HOM cavity diagnostics 10.5.2 – cascade and ACE3P simulations

EuCARD-SRF Annual review 2011

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EUCARD SC RF WP10.5: HOM Distribution

Sub-task 10.5.2: HOM Distributions and Geometrical Dependences (HOMGD). Combining finite element and S-matrix cascading techniques allows the eigenmodes in multiple accelerating cells and cavities to efficiently modelled. This will allow an investigation of the implication of typical fabrication errors, on the mode distribution –in particular the splitting of the mode degeneracy and the influence of the couplers on the mode frequencies will be investigated.

This is of particular relevance to FLASH/XFEL and the ILC in terms of:

1) Improving the emittance of the beam in terms of HOM BPM's

2) As the new 3.9 GHz cavities will have an increased wake-field as the iris is more than a factor of 2 smaller than the TESLA cavity so the associated modes will require careful monitoring to ensure that they do not appreciably dilute the emittance of the beam.

The HOM analysis is far more challenging in the 3.9GHz structure than for the TESLA structure.

Overview of the presentation – the essential aspects

➢1) The development of a pictorial modal dictionary to characterise the electromagnetic modal structure of ACC39 – expanding on the work by FNAL

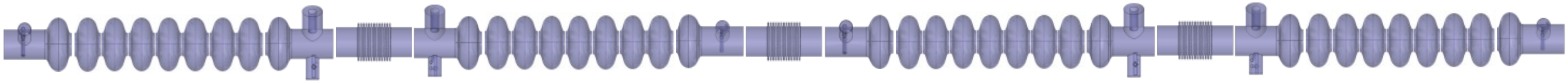
➢2) The need to better understand the coupled nature of the HOM's in ACC39 - The use of an extended circuit model analysis

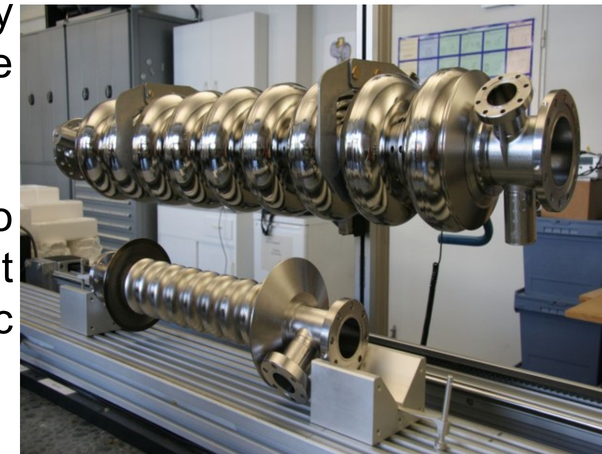
➢3) Understanding the experimental results from non-beam based results at FLASH. The effect of the couplers on the modal degeneracy and multi-cavity HOM's – The use of the generalised scattering matrix method (GSM).

➢4) Understanding the experimental results from beam based results at FLASH – The need for high performance computing and the use of the ACE3P computational software

➢5) Future aspects

A 3.9GHz bunch shaping cavity ACC39

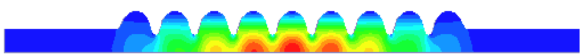


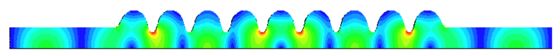


➢A third harmonic "bunch shaping cavity" counteracts the energy spread a bunch sees as a result of cosine fields used to accelerate the bunch. ACC39 has been built by FNAL and installed in FLASH.

➢FLASH uses one ACC39 module, XFEL will use three ACC39.

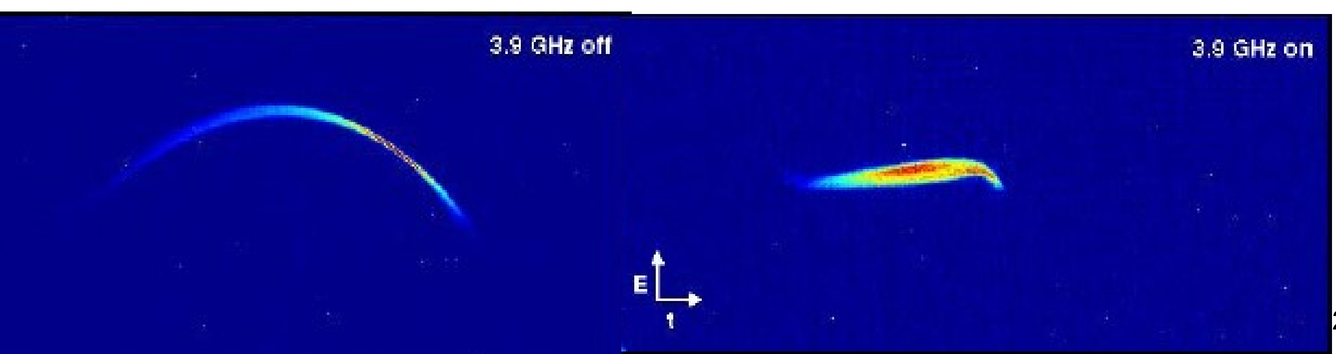
➢Need to understand the higher order modes (HOM) – can lead to beam break-up, wakefields, unwanted multicavity modes and prevent the accelerator from working….. We have made an electromagnetic dictionary up to 10GHz mapping out the modes.





➢Also can use the HOM's (which are a by-product) to produce an ultra fast beam position monitoring system – this is currently being designed.

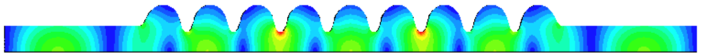
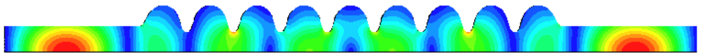
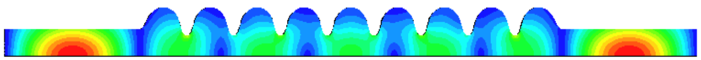
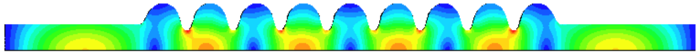
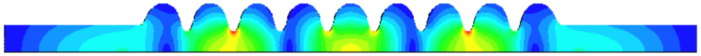
➢Part of collaborative effort with DESY, FNAL, University of Rostock and Royal Holloway - The University of London



A pictorial mode dictionary of all the cavity modes in the 3.9GHz cavity

- We have completed a pictorial modal dictionary of all the cavity modes up to 10GHz – this allows easy identification of trapped modes and modal types
- The HFSS results agree well with those predicted by MAFIA i.e. the FNAL report (fel2003-01).
- Modal dictionary available on request – coming soon as DESY note

Band	HFSS		MAFIA	
	f: GHz	R/Q:Ω/cm^2	f: GHz	R/Q:Ω/cm^2
1	4.2953	0	4.3019	0
1	4.358	0.29	4.3641	0.29
1	4.446	0	4.4514	0
1	4.5388	1.08	4.5428	1.07
1	4.5972	0.79	4.5993	0.82
1	4.6399	0.16	4.6422	0.13
1	4.7227	10.37	4.726	10.39
1	4.8312	50.2	4.8341	50.7
1	4.926	30.38	4.9282	30.41

Electric field pattern	ω/2π (GHz)	Band type	R/Q: Ω/cm^2
	4.2953	D Band 1 #1 boundary EE	0.00
	4.3580	D Band 1 #2 boundary EE	0.29
	4.4460	D Band 1 #3 boundary EE	0.00
	4.5388	D Band 1 #4 boundary EE	1.08
	4.5972	D Band 1 #5 boundary EE	0.79
	4.6399	D Band 1 #6 boundary EE	0.16

Insights from the pictorial modal dictionary

- 1) The majority of the HOM's within the cavities are multi-cavity modes (modes above the cut-off frequency). This is disadvantageous in terms of analysis and use as a HOM BPM system because:

  - a) The modes will not be localised within any single cavity but will propagate throughout the entire cavity string
  - b) The eigen mode analysis (i.e. the modal dictionary) based on an idealised cavity will be insufficient as multicavity coupling is not considered.

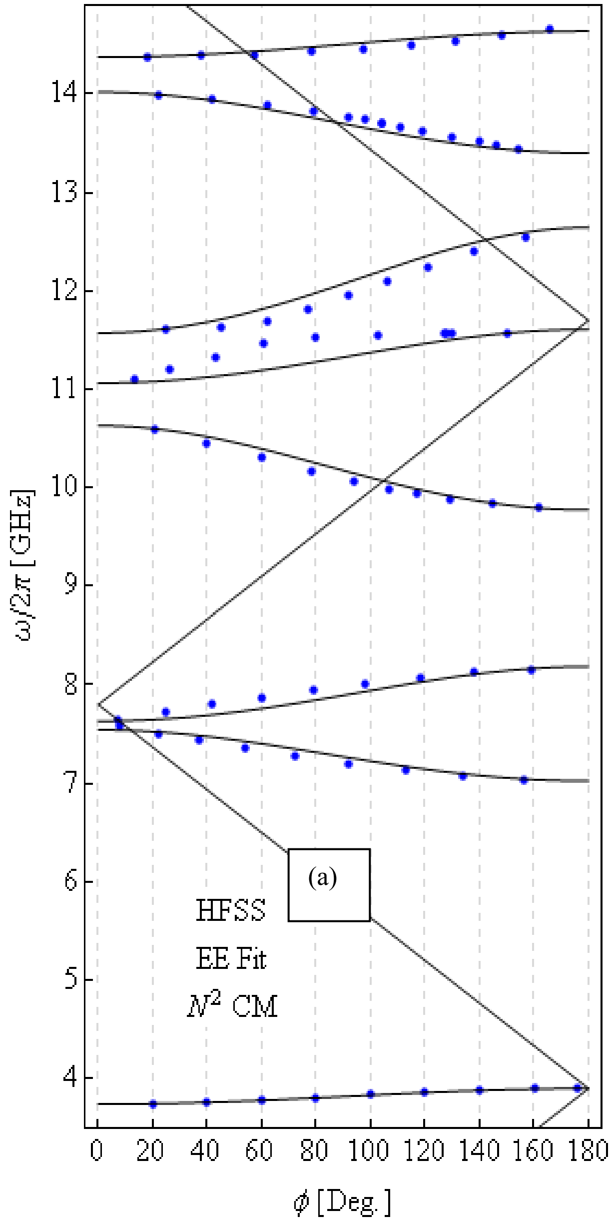
- 2) Despite the greater part of the HOM's being multi-cavity in nature there are a few immediate regions where trapped modes exist that can be well understood and potentially used as HOM BPM's

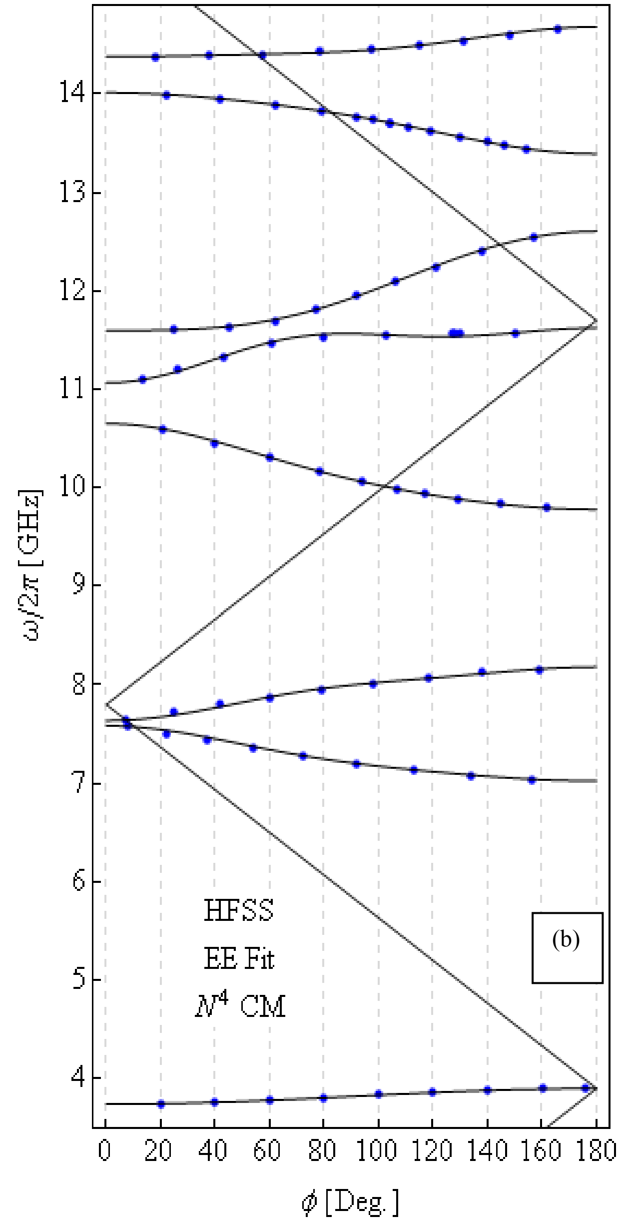
  - First dipole Beam-pipe band: ~4.15GHz
  - First quadrupole band: 6.56GHz – 6.71GHz
  - The 5th Dipole band: 9GHz-9.07GHz

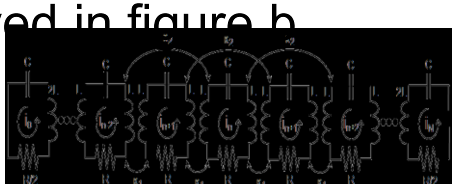
- What is required for better understanding of the system is a coupled cavity model – circuit model analysis

Monopole circuit model for the 3.9GHz cavity

- A study involving the circuit model applied to the monopole bands was conducted by B. Szczesny, in which it was shown that the traditional nearest neighbour coupling model (nc=2) found in the literature (i.e. by Bane and Gluckstern) gives significant discrepancies between for the higher bands (figure a)
- Adding coupling from two additional neighbours (nc=4), improves the prediction significantly as displayed in figure b



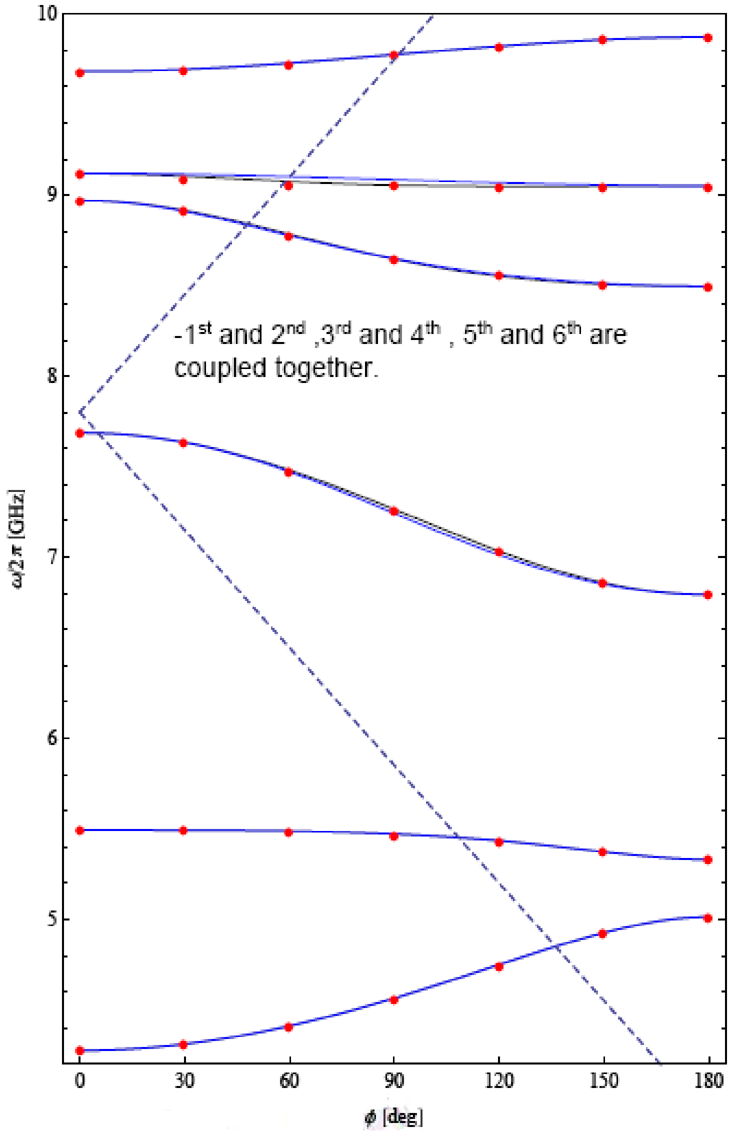




Dipole circuit model for the 3.9GHz cavity – the traditional model found in the literature

- The traditional double chain circuit model applied to the 3.9GHz structure works well for the lower bands when directly applied to this structure, i.e:
  - 1st and 2nd bands are coupled (giving bands 1 and 2)
  - 3rd and 4th bands are coupled (giving bands 3 and 4)
  - 5th and 6th bands are coupled (to give bands 5 and 6)

- However discrepancies arise in modelling the higher dipole bands – this suggests cross coupling between the different bands



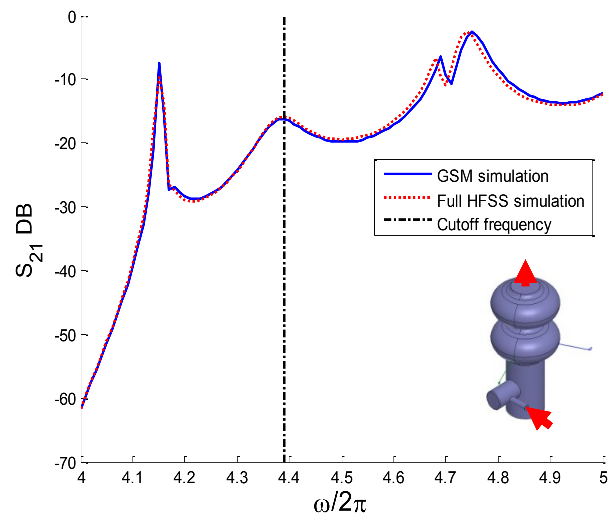
Insights from the circuit models

- 1) The circuit model analysis clearly shows the strong coupling dependence between the cells and therefore the cavities themselves, as suggested by the pictorial modal dictionary.
- 2) The circuit model also shows the sensitivity of machining alignment errors in terms of the field flatness - can be quite sensitive as much as a 20MHz shift or greater in the resonant frequencies from a small 5% RMS error in the cavities.

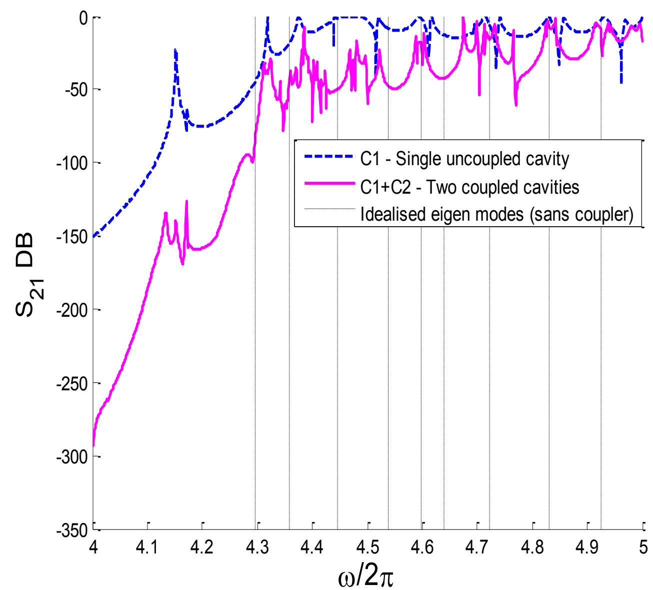
- However the circuit model uses an idealised ACC39 structure; better understanding of the effects of complicated structures such as the couplers and bellows within ACC39 is required – what is required is the generalised scattering matrix technique (GSM).

The generalized scattering matrix method: GSM

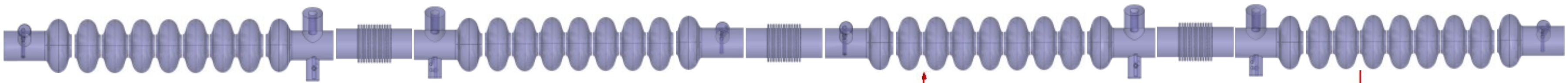
- GSM is a semi analytical technique used to simulate large RF structures that cannot be simulated by numerical techniques due to time and memory constraints
- GSM successfully applied to complicated structures – coaxial ports.
- GSM works well within a structure where there is at least one propagating mode, if this is not the case then a large number of evanescent modes will have to be considered to obtain an accurate answer.



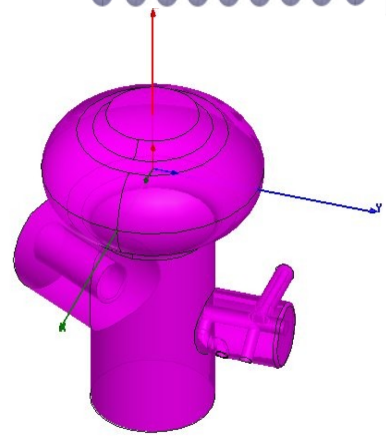
- Here is a comparison between a single cavity using GSM and two coupled cavities using GSM
- GSM calculations confirm strong presence of HOM multicavity coupling – problem for present diagnostic design



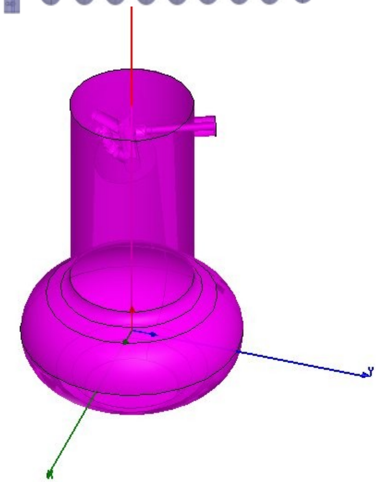
3.9GHz unit cells



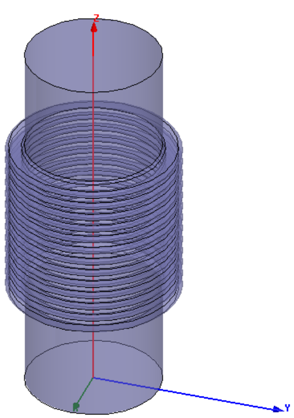
- All unit cells are calculated in HFSS using 30um surface mesh and 10000 volume mesh
- Fast frequency sweep is used in order to reduce calculation time.
- 1MHz frequency step is used
- 10 modes per port



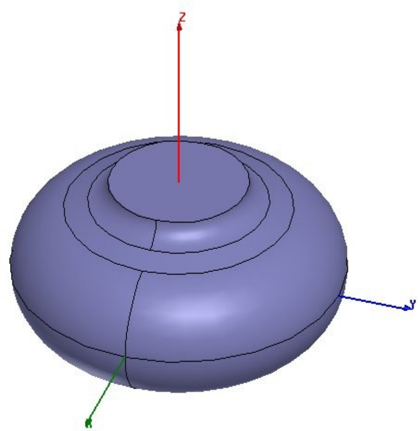
C8 HOM power



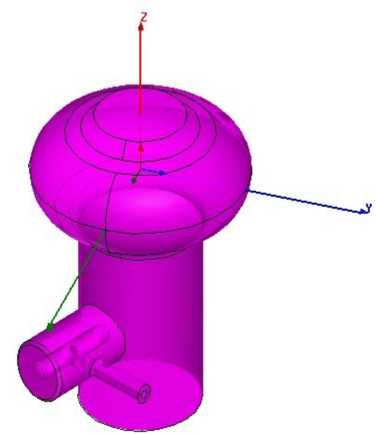
C8 HOM pickup



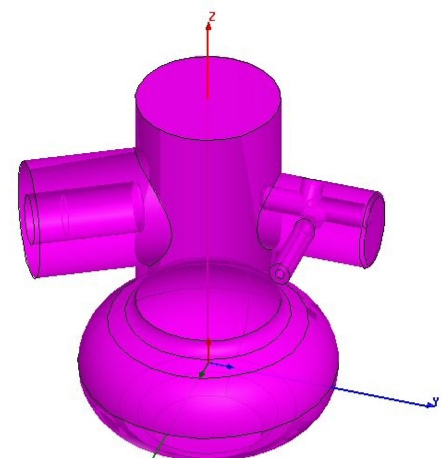
Bellows



Middle cell

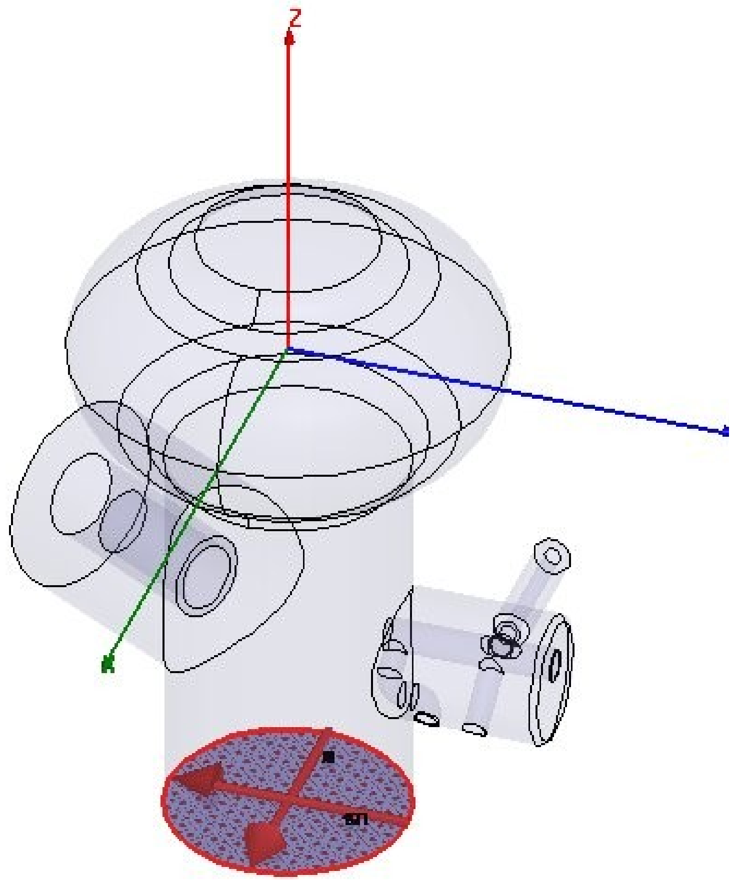


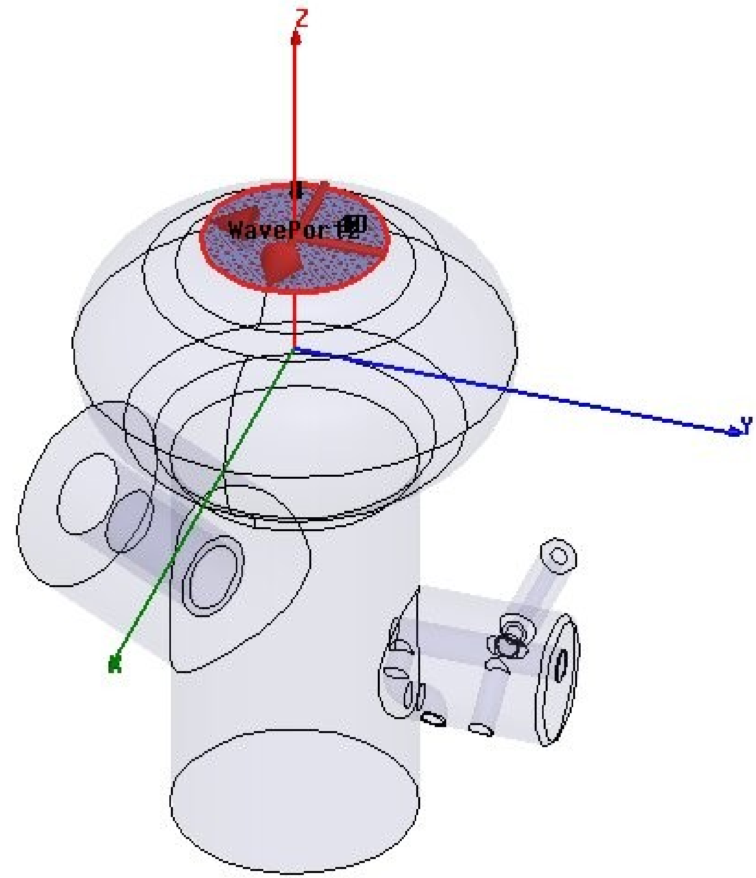
C3 HOM pickup



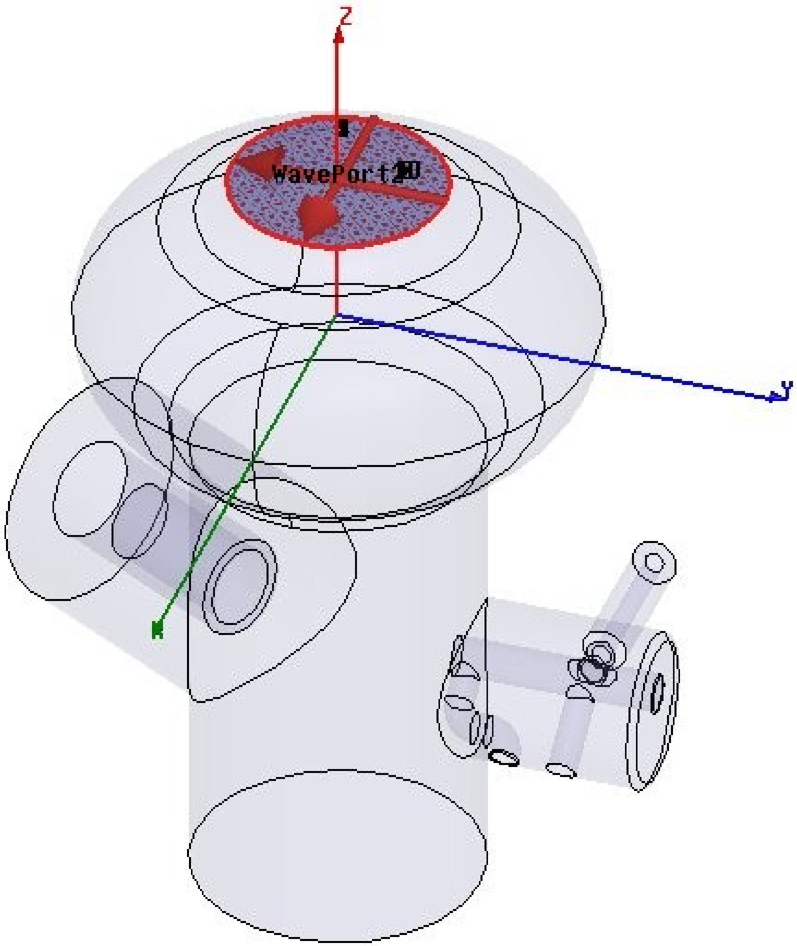
C3 HOM power

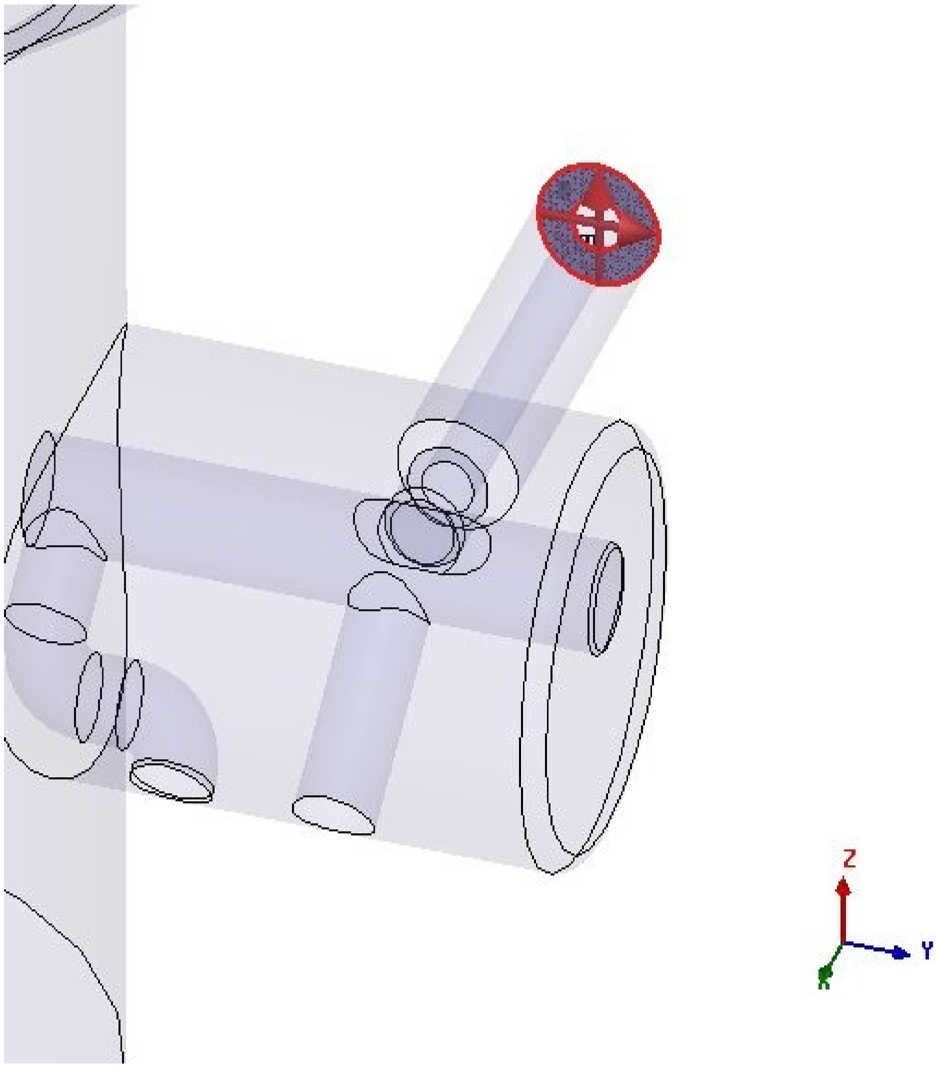
Throughput book keeping



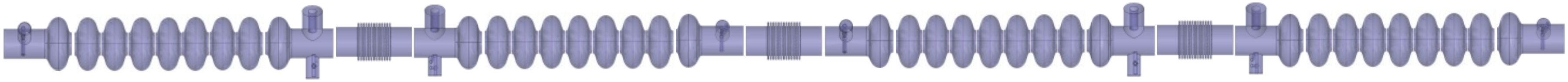


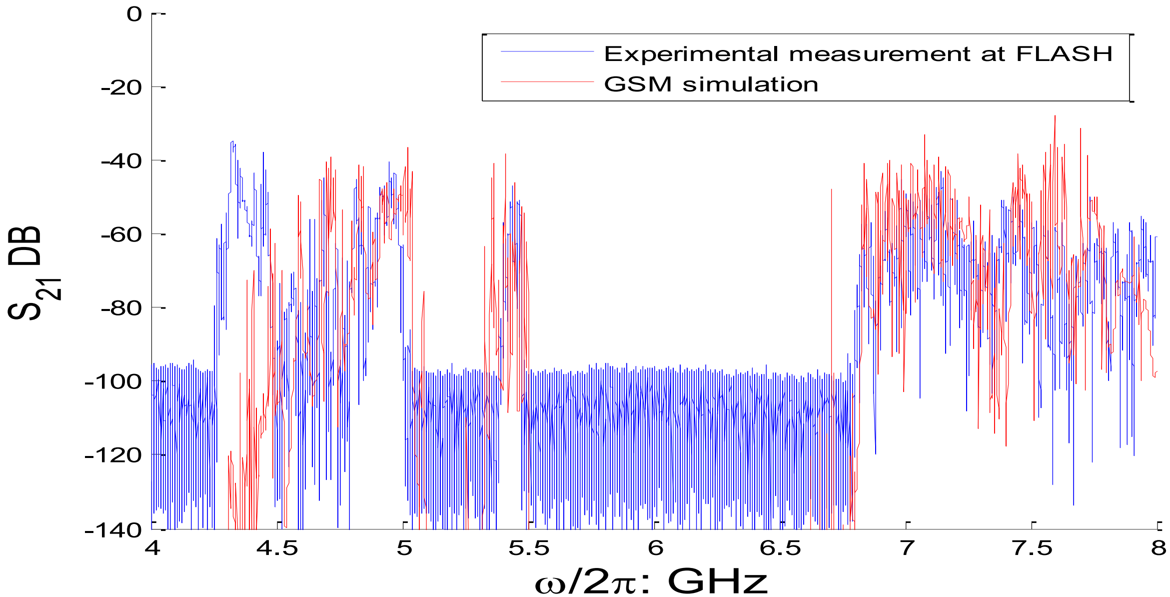
HOM coupler book keeping





ACC39 GSM





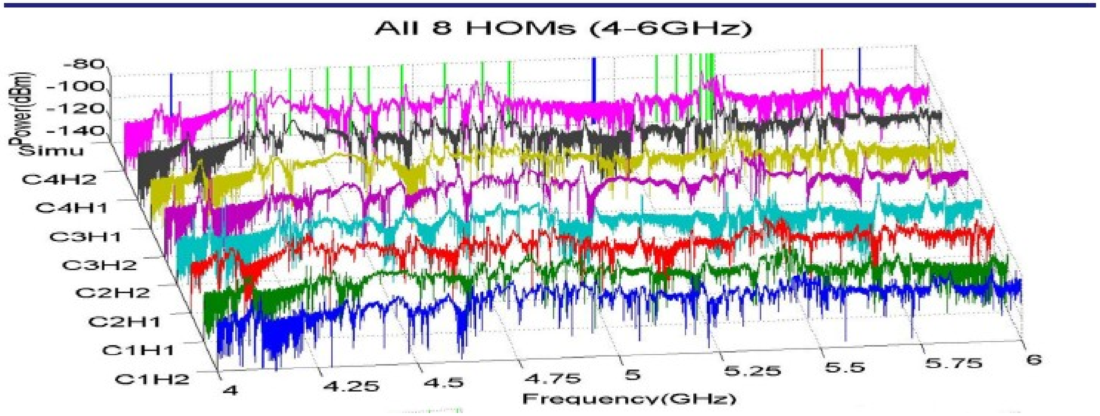
- Full ACC39 modelled using GSM.
- Good qualitative agreement with experimental data above cut-off. Results very similar to those calculated by the CSC technique of Rostock.
- GSM calculations confirm strong presence of HOM multicavity coupling – problem for present diagnostic design

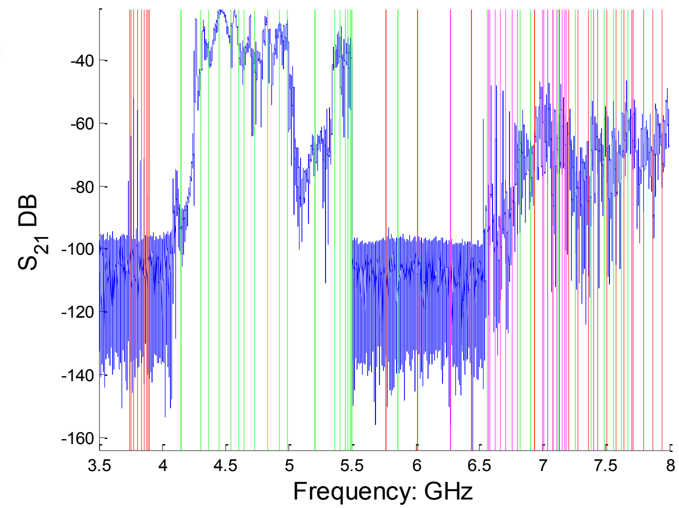
A closer look at the data

➢From the experimental data (and the GSM/CSC results) we can see that clearly see that each cavity has a different set of resonances.

➢This is clear multi-cavity behaviour, and makes it extremely difficult to identify the true nature of these HOM's

Straight lines are eigenmode simulations of ideal cavities
cavity dipole modes (green),beampipe dipole modes (blue), red (monopole)





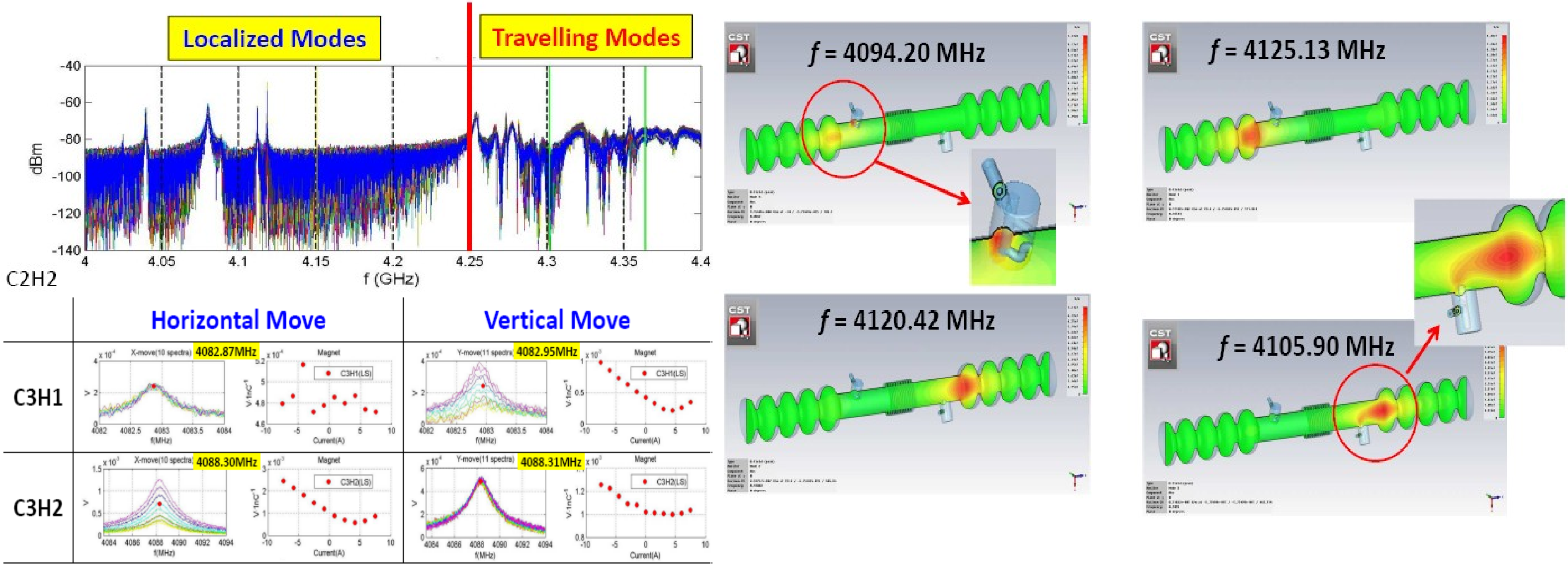
➢What is needed is to be able to calculate the field within the structure to understand how and where the modes are being propagated and localised.

➢ Although these fields could be calculated via a mode matching technique, this is a very challenging aspect for complicated structures, such as couplers. It is also no easy to model a beam through the cavities using these techniques….

The need for modelling the EM field in its entirety

➢The simplest way in which to obtain the fields within ACC39 with and without beam is to use a numerical EM piece of software such as CST, HFSS etc

➢However due to computational limitations we cannot use these codes to model ACC39 in its entirety accurately, we can only model small sections.



➢From the small sections that have been looked at in detail – we obtain good agreement with experiment and we are able to explain the presence of additional modes etc.

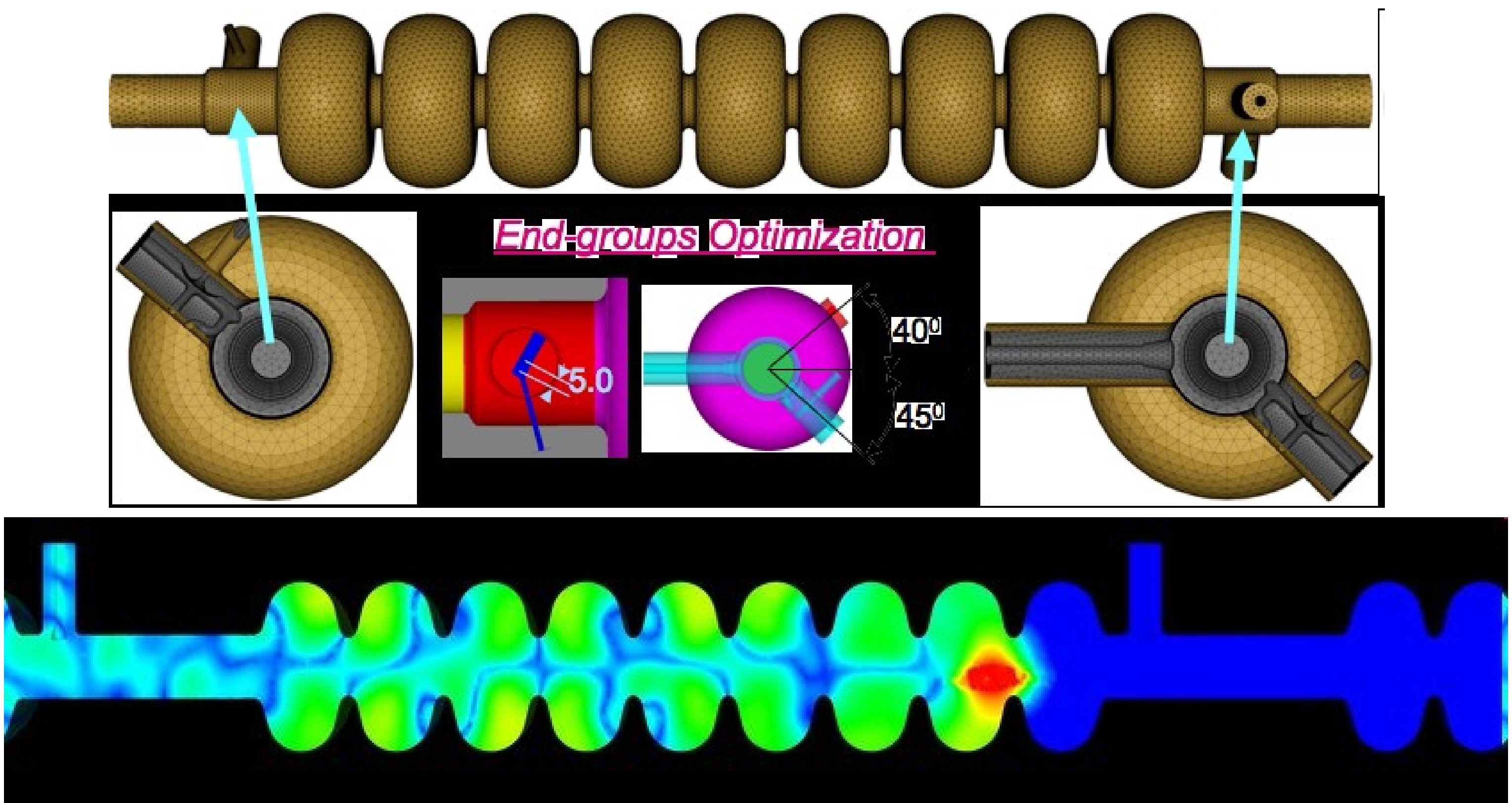
➢What is needed is a very powerful code that can be run on a supercomputer cluster

ACE3P

➢ACE3P is a large scale parallel EM suite of codes that have been developed at SLAC over a period of 20 years by SLACS ACD group (advance computing department)- Zenghai Li et al: http://www.slac.stanford.edu/grp/acd/ace3p.html

➢ACE3P can solve a variety of problem types including eigen mode analysis (OMEGA3P), Scattering matrix analysis (S3P), Transient beam solver (T3P) and many other cases.

➢It is a highly modular code, and very powerful. It currently hold the record for the largest full scale EM numerical problem, which was 3 TESLA cryomodules.



The ACE3P timeline – in terms of solving an ACC39 problem

- 1) Writing a parameterized script within the CUBIT meshing program ~1 week (comparable to commercially available codes such as HFSS, CST etc)

- 2) Meshing the problem within CUBIT, this is a semi manual process it is up to the user to manually correct any elements that are not within tolerance by adjusting the mesh itself ~2 weeks (can be difficult if your structure contains small features that require web-cutting etc)

- 3) Converting the CUBIT mesh to ACE3P mesh using ACDtool ~ 10mins

- 4) Writing ACE3P and job submission scripts ~ 30mins

- 5) Transferring files to a high performance cluster (FRANKLIN) ~ 1hr

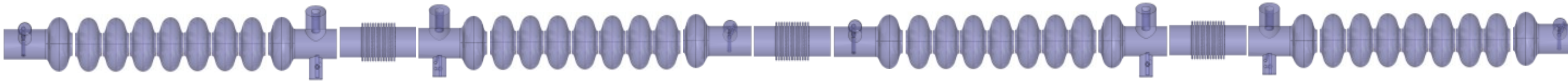
- 6) Submitting jobs to the HOPPER queue system ~ 1min

- 7) Wait for job to go to the front of the queue ~ ?????

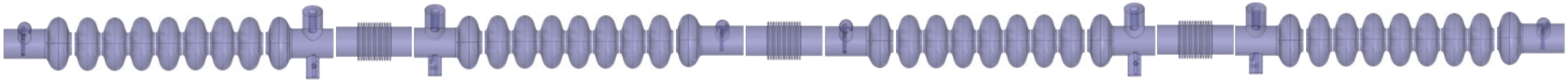
- 8) Wait for job to run – 1024 nodes will take about 12hours for a big problem (here jobs much larger than commercially available codes can be run – this is the advantage of ACE3P)

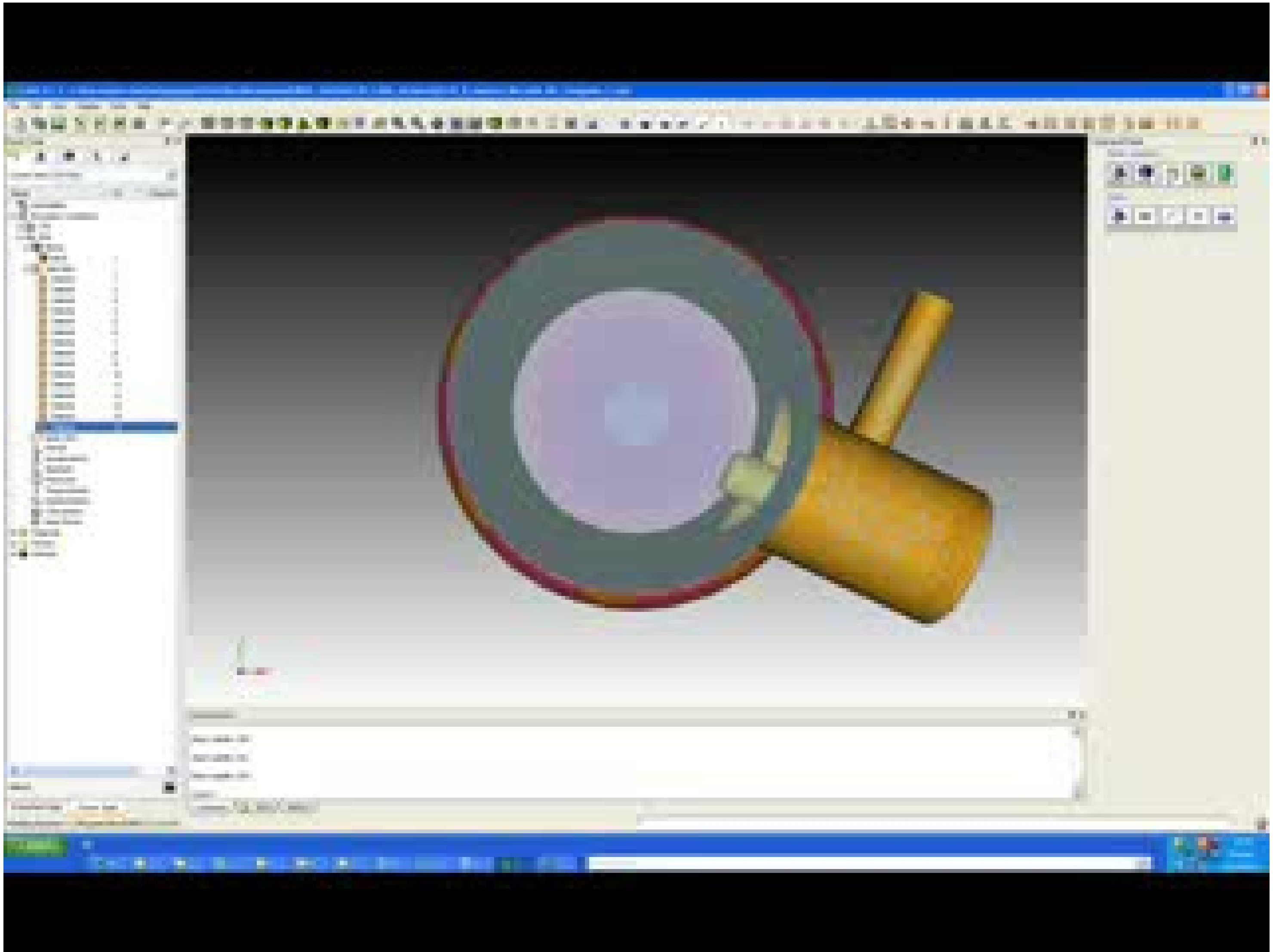
- 9) Analyse data using Paraview by either running locally on FRANKLIN or transferring data back.

Drawing ACC39 in CUBIT – in real time



A flythrough of the meshed CUBIT ACC39 structure





ACC39 ACE3P results

- Originally when I first created the FRANLKIN ACC39 job I used 16million mesh cells, most of these were concentrated in the bellows regions due to initial interest being in starting to understand the first dipole bad beam-pipe modes.
- The largest OMEGA3P (the eigen solver of ACE3P) mesh that has been solved is 3million mesh (second order)
- So I have had to downsize my mesh and resubmit
- I am still waiting for results…..

ACC39 ACE3P future aspects

- Full eigen mode and driven modal analysis of ACC39 regions of interest using ACE3P
- Beam based analysis of ACC39 using ACE3P.