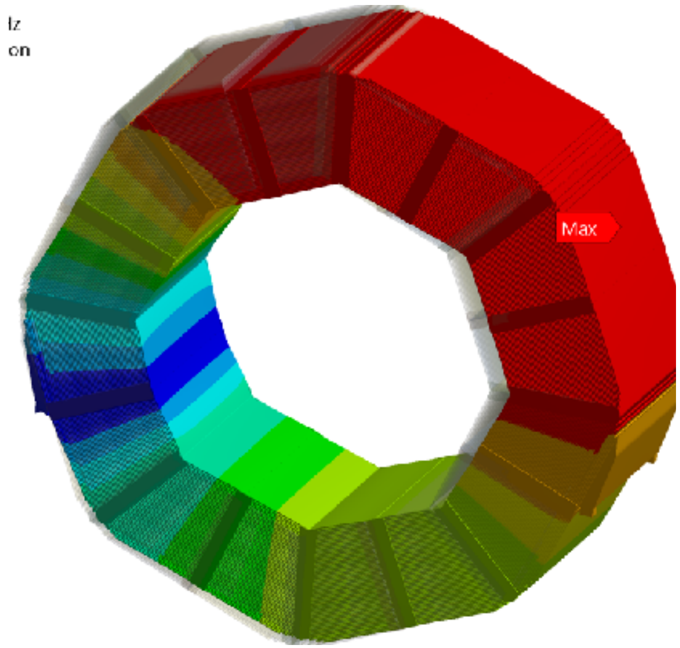
Methods for a seismic stability validation of the AHCAL structure

Karsten Gadow, Martin Lemke, Felix Sefkow

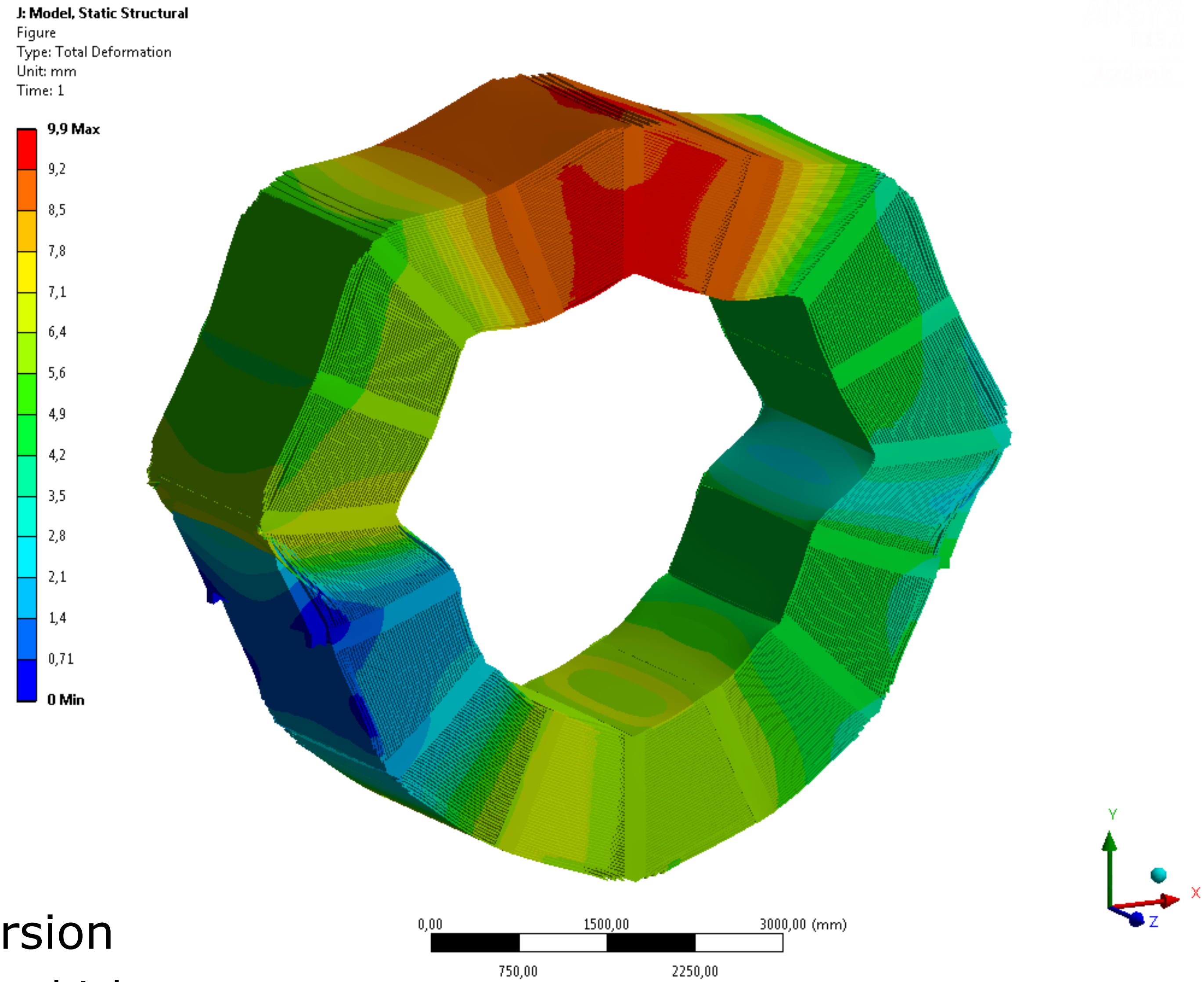


Mini-Workshop on ILC Infrastructure and CFS for Physics and Detectors
KEK, Tsukuba, September 28, 2017

Outline

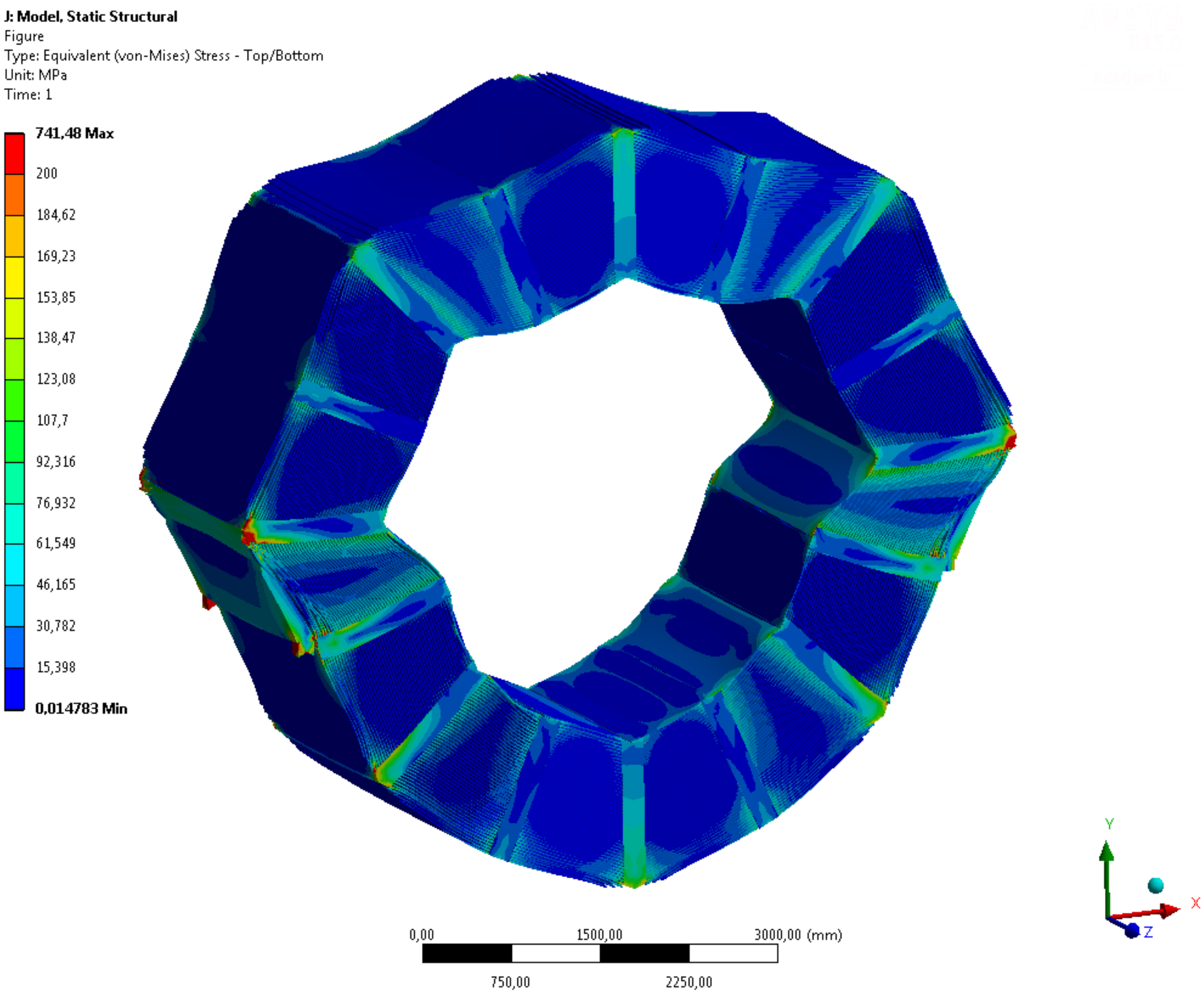
- Previous studies
- Sub-structuring method
- Validation with a toy model

Static deformations



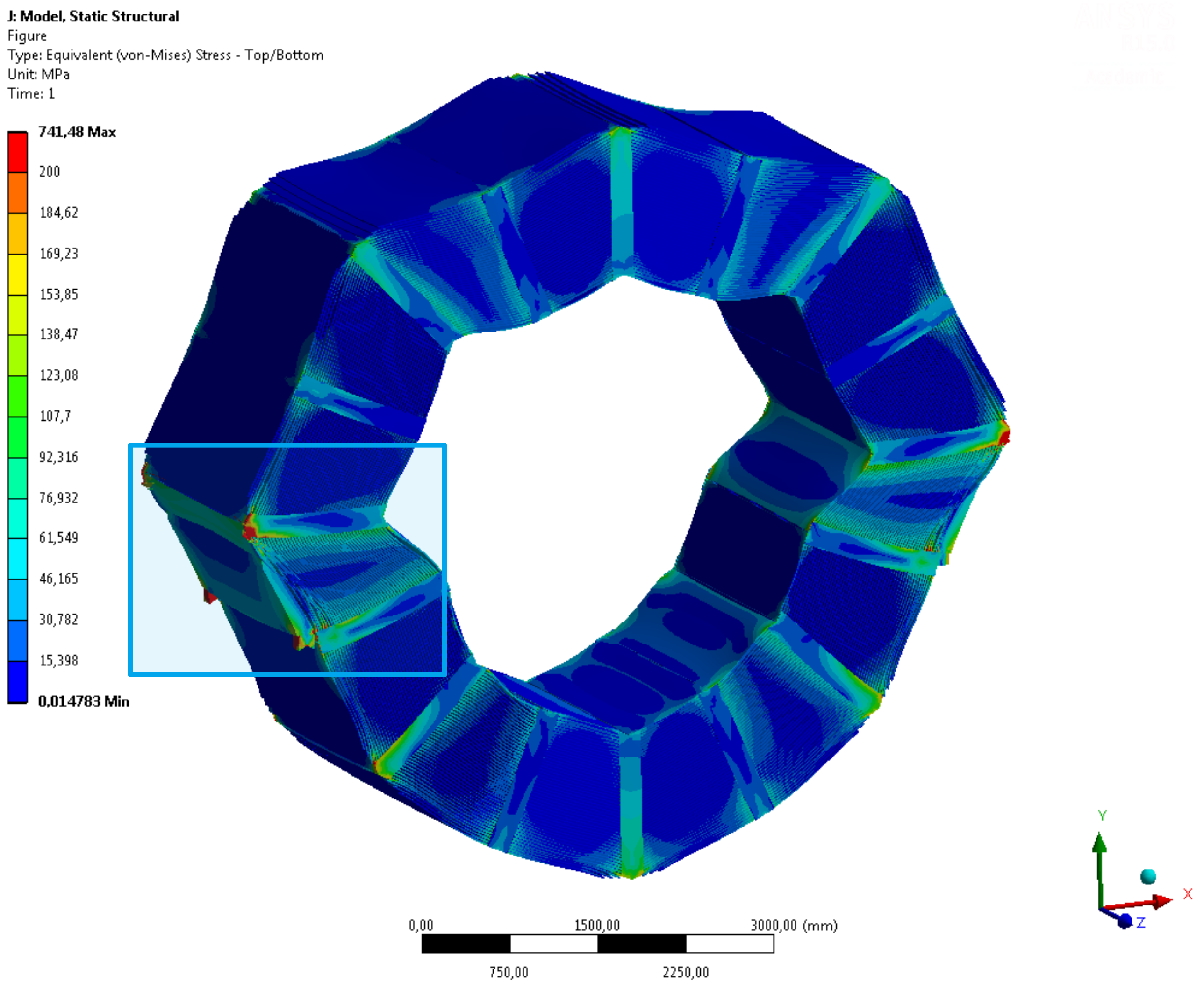
- outdated version
  - plates now thicker

Local stress peaks



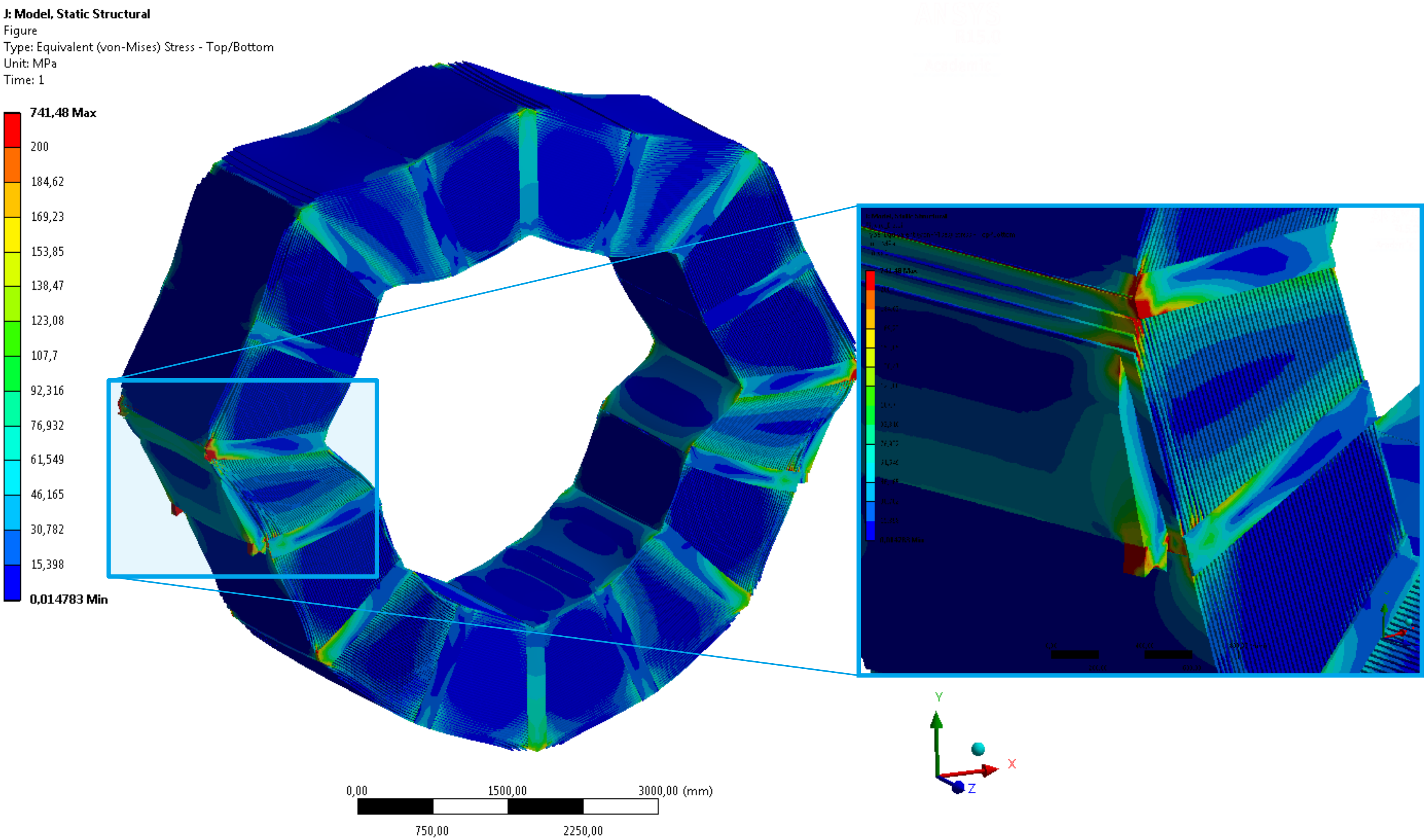
- local analysis to be refined, structure to be optimised

Local stress peaks



- local analysis to be refined, structure to be optimised

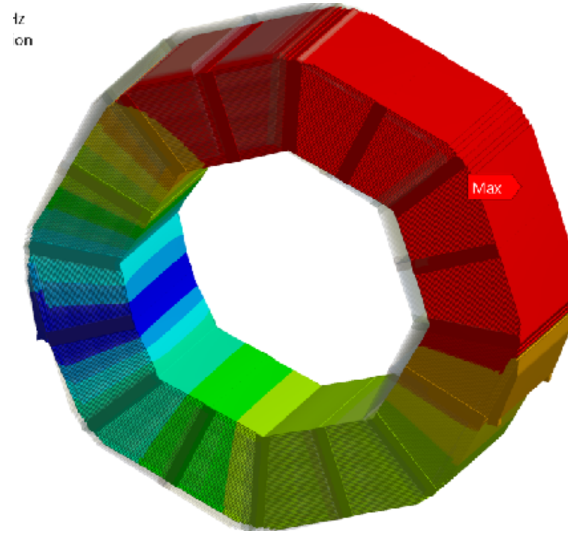
Local stress peaks

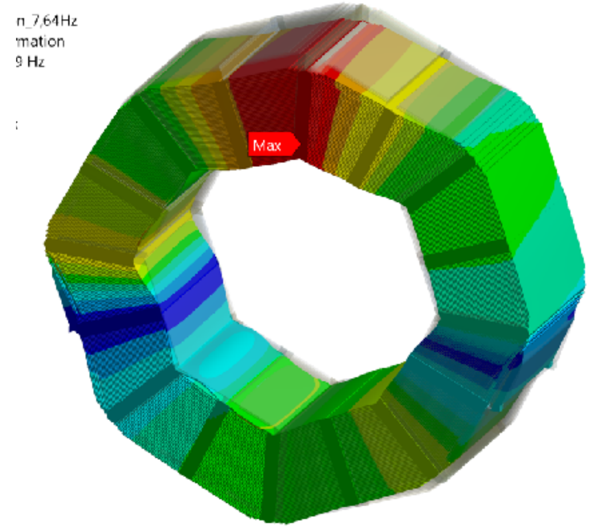


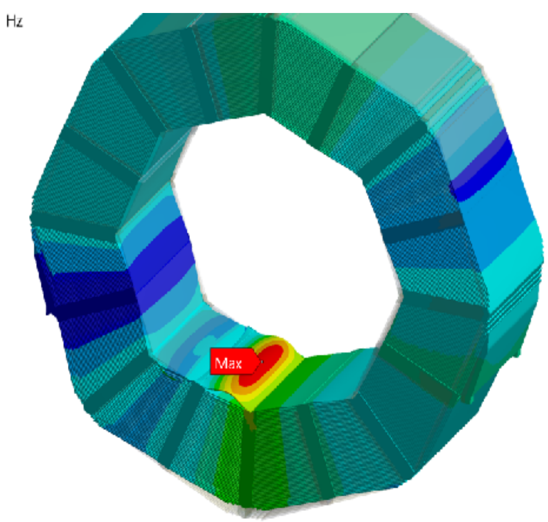
- local analysis to be refined, structure to be optimised

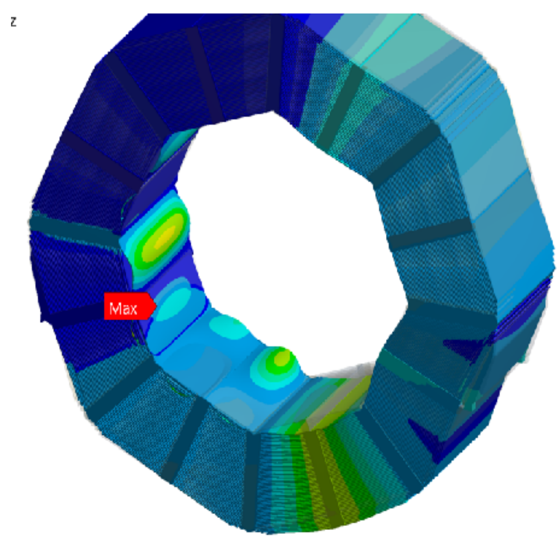
Eigen mode analysis

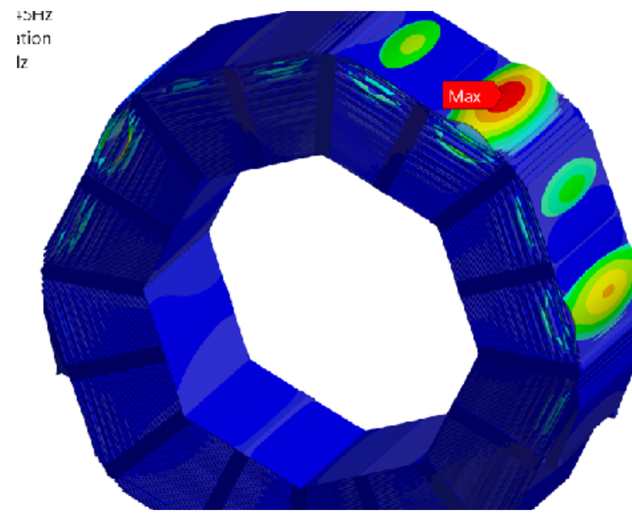
- Swinging barrel: 3Hz
- Swinging module: 8Hz
- Swinging plate: 6Hz
- Higher modes: 15 Hz
- Several plates: 45 Hz









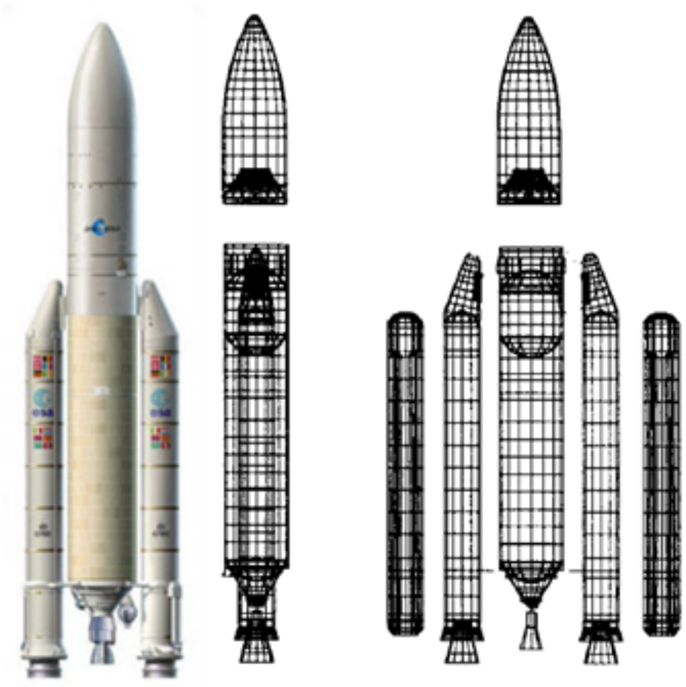


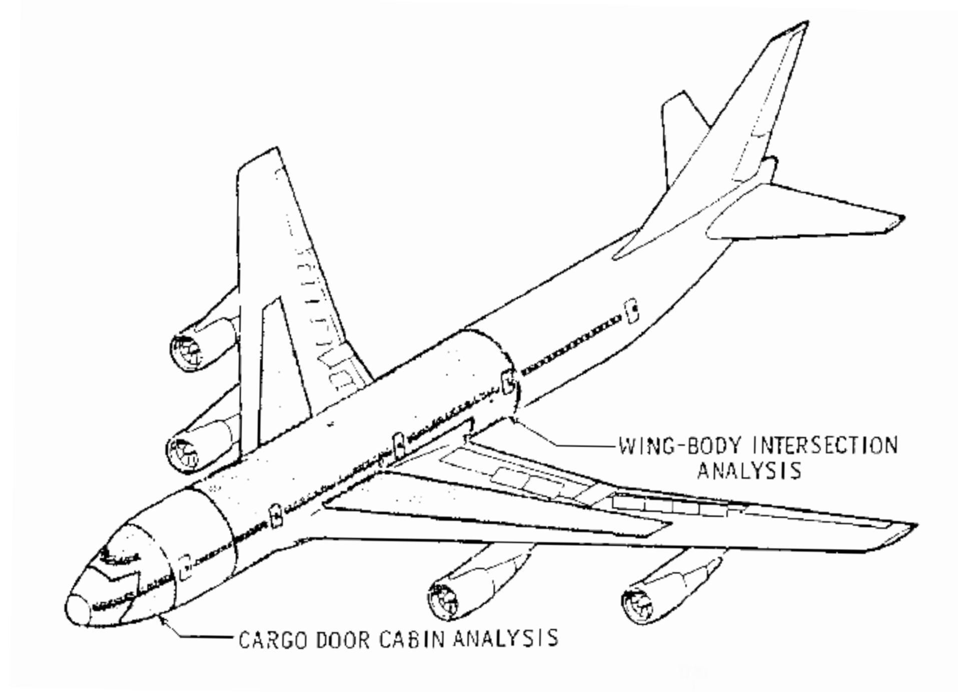
Computational challenges

- Within reasonable effort, first 200 eigen modes calculated
- In order to obtain response spectrum with a frequency sweep, need to introduce damping: further complication
- Computation failed

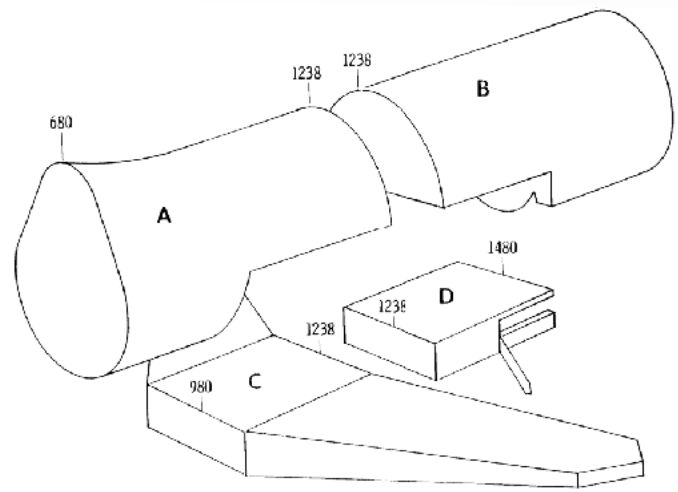
- Possibilities to simplify:
  - omit details: use shells, beams, point masses, rigid bodies
    - loss of realism and predictive power
- More efficient approach: **sub-structured analysis**
  - condense group of elements into a "super-element"
  - model behaviour for the overall structure in a matrix describing the characteristic properties of the super-element
    - rigidity matrix exact, mass and damping matrix approximative

Examples

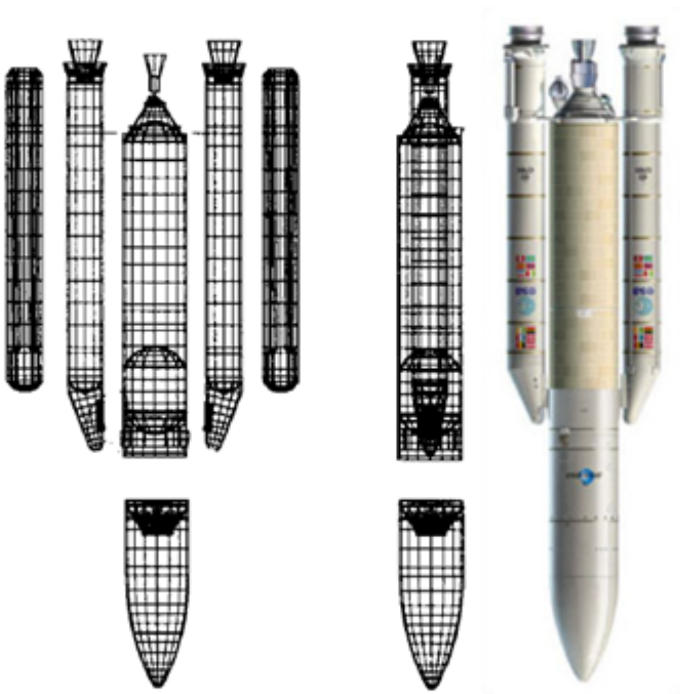


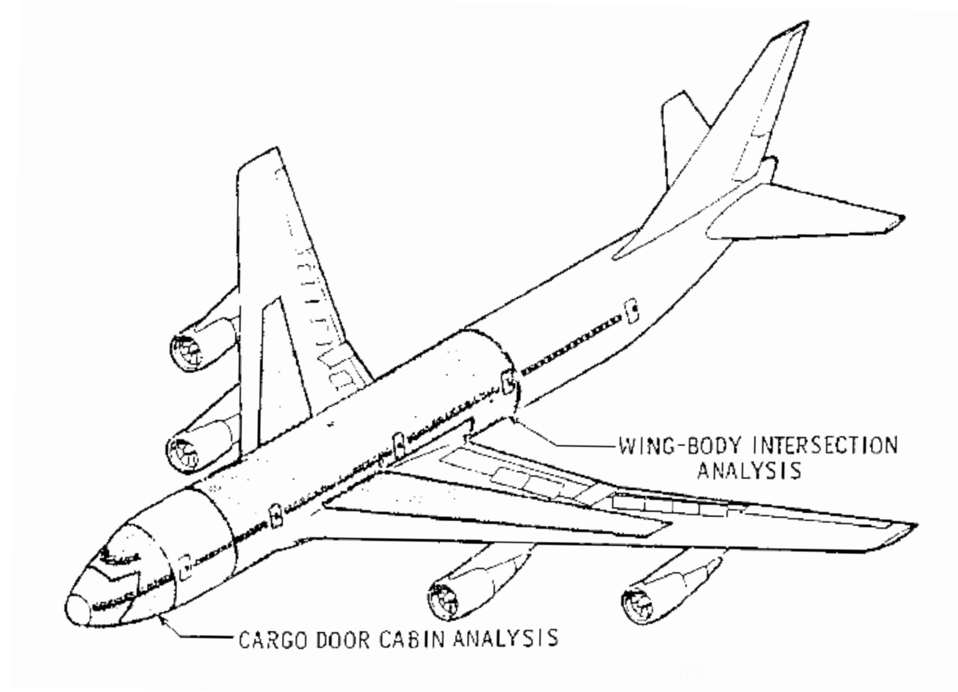


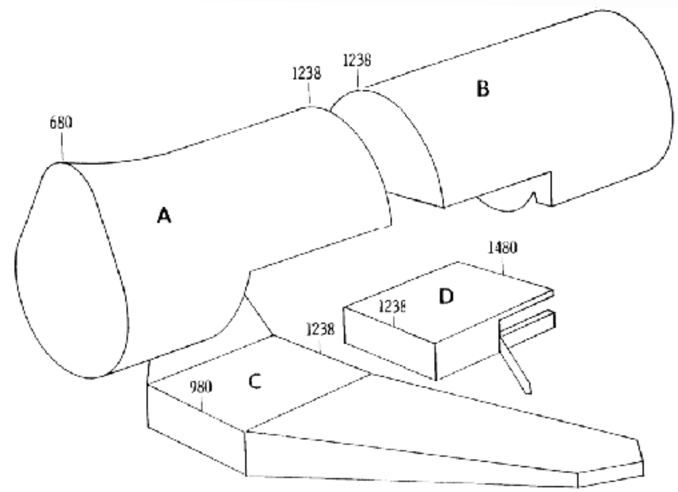
- Method commonly used in aerospace and automotive engineering since 1970s



Examples



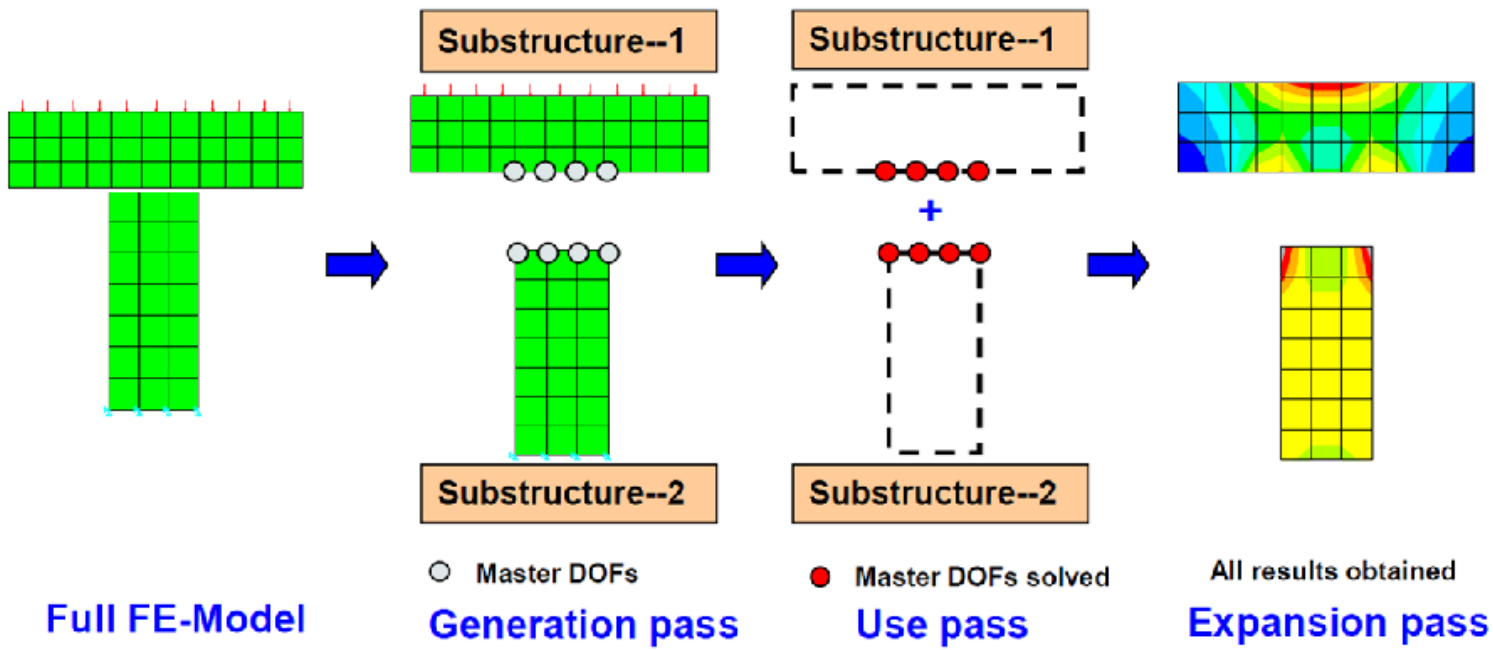




- Method commonly used in aerospace and automotive engineering since 1970s

Sub-structured analysis method

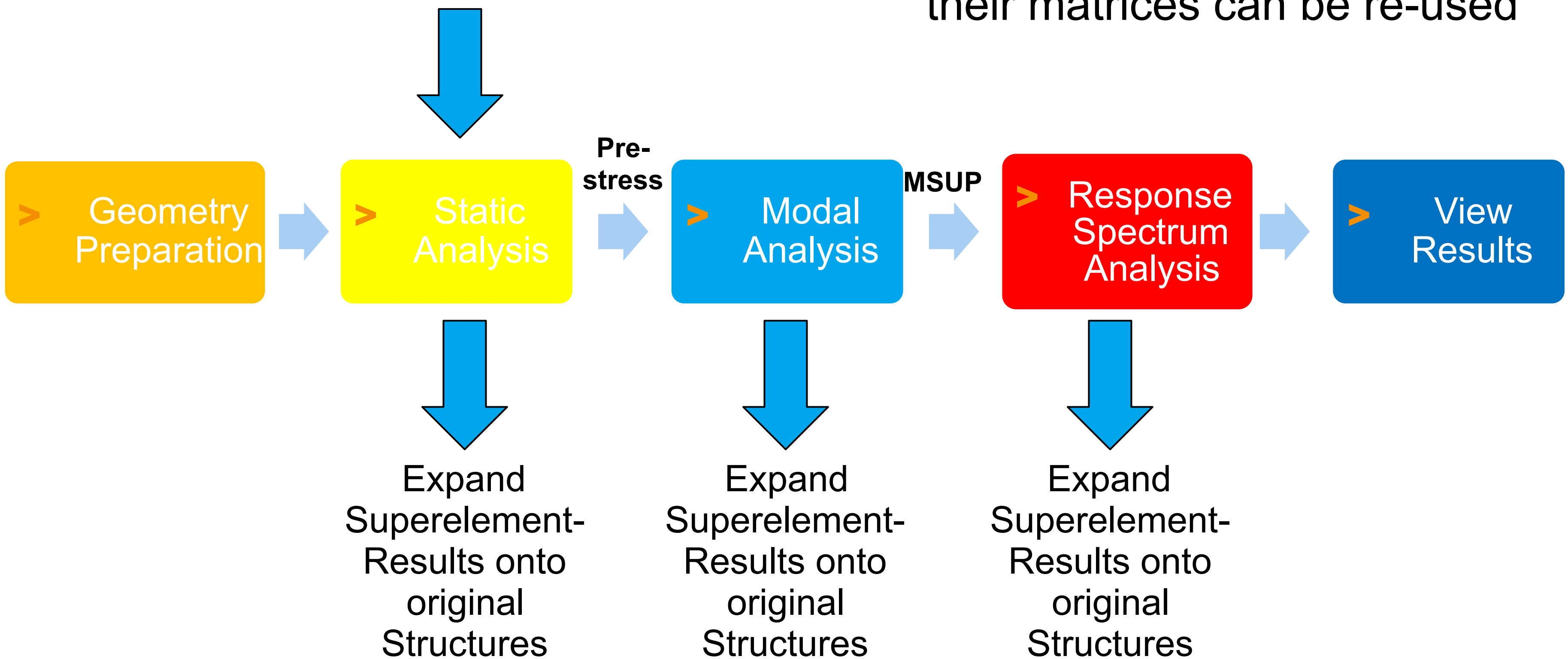
- "Component mode synthesis
- Using ANSYS parametric design language APDL
- Generation pass: calculate matrices and master degrees of freedom (MDOF) at super-element boundaries
- Use pass: integrate full structure, using MDOFs
- Expansion pass: back-propagate results into super-elements



Substructuring – Implementation

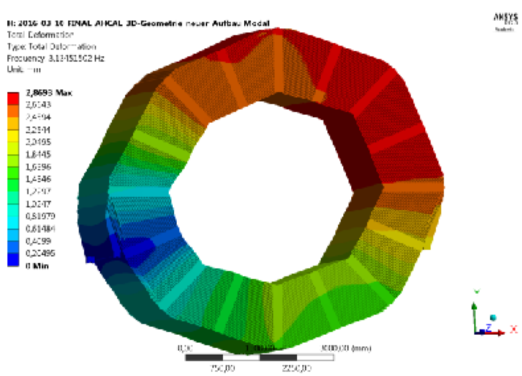
- Generation pass must be done only once
- reduced super-elements and their matrices can be re-used

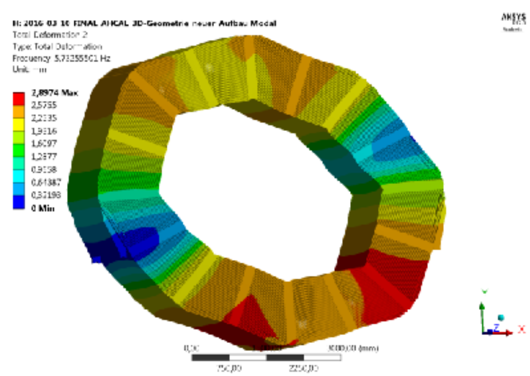
Built up CMS-Model
with Generation
and Use Pass

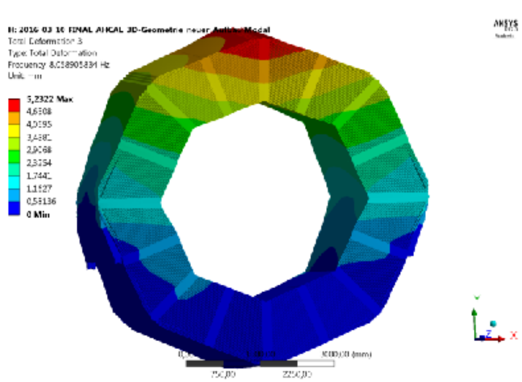


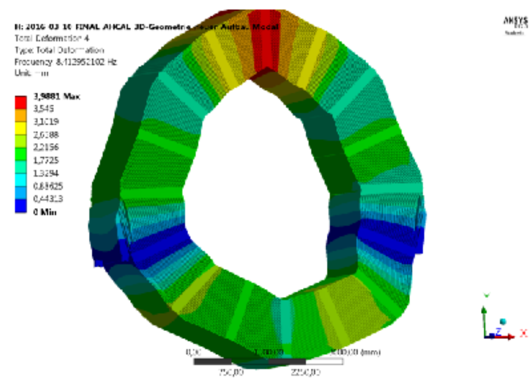
General AHCAL-Model

> Results CMS-Model:





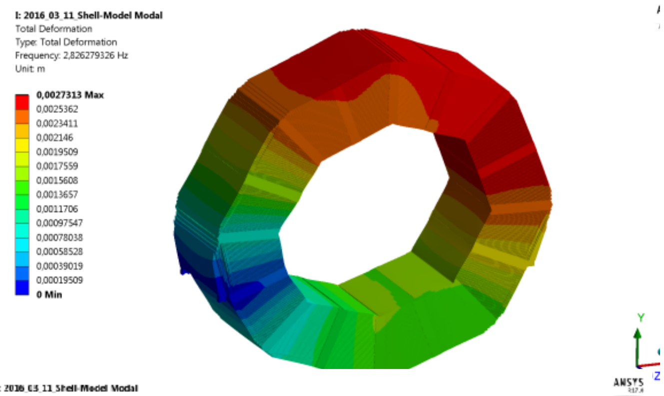


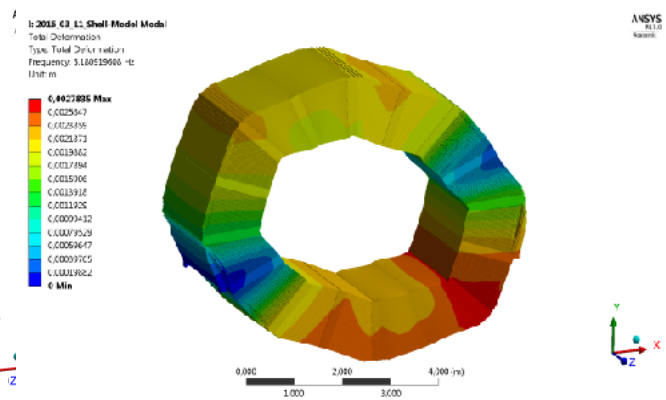


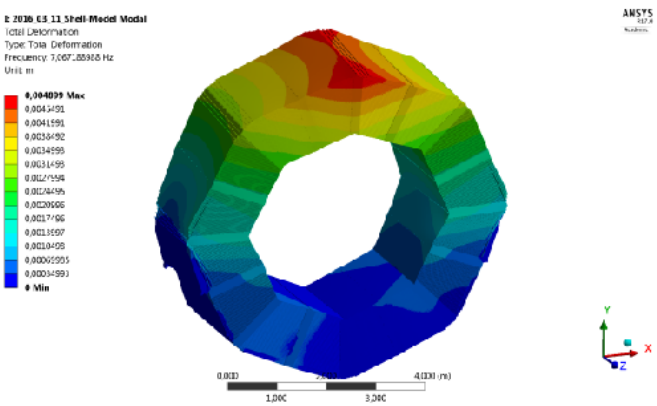
Shell-Model (prestressed)		Shell-Model (free)		CMS-Model (free)	
Nr.	f [in Hz]	Nr.	f [in Hz]	Nr.	f [in Hz]
1	2,97	1	2,83	1	3,13
2	5,27	2	5,18	2	5,73
3	6,11	3	7,07	3	8,06
4	7,65	4	7,46	4	8,41
5	9,16	5	9,94	5	10,84
6	9,85	6	11,60	6	12,91
7	11,68	7	13,65	7	15,02
8	13,32	8	14,70	8	16,47
9	14,65	9	15,37	9	16,83
10	14,67	10	17,18	10	18,07
11	15,76	11	18,75	11	20,38
12	17,37	12	19,29	12	21,14
13	18,32	13	20,21	13	22,44
14	19,37	14	21,46	14	23,34
15	20,29	15	22,48	15	24,44
16	21,99	16	23,63	16	26,12
17	22,83	17	25,52	17	27,06
18	24,05	18	31,37	18	32,28
19	24,49	19	33,39	19	38,16
20	25,23	20	35,12	20	39,50
21	31,22	21	41,07	21	41,03
22	35,29	22	42,68	22	41,03
23	38,82	23	42,68	23	41,03
24	39,76	24	42,72	24	41,03
25	40,52	25	42,72	25	41,03
26	40,55	26	42,72	26	41,03
27	41,00	27	42,72	27	41,03
28	41,27	28	42,72	28	41,04
29	42,32	29	42,81	29	41,04
30	43,78	30	43,33	30	41,04

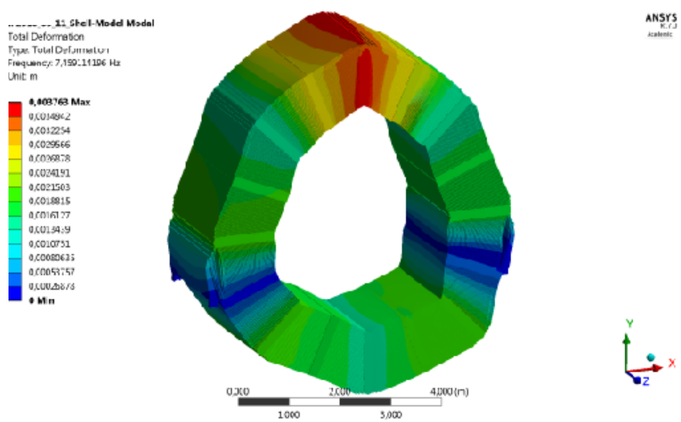
General AHCAL-Model

> Results 3D-Model:









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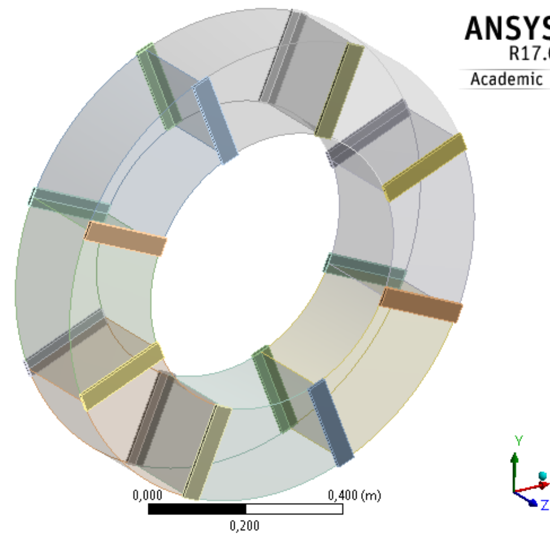
27	41,00	27	42,72	27	41,03
28	41,27	28	42,72	28	41,04
29	42,32	29	42,81	29	41,04
30	43,78	30	43,33	30	41,04

Status May 2017, and recent work

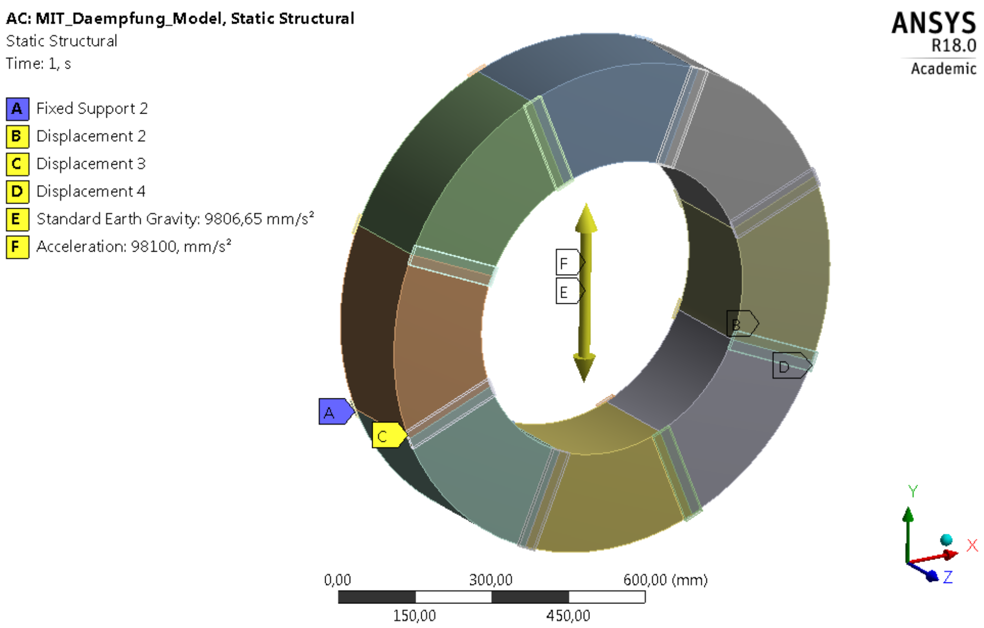
- Status 4/2016: validated against full shell model for deformations and eigen-modes
- Resumed fall 2016. following parental leave of key engineer
  - Common project with DESY central mechanics service
  - Progress is slow (< 0.2 FTE)
- Go one step back and establish method with a simpler wheel-type toy model first
- Full analysis chain for toy model appeared in reach for May meeting
- However still many computational problems



- Intensified ANSYS support
  - increasing interest at DESY
    - civil engineering, astrophysics
  - ANSYS provider uses AHCAL as demonstrator
- Concluded toy model study

Test model: ring structure with 8 sectors

- At small scales, represent problem, including several segments, contacts between segments via connection plates, and overall ring shape
- Support analogue to complete AHCAL model, but additional ECAL masses not included
- Can easily be adapted for different investigations
- The full pass through the analysis can in principle be transferred to the AHCAL FE model



Computational progress

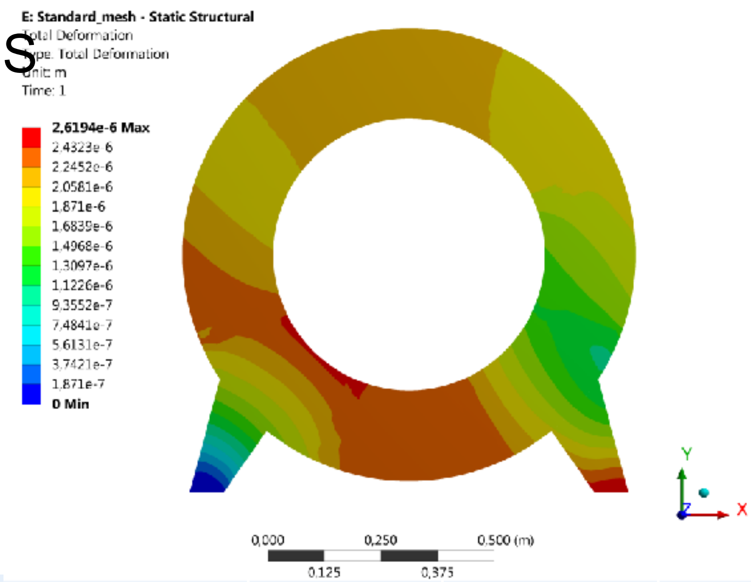
- Keep data amount and computing needs under control
- Re-organise analysis flow and re-use of results
- Generate rotation-symmetric structure automatically

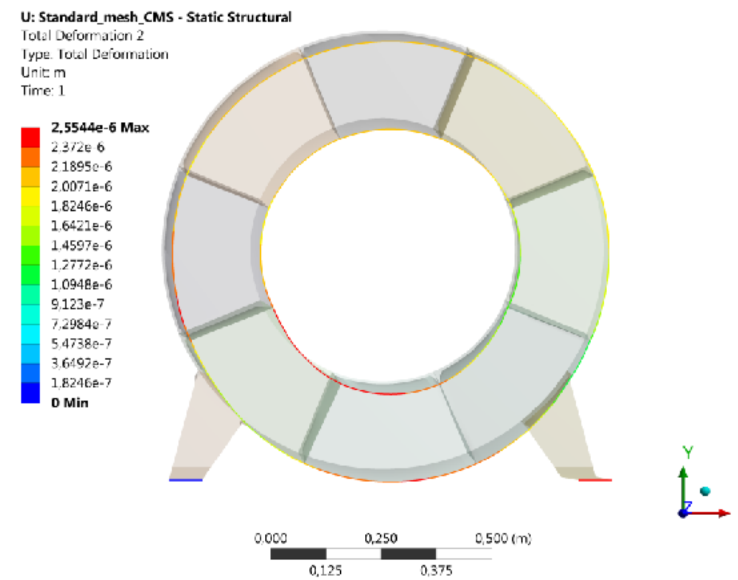
- For toy model quasi-interactive analysis
  - few 10 seconds turn-around for static case

- 1. Static deformation under gravity
- 2. Eigen-Mode analysis
- 3. Frequency sweep: find resonances
- 4. Excitation with realistic pulse

3D <> CMS: Static analysis

- Left 3D, right CMS

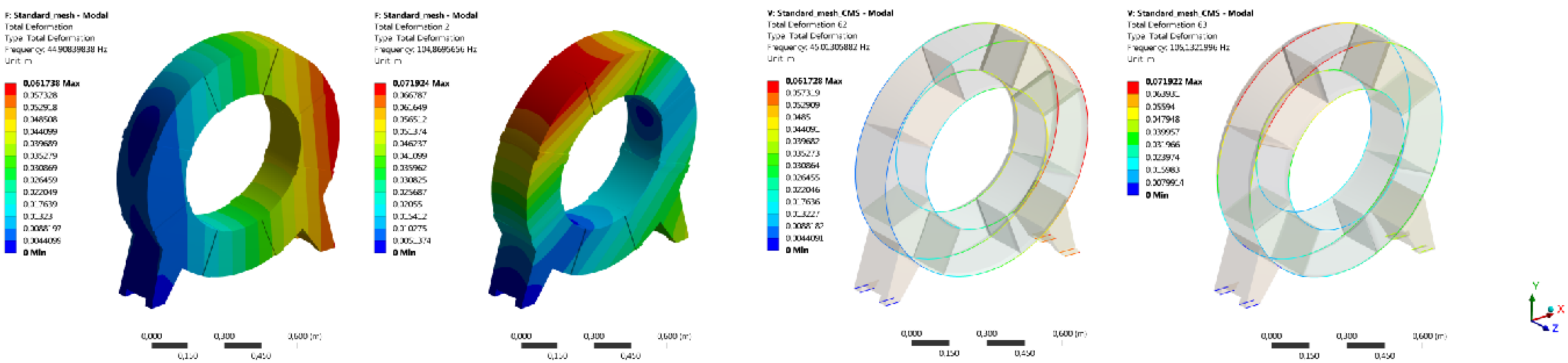




Pos.	general Meshing	Type (3D/ CMS)	Mesh-Nodes	Total-CPU-time [in sec]	Used RAM [in MB]	Result-File size [in MB]	Max. Deformation [in m]
1	very coarse mesh	3D	13.328	15	211	4,50	2,567E-06
2	coarse mesh	3D	31.821	13	557	11,10	2,586E-06
3	standard mesh	3D	186.370	52	4.818	60,00	2,619E-06
4	fine mesh	3D	315.817	169	10.589	98,00	2,635E-06
5	very coarse mesh	CMS	11.730	21	121	0,90	2,396E-06
6	coarse mesh	CMS	31.766	20	214	1,00	2,494E-06
7	standard mesh	CMS	238.900	148	828	1,50	2,554E-06
8	fine mesh	CMS	369.796	93	1.703	2,00	2,605E-06

3D <> CMS: Modal analysis

> Left 3D (Mode1, Mode2),
> Right CMS (Mode1, Mode2)



Pos.	general Meshing	Type (3D/ CMS)	Mesh-Nodes	Total-CPU-time [in sec]	Used RAM [in MB]	Result-File size [in MB]	Eigenmode 1 at f [in Hz]	Eigenmode 2 at f [in Hz]	Eigenmode 3 at f [in Hz]	Eigenmode 4 at f [in Hz]
1	very coarse mesh	3D	13.328	64	427	284,25	45,08	105,12	136,72	307,56
2	coarse mesh	3D	31.821	116	1.064	826,06	45,11	105,20	139,41	309,64
3	standard mesh	3D	186.370	74	**8.144**	**3.939,51**	**44,91**	**104,87**	138,56	308,07
4	fine mesh	3D	315.817	890	**17.231**	**5.778,50**	44,87	104,73	138,01	307,38
5	very coarse mesh	CMS	11.730	120	162	7,38	45,57	106,86	144,21	317,34
6	coarse mesh	CMS	31.766	166	270	10,38	45,25	105,89	141,38	312,64
7	standard mesh	CMS	238.900	1.885	1.308	23,63	**45,01**	**105,13**	139,10	309,03
8	fine mesh	CMS	369.796	1.215	1.772	33,00	46,06	106,15	139,47	308,53

3D <> CMS: Harmonic analysis

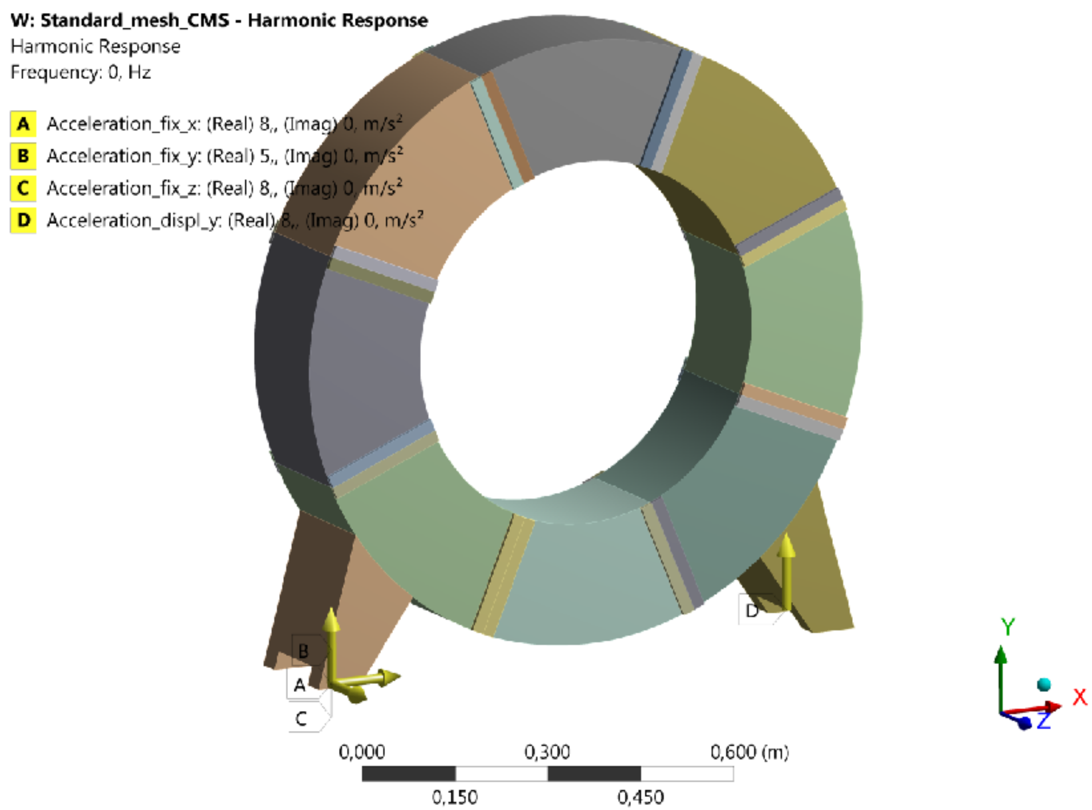
- computing needs for frequency sweep

Pos.	general Meshing	Type (3D/ CMS)	Mesh-Nodes	Total-CPU-time [in sec]	Used RAM [in MB]	Result-File size [in MB]	Max. Deformation [in m]
1	very coarse mesh	3D	13.328	566	250	3.670,00	4,847E-03
2	coarse mesh	3D	31.821	1.232	590	**11.261,11**	4,838E-03
3	standard mesh	3D	186.370	3.640	4.874	**60.526,67**	**4,882E-03**
4	fine mesh	3D	315.817	10.200	11.016	**93.694,34**	
5	very coarse mesh	CMS	11.730	1.703	162	125,69	4,739E-03
6	coarse mesh	CMS	31.766	22.620	232	181,50	4,807E-03
7	standard mesh	CMS	238.900	15.840	1.233	421,63	**4,860E-03**
8	fine mesh	CMS	369.796	24.540	1.758	595,00	4,647E-03

Boundary conditions harmonic analysis

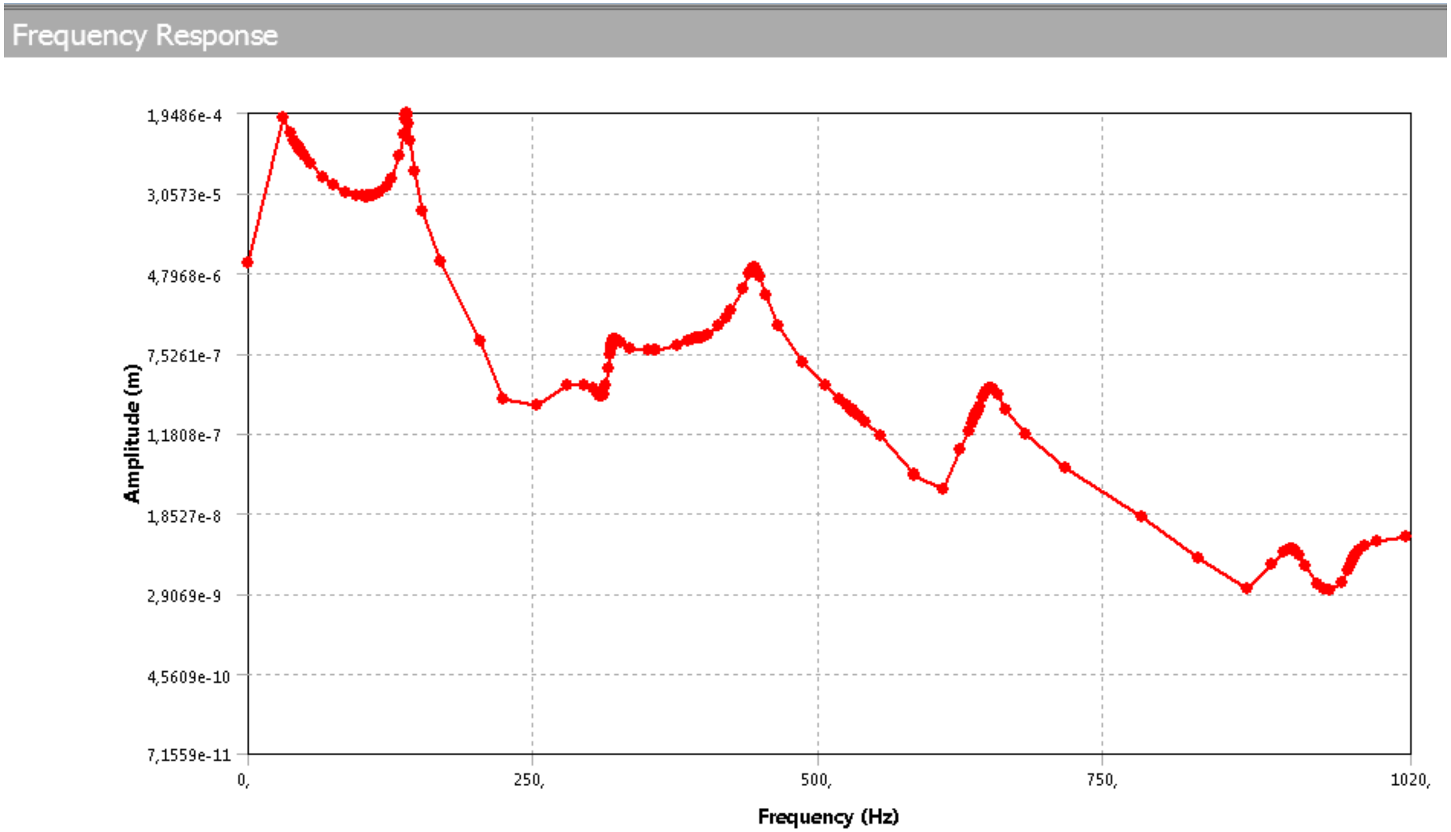
- apply acceleration amplitude in all 3 directions to supports
- Sweep 0Hz - 3.000Hz

Details of "Acceleration_fix_x"	
Scope	
Boundary Condition	Fixed Support
Definition	
Base Excitation	Yes
Absolute Result	Yes
Define By	Magnitude - Phase
Magnitude	8, m/s²
Phase Angle	0, °
Direction	X Axis
Suppressed	No



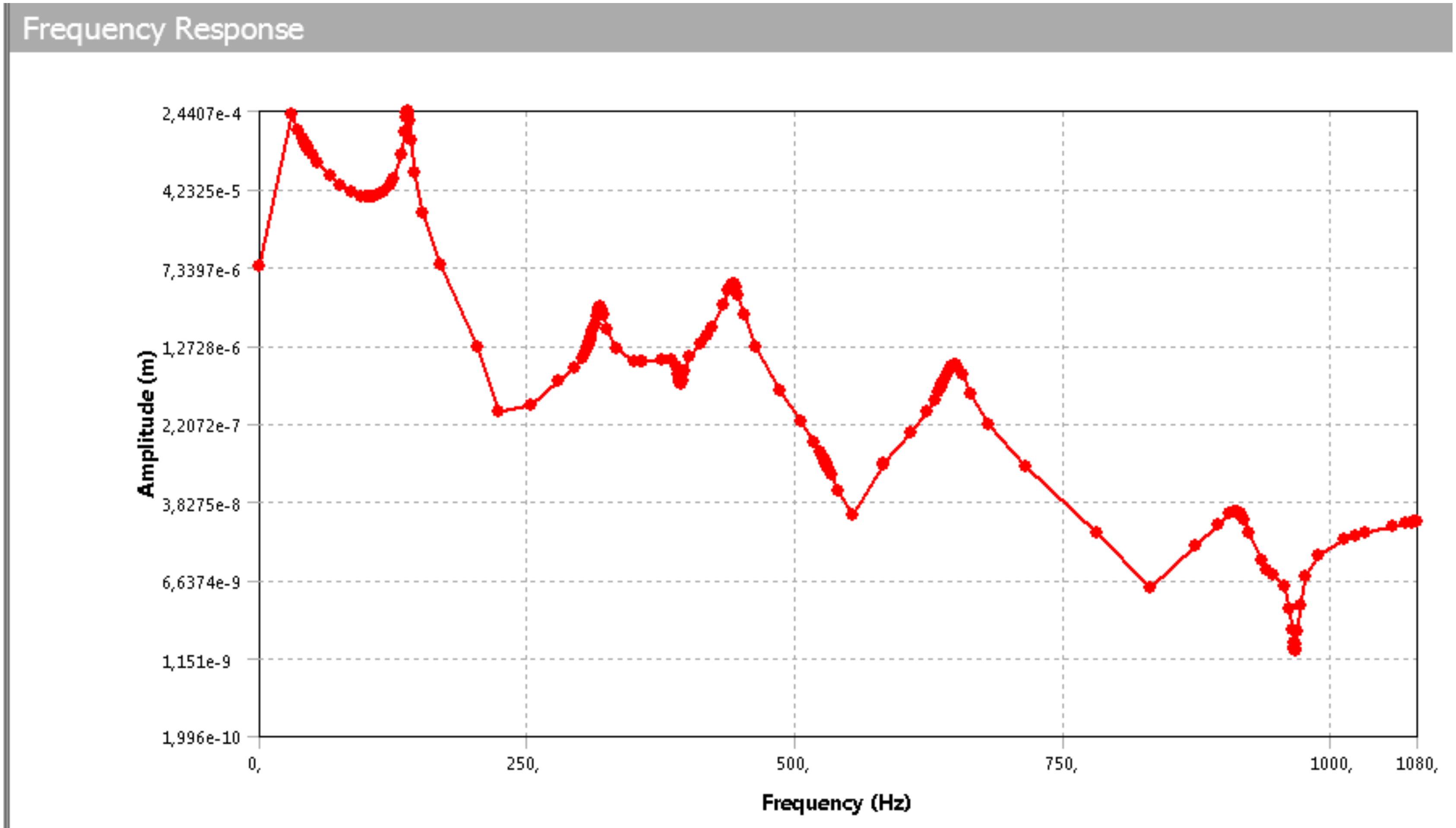
3D <> CMS: Harmonic analysis

- CMS-Modell with „Standard Mesh“
- Results for x direction: maximum displacement over full side contour



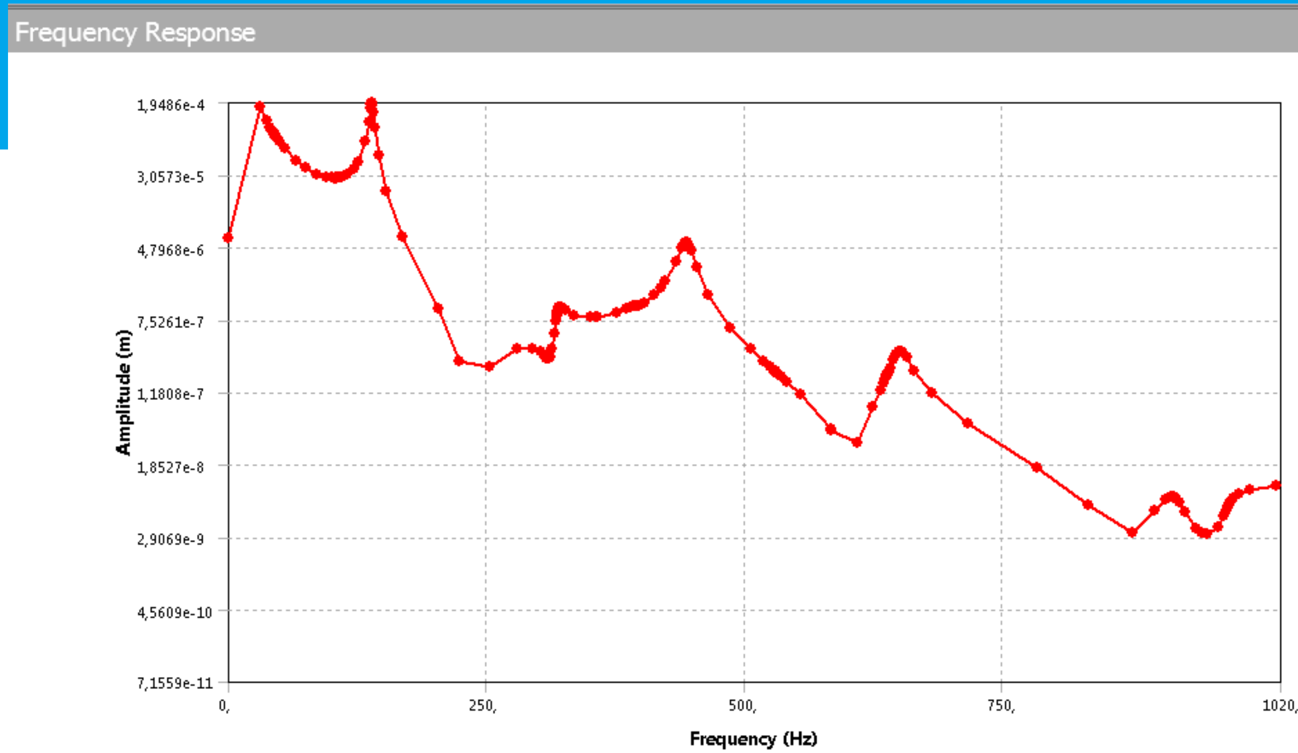
Vergleich 3D <> CMS: Harmonische Analyse (MSUP)

- Same Bode plot for 3D-Model with „Standard Mesh“
- Maximum in x-direction



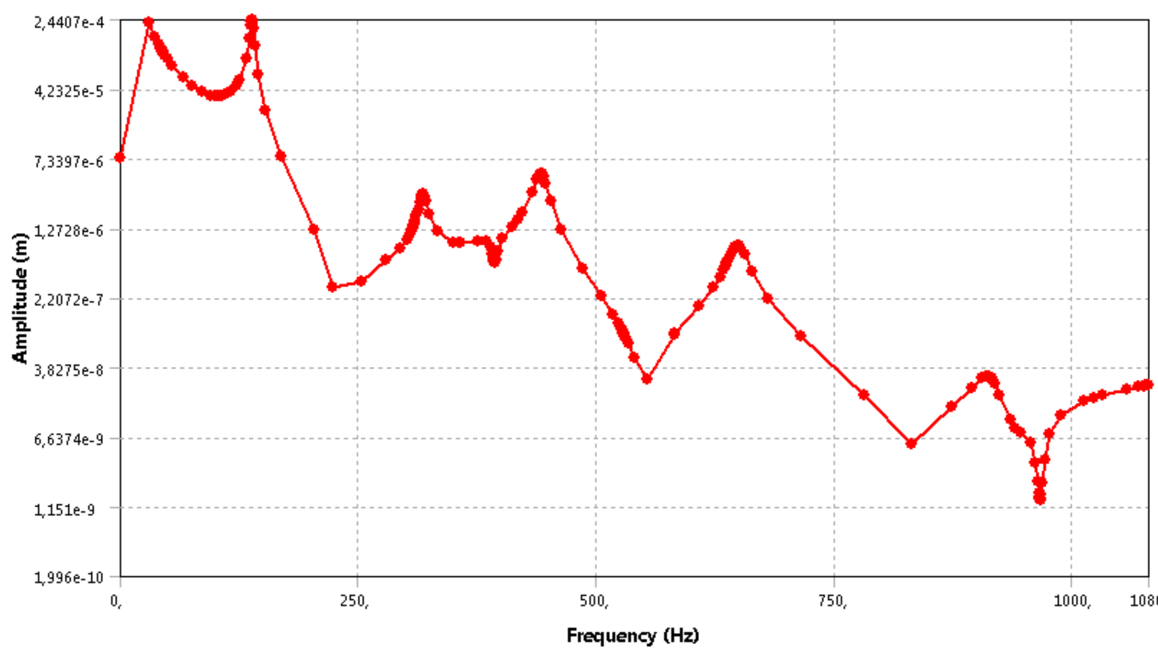
Both

> CMS



Frequency Response
1,9486e-4
3,0573e-5
4,7968e-6
7,5261e-7
1,1808e-7
1,8527e-8
2,9069e-9
4,5609e-10
7,1559e-11
Amplitude (m)
0,
250,
500,
750,
1020,
Frequency (Hz)

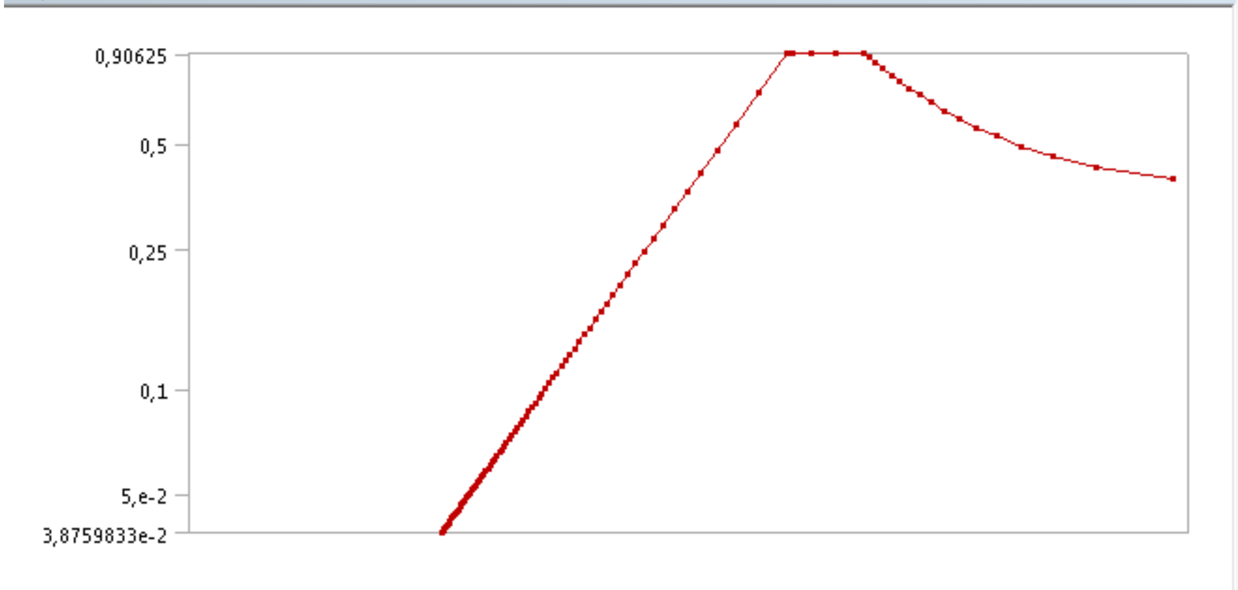
> 3D



2,4407e-4
4,2325e-5
7,3397e-6
1,2728e-6
2,2072e-7
3,8275e-8
6,6374e-9
1,151e-9
1,996e-10
Amplitude (m)
0,
250,
500,
750,
1000,
1080,
Frequency (Hz)

CMS: Response spectrum analysis

- Using earth quake data by NIED (Ichoniseki, 2011)
- For each axis input pulse on all supports
- Full pass through analysis successful



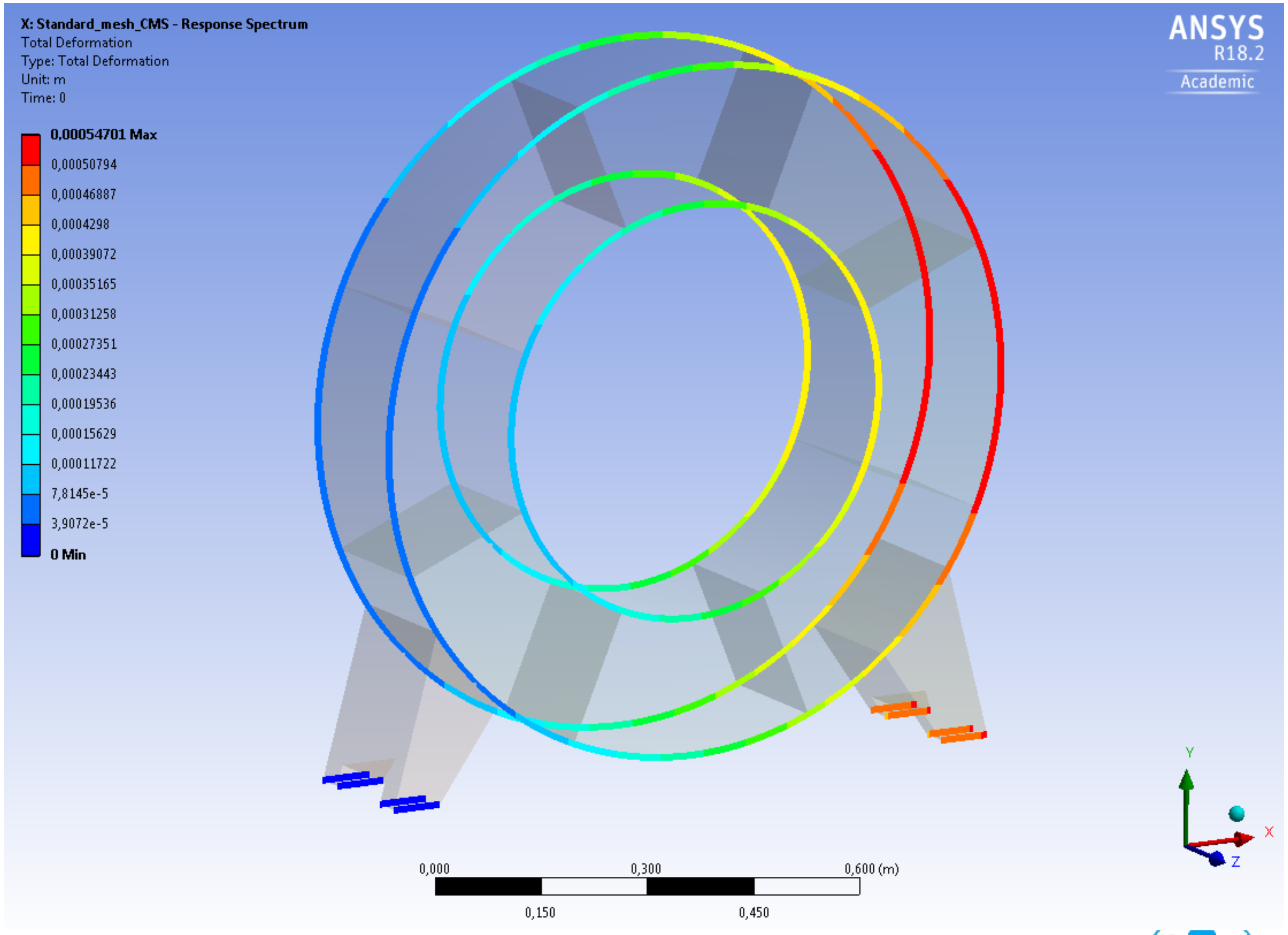
Tabular Data

	Frequency [Hz]	Acceleration [(m/s²)]
1	0,127630737	3,8759833e-002
2	0,129280757	3,9260923e-002
3	0,130973999	3,9775139e-002
4	0,132712183	4,0303003e-002
5	0,134497124	4,0845067e-002
6	0,136330733	4,1401911e-002
7	0,138215029	4,1974148e-002
8	0,140152142	4,2562424e-002
9	0,142144325	4,3167425e-002
10	0,144193961	4,3789873e-002
11	0,14630357	4,4430535e-002
12	0,148475824	4,5090221e-002
13	0,150713556	4,5769791e-002
14	0,153019771	4,647016e-002
15	0,155397663	4,7192295e-002
16	0,157850625	4,7937228e-002
17	0,160382269	4,8706057e-002
18	0,162996443	4,9499948e-002

6 Messages | No Selection | Metric (m, kg, N, s, V, A)

CMS: Response Spektrum Analysis

- Maximum amplitude 0.5mm



Summary & Outlook

- CMS method is our only possibility for a dynamical calculation of complex calorimeter model
- Method validated against full 3D mesh calculation on a toy model that reproduces main features
  - final step still to be cross-checked
- Significant reduction in computing resource needs

- Next: apply to AHCAL structure
- Will also not be straight-forward
  - definition of sub-structures and boundaries needs engineering intuition
  - cross-checks with 3D model only possible up to modal analysis
  - then systematic studies
- However, we now know that we can do it

Backup

Conclusion

- Challenging project, new difficulties encountered at every step
- Circumventing computing power limitations requires brain power

- Next steps:
- Complete analysis
- Outlook:
- Validation
- use existing structures
- on a shaker

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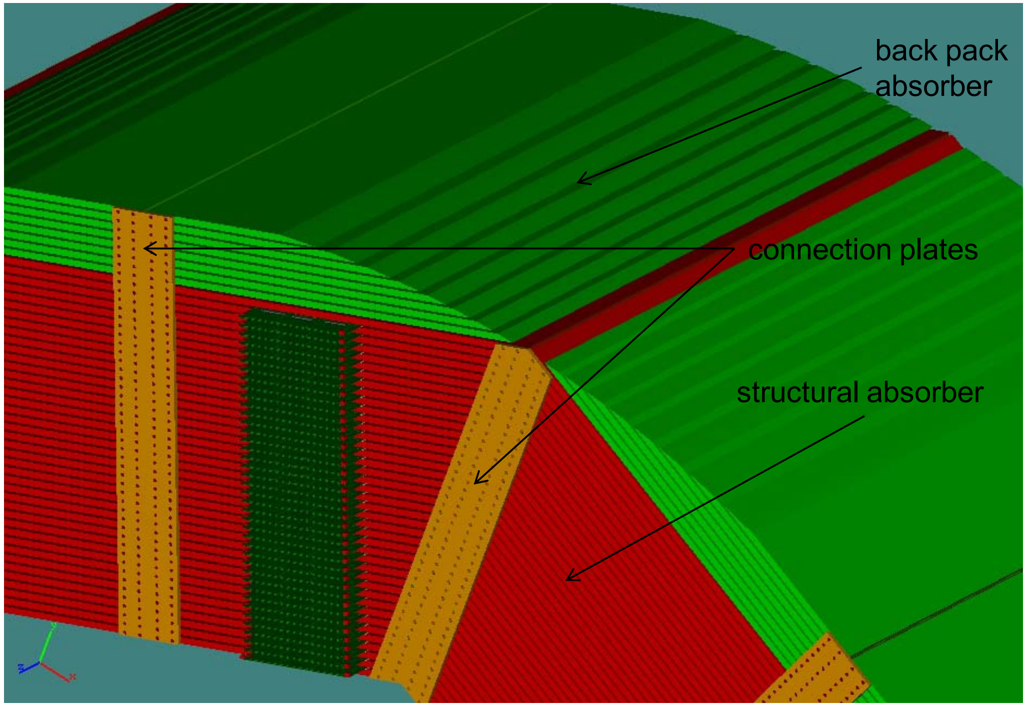
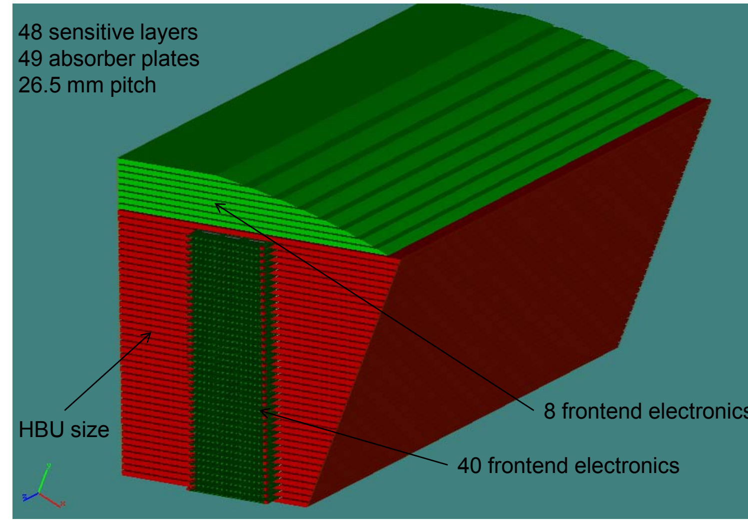
Design challenges

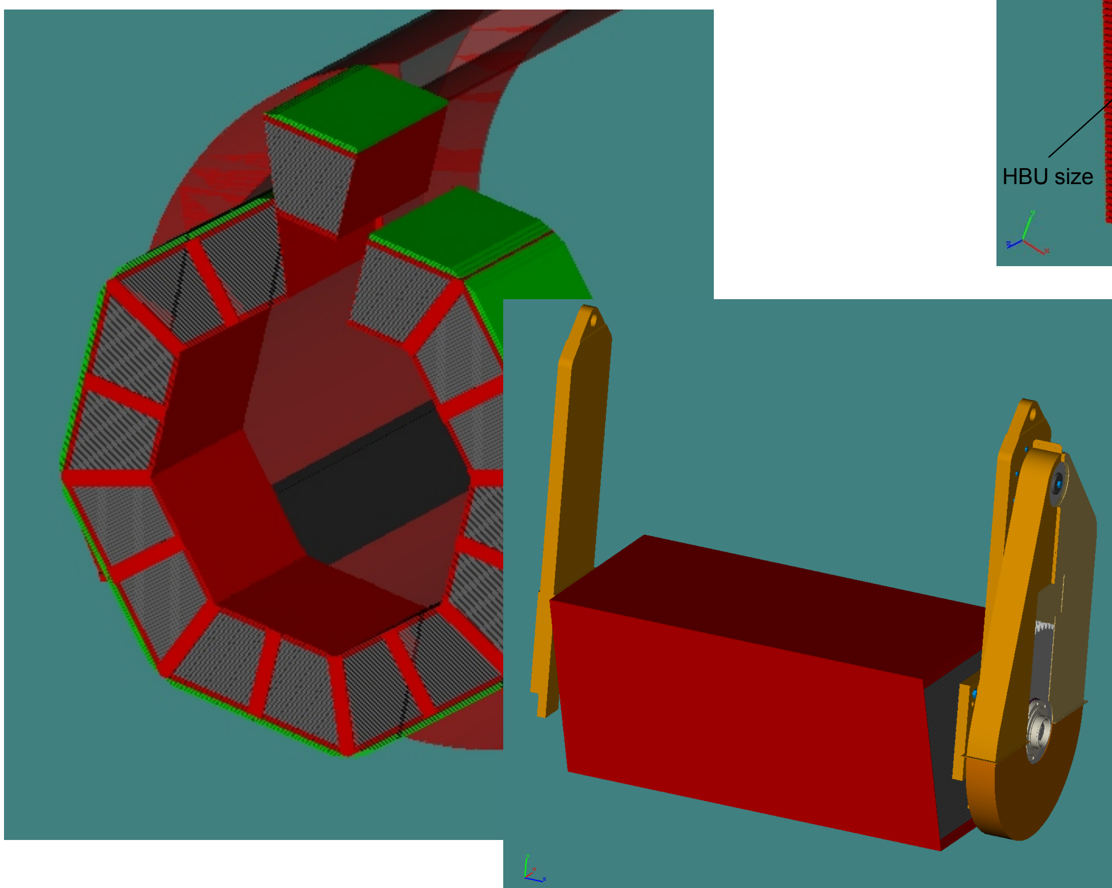
- Stainless steel
- Fine longitudinal sampling
  - 2cm plate thickness only
- No cracks, minimal un-instrumented regions
- Inside coil radius:
  - compact design to maximise no. of hadronic interaction lengths
  - tight tolerances over large dimensions
- Accessible electronics
  - external: short access
  - internal: longer shutdown or upgrade
- Earth quake stability
  - computational challenge



Small modules

- Small sectors (<18t) for easy transport and assembly in situ



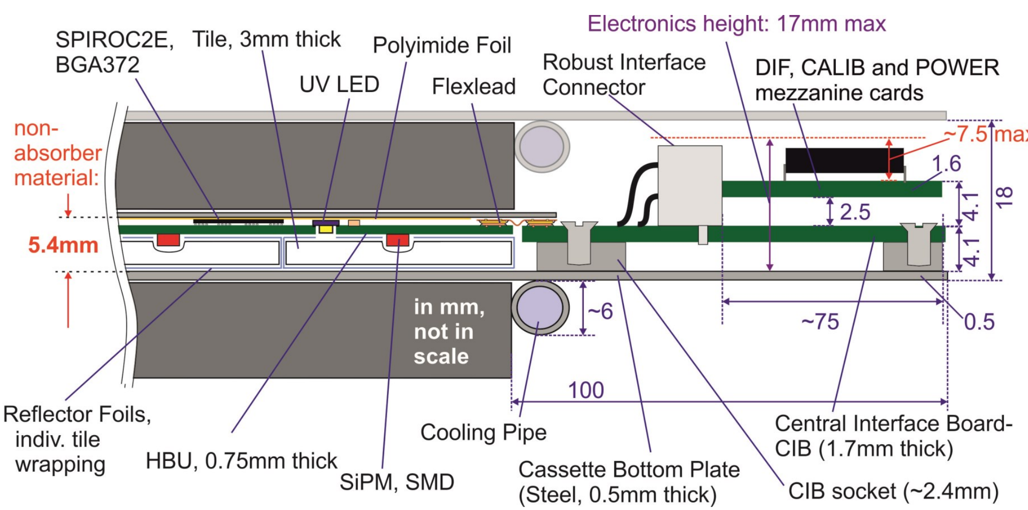


Design features

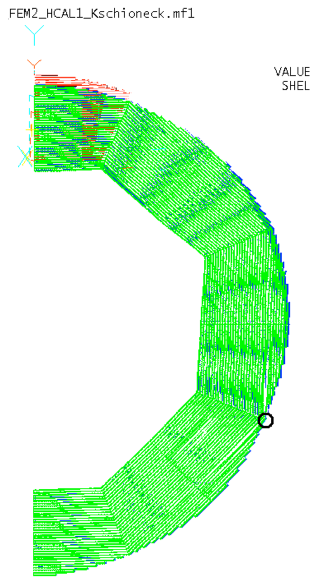
- Uniform sampling along shower axis
- Structure is made from rolled steel plates
  - flatness with roller levelling within 1mm verified
  - no machining: cost effective
- Assembly with screws
  - moderate tolerances
  - damping oscillations
- Thin side walls (5mm)
- 16 phi sectors, 2 rings
- Flexible structure, matched to flexibility of scintillator cassettes
- Varying layer width no problem for scintillator

Cassettes

- Housing the scintillator and electronics active layers
- Made from stainless steel and contributes to absorbing material
- Sum of absorber plate and cassette thickness = 20 m / layer
  - for both AHCAL and SDHCAL
  - material in absorber plate contributes to rigidity of structure
  - material in cassette contributes to load on structure
- AHCAL Physics prototype and early designs had 16 + 2x2 mm
- Present design and new prototype have 19 + 2x0.5 mm
- Weight is 17 kg /m2
  - cf SDHCAL 48 kg / m2 with 2x 2.5 mm cassette

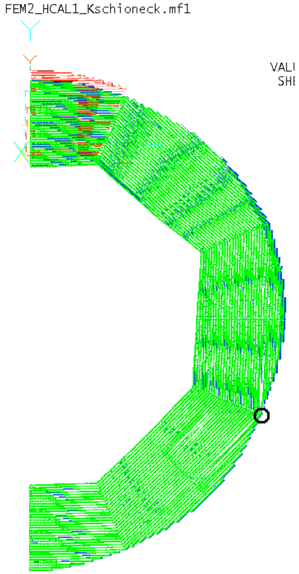


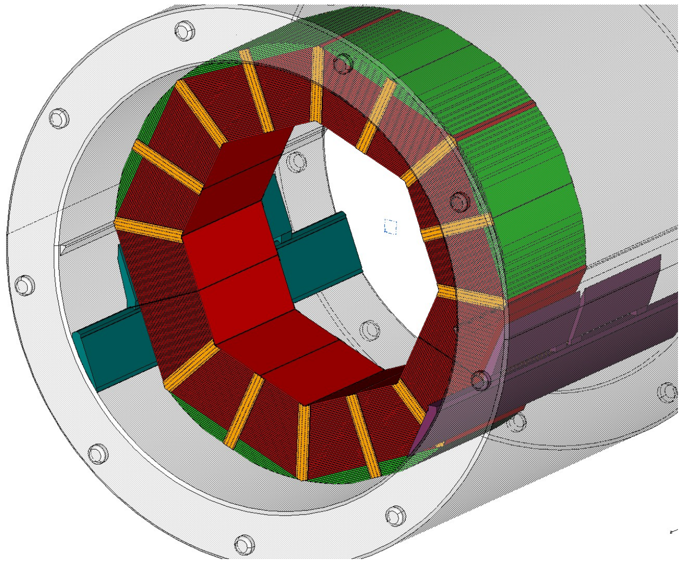
Orientation



- Earlier studies have shown that the “roman arc” structure shows less deformation with a tip at the top than with a flat top
- However, this leads to a conflict with ECAL endcap module structure and square insert

Orientation





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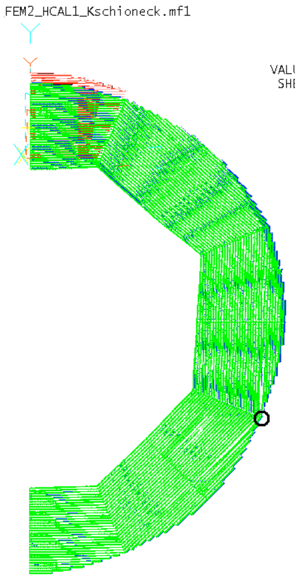

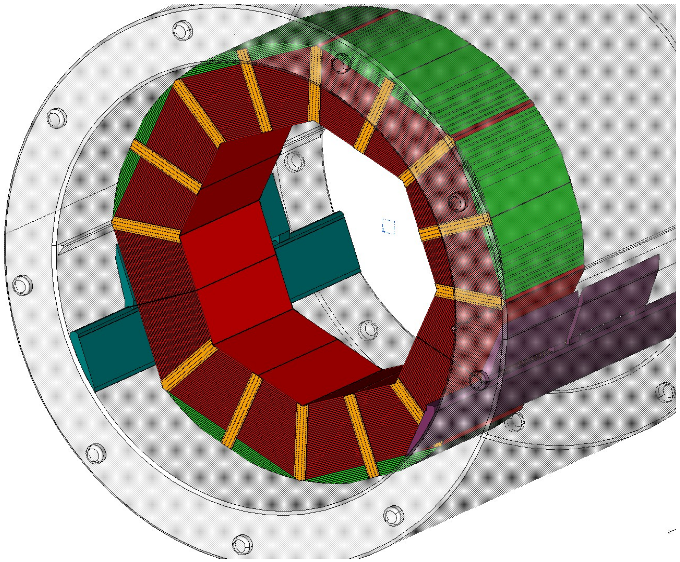

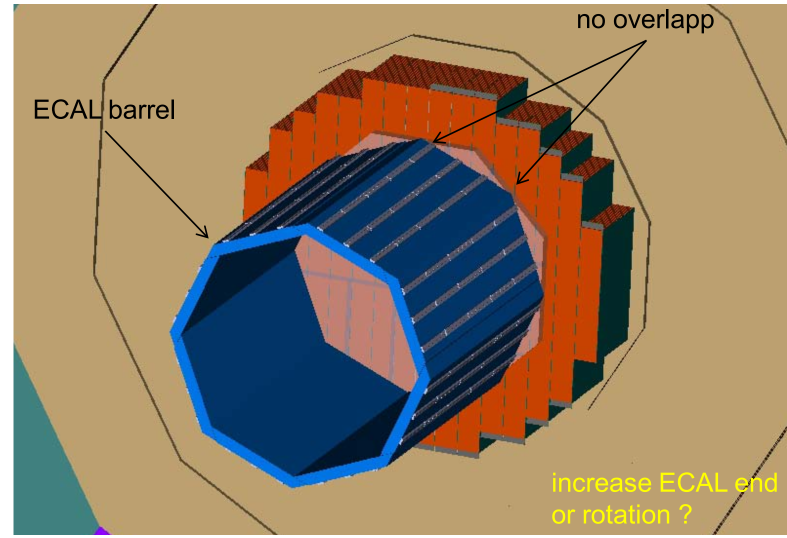

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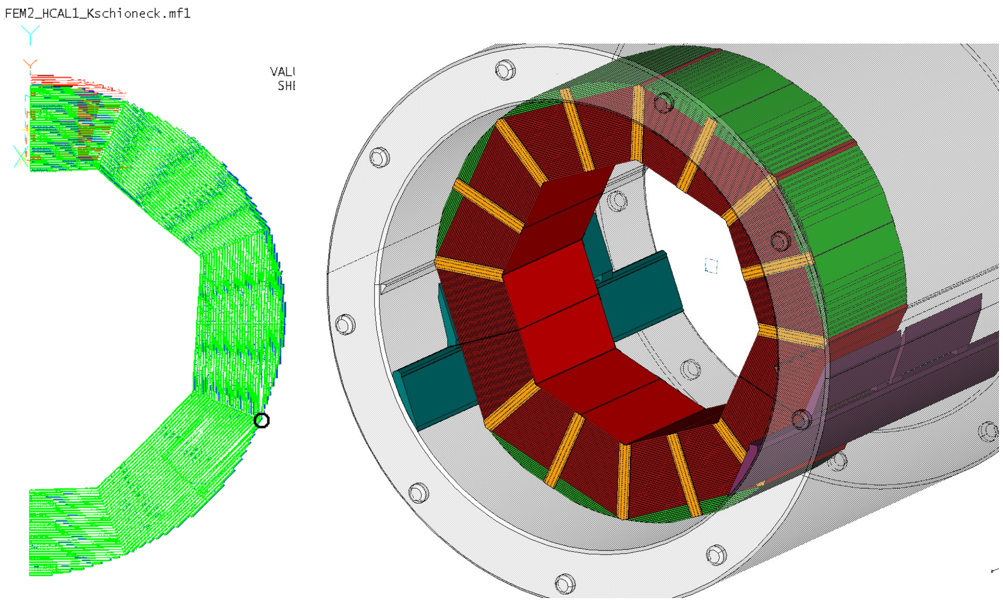

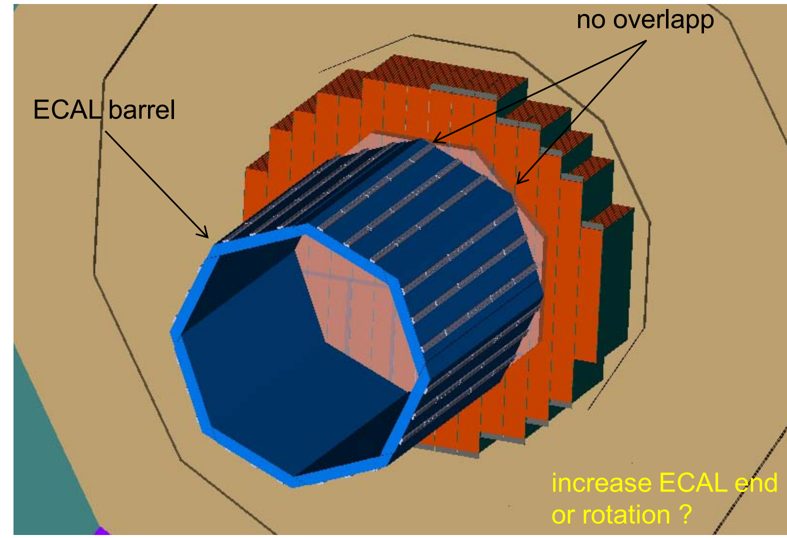

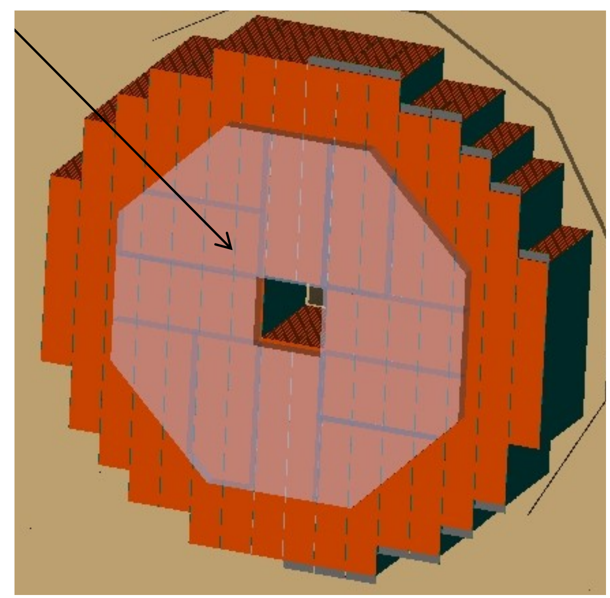

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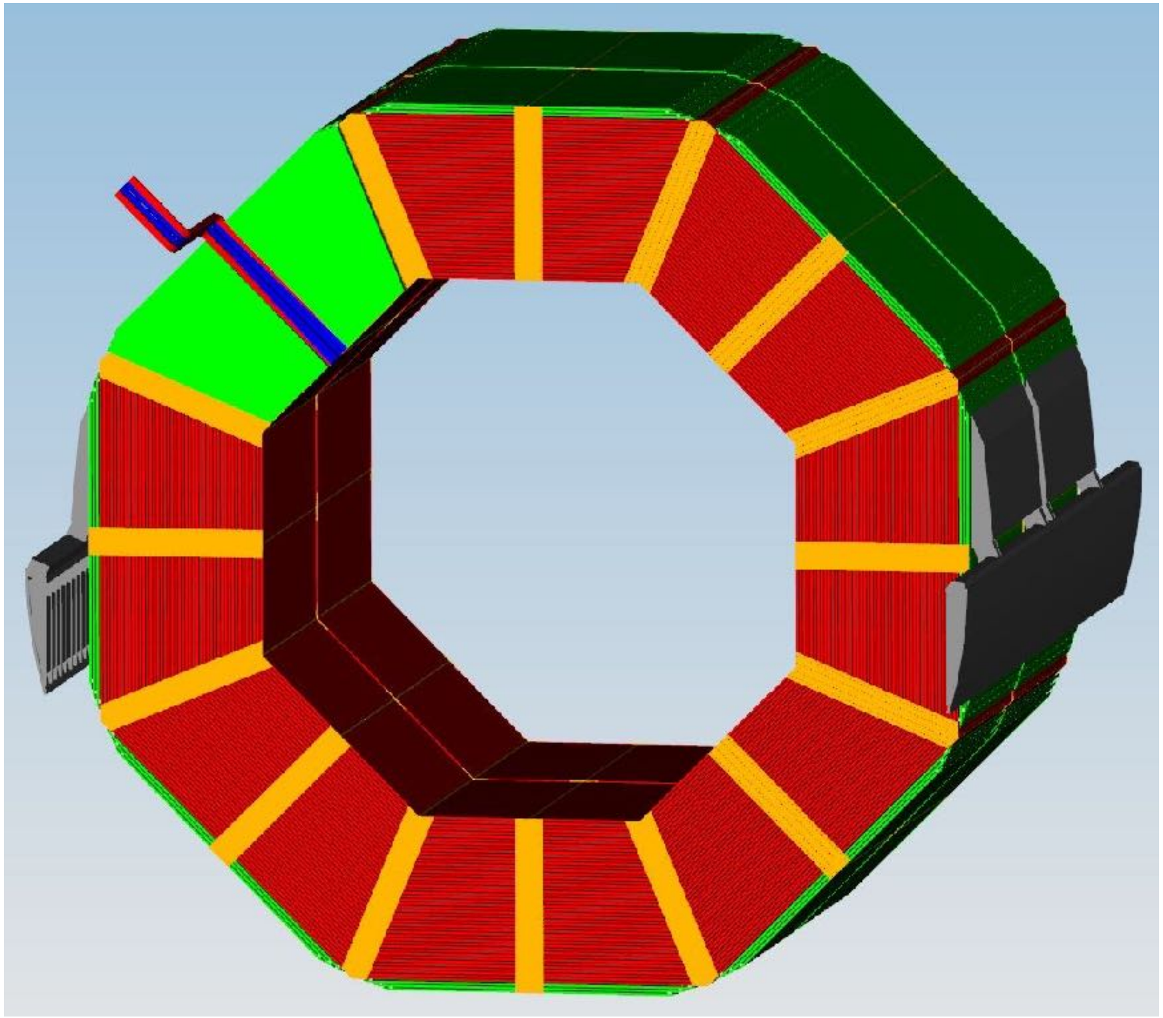
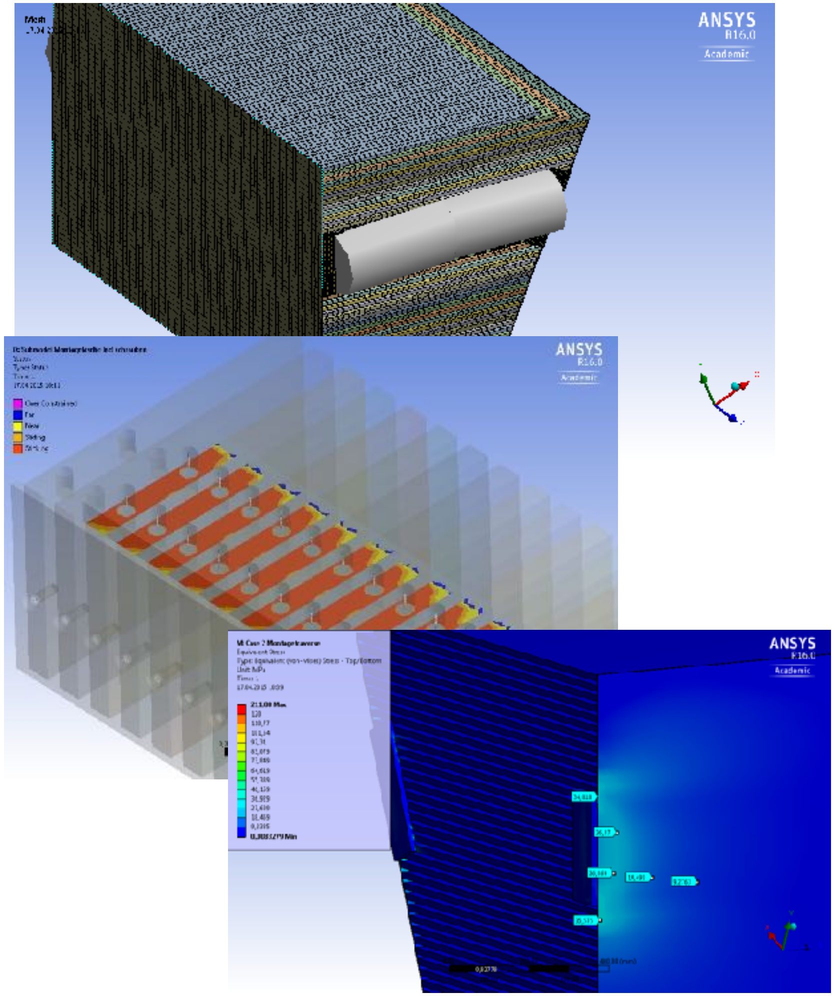
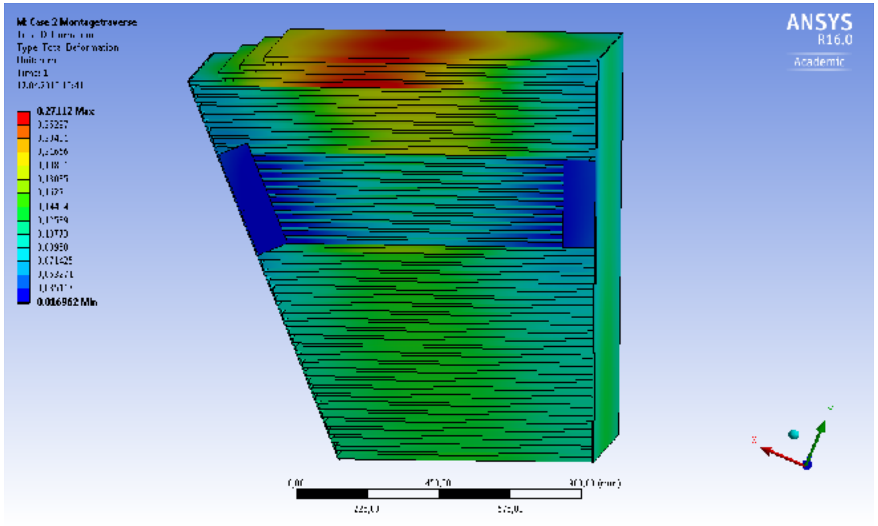
Alternative

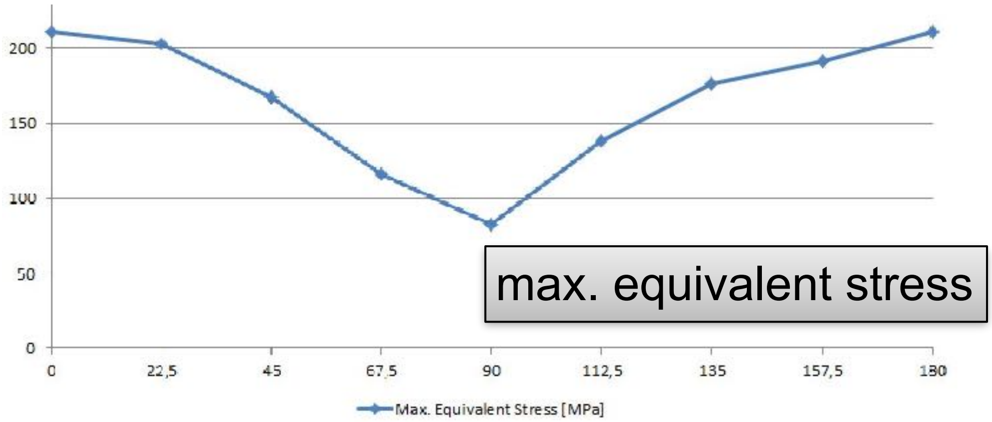
- Integration into cryostat done
- Stability calculation to be re-done
- Expect somewhat larger deformations
- On the other hand, stability improves with
  - up-to-date plate thickness
    - 16 -> 19mm
  - possibly even thicker plates
  - smaller radius



Module installation







- need some modification of module connection pates