UK contribution to SPS crab cavity cryomodule

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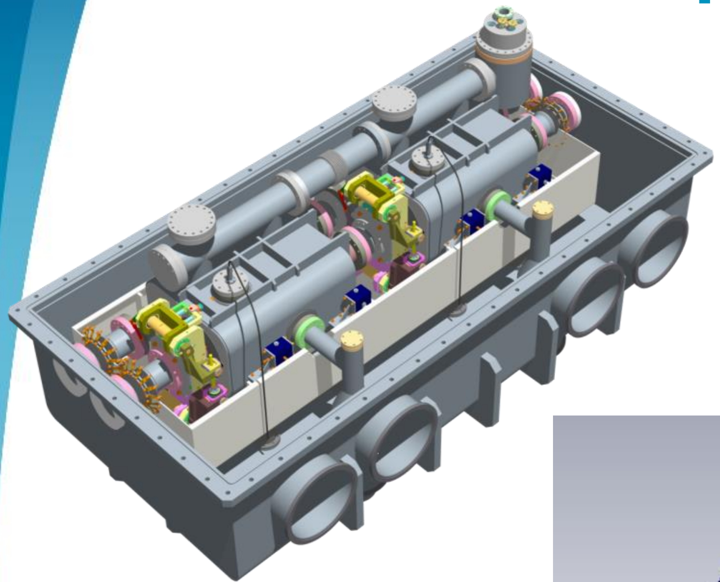
UK-HL-LHC Meeting, 26th May 2016

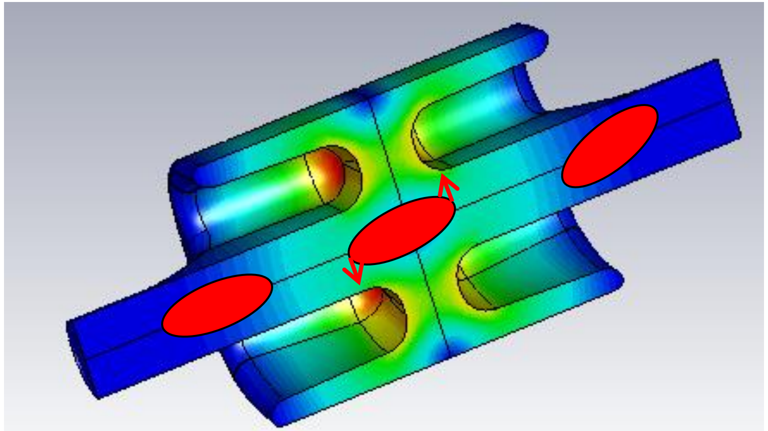
Previous work



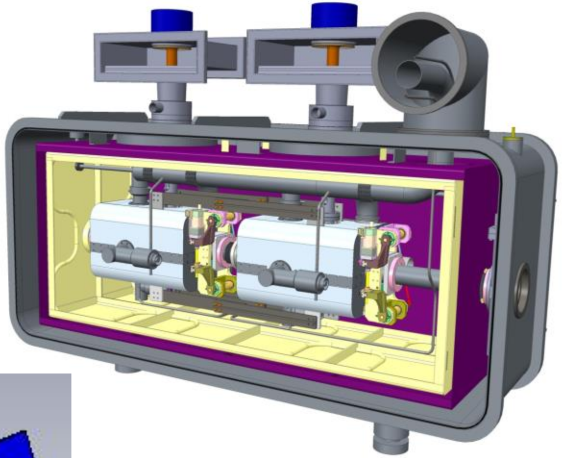
First crab cavity cryomodule design developed for 2012 review. Top loaded due to position of couplers.

Graeme involved in project since 2009

Shrikant, Tom and Nik since 2012



RF design by G. Burt and B. Hall (Cockcroft)



Side loaded crab cavity cryomodule design developed for 2013 review. Technique adopted as baseline, but has since been superseded.

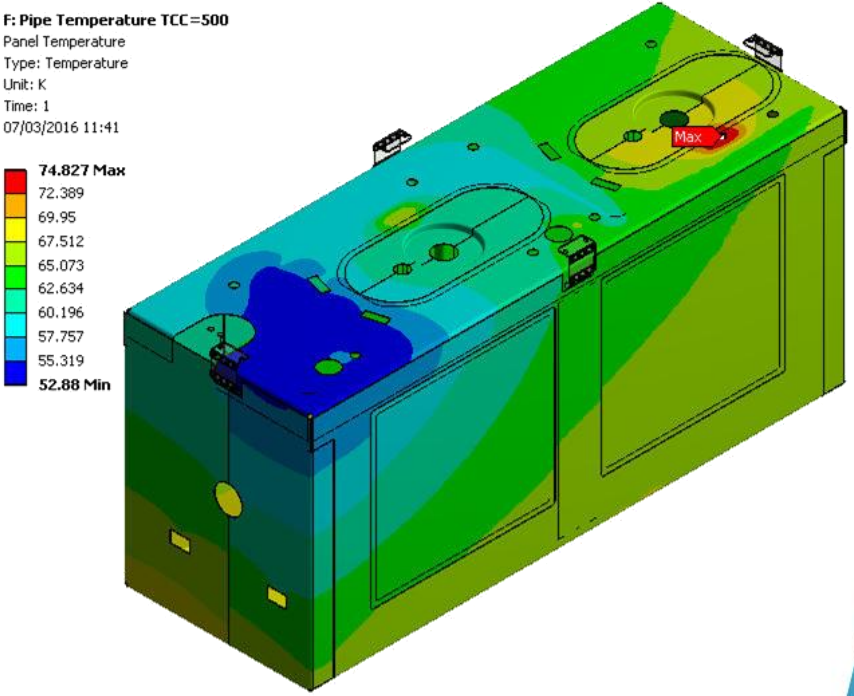
UK Involvement

Currently responsible for the delivery of the following for the SPS cryomodules;

- Thermal shield design
- 2K magnetic shields
- 300K magnetic shield design
- Analysis of overall cavity support system including identification of problematic vibration modes
- Fluid analysis for cavity BCP
- HOM and FPC Test box
- + any additional mechanical engineering tasks as and when required

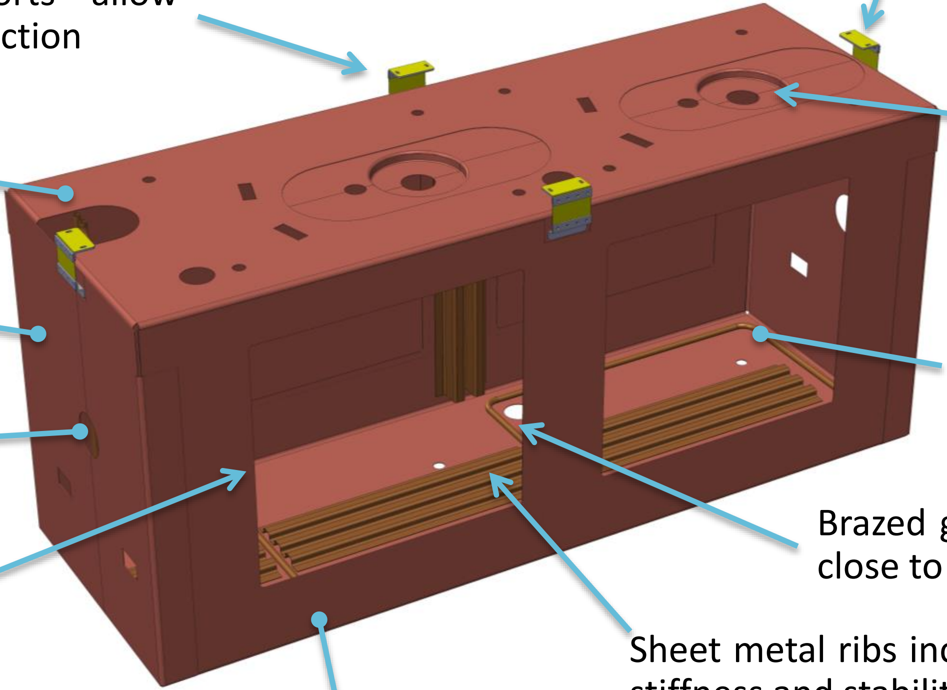
Thermal Shield

- Thermal screen reduces radiative heat loads to the cold mass
- Baseline decision to make shield in copper for compatibility with Stainless Steel tubing.
- Currently investigating design of thermal straps to ensure sufficient cooling of passively cooling components such at the FPC.
- Design optimisation of flexure supports to be completed to give correct balance of stiffness to thermal load.
- Detailed drawings to be completed after.



ANSYS Thermal Shield Analysis

Thermal Shield



Magnetic Shielding

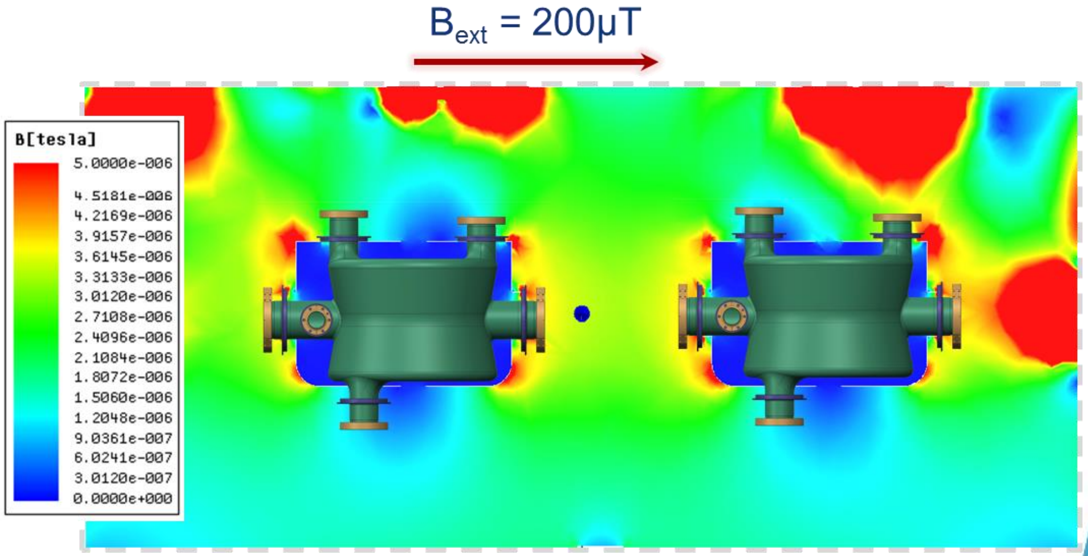
- Magnetic shielding is key to reducing ambient field at SRF cavity surfaces in order to minimise RF dissipation caused by trapped magnetic flux

- **Specification**: No more than 1 µT at cavity surface

- Double Layer Solution: Warm Shield + 2 Cold Shields

- SPS magnetic survey estimates no more than **60 µT**

Analysis: 200 µT external field applied in beam axis



ANSYS Maxwell electromagnetic field simulation

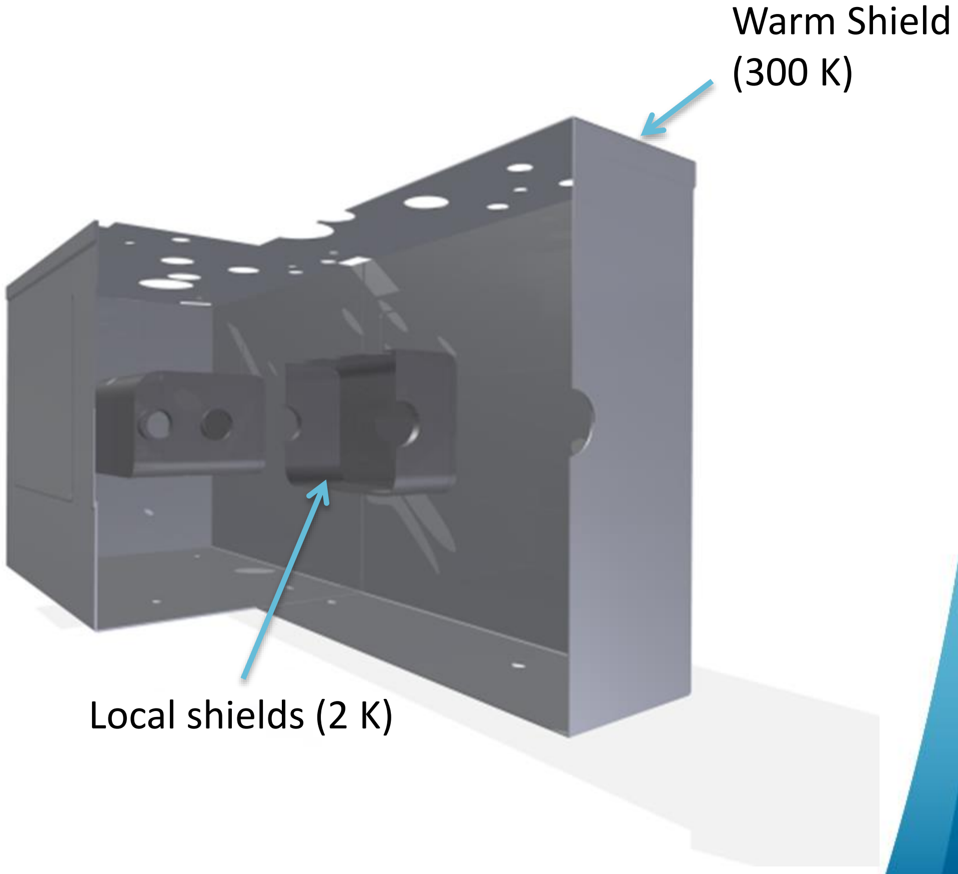
Cold Magnetic Shield

- Cryophy - 1 mm thick
- Housed internal to helium tank at 2 K
- Mounted from Gr2 Titanium brackets
- To be assembled around cavity in parallel with helium tank plates
- Design & analysis complete
- Manufactured, inspected and tested by Magnetic Shields LTD from the UK
- All shields delivered to CERN April 2016 and awaiting inspection/testing

Assembled RFD shield prior to shipping

Warm Magnetic Shield

- 3 mm Mu Metal outer magnetic shield
- Detail design ongoing in parallel with outer vacuum vessel & thermal shield
- Baseline concept is that mu metal will form 'second skin' within the lower outer vacuum chamber.
- Currently investigation joint between top and bottom plate. CERN providing support with magnetic modelling.
- Detail drawings to be completed.

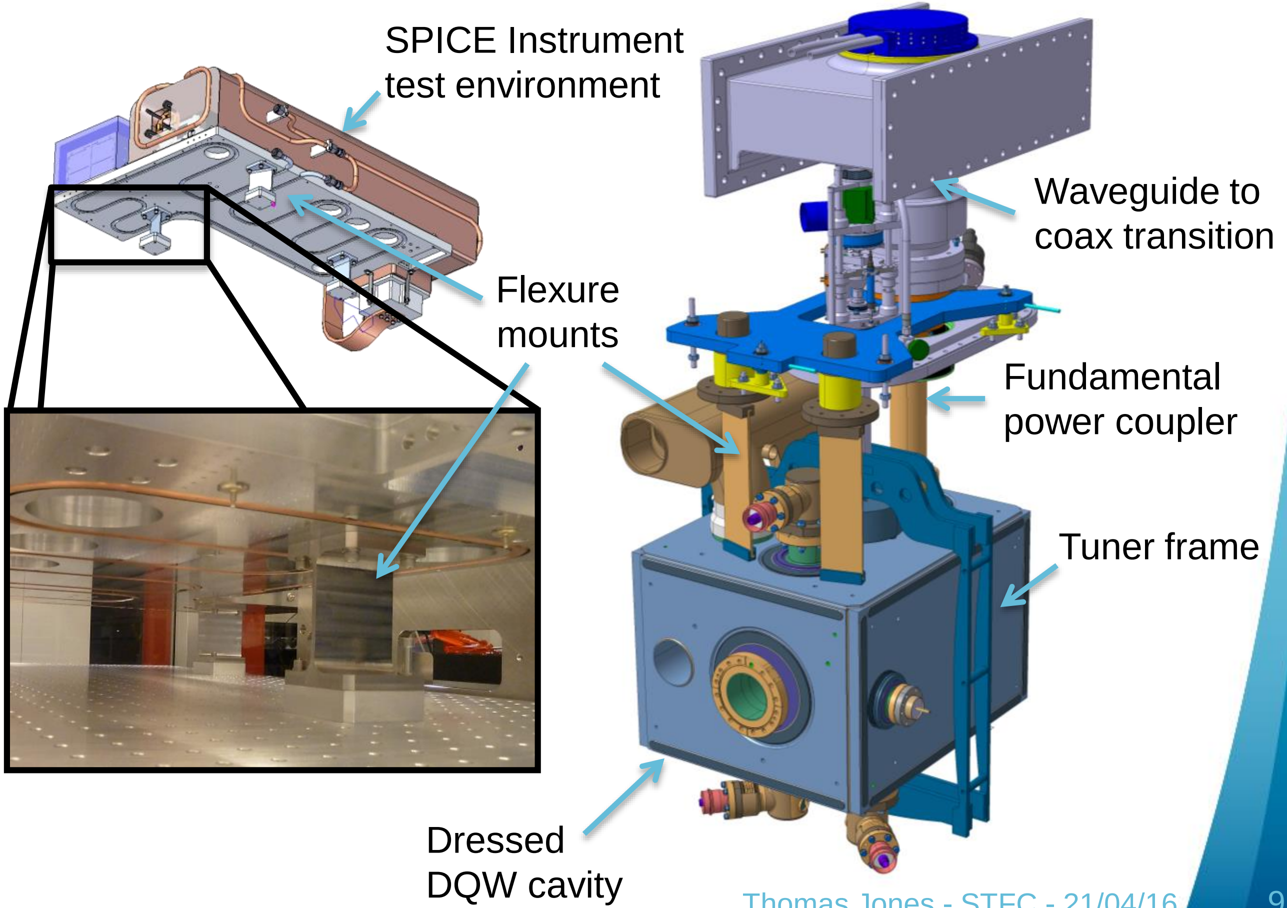


Cavity support structures

The support system must have a low cross sectional area to minimise ‘heat leak’ from the outside world.

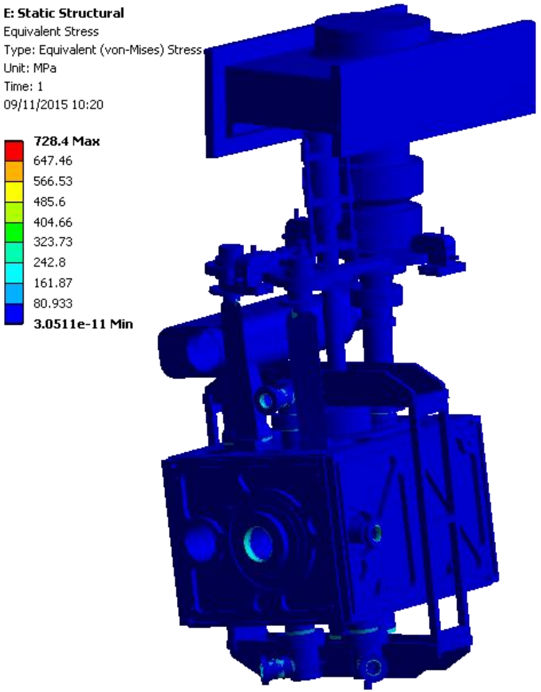
$$Q = \frac{k\mathbf{A}\Delta T}{x}$$

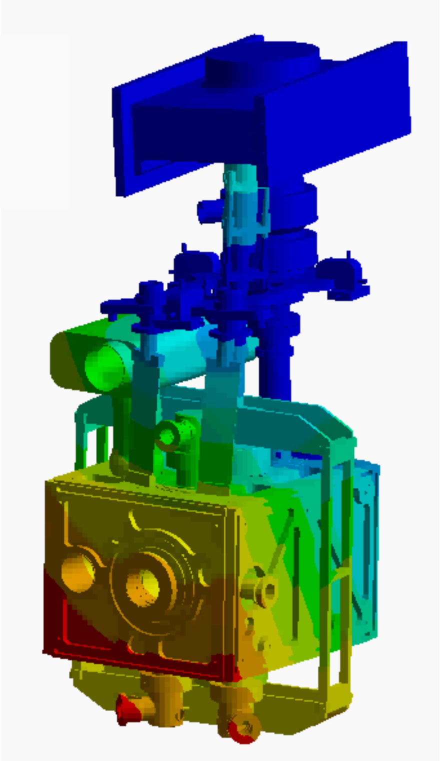
The supports should be sufficiently stiff so that vibration modes are above 15Hz while still allowing for thermal contraction.



Cavity support structures

- Cavity support stiffness gives fundamental mode at 19Hz.
- Stiffness needs to be assessed against reaction forces from bellows.
- This work can be completed, but need final bellows stiffness values from CERN.
- All other tasks, such as thermal stress on cooldown, static structural, transportation loads etc has been assessed and is acceptable.
- Revised tuner model can be analysed if required.





Fluid analysis of BCP processing

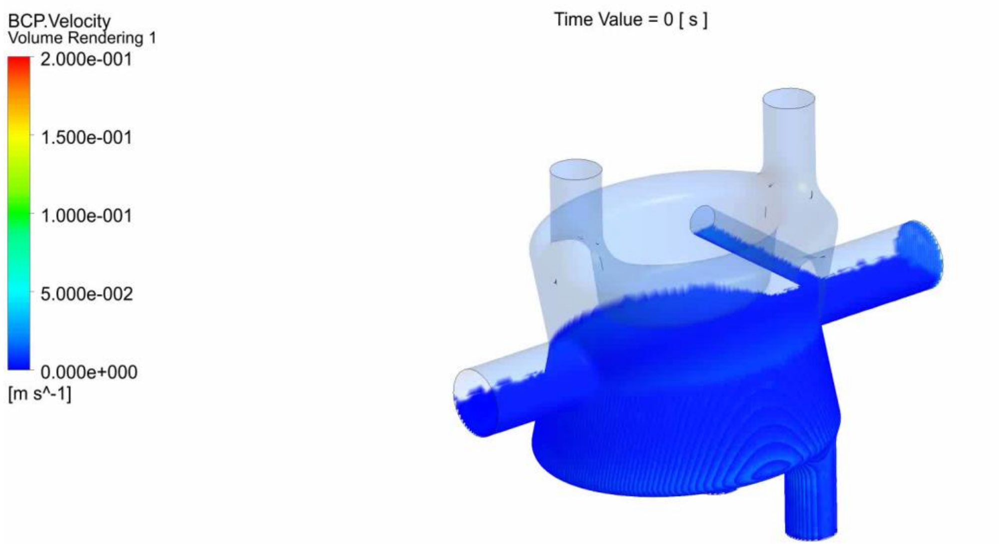
- Buffered chemical polishing is an acid etching process required to smooth the internal surfaces of the cavity and therefore improve performance.
- The operation frequency of the cavity is altered in the process due to the amount of material removal (typically ~250μm).
- For elliptical cavities the removal rates are well known via experimentation/experience and the detuning therefore fairly straight forward to predict.
- For the novel and complex geometry of the crab cavities this is more difficult.
- The UK team are currently in the process of using Computational Fluid Dynamics (CFD) techniques to identify the best technique of etching the cavities to give uniform material removal.
- It is also planned that an experiment will performed by the UK/CERN team to identify removal rate vs flow speed on more simple geometry.

Fluid analysis of BCP processing

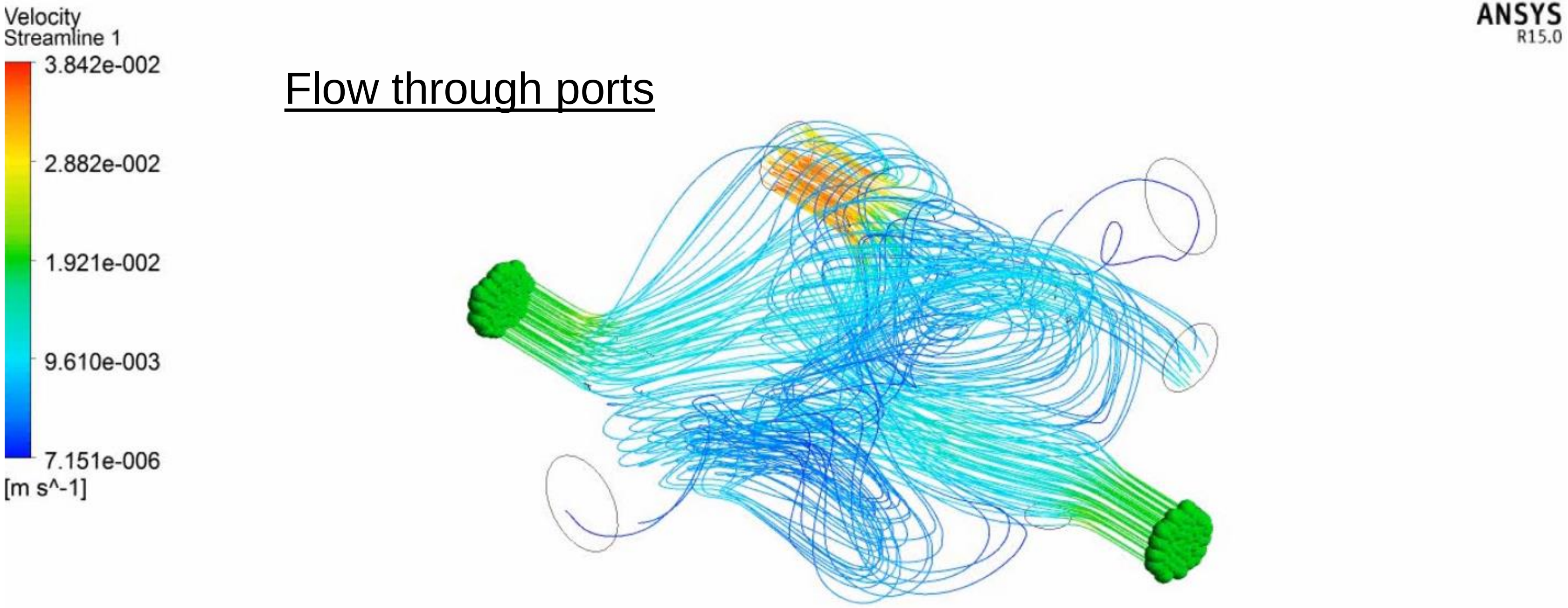
- Initially investigated rotating cavity, i.e. analised JLAB BCP method.
- Work now superseded as BCP will now be performed at CERN using flow through ports.
- However, completed analysis using same 20 monitor points for a comparison of rotation vs port flow to assess best practise.

Multiphase transient analysis

Velocity range: 1.73cm/s
Standard deviation: 0.58cm/s
Average velocity: 0.69cm/s



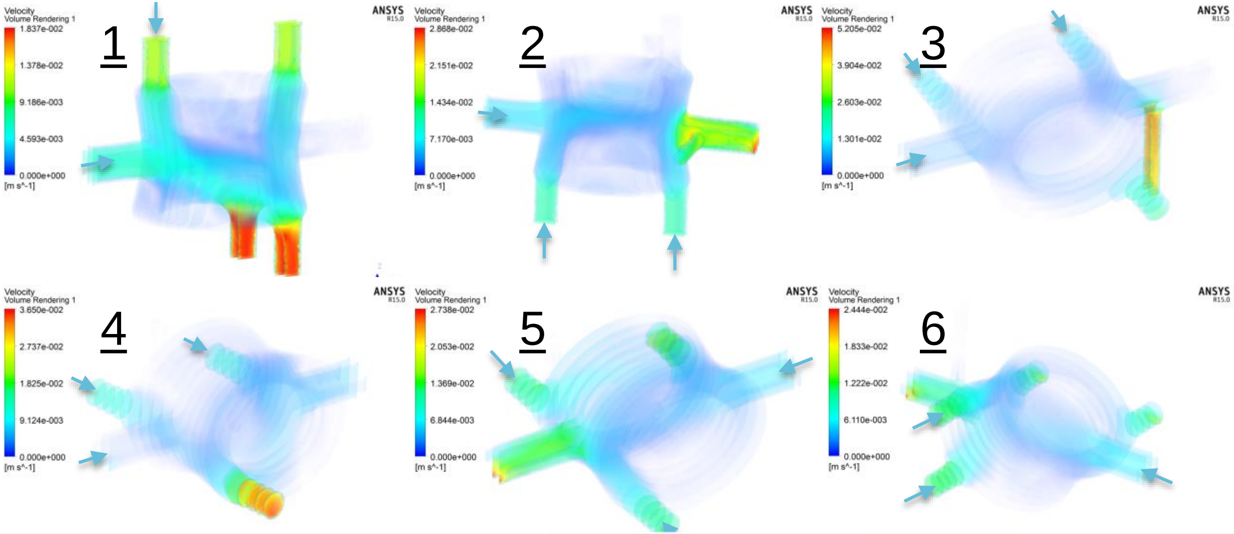
Fluid analysis of BCP processing



Flow through ports

Single phase steady state analysis

Fluid analysis of BCP processing



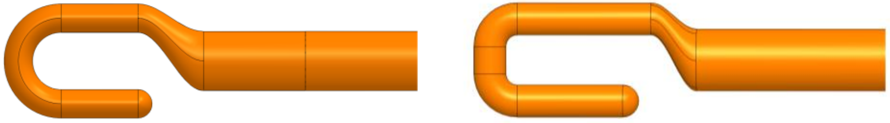
Analysis	1	2	3	4	5	6
Range (cm/s)	0.63	1.82	0.90	0.65	1.23	0.92
Standard Deviation (cm/s)	0.21	0.40	0.24	0.21	0.26	0.23
Av. Velocity (cm/s)	0.29	0.38	0.33	0.31	0.36	0.28

Data taken for 21 points throughout the cavity for each orientation

Introduction and Outline

FPC Test Box

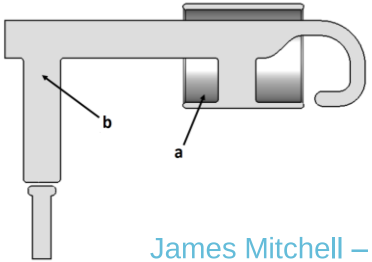
- Fundamental power couplers (FPCs) couple power into the cavity at 400 MHz.
- Couplers operational frequency needs to be checked after manufacture.
- Prior to installation, FPCs need to be conditioned in order for suitable operation at high power.
- Test box capable of characterisation and high power conditioning has been designed.



DQW (left) and RFD (right) HOM coupler hooks

DQW HOM Coupler Test Boxes

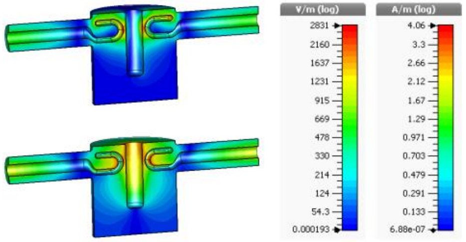
- Frequency response of HOM couplers is sensitive to geometric variations.
- Therefore the frequency response should be characterised before installation; ensuring there are no significant geometric deviations.
- Two low power DQW HOM coupler test boxes have been designed and the construction stage is well underway.
- High power versions and test boxes for the RFD HOM couplers are being investigated.



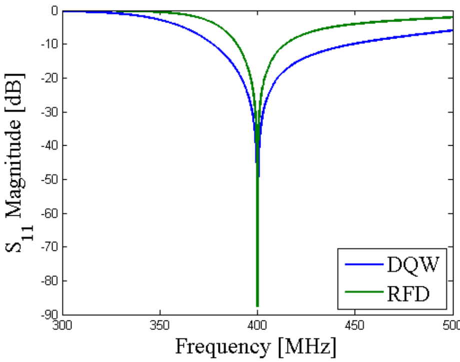
DQW HOM coupler hook cross section with LC stop-band structure (a) and an L-shaped pass-band filter (b).

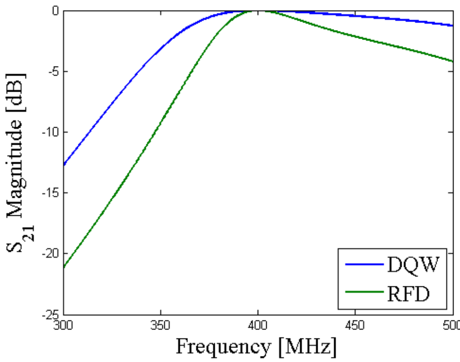
FPC Test Box

- Test box design is based on a Quarter Wave Resonator (QWR).
- The design allows the testing and conditioning of **both the DQW and RFD FPCs** – reducing cost and time needed – two sets of 'false walls' required to allow correct insertion depths.
- The structure has been designed to operate at the **deflecting mode frequency (400 MHz)**.
- A high transmission between the coupler ports allows conditioning of the couplers at high power (~ 100 kW) in order to prepare them for operation on the respective crab cavities.
- A **'dual' coupler test box** has also been designed. The orientation of the couplers needed to be altered in order to ensure good coupling between the fields and hence a good transmission.



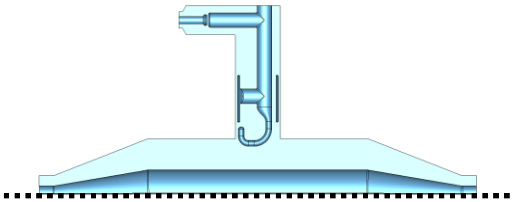
L-Electric (top) and magnetic (bottom) fields in DQW FPC test box.



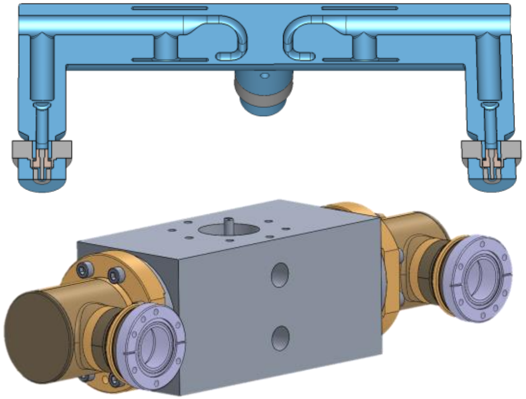


DQW HOM Coupler Test Boxes

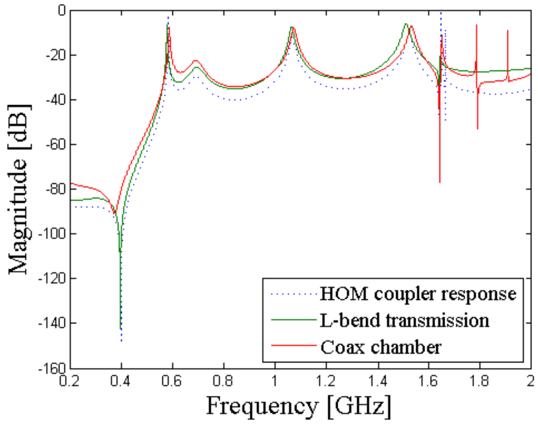
- Two test boxes have been designed for characterisation of the HOM coupler frequency response; **the coaxial chamber** and **the L-bend transmission line**.
- Both designs allow accurate measurement of the HOM coupler response.
- The test boxes will therefore allow any errors in operation to be quantified – the corresponding error causing geometries can then be identified.



Coaxial chamber test box
Constructed from rigid line components which are commercially available.



L-bend transmission test box
Uses L-shaped probes to pick up transmission characteristics of HOM couplers.

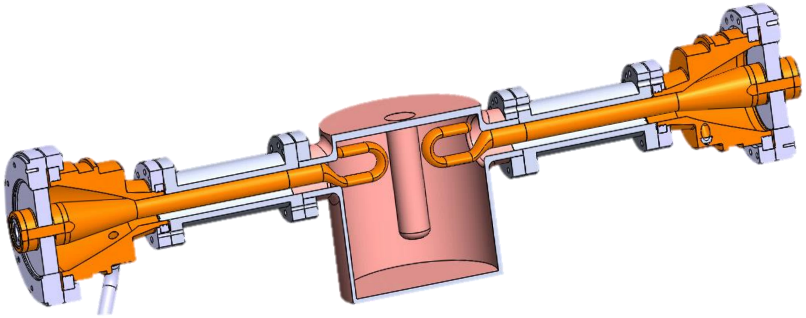


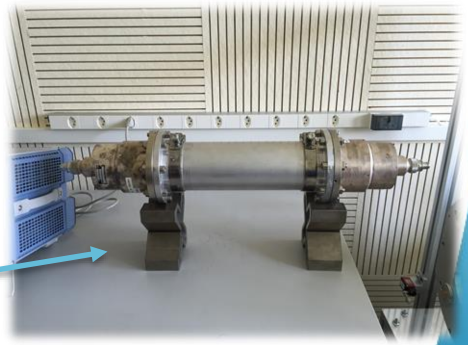
S21 frequency responses

Test Box Manufacture

- For the FPC test box, currently the CAD is being finalised.
  - A re-design means the same test box can now be used for the DQW and RFD FPCs.

- For the DQW HOM coupler test boxes:
  - The L-Bend transmission line test box body (below) has been machined at Lancaster University. The probes are currently under manufacture.
  - The coax chamber is in its final design and optimisation stages. Following this, procurement of the parts and CAD drawings of the few necessary adaptations will be made.





Example of rigid line components to be used on the test box.

Future plans

- Thermal shield design complete with manufacturing drawings
- 2K magnetic shields testing and acceptance
- 300K magnetic shield design including technical drawings
- Calculation of support stiffness/bellows reaction forces
- Complete fluid analysis for cavity BCP, predict BCP detuning
- Investigate DQW HOM coupler test boxes at high power
- Design/adapt test boxes for RFD HOM couplers
- Assembly tooling for SPS?

Any Questions?