FUTURE CIRCULAR COLLIDER

UPDATE ON THE MECHANICAL STRUCTURE OF THE DRIFT CHAMBER FOR THE IDEA EXPERIMENT AT FCC-EE

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On behalf of INFN of Bari and Lecce

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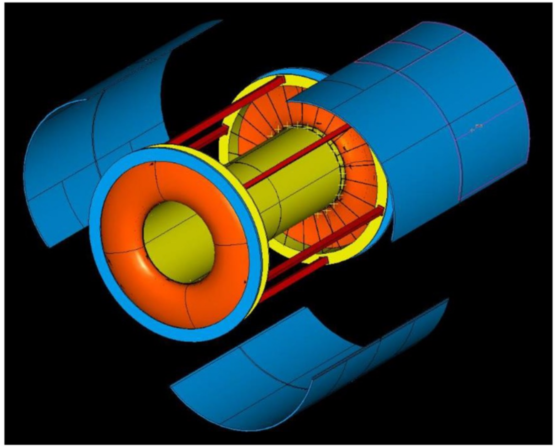
Drift chamber details



- Low mass cylindrical with **2T** solenoid field and a gas mixture **He 90% - iC_4H_{10} 10%**
- Inner radius **R_{in} = 35 cm**, outer radius **R_{out} = 200 cm**, length **L = 400 cm**
- **112 co-axial layers**, at alternating-sign stereo angles, arranged in 24 identical azimuthal sectors
- **343968 wires** in total:
  - 56448 sense wires – 20 μm diameter W(Au)
  - 229056 field wires – 40 μm diameter Al(ag)
  - 58464 field and guard wires – 50 μm diameter Al(ag)

Drift length ~ 1 cm, drift time ~150 ns, σ_{xy} < 100 μm σ_z < 1 mm

Thin wires → **increase the chamber granularity** → reducing both multiple scattering and the overall tension on the end plates

Cluster counting allows to reach dN_c/dx resolution < 3% for particle identification

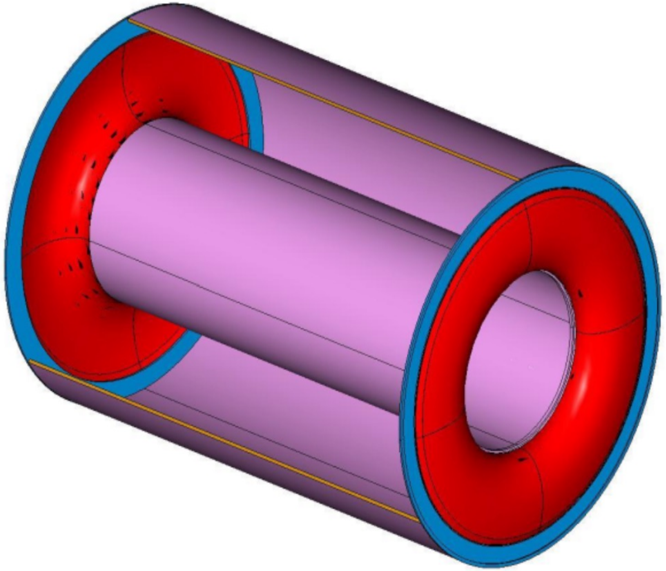
Drift chamber: separation of functions

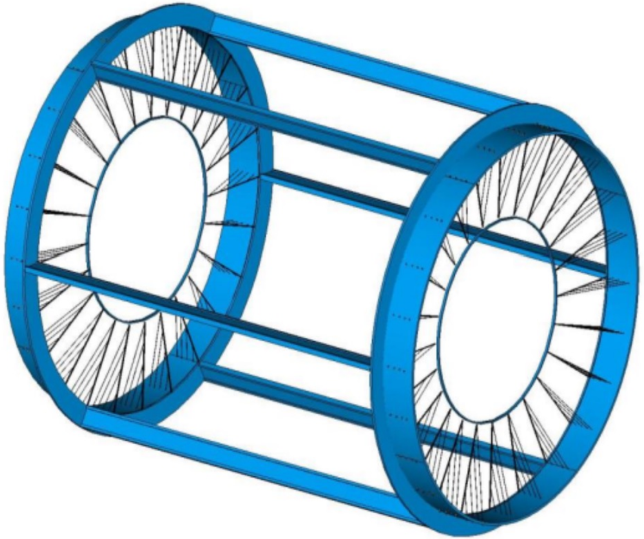
Gas containment

Gas vessel can freely deform without affecting the internal wire position and mechanical tension.

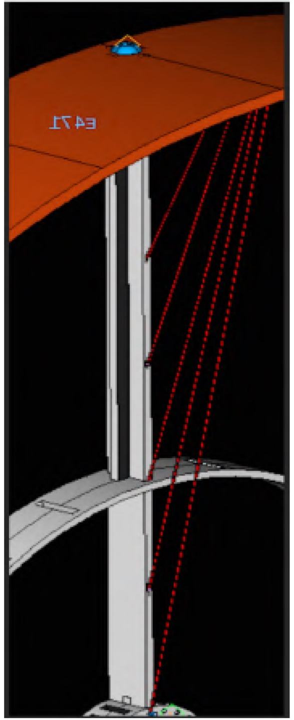
Wire cage

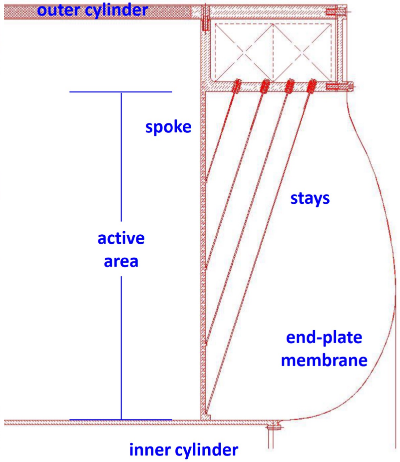
Wire support structure not subject to differential pressure can be light and feed-through-less.

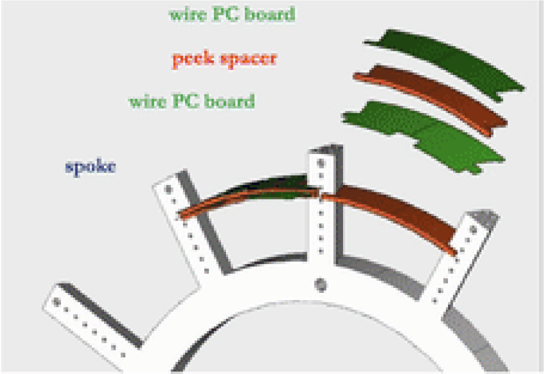


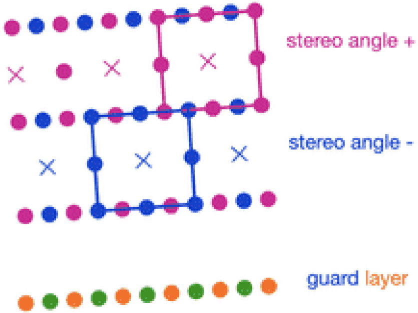


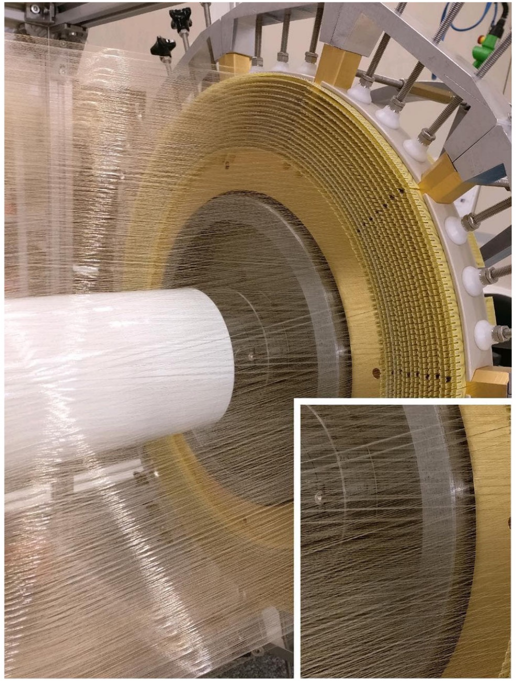
Drift chamber: a closer eye on wire cage



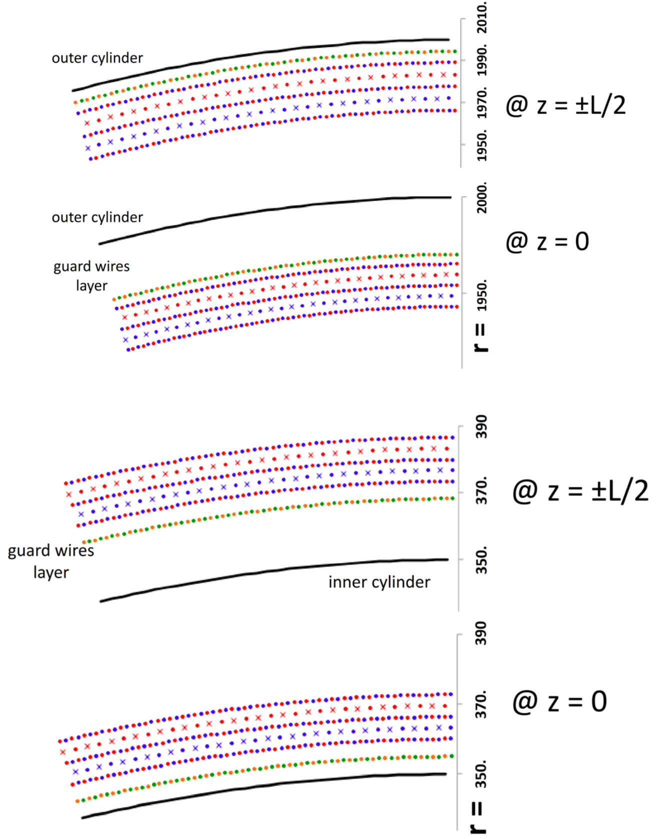








Drift chamber layout



Radii (at z = 0)		
Inner Cylinder	350	mm
Guard wires layer	354	mm
First active layer	356	mm
Last (112th) active layer	1915	mm
Guard wires layer	1927	mm
Outer Cylinder	2000	mm

Radii (at end plate)		
Inner Cylinder	350	mm
Guard wires layer	366	mm
First active layer	369	mm
Last (112th) active layer	1982	mm
Guard wires layer	1995	mm
Outer Cylinder	2000	mm

Active length	2000	mm
Number of super-layers (8 layers) Number of sectors	(14x8) = 112 24	
Number of cells per layer / per sector	192÷816 / 16	
Cell size (at z=0)	11.8 ÷ 14.9	mm
2α angle	30°	
Stereo angle	43 ÷ 223	mrad
Stereo drop	12.5 ÷ 68.0	mm

sense wires	56 448
field wires	284 256
guard wires	2 016
Total wires	342 720

Big Problem to manage!

The accuracy of the position is in the range of **100-200 μm.**
The position of the anodic wire in space must be known with an accuracy better than **50 μm** at most.

The anodic and cathodic wires should be parallel in space to preserve the constant electric field.

A 20 μm tungsten wire, 2 m long, will bow about 100 μm at its middle point, if tensioned with a load of approximately 30 grams

30 gr tension for each wire → **10 tonnes of total load on the endcap**

Simulation studies

Finite Element Method

Development of the **Finite Element Method**

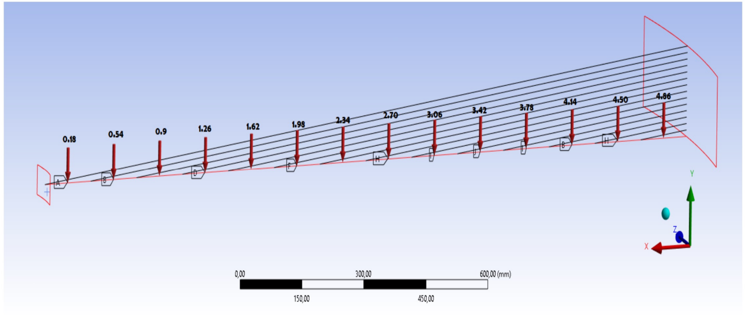
- Element to test**:** surface body modelled with **Shell element**, spokes with **Beam element** and cables with **Truss element**
- Loading to apply: uniformly distributed line pressure
- Boundary conditions: fixing the face of the outer cylinder (undeformable) or fixing the edge of the outer cylinder (deformable)
- Parametric study on mesh size

Design	Mesh	Total deformation Maximum		Equivalent Stress Maximum in Outer Cylinder			Equivalent Stress Average in Outer Cylinder			Maximum Axial Force	Equivalent Stress Maximum	Mesh Min	Mesh Average	Solution Elapsed	Number Mesh
No	Size	Model	OuterCylinder	Averaged	Unaveraged	Nodal diff	Averaged	Unaveraged	Nodal diff	Spokes	Cables	Quality	Quality	Time	Elements
DP 0	50	142.993	16.637	1763	3233	2932	223	286	201	12132	3197	0.13	0.80	5	189
DP 1	45	145.261	17.378	821	1824	1694	219	273	190	12139	2992	0.34	0.89	7	206
DP 2	40	139.848	15.347	1777	3293	2996	226	282	200	12126	3204	0.39	0.92	12	216
DP 3	35	139.495	15.478	1329	3262	2937	213	261	197	12145	3184	0.47	0.93	7	251
DP 4	30	138.848	15.258	1273	2367	2069	212	253	178	12219	2880	0.46	0.92	12	266
DP 5	25	142.349	16.348	1259	2249	1939	194	228	141	12175	2853	0.44	0.95	9	320
DP 6	20	139.726	15.968	2028	2994	2603	157	180	104	12233	3056	0.68	0.97	17	425
DP 7	15	130.568	14.311	1750	3104	3007	162	177	81	12559	3146	0.04	0.96	27	607
DP 8	10	135.217	15.275	2376	2497	2058	143	151	52	12368	3227	0.67	0.99	22	1120
DP 9	5	135.033	14.734	1976	2386	1908	140	144	34	12294	3246	0.60	0.99	77	3838
DP 10	4	133.568	15.002	1860	2249	2043	137	141	30	12476	3221	0.60	0.99	324	5900
DP 11	3	134.377	14.570	2042	2683	2330	139	141	26	12311	3225	0.67	0.99	291	10228
DP 12	2	137.256	15.212	1681	2156	1998	136	139	24	12243	3275	0.67	0.99	2149	22337
DP 13	1	133.266	13.931	2472	2570	1981	131	132	7	12283	3152	0.59	1.00	12892	85442

1 mm mesh size is numerically accurate

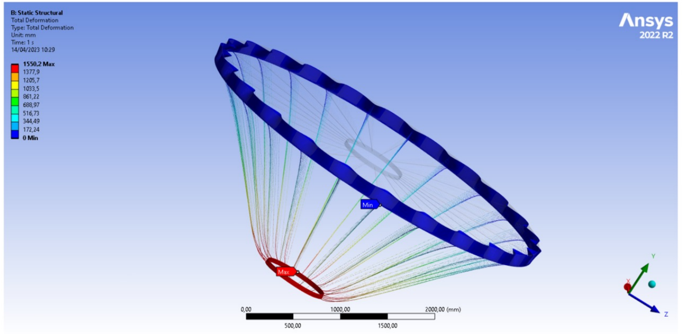
FEM analysis: preliminary stage

A full scale model is built with ANSYS Workbench and loaded with uniformly distributed line pressure.
Materials: carbon for spoke, stainless stell for cables



Linear analysis

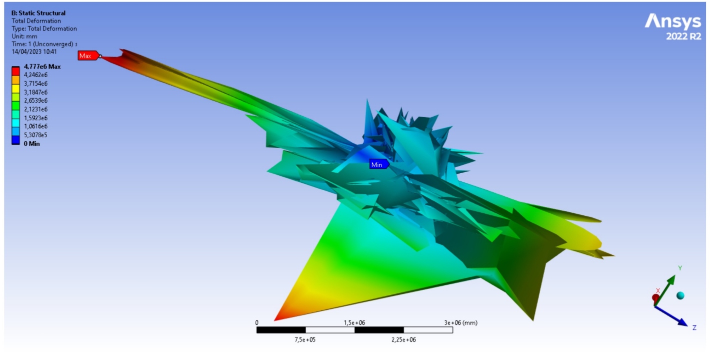
HP: small deformations



The maximum deformation occurs on inner cylinder
1550,2 mm

Non-Linear analysis

HP: Large strain, rotation, stress stiffening

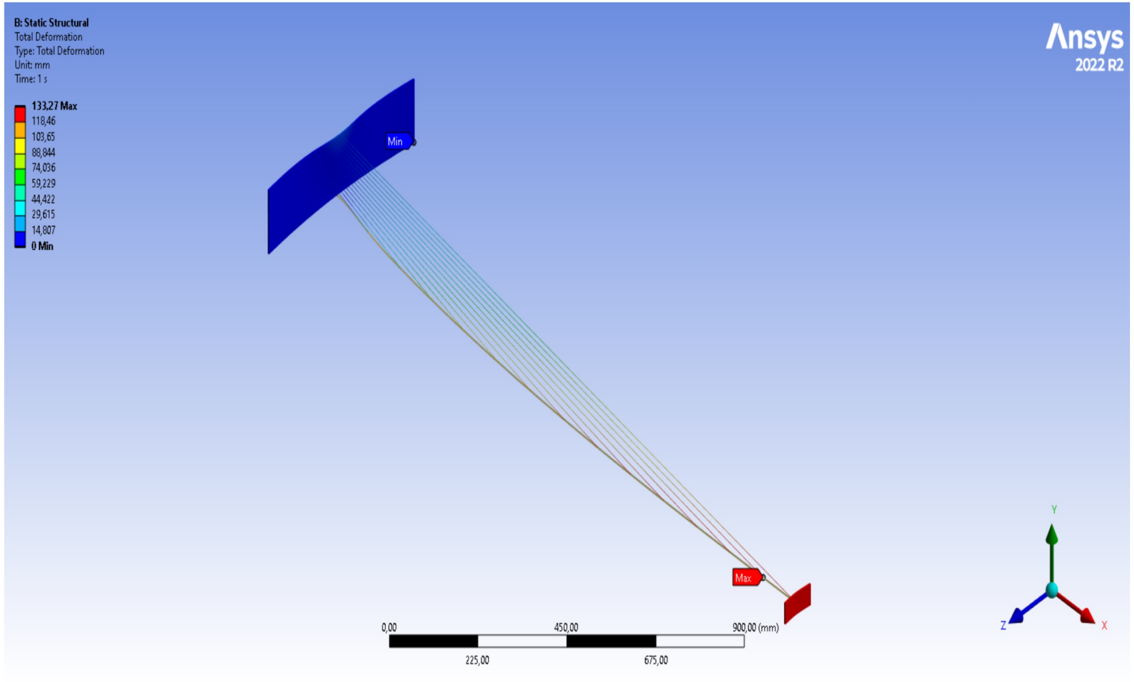


Non-convergent solution

FEM analysis: preliminary stage

Time stepping algorithm

- the time step size are automatically determined in response to the current state of the analysis under consideration.
- estimate the next time step size Δt_{n+1}, based on current t_n and past analysis Δt_n conditions, and make proper load adjustments



The maximum deformation occurs on inner cylinder **133,27 mm**

FEM analysis: preliminary stage

conclusion

Model validation with 3 different models.

1. **Materials**: composite and steel
   Boundary conditions: fixing the lower edge of the outer cylinder.
2. **Materials**: composite and steel
   Boundary conditions: fixing the face of the outer cylinder.
3. **Materials**: Structural steel
   Boundary conditions: fixing the lower edge of the outer cylinder

Conclusion

- The goal is to improve the stiffness of the outer cylinder.
- Good behaviour of the system
- Structure collapsed in terms of stresses as well as meeting the deformation criteria.

	Edge fixed	Face fixed	Edge fixed
Material type	Composite and steel	Composite and steel	structural steel
Max. Total deformation in model (mm)	135.03	96.83	108.37
Max. Total deformation in outer cylinder (mm)	14.73	-	7.84
Min. Axial force in Spokes (N)	-365.87	-1957.80	-1312.40
Max. Axial force in Spokes (N)	12294.00	13497.00	13103.00
Max. Equivalent stress in Cables (MPa)	3245.70	3350.90	3330.50
Avg. Equivalent stress in Cables (MPa)	71.49	89.95	82.88
Max. Equivalent stress in Inner cylinder (MPa)	1646.70	1885.20	1952.90
Avg. Equivalent stress in Inner cylinder (MPa)	280.11	317.02	335.90
Max. Equivalent stress in Outer cylinder (MPa)	1976.00	-	1618.30
Avg. Equivalent stress in Outer cylinder (MPa)	139.77	-	224.33
Mass (kg) per sector	0.69587	0.69587	2.7773
Volume (mm^3) per sector	3.54E+05	3.54E+05	3.54E+05

FEM analysis: Parametric Design Exploration

Design exploration: varying input parameters in some possible ranges in order to see how the system responds - Response Surface Methodology (**RSM**) is used.

The input parametric variables are:

1. Height and thickness of the outer cylinder;
2. Dimensions (breadth and depth) of the spokes;
3. Dimensions (radius) of the cables;
4. Thickness of the inner cylinder.

Change the material: from carbon fiber to o Epoxy Carbon Unidirectional Prepeg

Parameters:	
Height:	200 mm
Innerthickness:	10 mm
Outerthickness:	14.4 mm
Rectangle_B:	9.6 mm
Rectangle_H:	16.6 mm
Circle_R:	1.5 mm

Responses:	
Maximum_Deformation:	22.995 mm (Linear Analysis)
Maximum_Deformation:	21.643 mm (Non-Linear Analysis)
Total_Mass:	2.6269 kg per sector
Total_Deformation_Load_Multiplier:	2.2068

Conclusion

- Select the optimal dimensions of the drift chamber
- Total deformation of the model from **135,03 mm** to **21,64 mm.**

It is still **too high!**

FEM analysis: Composite material

We develop, validate and calibrate a **Layered Composite Material** made from Epoxy carbon prepeg with the fibres oriented at 0°

Component Type	Orientation of Ply	No. of Ply	Total thickness (mm)
Outer Cylinder	0°	72	14.40
Inner Cylinder	0°	50	10.00
Spokes	0°	83	16.60

		Spokes			Outer Cylinder		
	Total Load (N)	Min (mm)	Max (mm)	Average (mm)	Min (mm)	Max (mm)	Average (mm)
Composite design	100000	0	24.339	14.757	0	1.2846	0.4742
Monolithic design		0	25.385	15.375	0	1.2649	0.33894
Composite design	70000	1.23E-03	17.913	10.681	0	0.9274	0.340
Monolithic design		0	18.309	10.922		0.8913	0.24046
Composite design	60000	1.53E-03	15.63	9.2621	0	0.8034	0.29447
Monolithic design		0	17.206	10.256		0.84069	0.22506
Composite design	50000	1.28E-03	13.26	7.8075	0	0.67658	0.24747
Monolithic design		0	13.356	7.8823	0	0.64765	0.1733
Composite design	30000	7.73E-04	8.271	4.801	0	0.41502	0.15116
Monolithic design		0	8.1818	4.7763	0	0.39178	0.10481
Composite design	10000	2.59E-04	2.8733	1.6412	0	0.14145	5.13E-02
Monolithic design		0	2.7856	1.6081	0	0.13163	3.52E-02

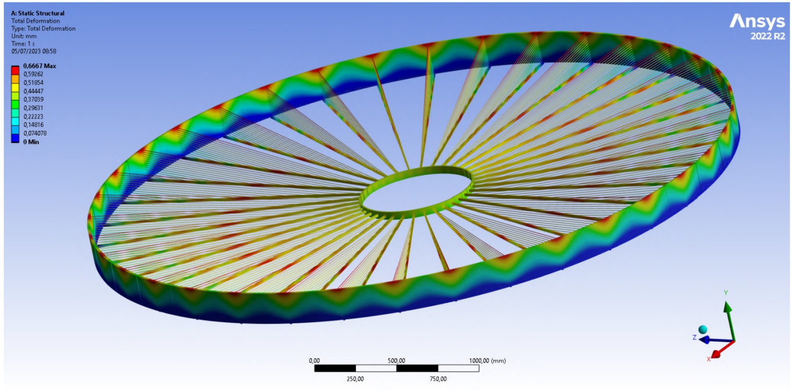
FEM analysis: Prestressing

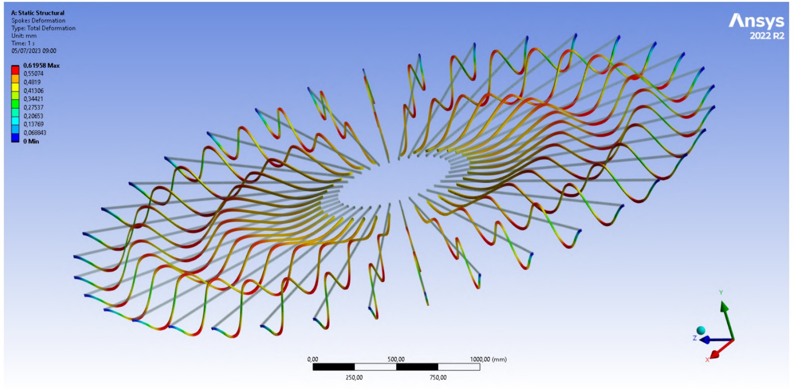
Goal: minimizing the deformation of the spokes using prestressing force in the cables

Finding the correct prestressing force in 14 cables → solving 15 dimensional optimization problem

Total deformation (mm) of the drift chamber with the edge of the outer cylinders fixed

No prestress		Prestress in the cables	
Spokes	Outer cylinder	Spokes	Outer cylinder
14.099	0.63	0.62	0.67





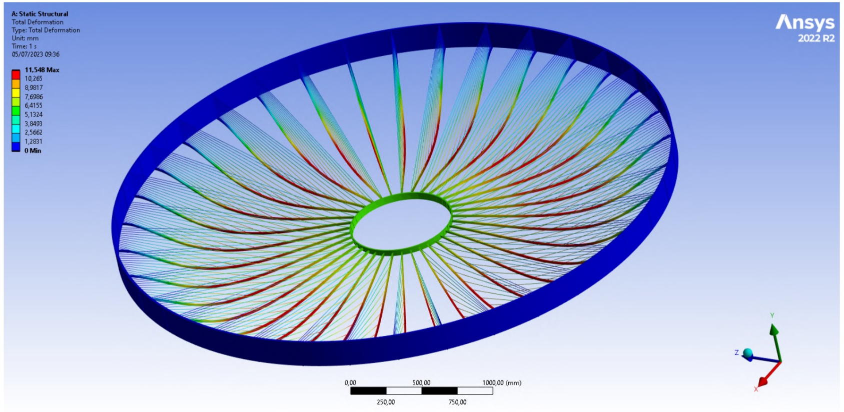
FEM analysis: Prestressing

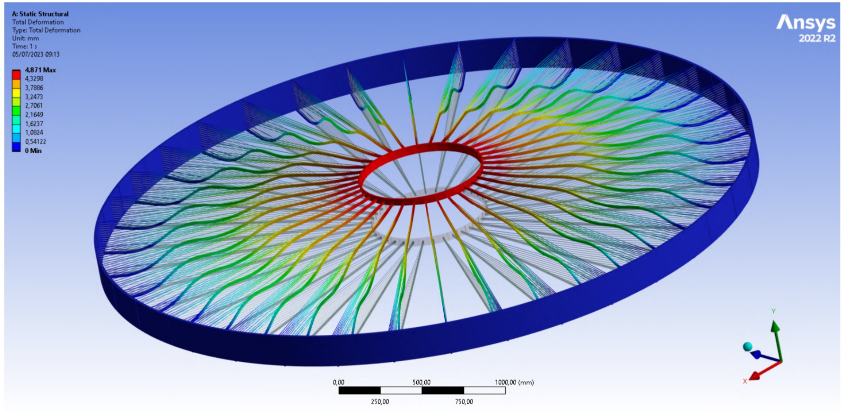
Constraint: **face of the outer cylinders fixed**

- drift chamber pulled upwards
- very high total deformation

Total deformation (mm) of the drift chamber with the face of the outer cylinders fixed	
No prestress	Prestress in the cables
Drift chamber	Drift chamber
11.54	4.871

Accurate definition of **boundary conditions** on the overall deformation of the spoke



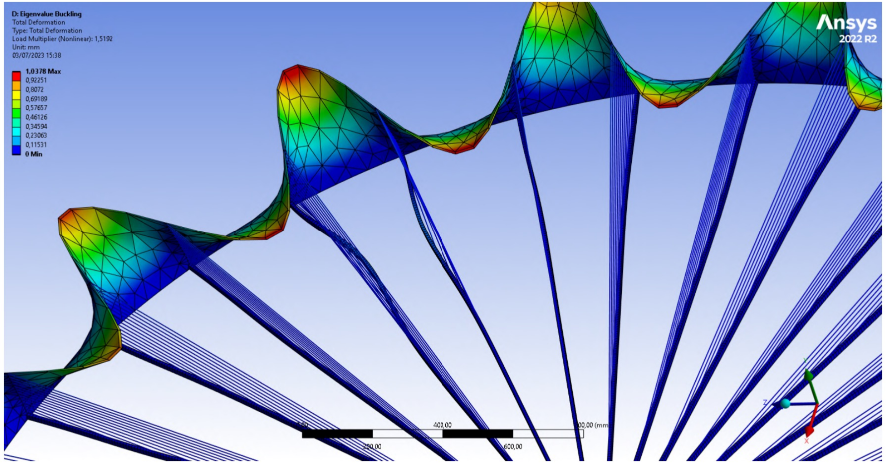


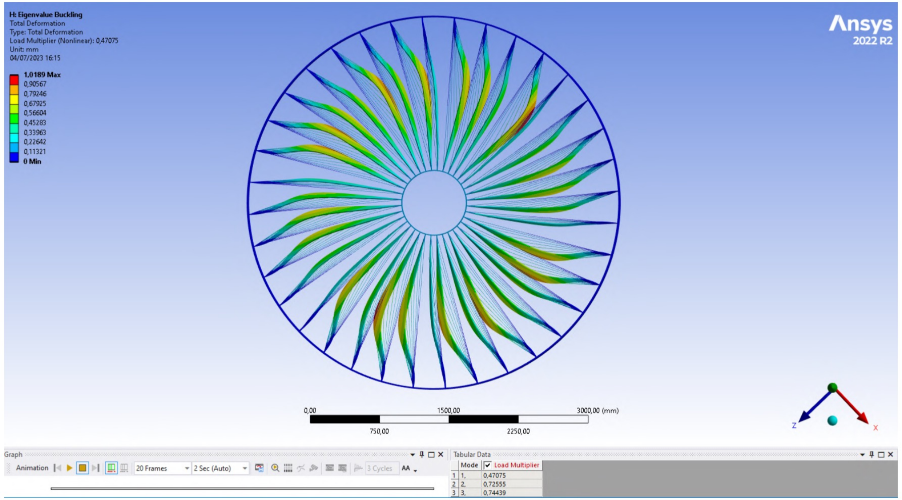
FEM analysis: Buckling analysis

Buckling behaviour is essential for us to ensure the **safety** and **reliability** of this drift chamber.

Linear buckling analysis assumes small deflections and linear material behavior.

Failure primarily occurs in the spokes while the outer cylinder remains undamaged (right).



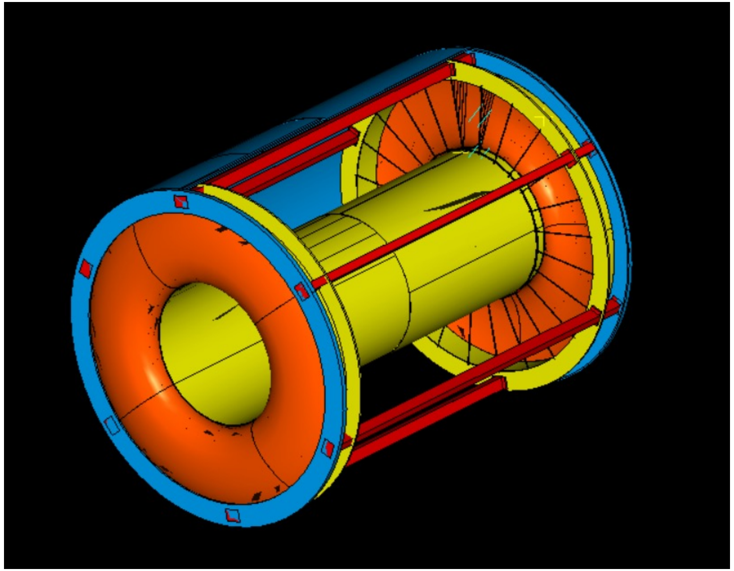


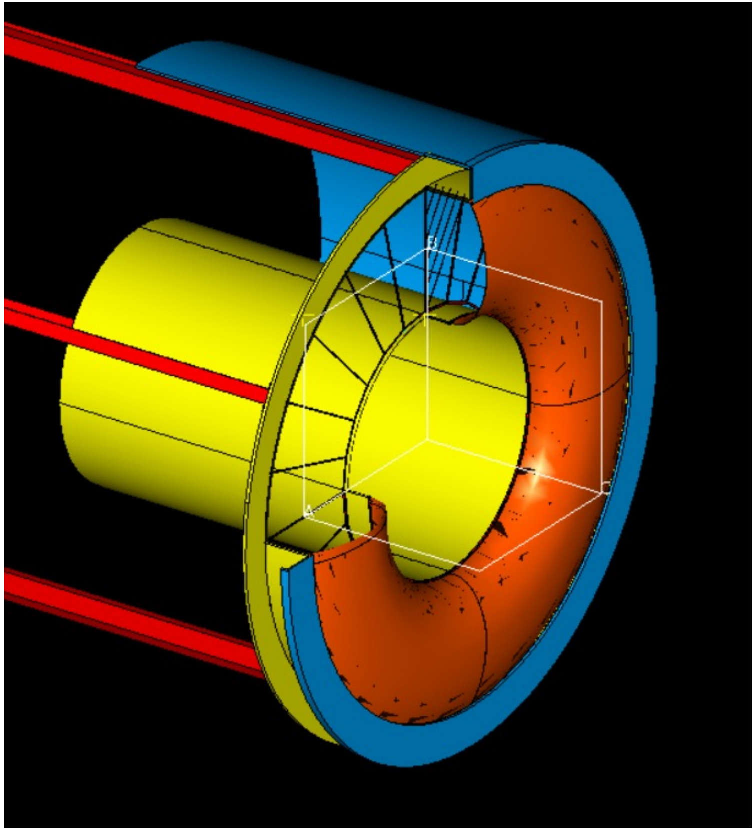
- Spokes interact with the cylinder
- Deformation near the outer cylinder (left)

Realistic model (ongoing)

Realistic model: overview

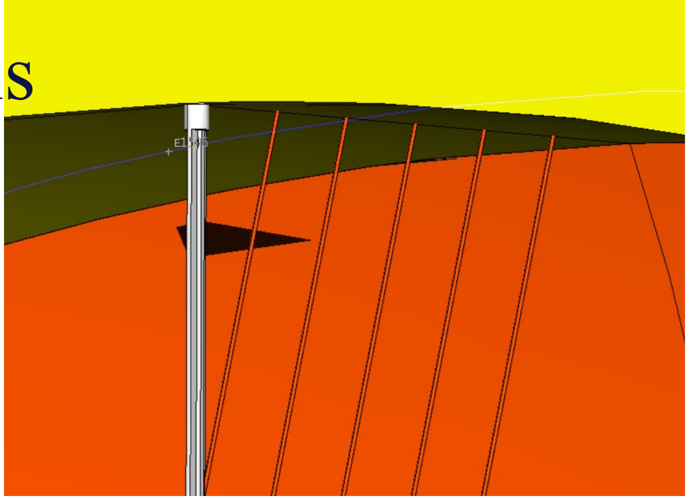
1. Mechanically accurate
2. Precise definition of the connections of the cables on the structure
3. Connections of the wires on the PCB
4. Location of the necessary spacers
5. Connection between wire cage and gas containment structure

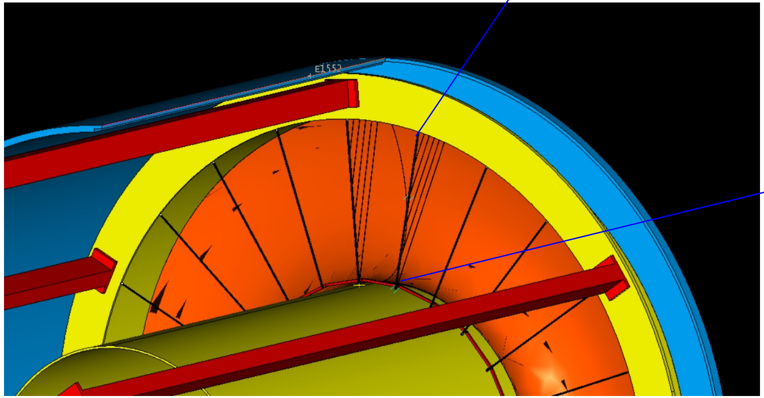




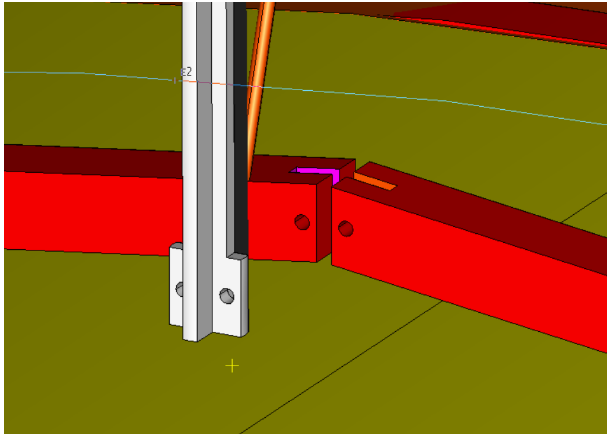
Realistic model: details

Upper junction: cross profile spoke and supporting cables





Lower junction: joint design



Future studies

What happens now?

Our main goal was to limit the deformation of the spokes to **200 µm** while ensuring the structural integrity.
The structure exhibited a deformation of **600 µm**

Next developments

- Try alternative approaches, including **prestressing of spokes**
- Investigate various composite **failure criteria**
- Extend **nonlinear** buckling analysis
- Depth understanding of our **composite structure**

- **Real model design in collaboration with EnginSoft**

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