demonstrate that the emittance of a muon beam can be reduced, the muon beam can be “cooled”
- Liquid Hydrogen and LiH absorbers.
- Establish feasibility of muon accelerators for particle physics.
- Enabling technology for investigating neutrino physics.
- Capability to deliver constituent collisions more energetic than those that can be achieved at the LHC.
- MICE will deliver the necessary, seminal, demonstration of cooling required for these future experiments.

MICE Experiment

MICE will be completed in 2 stages

- Step IV
  - Measure absorber properties
    - liquid hydrogen
    - lithium hydride, LiH
- Demonstration of Ionisation Cooling
  - Demonstrate cooling of Muon beam using LiH absorber with re-acceleration from 2 normally conducting RF cavities.

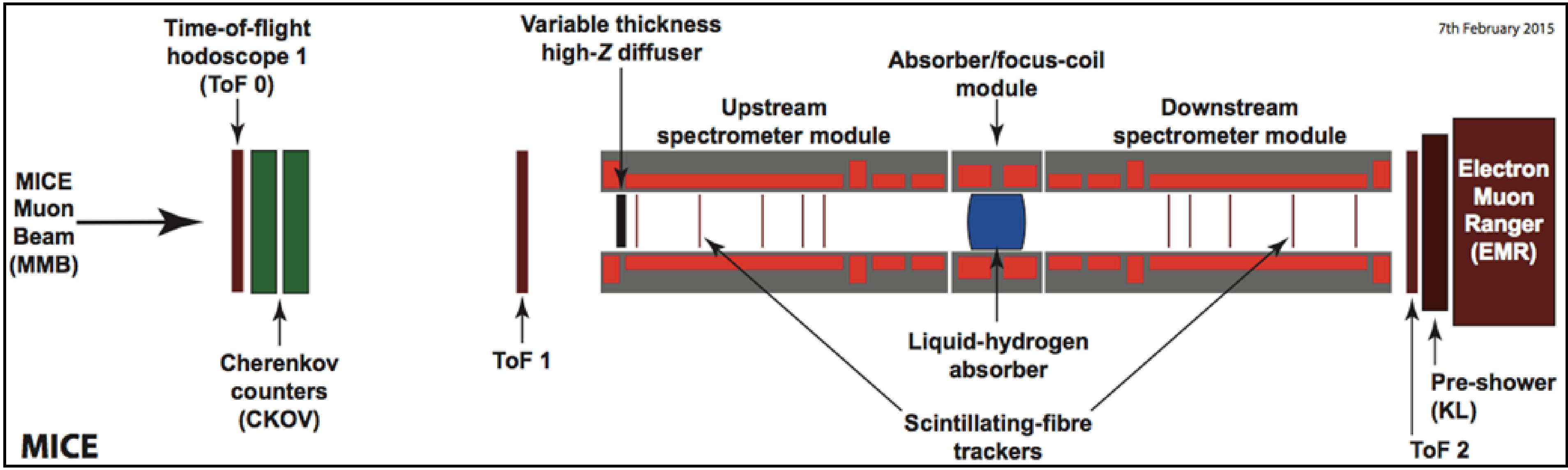
MICE Step IV

Modules

- 3 superconducting magnets, comprising 12 coils
- Liquid hydrogen/LiH absorber
- High Z variable diffuser

Detectors

- 2 scintillating-fibre trackers, 5 planes each
- 3 Time of Flight hodoscopes
- 2 Cherenkov counters
- Kloe Light (KL) detector
- Electron Muon Ranger (EMR)

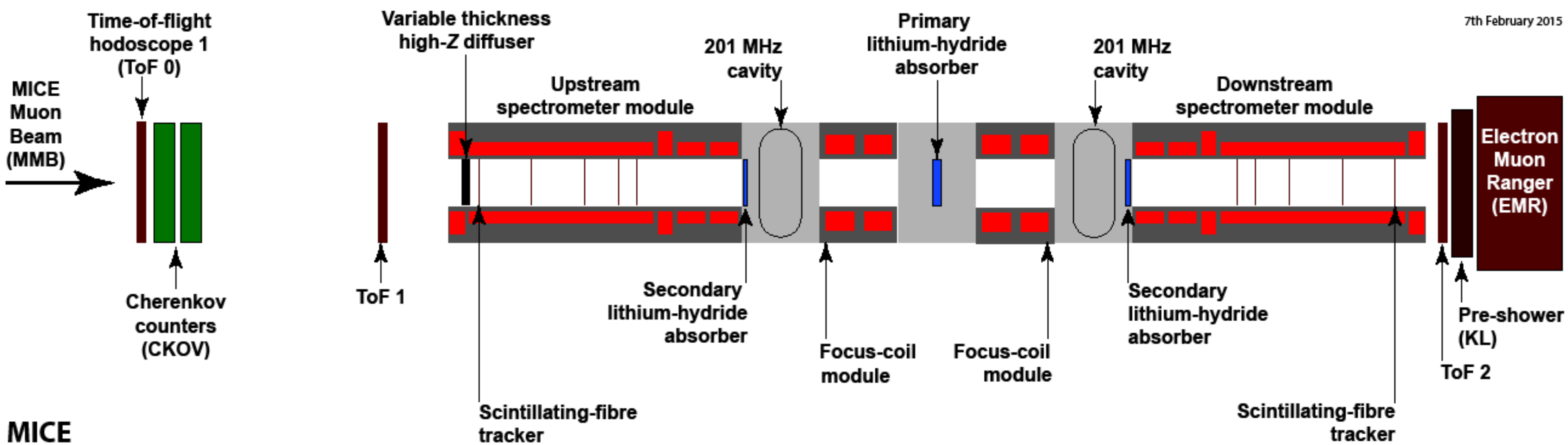


Cooling Demonstration

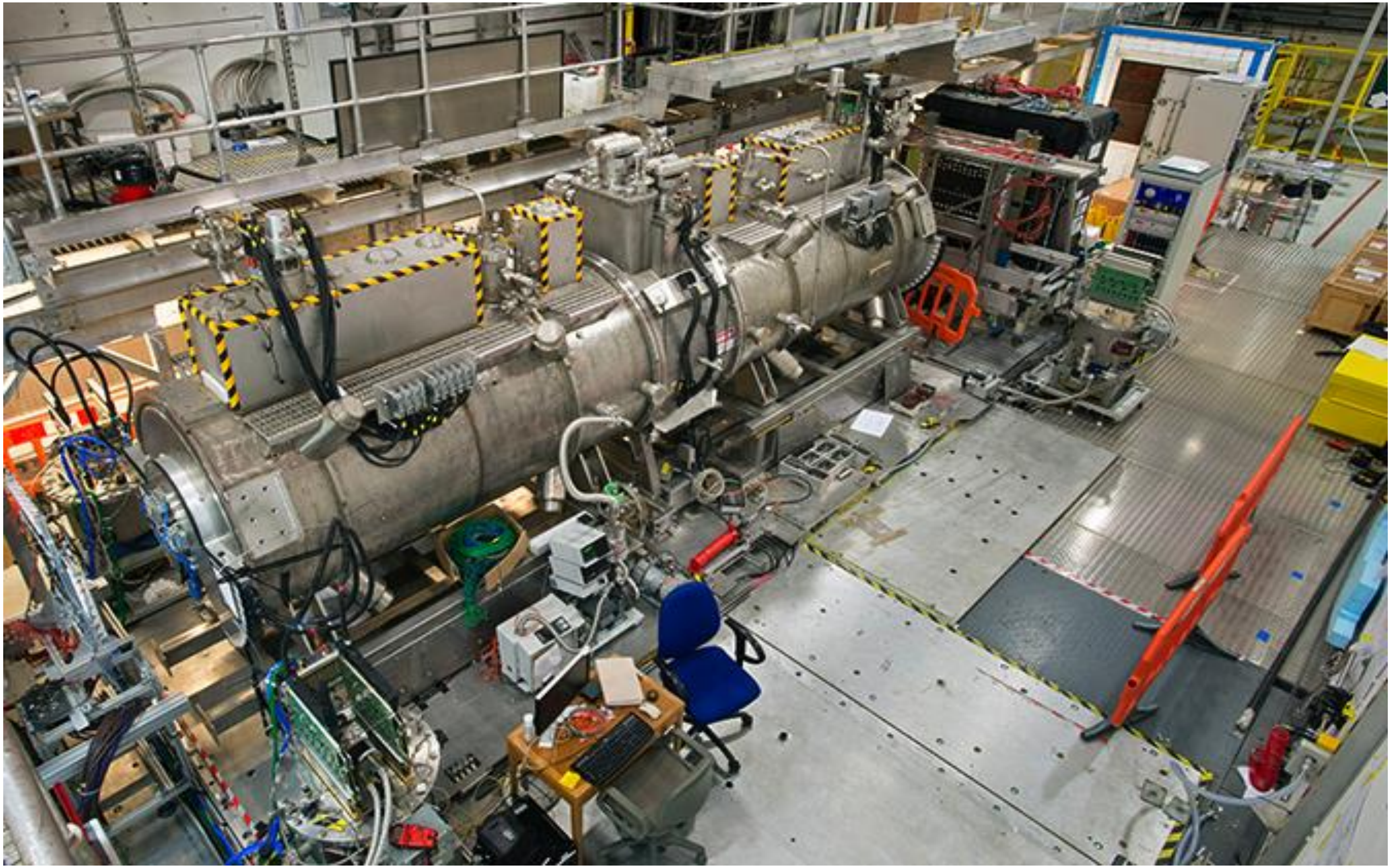
Installation start 1st June 2016.
2 RF cavities, 2 secondary absorbers bracketing main absorber

- 2 x 2MW 201MHz amplifier chains – UK
- RF infrastructure support - UK
- RF controls and monitoring – UK
- Muon phase determination - UK

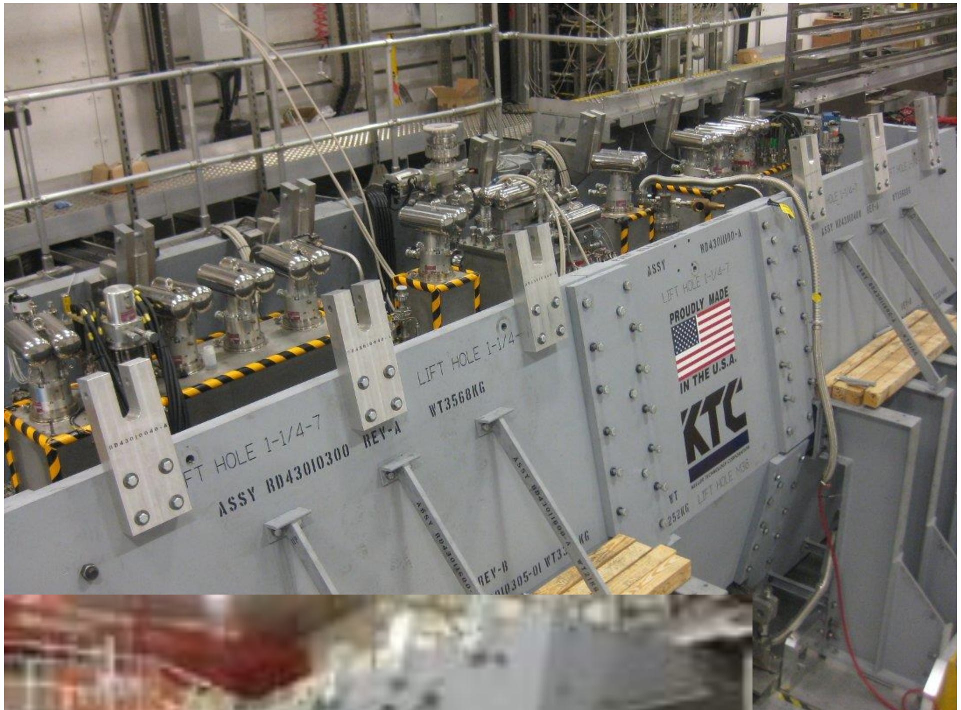
- Extended Partial Return Yoke – USA
- 2 x 201MHz cavities - USA
  - Be windows
  - Tested in B field to 14MV/m



MICE Step IV



Partial Return Yoke (PRY)



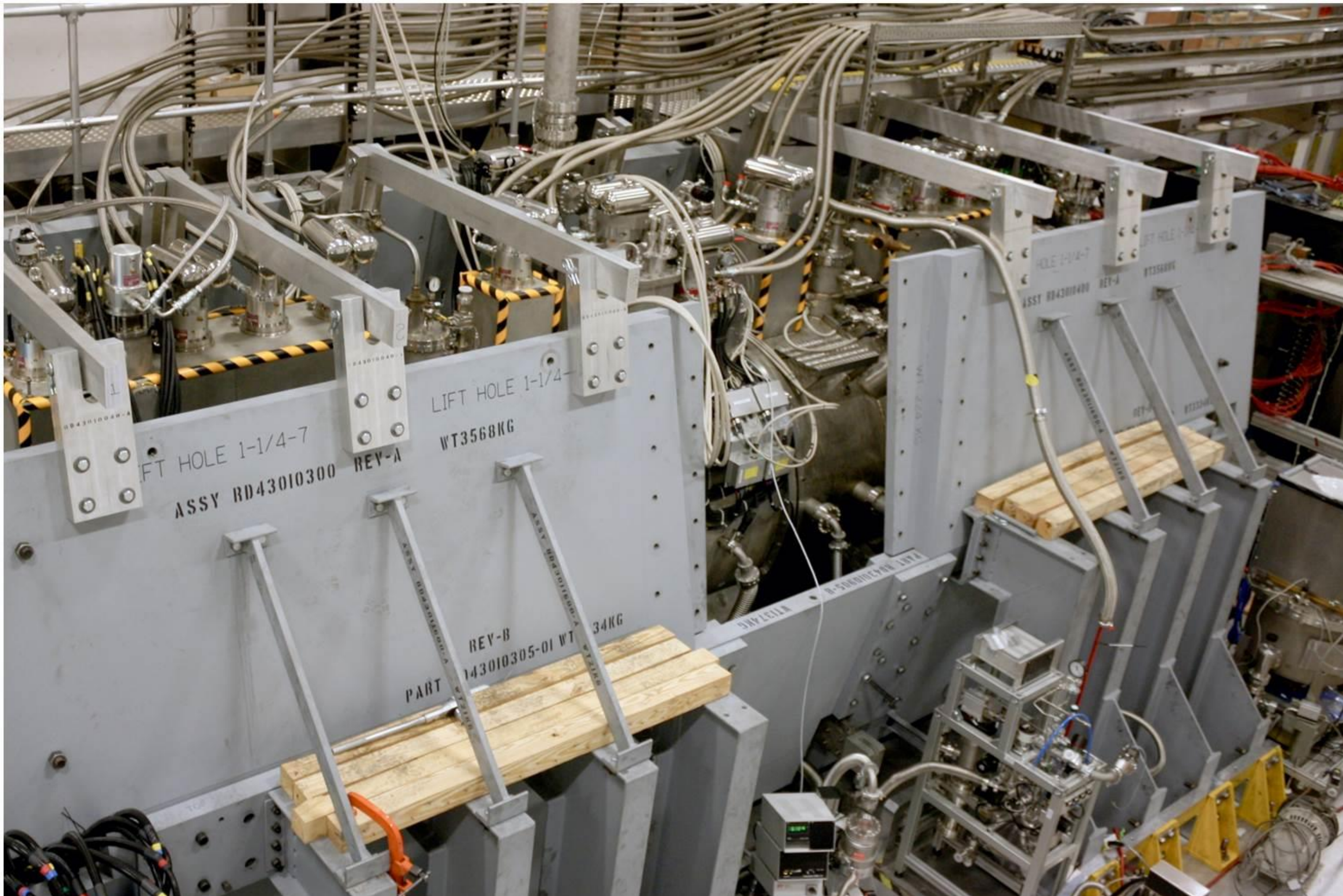
Flux return path to protect sensitive equipment from fringe field of magnet chain.

- 100mm thick soft iron plate
- 2 angled plates per side, each fabricated from 3 sections
- End plates made in 2 sections
- Bracing structures
- Made in the USA
- Support structure made in UK
- Shipped to UK and installed to schedule

5 Gauss perimeter now runs just outside PRY supports.

- stray field concerns in critical areas eliminated

Partial Return Yoke (PRY)



Step IV: Magnets

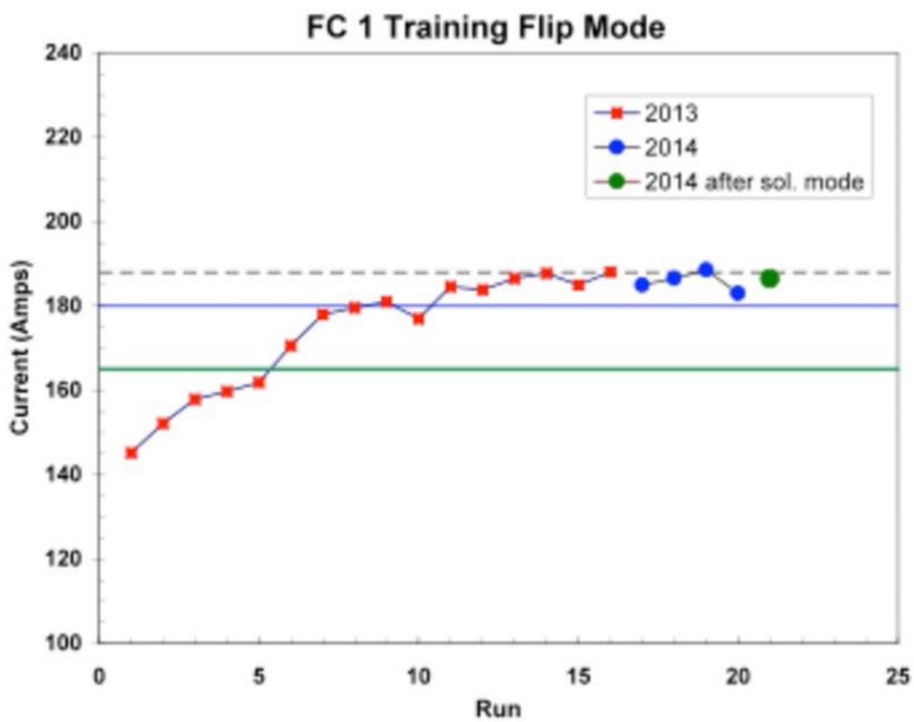
2 spectrometer solenoids with matching coils

- Fabricated in US
- Trained successfully to operating current
  - 10-20 quenches each, training not retained after warming.
  - Field mapped.

- Shipped to UK
- On translation stages in hall
- Compressors installed plumbed, wired and connected
- Successful cool-down
- Independent training in progress.

2 Focus coils (only one required in current configuration)

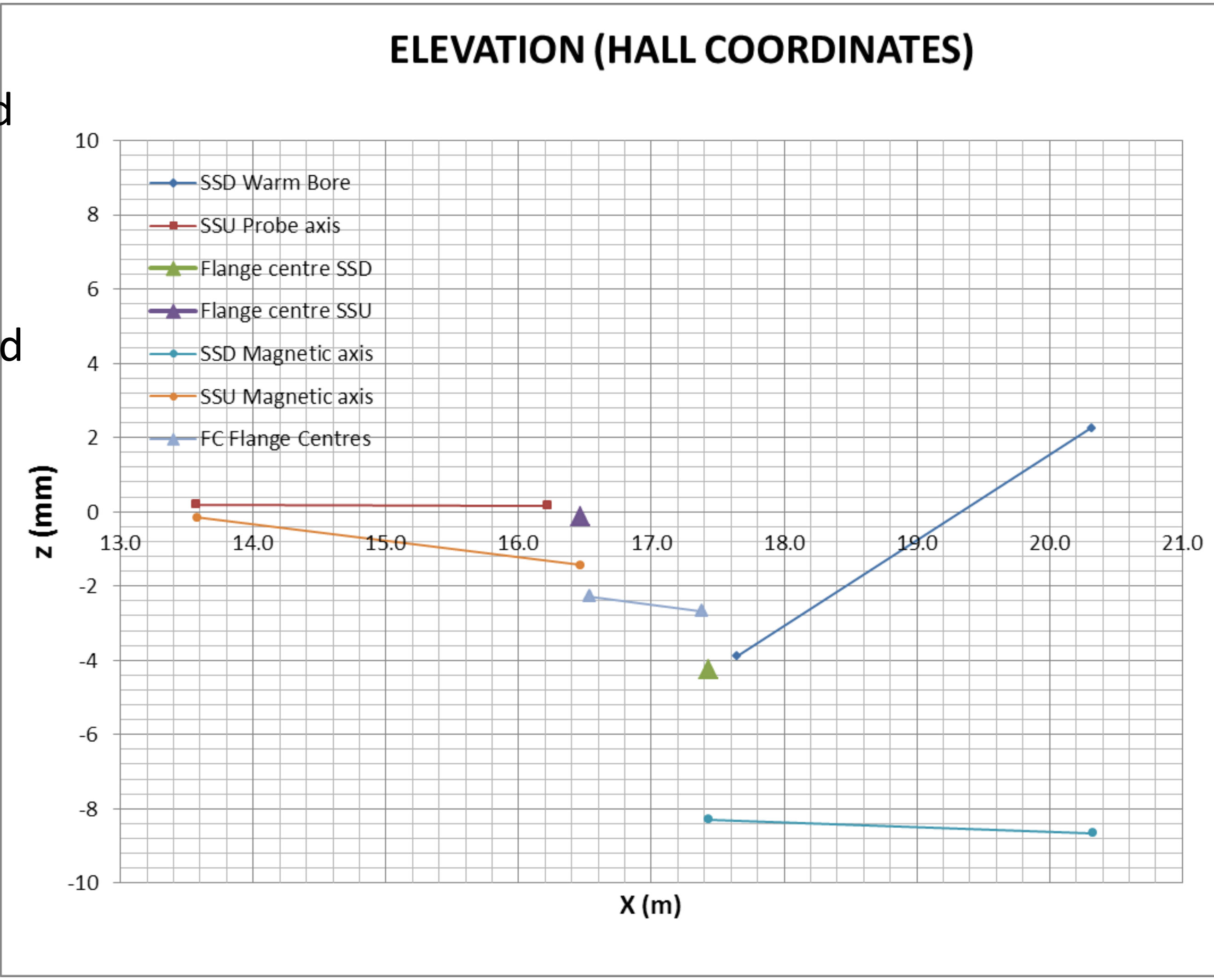
- Constructed in UK
- Trained to operating current
- Installed in hall



Magnetic Alignment

Spectrometer solenoids and Focus coil connected with hydro-formed bellows

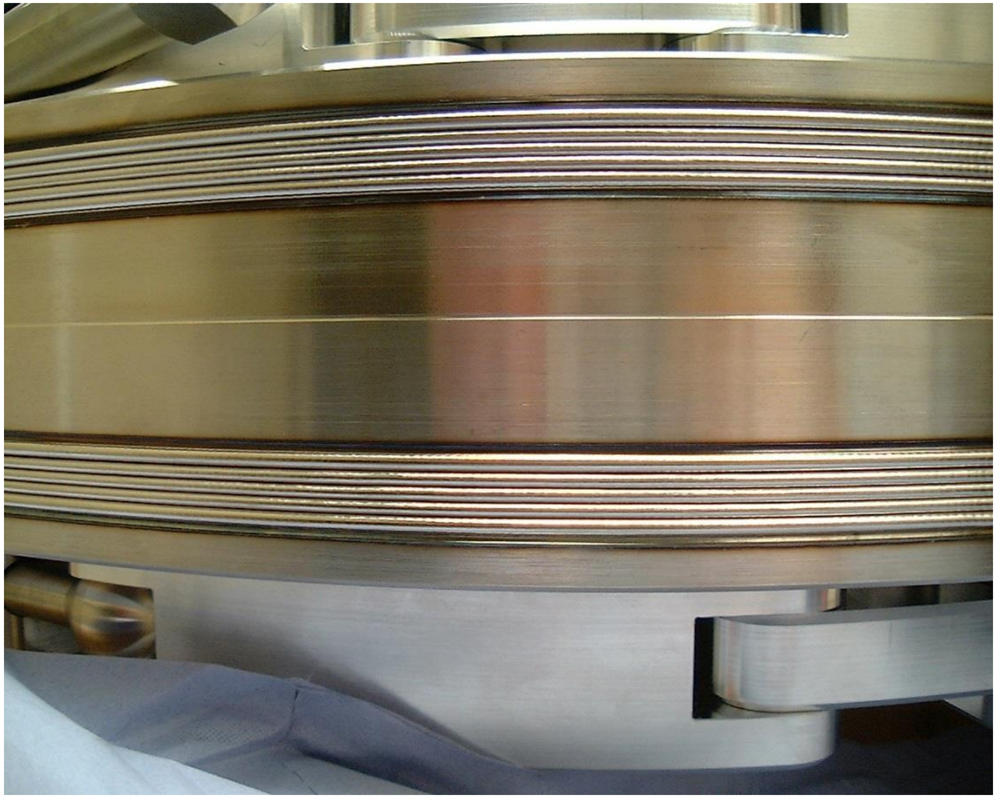
- Measured offsets between warm bores and magnetic field at manufacture.
- Hydro-formed bellows are relatively 'stiff' and allow angular but not axial offset
- Correct with bespoke offset bellows
- Quench forces must be considered.



Bellows

692.15mm OD x 539.75mm ID nested bellows :

Extended length 66mm
Closed length 14mm
Stroke 52mm
nom free length 40mm
Axial stiffness 200N/mm.
316L, 0.91mm thk.
End terminals: 316.



Cold Heads and Compressors

Each Spectrometer solenoid has 5 cold heads

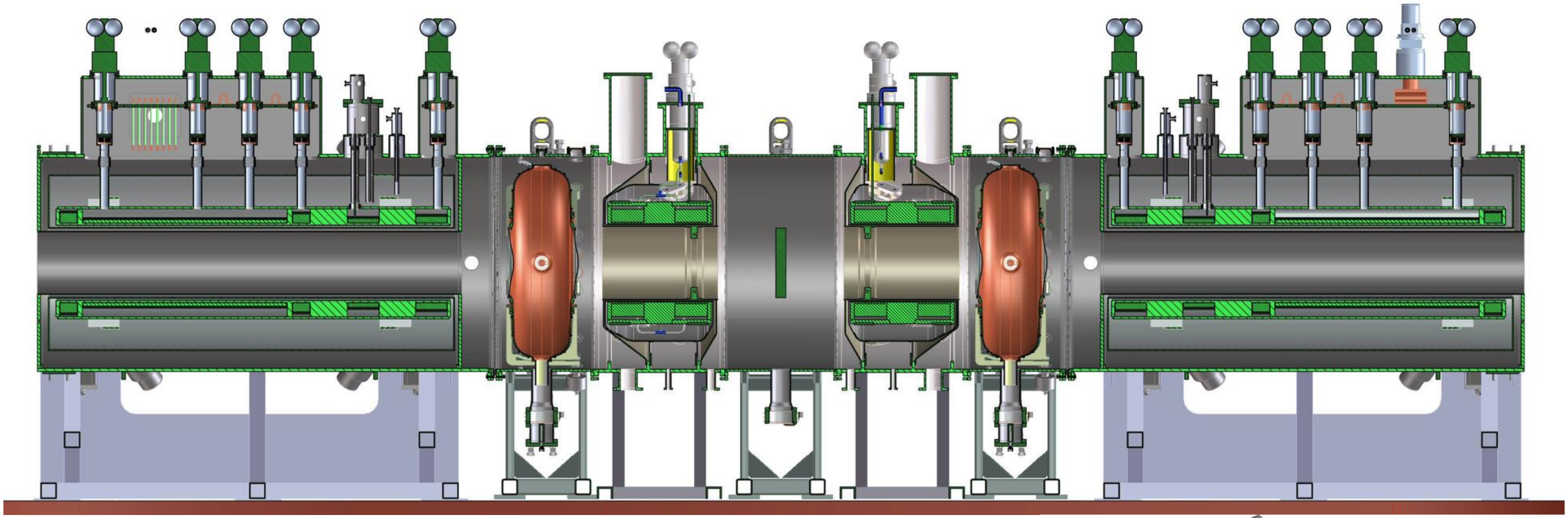
- 1 compressor per cold head
- Compressors installed 30m distant on 'West Wall'
- Conventional specification; max hose length = 20m
  - 30m hoses produce insignificant losses for SS

Focus Coil, 2 cold heads

- 1 Compressor per cold head
- Possible reduced cooling margin seen
- Compressors moved close on 'South Mezzanine'

He compressors and lines

Cooling: RF Modules

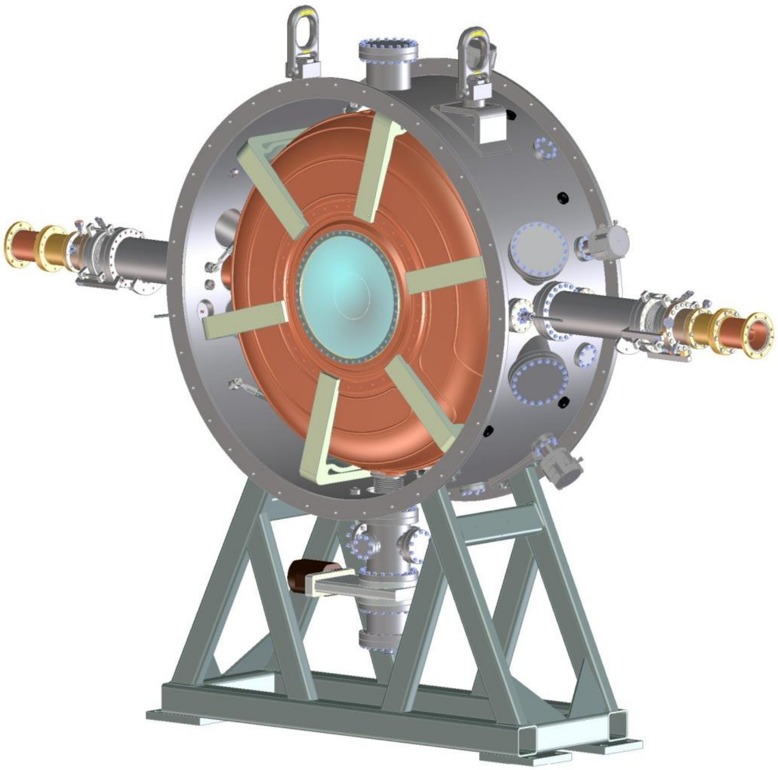


2 RF modules

- One RF cavity, two Be windows two RF power couplers
- One vacuum vessel, common with absorbers
- Six tuner arms and six actuators
- Cavity support struts
- Vacuum pump system and water cooling
- Diagnostics and bypass lines

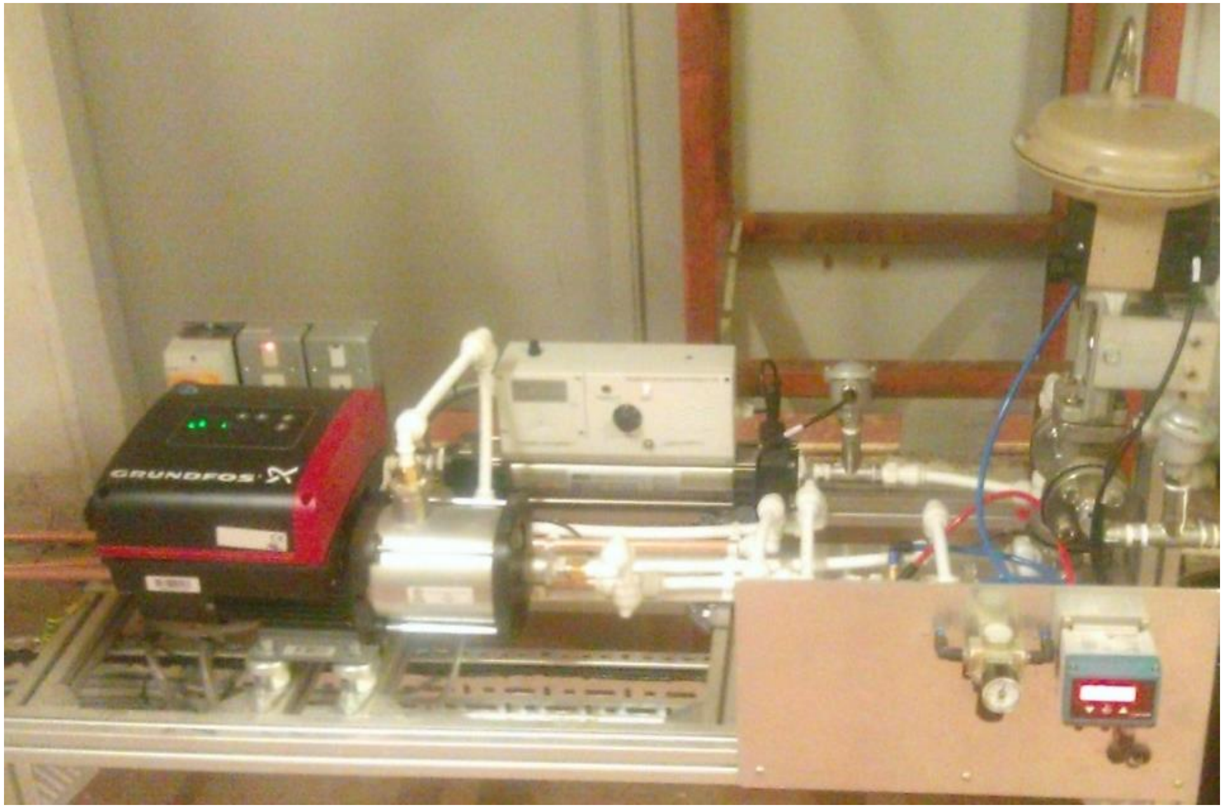
RF Module

Designed/fabricated LBNL. Electropolished, plated couplers
Tested to 14MV/m in magnetic field at FNAL (10.2MV/m required)
Tuning via air actuators demonstrated at high power with recovery.



Cavity Temperature

- Cavity on frequency at 36.5 degrees
- water cooling system with heater, cold water and mixing valve control by high resolution process controller that self learns
- Water flow rates on cavity are restricted due to small cooling pipes
- 0.05 degrees cavity temperature stability achieved
- RF trips result in cavity detuning which can take 5 minutes for recovery
- RF is always applied at effectively maximum



HPRF System Status

- MICE RF systems demonstrated
  - Nominal power levels 2MW, Frequency (201.25MHz) for 1ms @ 1Hz
  - First amplifier tested in MICE hall
  - Triode amplifier (output stage) remains installed
    - Tetrode and all modulator racks shipped to Daresbury

- New higher voltage solid state crowbar tested
- Triode 2 will be tested using No. 1 tetrode and modulators
  - Will use upgraded Triode No.1 modulator
  - Each major No. 1 subsystem will be swapped for No. 2 sequentially
  - Fault finding more rapid
  - Remote control philosophy in developement
  - Will be tested during commissioning of No. 2 system

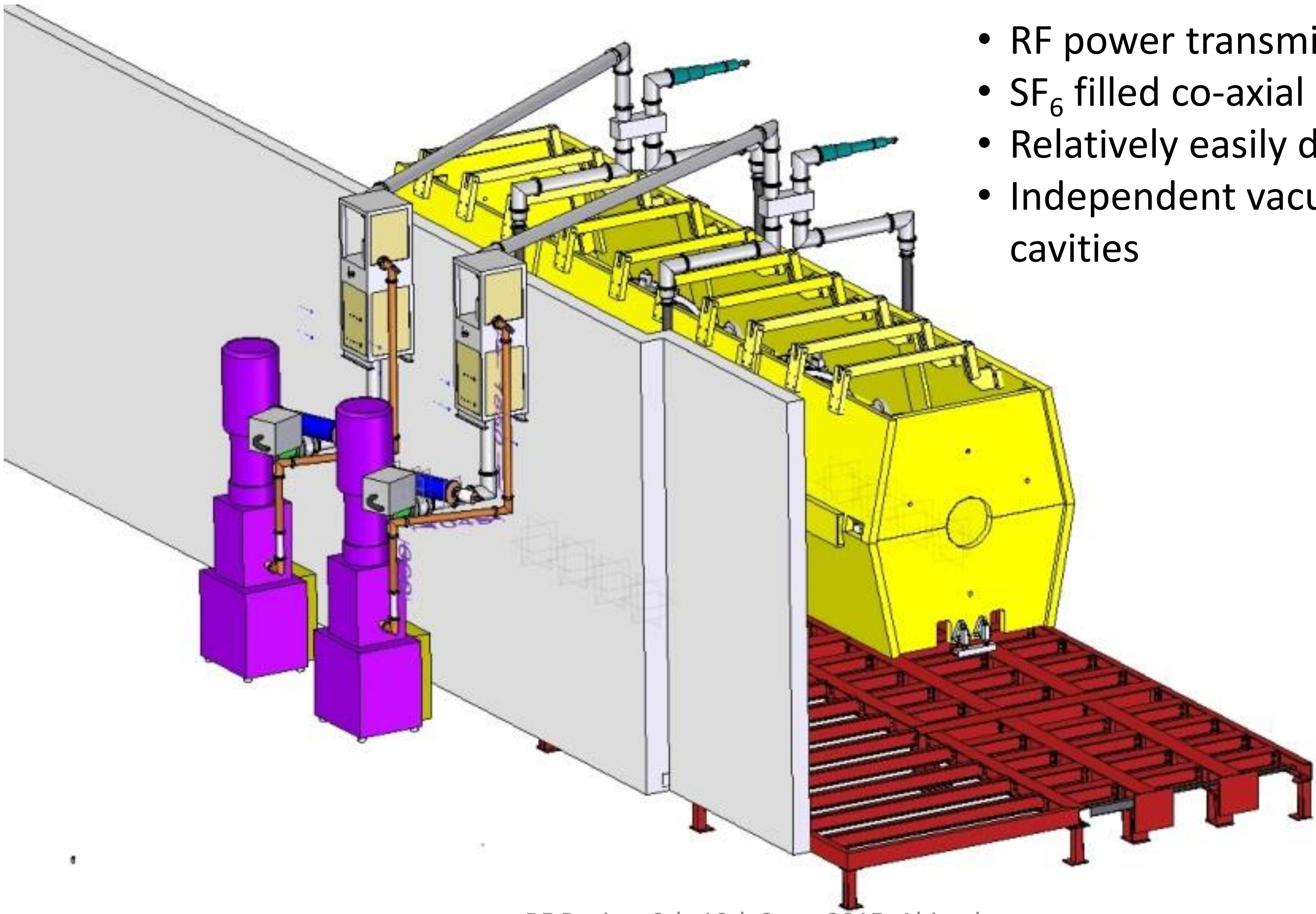
HPF Re-baseline changes

- Certain risk and procurement items have been eliminated or mitigated
  - Distribution network simplified
  - 9 cavities available (2 needed)
  - 4 off Thales 116 Triode valves available (2 required)
  - 2 spare sets of valve amplifier assemblies readily available

MICE & ISIS RF Subsystem: Synergies and Interaction

- Strong correlations between MICE and ISIS Linac RF systems
  - MICE RF Engineer has requested to participate in ISIS Linac commissioning
  - ISIS Linac RF amplifier test station similar to MICE amplifier installations
  - MICE RF Team working with ISIS Linac RF Team on LLRF systems
  - ISIS Linac control philosophy used as model for MICE RF
  - MICE RF system safety under MICE-ISIS Safety committee

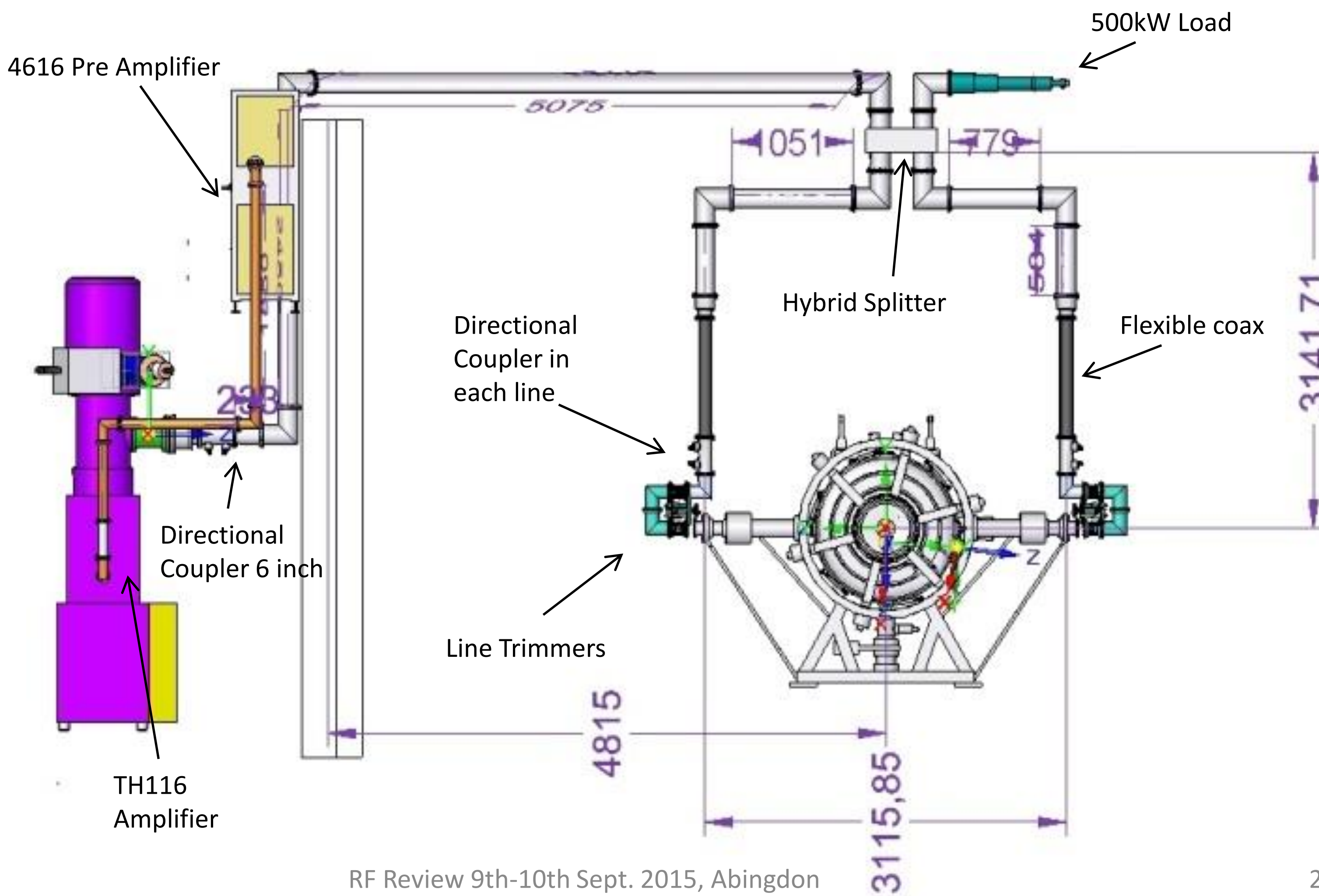
RF Power distribution



- RF power transmission overhead
- SF_6 filled co-axial lines
- Relatively easily de-mountable
- Independent vacuum system for cavities

RF Power

- Simplified distribution network- overhead
- Off-centre mounting of hybrid takes up phase shift
- Minimised length of 4” line- minimises losses



Cooling Demonstration

Muon Ionisation Cooling Experiment.

Demonstrate that the emittance of a muon beam can be reduced, the muon beam can be “cooled”

- Superconducting magnet ‘string’. Partial return yoke
- LiH absorber.
- 2 normal conducting RF cavities with Be windows.
- 2 high power RF amplifier chains.

MICE will deliver the necessary, seminal, demonstration of ionisation cooling required for future experiments.