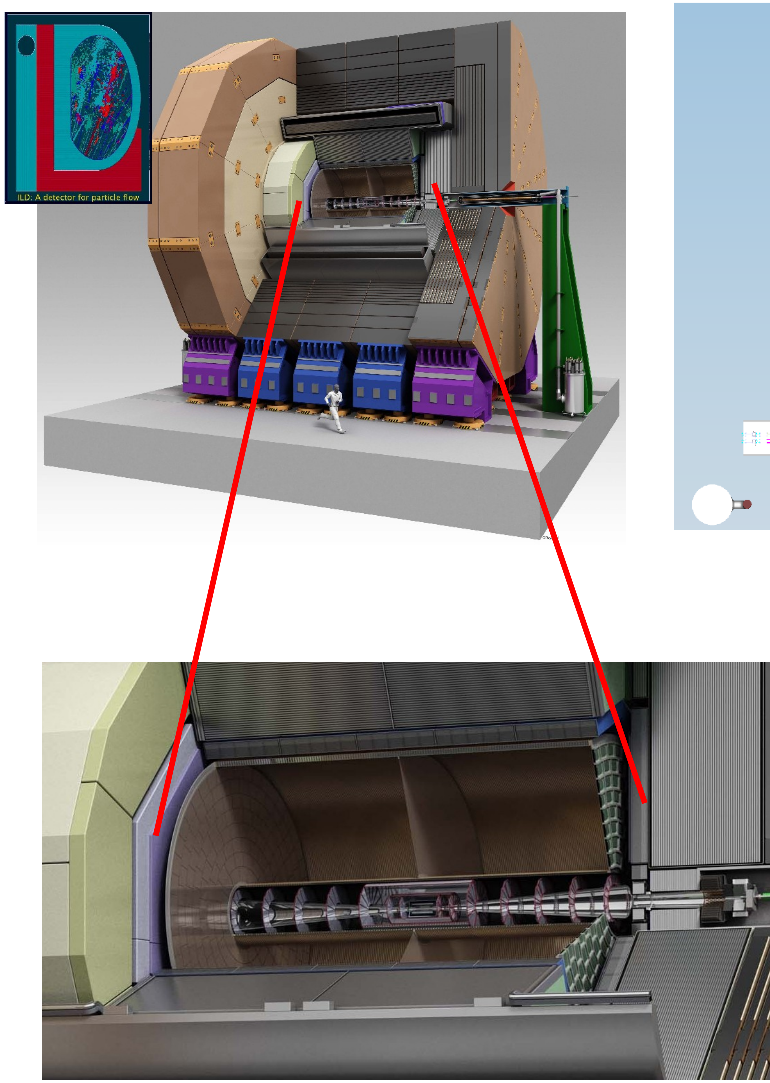
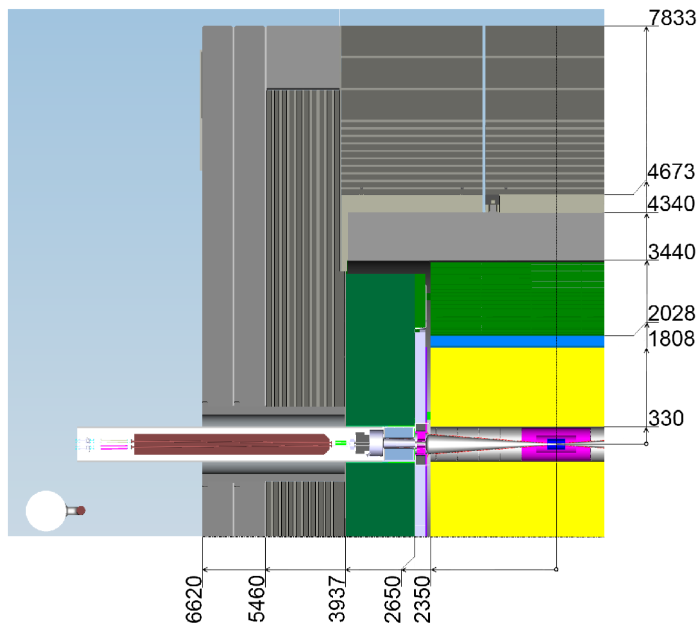
Studies on mechanical aspects of the ILD TPC

J. Kaminski
for the LCTPC collaboration

ECFA Detector R&D panel
Hamburg, 4.11.2013

Geometrical Layout of the ILD TPC





<u>Conclusion in LOI:</u>
... for the range of *B* and *R* spanned by the LDC and GLD detector concepts, the differences in momentum resolution are relatively small … the tracking resolutions depend much more strongly on the sub-detector technologies and tracking system layout than on the global parameters (*B* and *R*) of the detector.

Size of Detector	Overall Size	Sensitive Volume
Length	2.350 m	2.247 m
Inner Radius	0.329 m	0.395 m
Outer Radius	1.808 m	1.739 m

Material Budget

A low material budget is a strong argument for a TPC.

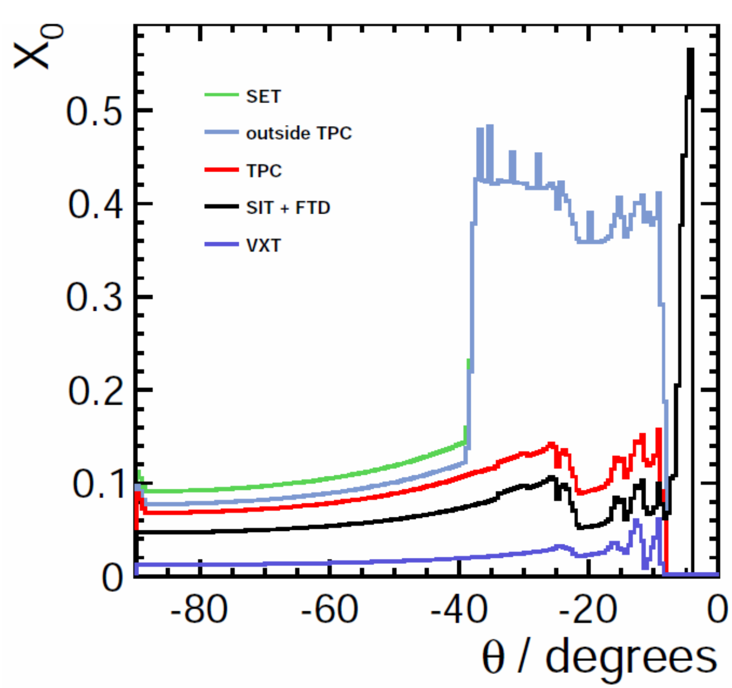
0.05 X_0 in the barrel region

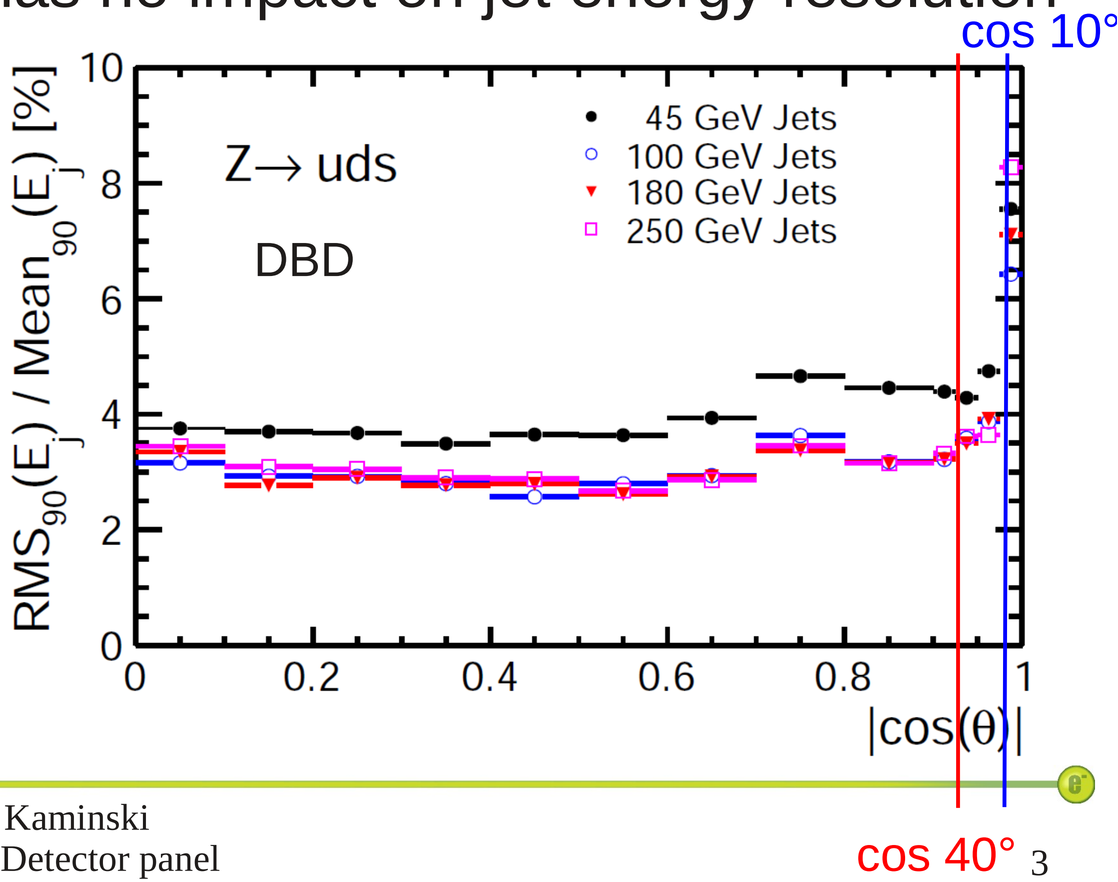
0.25 X_0 in the endcap region

	45 GeV	100 GeV	250 GeV
15% X_0	0.28±0.01	0.32±0.01	0.47±0.02
30% X_0	0.30±0.01	0.31±0.01	0.47±0.02
45% X_0	0.30±0.01	0.32±0.01	0.52±0.02
60% X_0	0.32±0.01	0.33±0.01	

TPC – PRC2010 report

=> Increased material in endcap has no impact on jet energy resolution



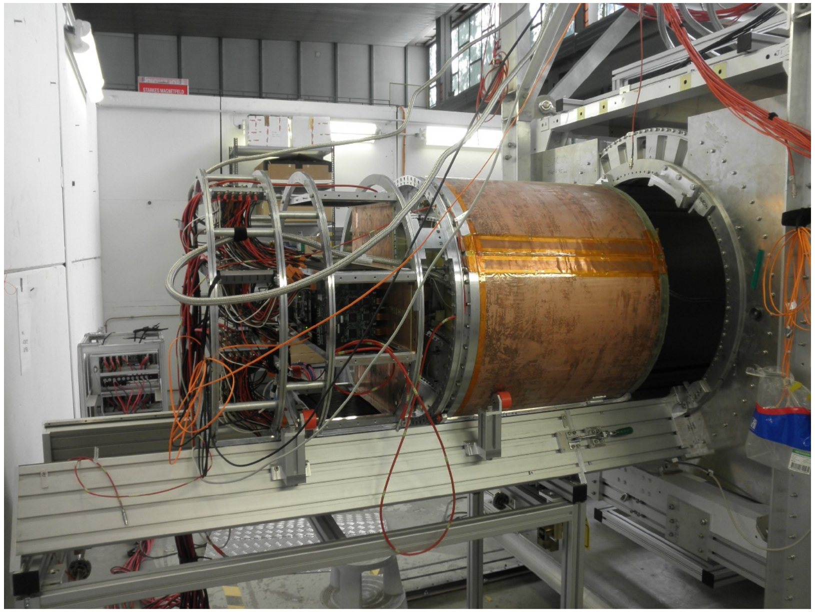


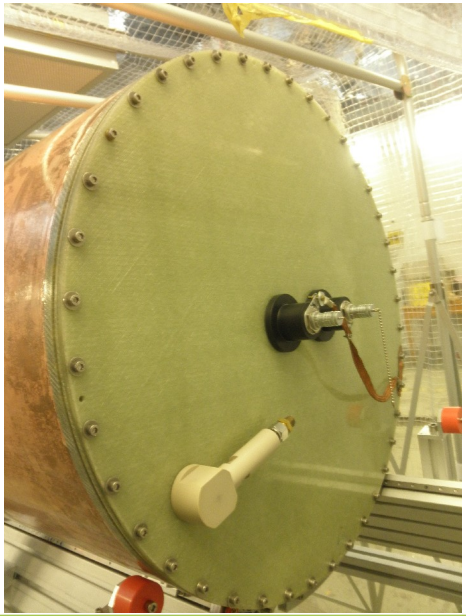
Large Prototype

Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues.

But serves also for first experiences to build a large TPC.

Requirements: - Must fit in PCMAG (outer radius: < 77 cm)
- Minimal material budget
- Electrical insulation up to 25 kV
- High precision and stability

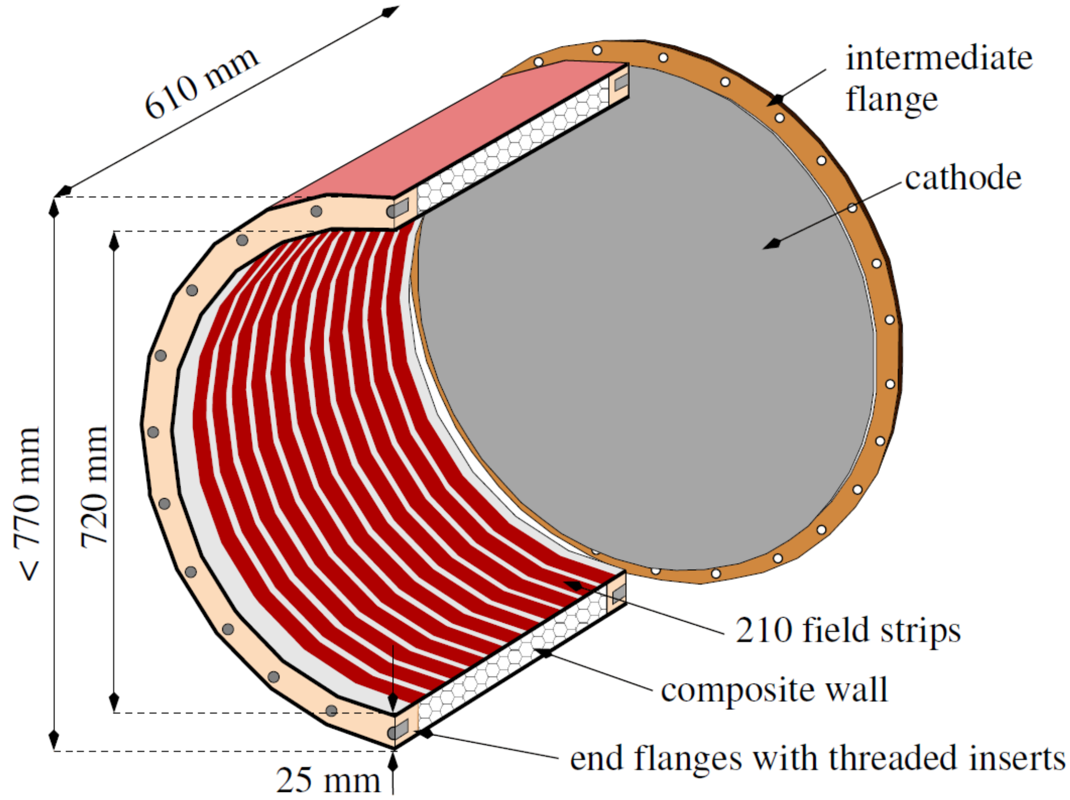


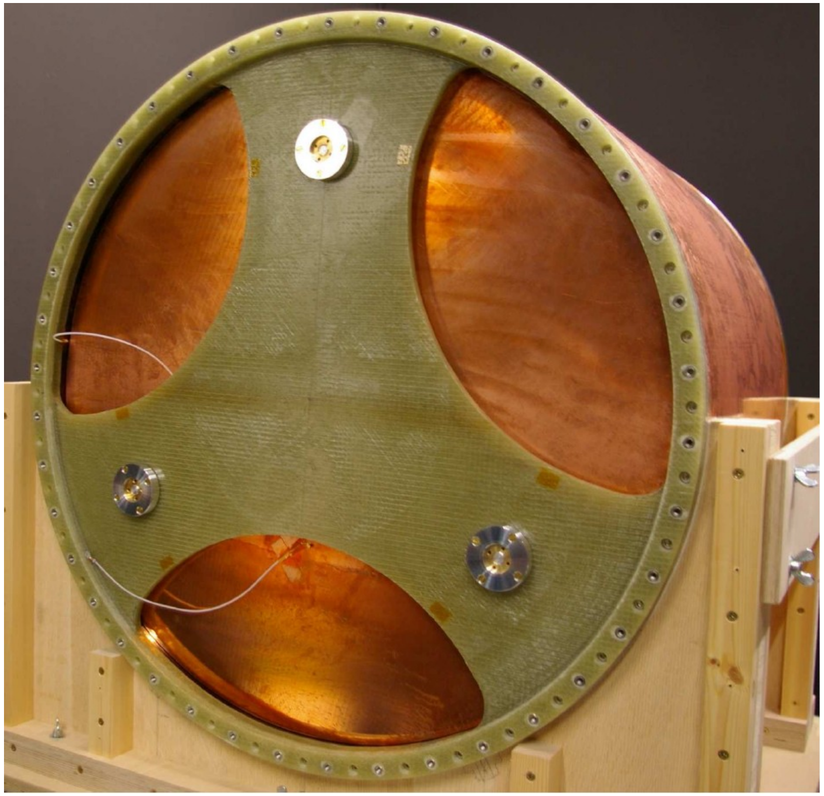


Field Cage

Field Cage of the LP

Size of detector	Overall Size	Sensitive Volume
Length	61 cm	57 cm
Outer Radius	77 cm	72 cm



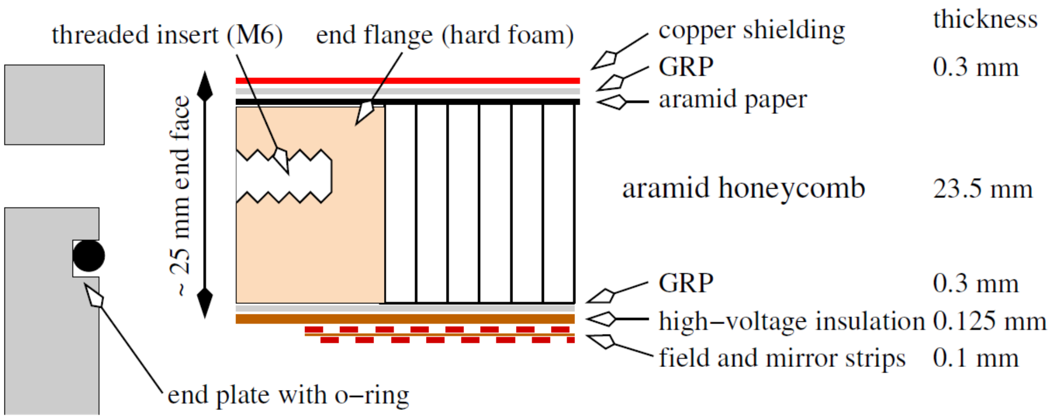


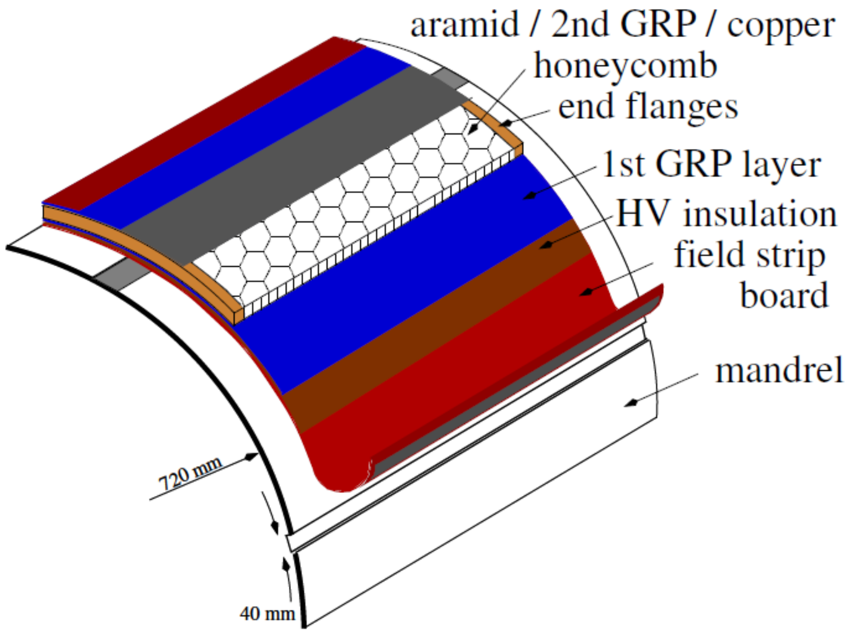
Layers

Field cage consists of a multi-layer structure.

All layers were laminated on a reusable mandrel.

Construction was done in co-operation with a specialized company.





Material Budget

Material budget of 1.21 % X_0 was reached.

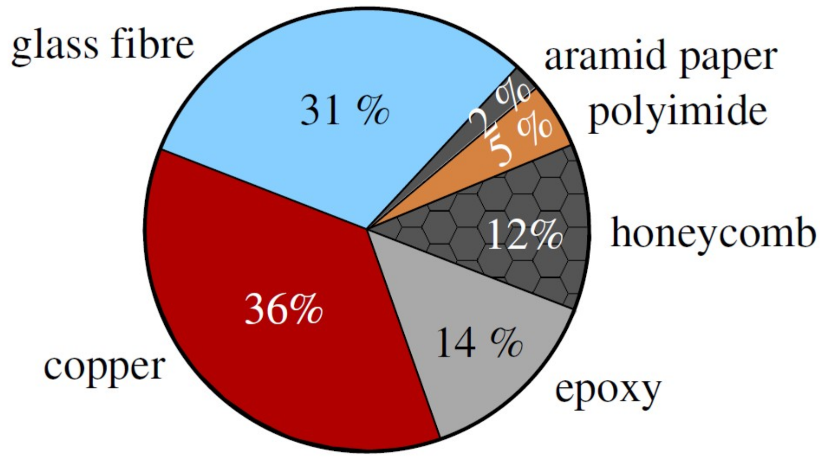
Need 1 % X_0 for the inner field cage of the ILD TPC.

=> Within reach.

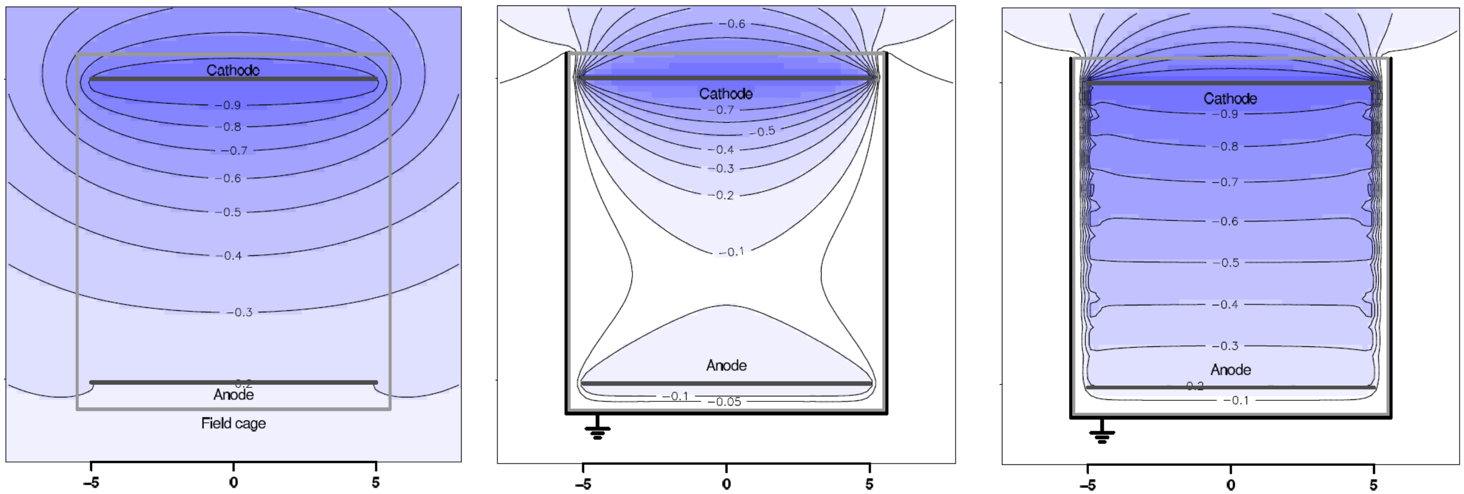
Copper is a large fraction of the material budget.

→ Could be improved.

layer of the wall	d [cm]	X_0 [cm]	d/X_0 [%]
copper shielding	0.001	1.45	0.07
polyimide substrate	0.005	32.65	0.02
outer GRP	0.03	15.79	0.19
aramid paper	0.007	29.6	0.02
honeycomb	2.35	1383	0.17
inner GRP	0.03	15.79	0.19
polyimide insulation	0.0125	32.65	0.04
mirror strips	$0.8 \cdot 0.0035$	1.45	0.19
polyimide substrate	0.0050	32.65	0.02
field strips	$0.8 \cdot 0.0035$	1.45	0.19
epoxy glue	$\approx 6 \cdot 0.007$	≈ 35.2	0.12
		$\sum$	1.21

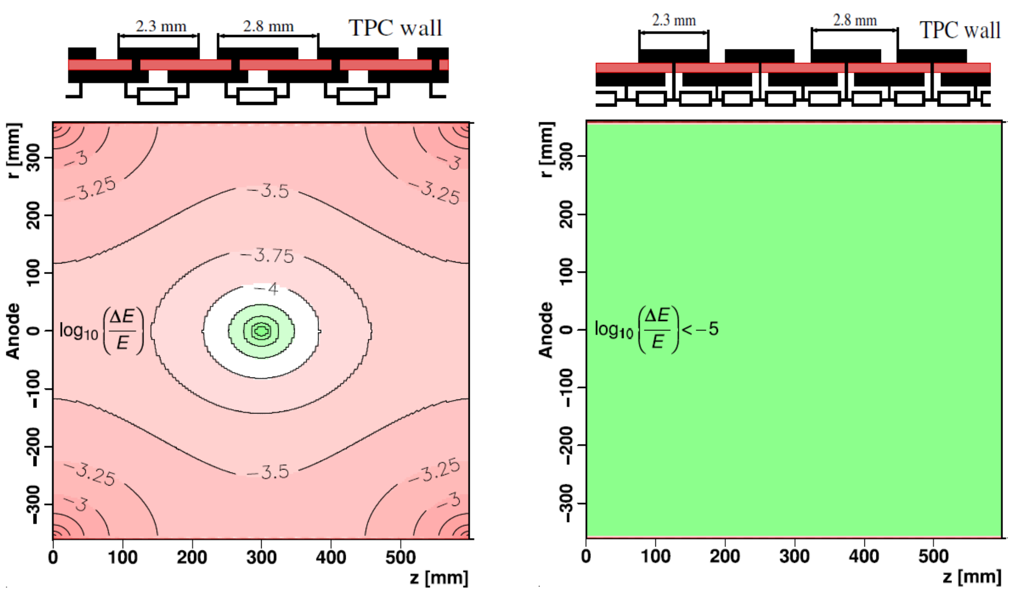


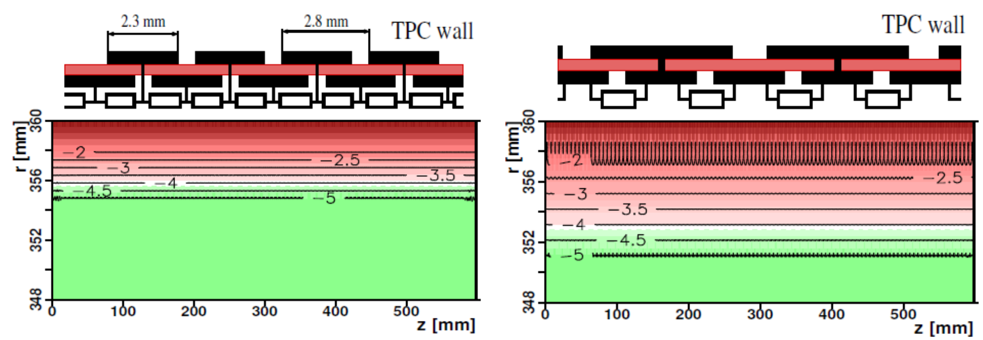
Field Strips



Requirement on field homogeneity is 2×10^{-4}.
Need mirror strips.

Parallel plate capacitor + ext. shielding (gnd) + field strip and resistors



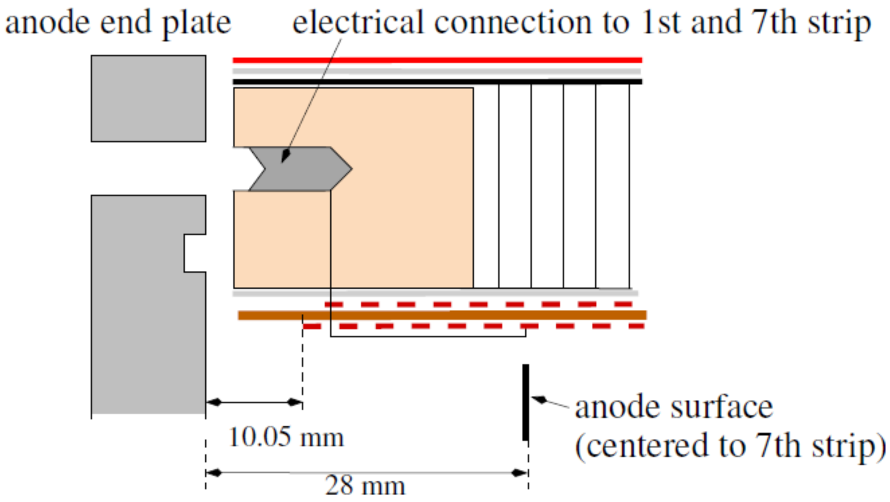


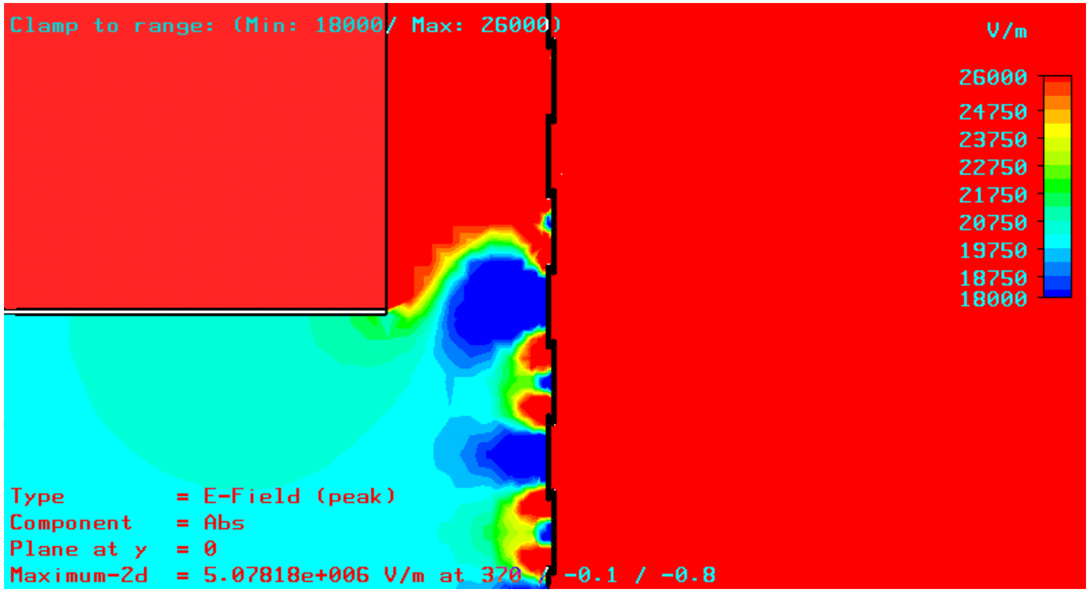
- 210 field and mirror strips
- Resistors: 1 MΩ ± 100 Ω
  → $\Delta R/R = 10^{-4}$

Gap: Field Strips/Anode

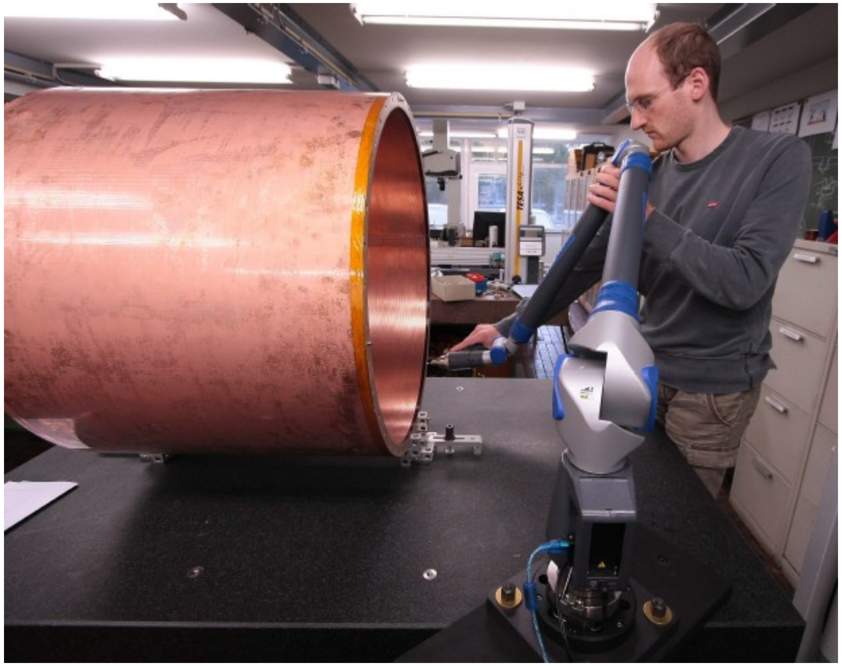
7th field strip is at position of anode.
To get best field homogeneity:
- Put 1st field strip on higher potential than 7th field strip.

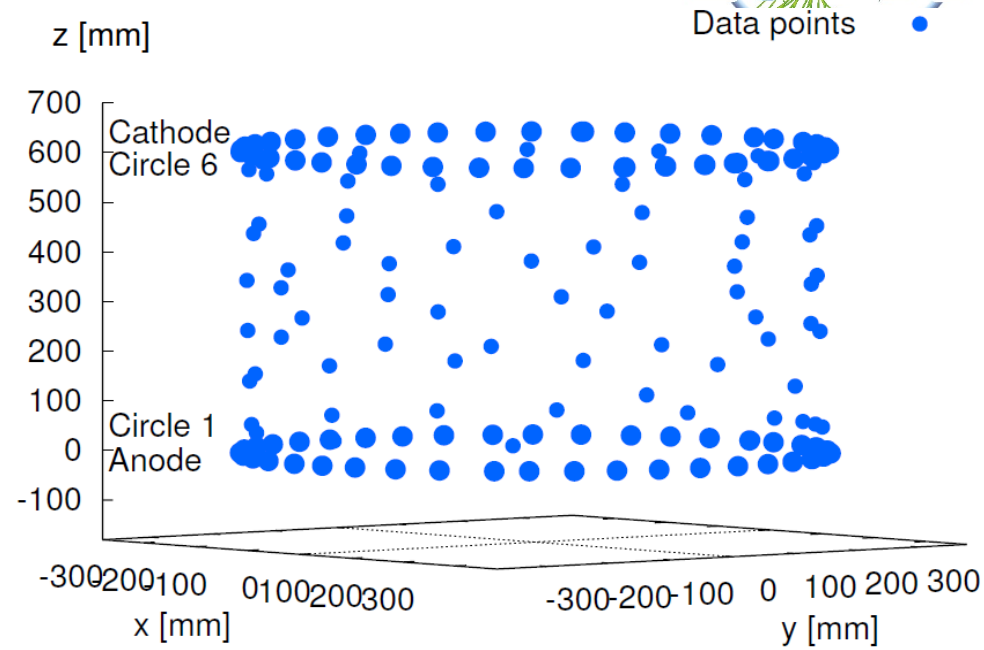
But usually 1st field strip is grounded.

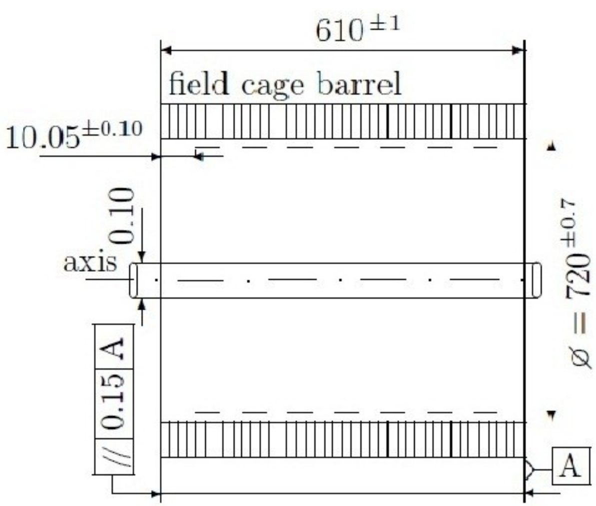


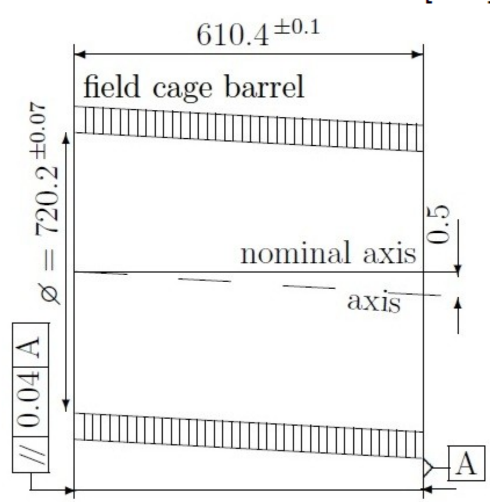


Measurements





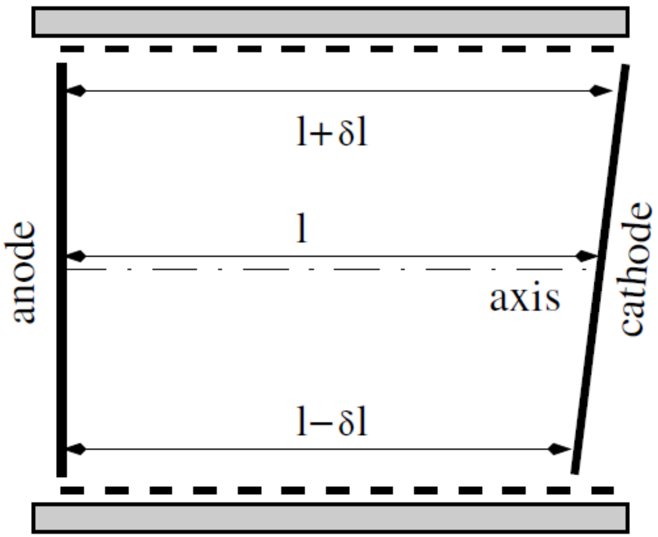




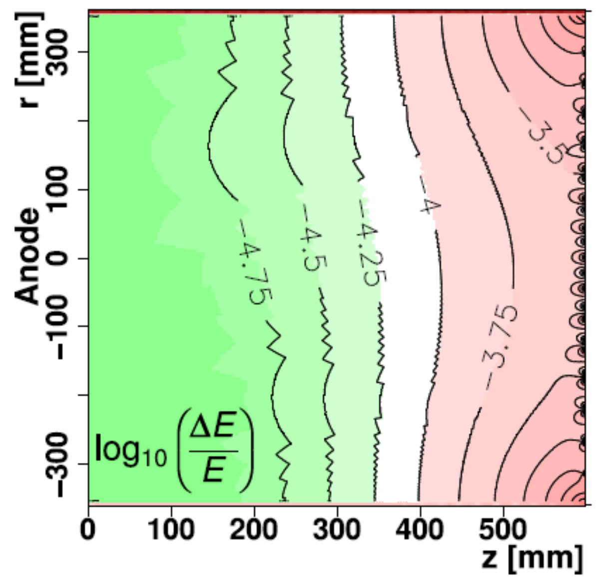
Alignment of the endplates:
$\delta < 40$ µm
Alignment of field cage axis:
Offset at the cathode ~ 500 µm
Field homogeneity:
$10^{-4} < \Delta E/E < 10^{-3}$

Influence on Electric Field

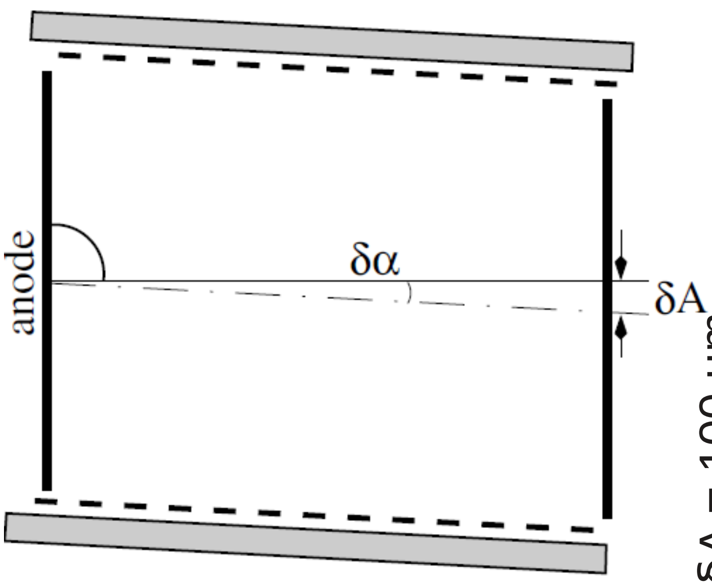
Alignment of anode - cathode



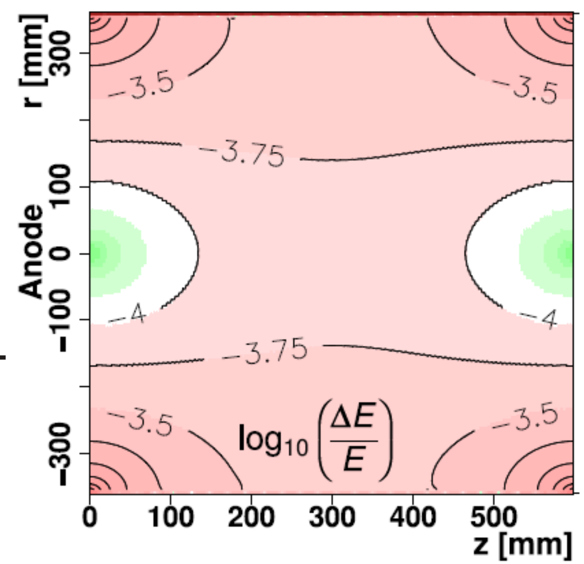
δl = 100 µm



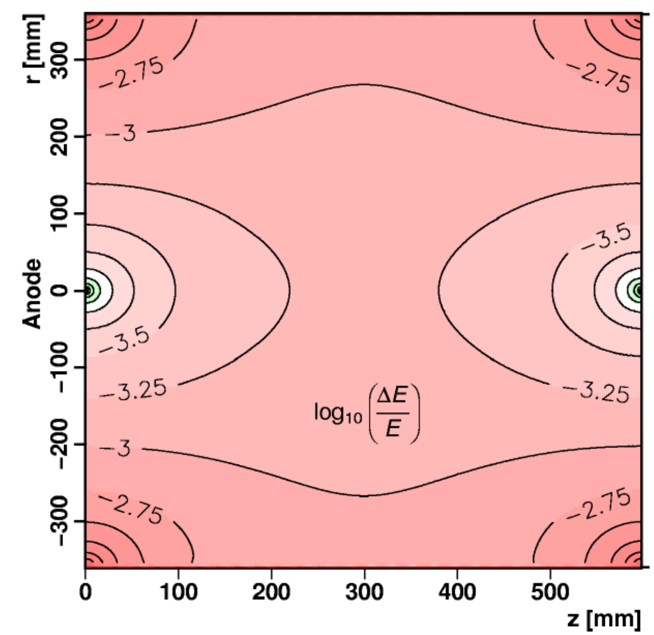
Tilt of the field cage axis



δA = 100 µm

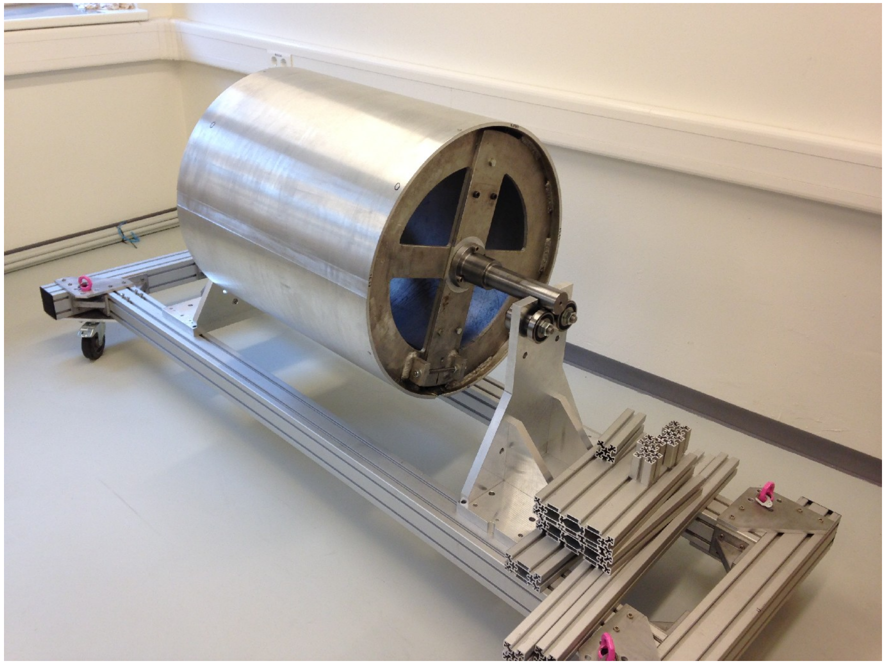


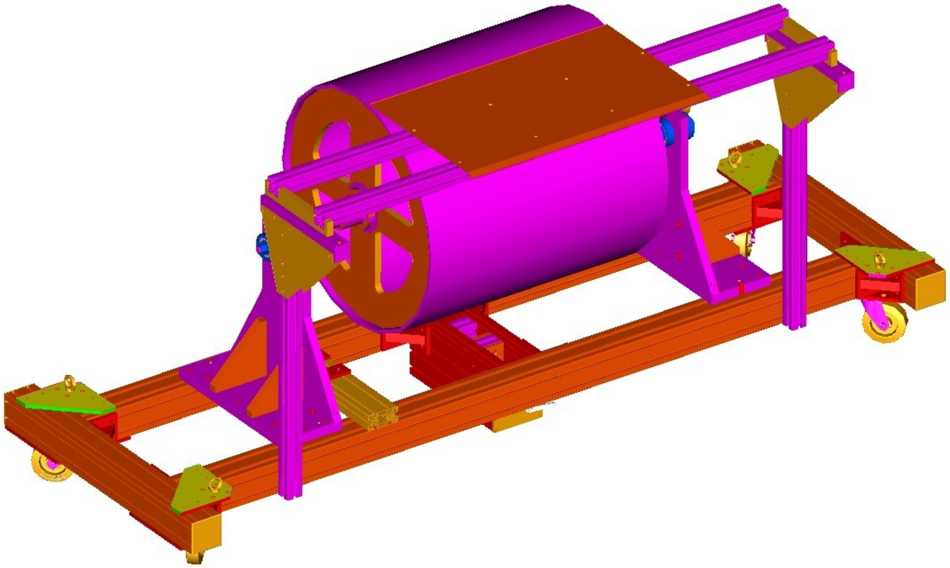
For δA = 500 µm



New Field Cage
Planned Improvements

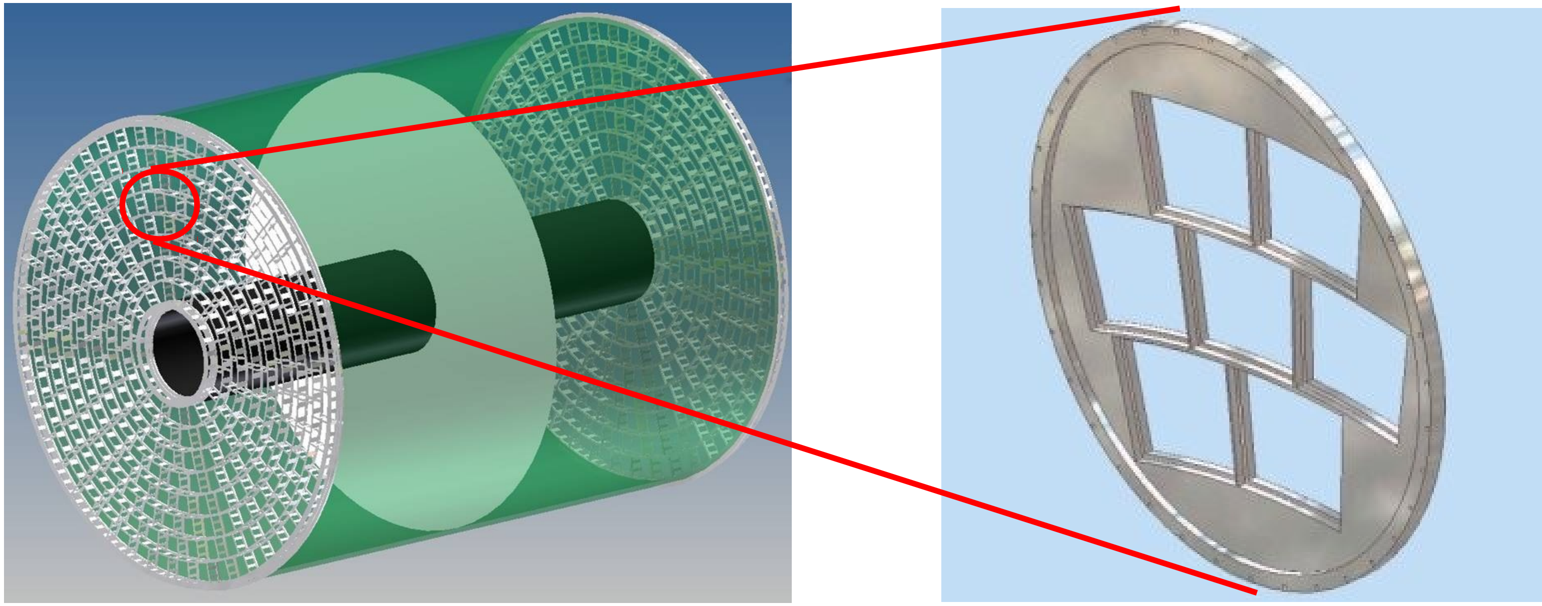
Production at DESY: Gain experience in handling materials and the large mechanical structures
New fieldcage with better precision
Investigate better materials (replace GRP with Aramid paper, Al strips,..)
Improve other details, e.g. HV for the 7th field strip





Endplate

Design of Endplate



- Development of the endplate and module mechanical structure to satisfy the material and rigidity requirements of the ILD
- During ILD TPC design constructing prototypes for LP as validation
- Requirements for LP: fit 7 modules on endplate to study integration
- Modules have size of $22 \times 17\ \text{cm}^2$
- Measure deformation of endplate

Requirements for ILD-TPC Endplate

Detector module design:

Endplate must be designed to implement MPGD readout modules.
Modules must provide near-full coverage of the endplate.
Modules must be replaceable without removing the endplate.

Low material 25% X_0 in total, including

Readout plane, front-end-electronics, gate	5%
Cooling	2%
Power cables	10%
Mechanical structure (this talk)	**8%**

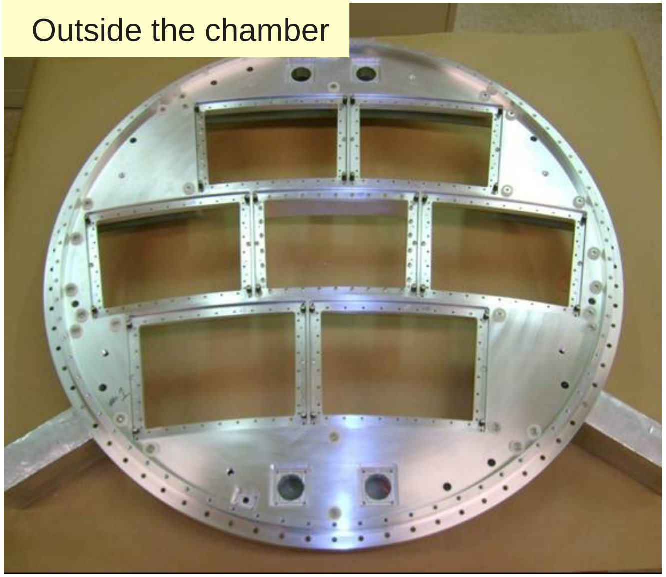
Rigid - limit is set to facilitate decoupled alignment of **magnetic field** and **module positions**.

Precision and stability of x,y positions **< 50 µm**

Thin – **100 mm** of longitudinal space between the **gas volume ECAL**.

First Endplate (LP1)

In 2008, Cornell constructed two endplates for the LP.
These were shipped August 2008 and February 2010.

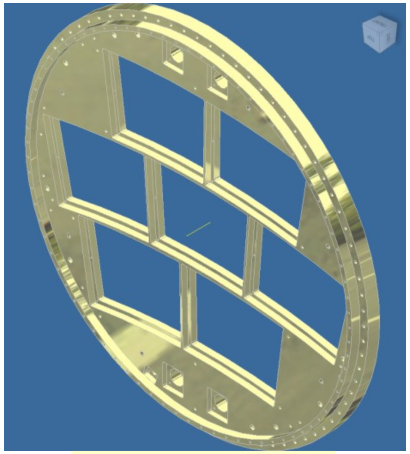


The endplate construction was developed to provide the precision required for ILD; precision features are accurate to ~30 μm.

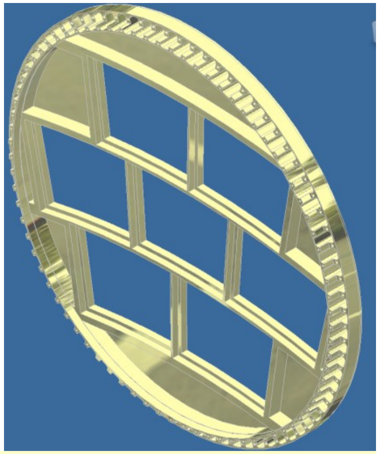
The accuracy was achieved with a 5-step process, with 3 machining steps and 2 stress relief (cold shock) steps.

The LP1 endplate was not meant to meet the material limit;
the bare endplate has mass 18.87 kg over an area of 4657 cm^2,
(mass/area) / (aluminum radiation length (24.0 g/cm^2)) = 16.9% X_0, 2x goal.

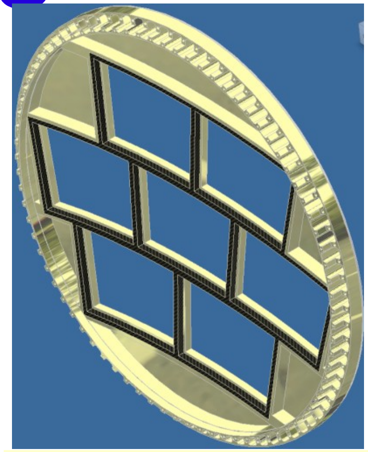
The Challenge of Meeting the Material Budget



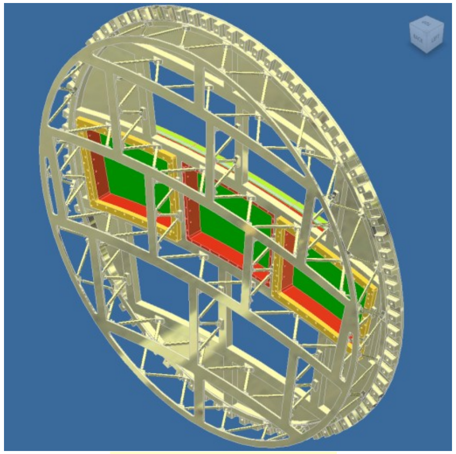
LP1 endplate, thick aluminum



lightened, all aluminum



aluminum/carbon fiber hybrid



space frame

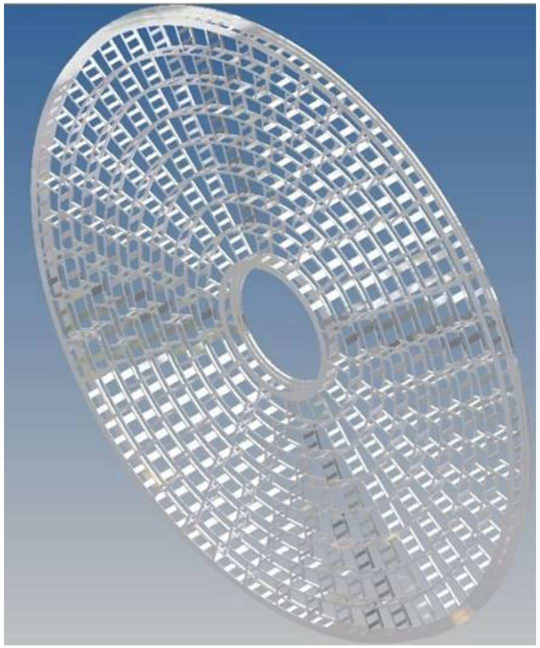
Strength of various **lightened endplates** were evaluated.

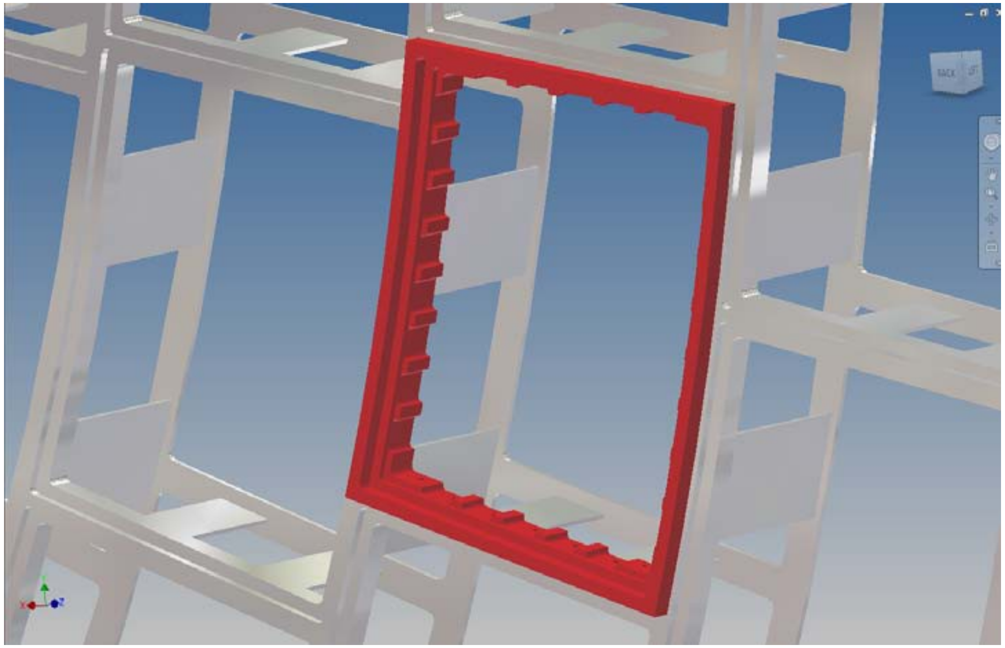
Low material **hybrid construction** was considered to provide the strength of the LP1 design, with significantly reduced material.
But, there is insufficient rigidity when scaled to the size of the ILD.

Only a **space-frame** provides the required strength-to-material.

ILD TPC Endplate

The **ILD endplate design** is a space-frame and shown here as the **solid model** used for the Finite-Element-Analysis.





New backframe design is lightened, i.e. material is reduced to minimum.

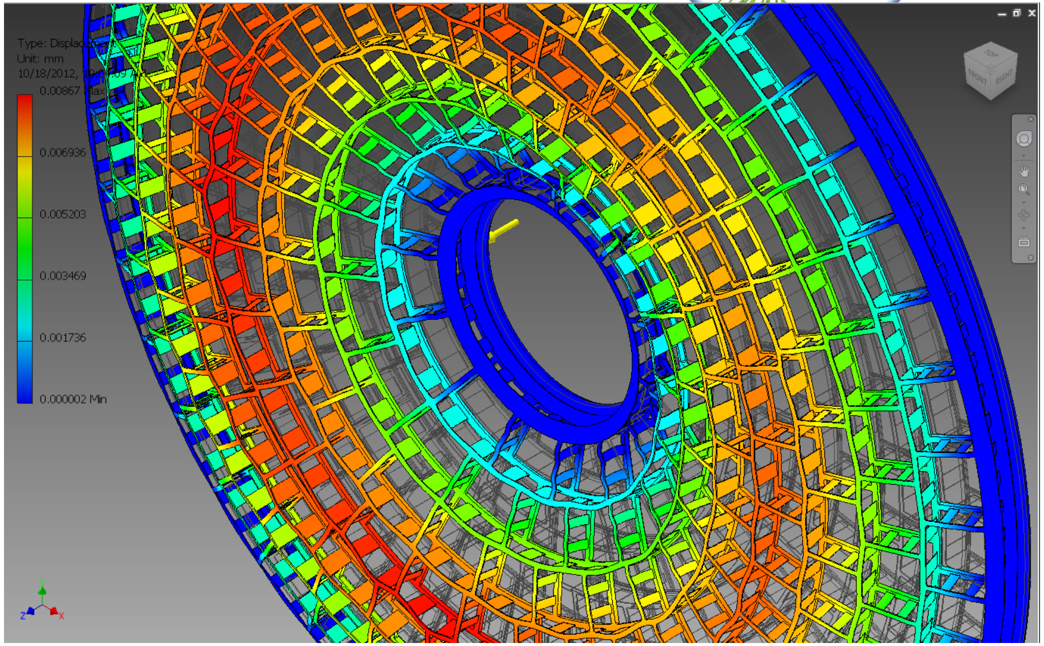
This model has a full thickness of 100 mm and a mass of 136 kg,
=> material thickness (frame only) 1.37 g/cm^2, **5.7% X_0**.

The new module back-frames have mass 290 g.
With 240 modules, the total mass is 69.6 kg or **2.9% X_0**.

Thus the total material is 8.6% → Produce back-frames in carbon fiber.

FEA Module of the ILD TPC

Endplate deflections were calculated with finite element analysis (FEA).



Maximum deflection of the model:
0.00867 mm/100 N

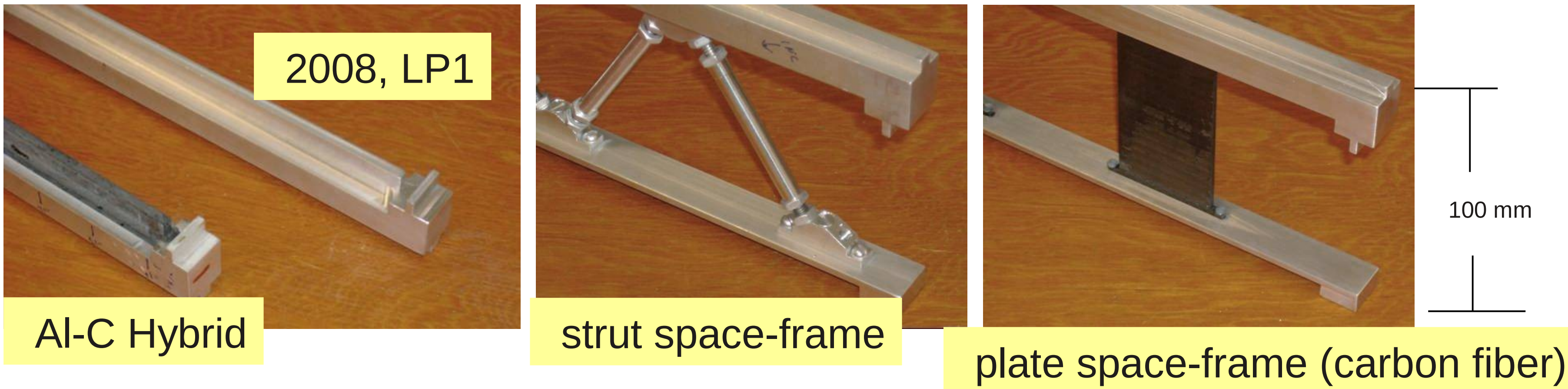
Calibration:
100 N is the force on LP1
due to 2.1 millibar overpressure
ratio of areas: (area of ILD)/(area of LP1) = 21.9

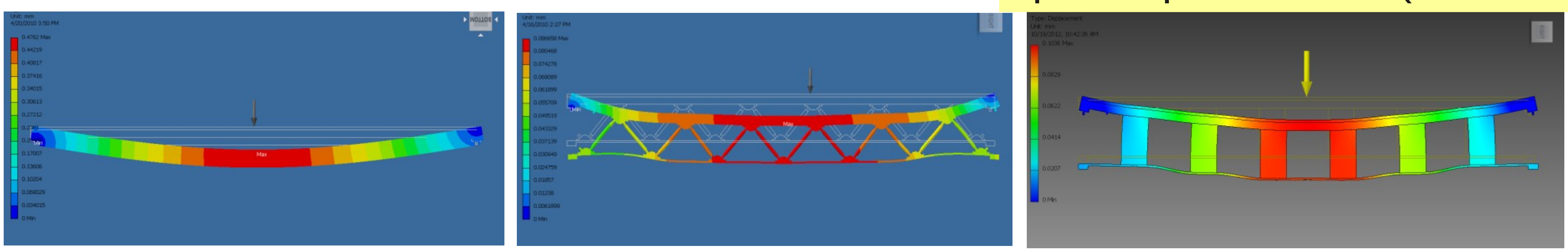
ILD TPC endplate deflection for 2.1 millibar overpressure (2190N) = 0.19 mm

Without the space-frame structure, the simple endplate deflects by 50mm

How to build a space-frame?

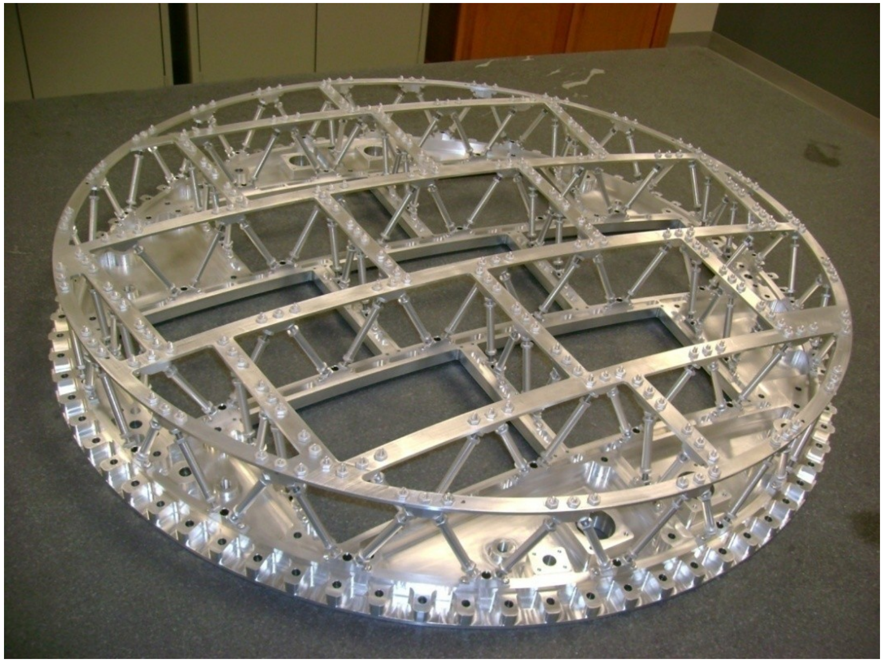
The ILD endplate **solid model** is modeled in the “equivalent-plate” space-frame design; the separating members are thin plates.

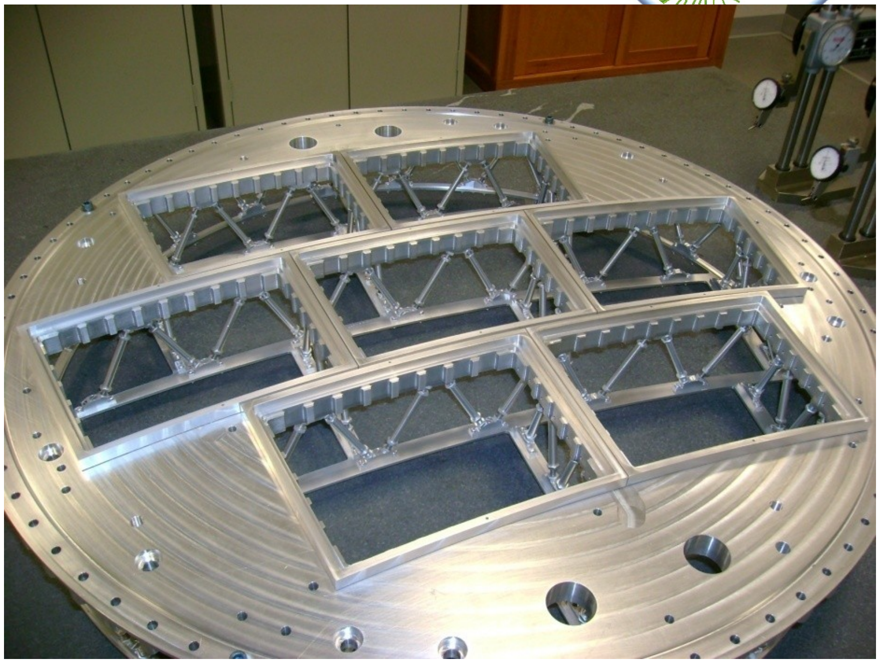




- Small test samples were built representing sections of the LP1/LP2 endplate.
- For each small test sample, there is a solid model that was used for the FEA.
- Deflection of the physical prototypes was compared to the FEA.
- **Deflection measurements of the physical prototypes agree with the FEA.**

Larger Scale Validation - LP2





Two LP2 space-frame endplates were built as fully functional replacement for LP1 endplate.

One has been sent to DESY this summer, the other will be kept at Cornell for measurements of long term stability and lateral strength/accuracy.

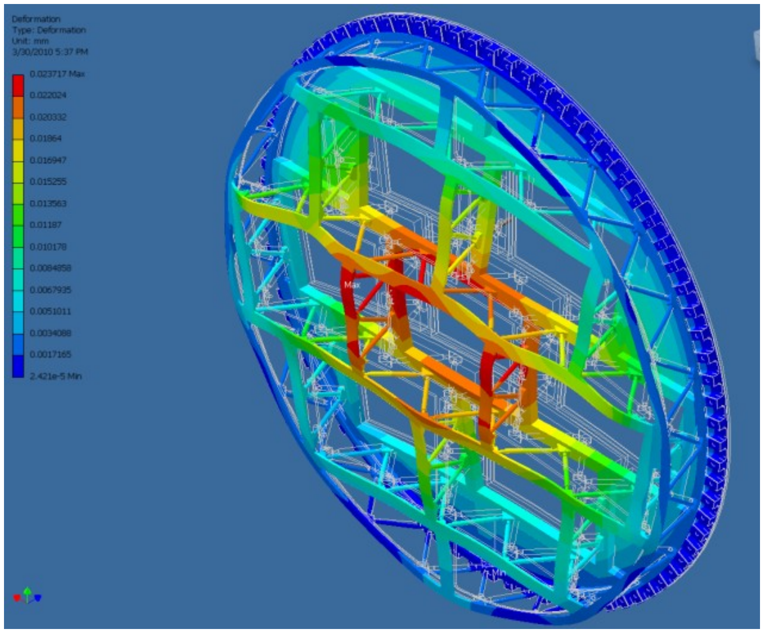
Constructed LP2 endplate is a “strut” space-frame.

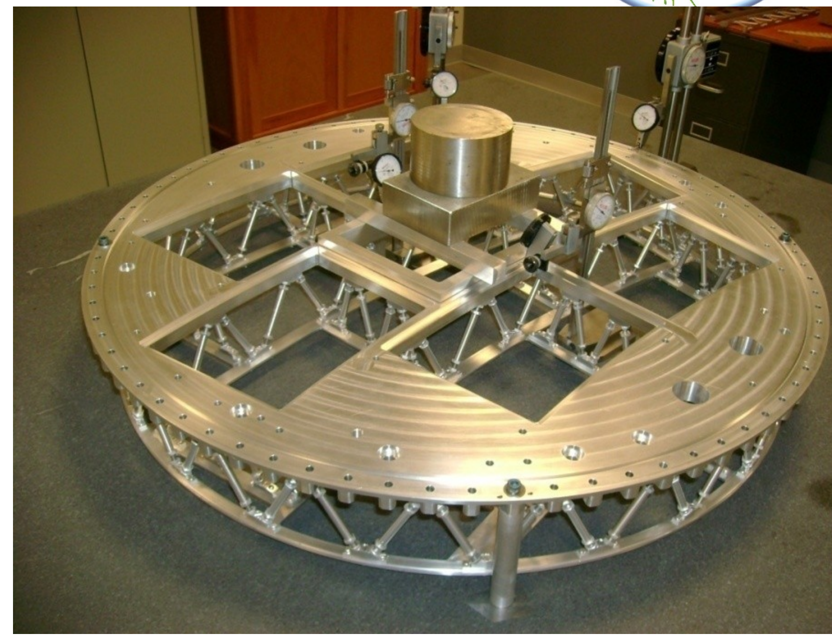
132 struts, 5 minutes to install per strut ~11 hours

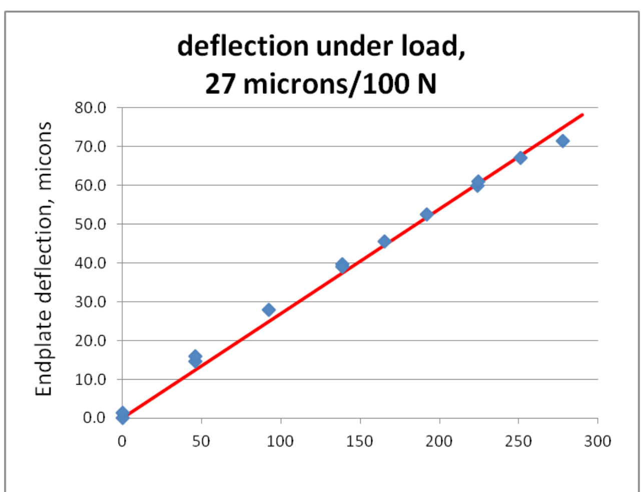
alignment iteration: ~ 2 hours

Comparison with FEA

Maximum deflection is 23 µm for 100N at the center module.







Measured deflection is 27 µm/100 N load, 17% higher than predicted by FEA.

Choosing the Model

	mass kg	material $\%X_0$	calculated deflection µm (100 N)	stress MPa (yield: 241)	measured deflection µm (100 N)
LP1	**18.87**	**16.9**	**29**	**1.5**	**33**
LP2 Space-Frame (strut or equivalent plate)	**8.38**	**7.5**	**23**	**4.2**	**27**
Lightened	8.93	8.0	68	3.2	
Al-C hybrid (channeled plus fiber)	**Al 7.35 C 1.29**	**7.2**	**(68-168)**	**(3.2-4.8)**	
Channeled	Al 7.35	6.5	168	4.8	

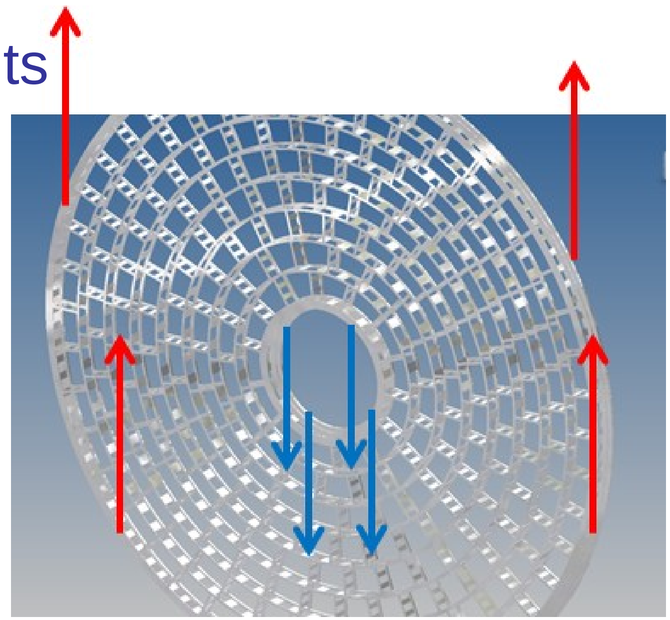
In both LP1 and LP2, the measured deflection is about 15% higher than from the FEA, which is close for the level of detail of the model.

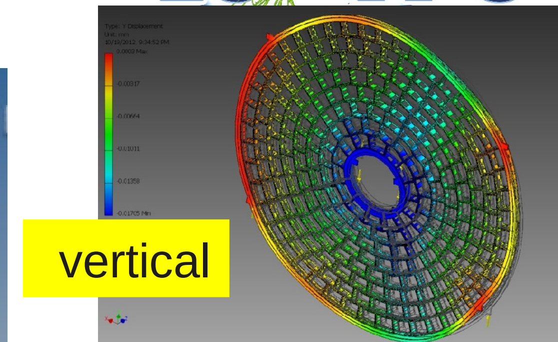
With this model, several aspects were studied, e.g. the influence of extra stress generated by an off-tolerance module

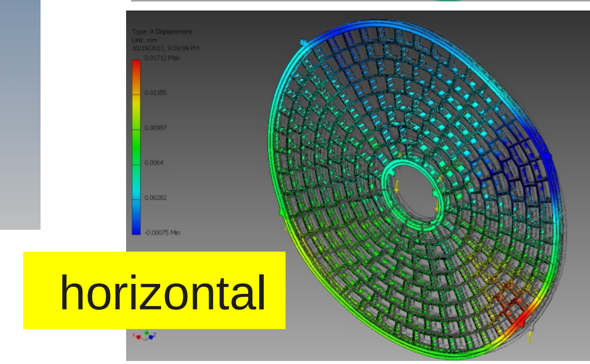
Endplate Support

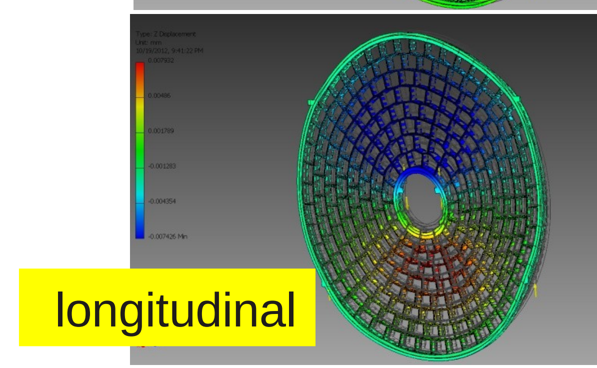
Endplate is supported at 4 points
(*red arrows*)
upper points are constraints,
right fixed, left sliding
lower points are forces

Endplate load at center,
4 points, 400 N total
(***blue arrows***)







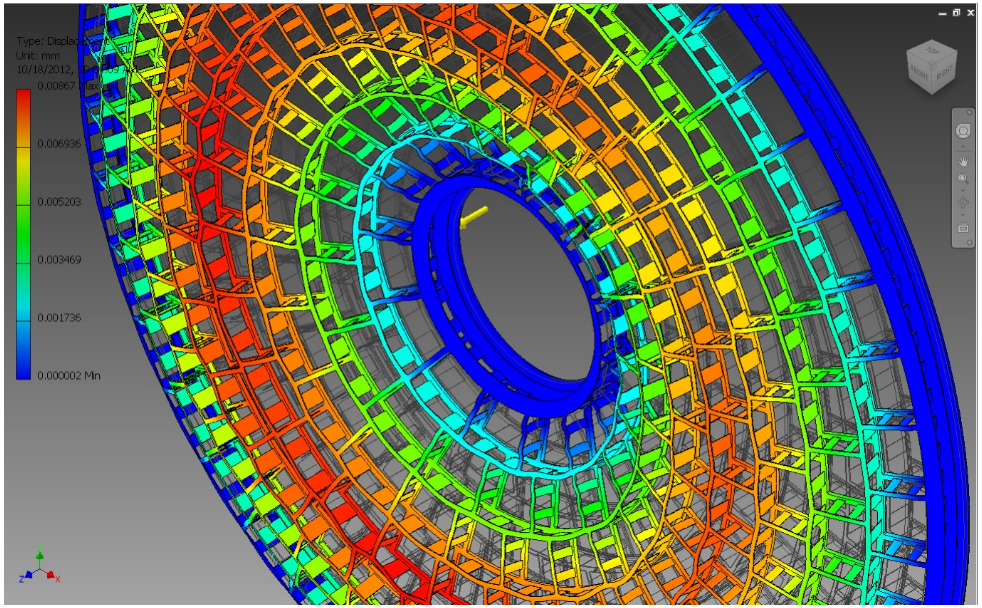


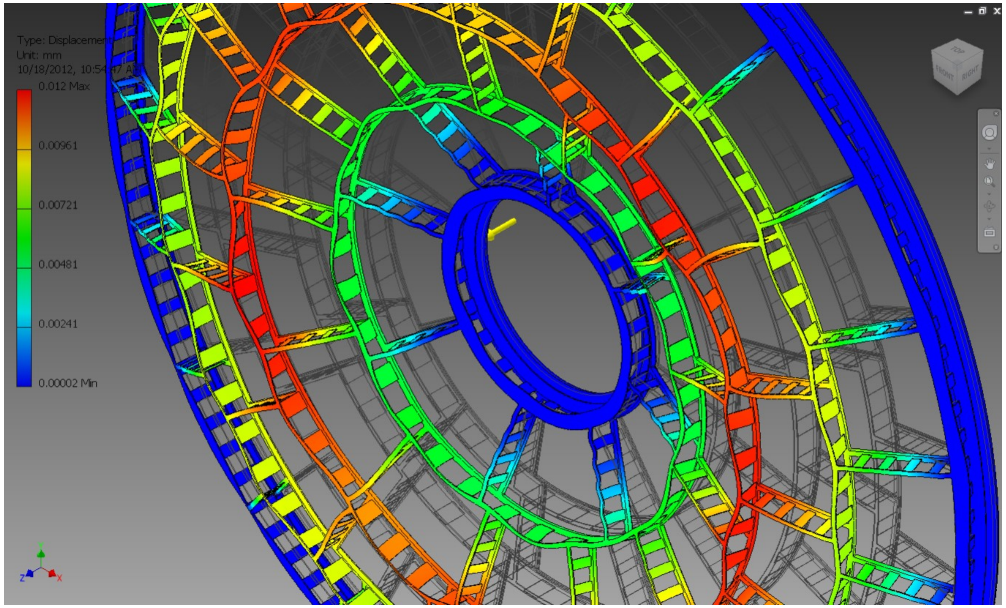
Longitudinal position at outer O-ring is fixed (by the field cage).

If the total load per endplate is 1000 kg, or 10,000 N, total vertical motion is 0.43 mm .

However, the motion is smooth over the distance; the motion over a module is ~50 μm .

Changing Number of Module Rows





We can consider an endplate with larger modules (8 to 4 rows).

Module size increase from 377 cm^2 per module to 1450 cm^2.

Longitudinal displacement increases by a factor of 1.4.

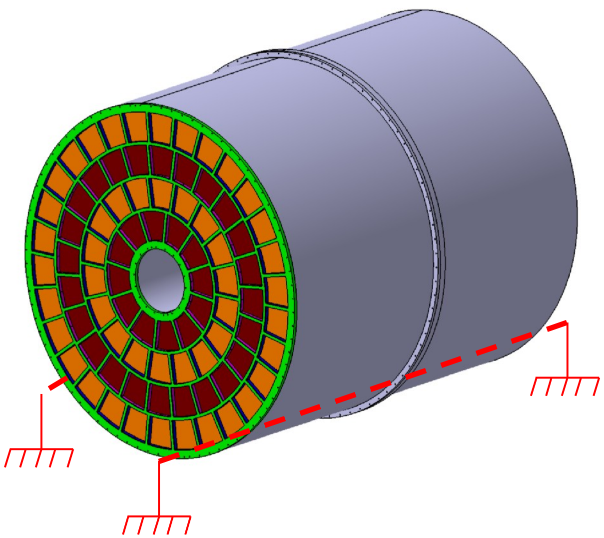
In the 4-row design, local distortions of 44 µm (2 µm/100 N) appear.
(not in longitudinal, but x-direction).

Mounting of Complete TPC

Influence of Overpressure

Material and Weight:

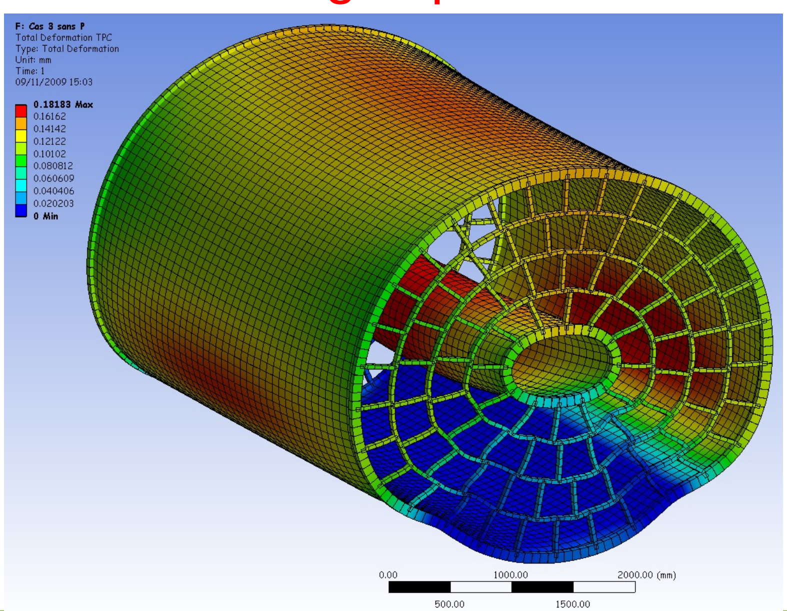
Endplate: 2 x 370 kg (aluminium)
PCB: 2 x 530 kg (on basis of 7kg/module, G11)
Field Cage: 265 kg (composite NIDA)
TPC is supported by two rails

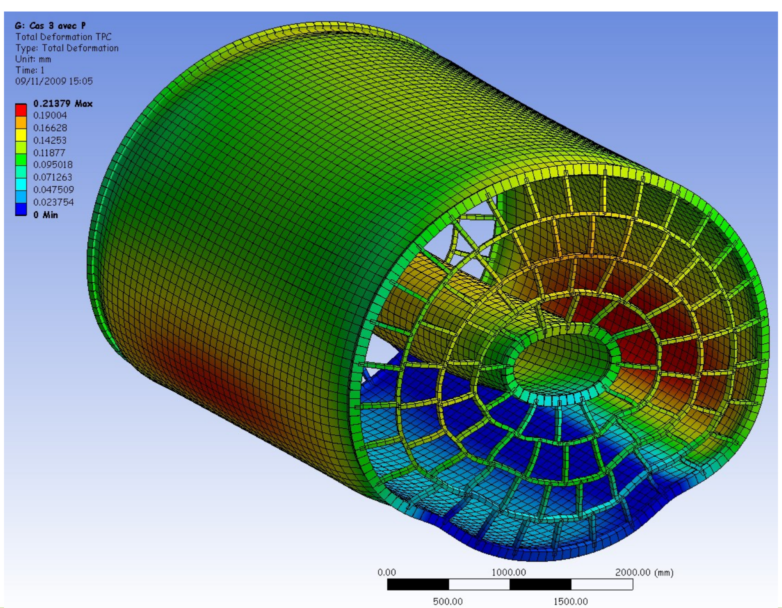


Loaded:

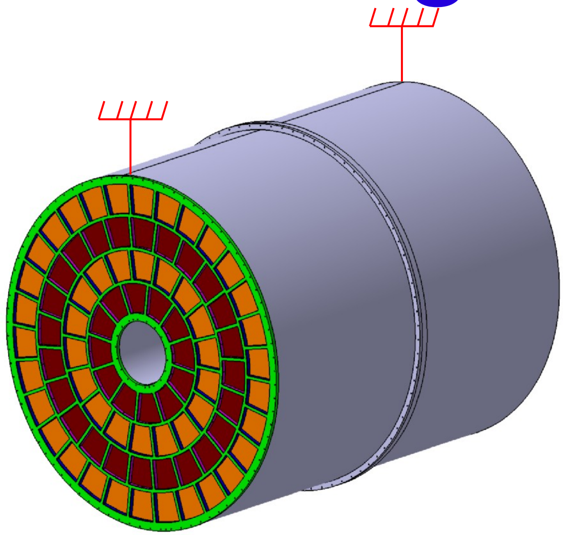
With and without gas overpressure Δp = 3 mbar

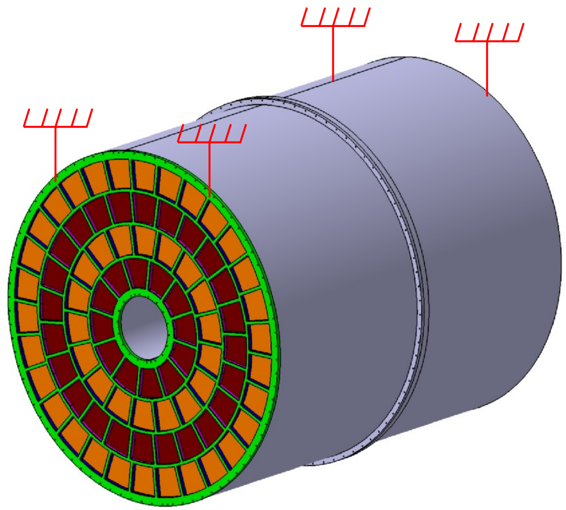
Deformation without gas pressure: 180 µm
Deformation with gas pressure: 210 µm

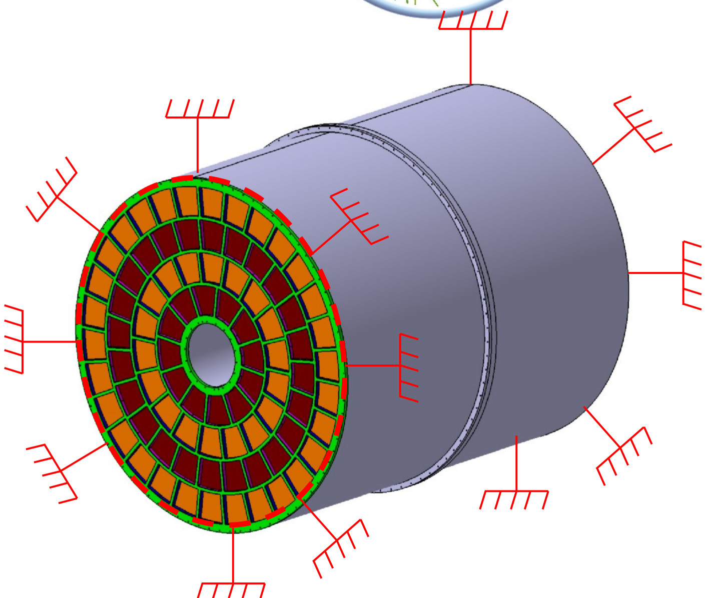


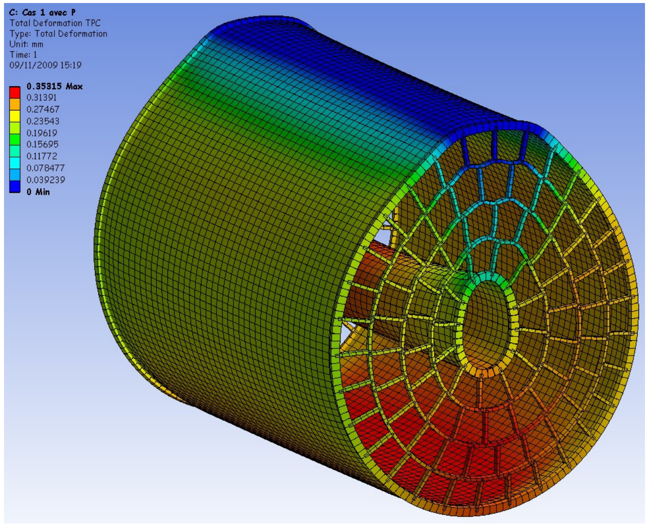


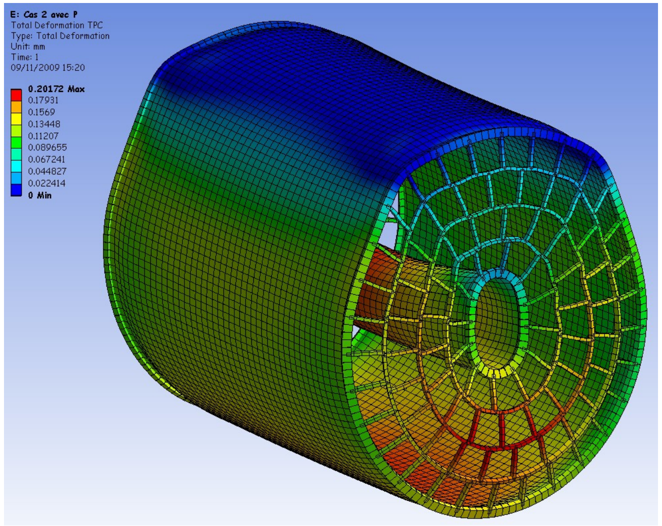
Various Possibilities of Mounting TPC

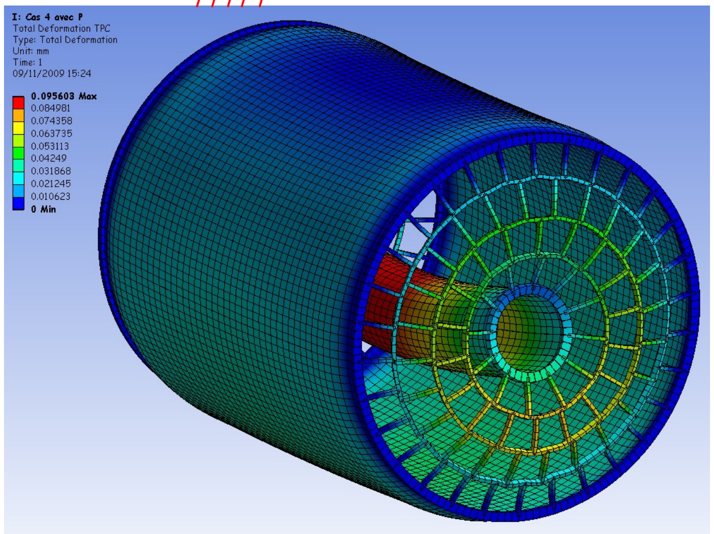












Earth Quake Issues

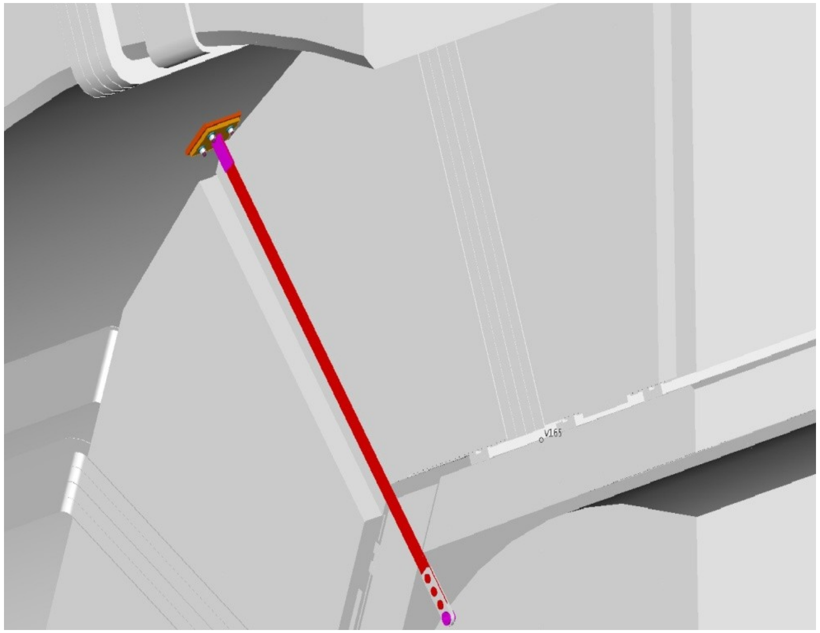
Values of basic peak acceleration for the North site $a_0 < 1.5\ m/s^2$

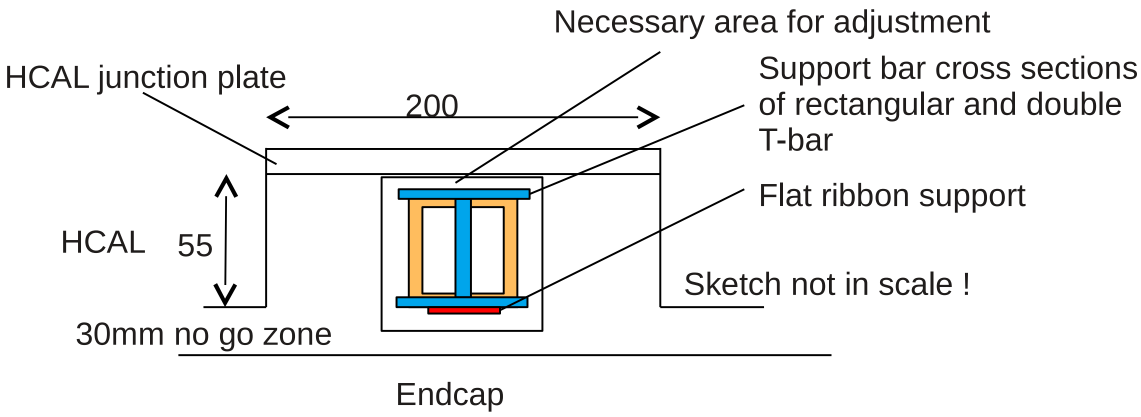
TPC weight for calculation: 2000 kg >20000 N (Incl. FTD, SIT, Vertex)

Seismic load force: 3000 N in x,y,z calculated with $a_0 < 1.5\ m/s^2$

The additional force load in longitudinal direction of the bar support should not be an issue.

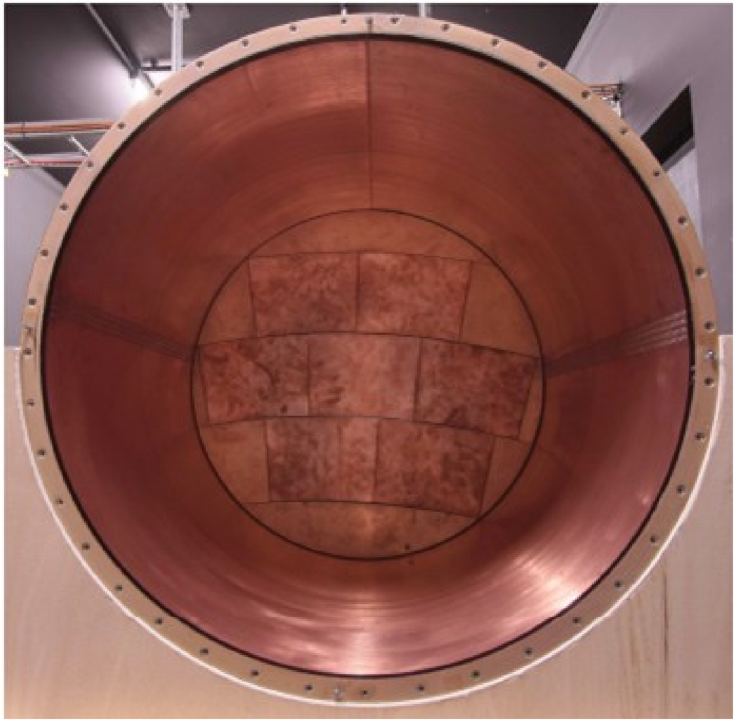
A max. deflection of 1mm will be the aim => bar or flat ribbon





Summary

<u>Large Prototype was built:</u>
- For testing different readout techniques
- For gaining experience of building larger detectors



<u>Field Cage:</u>
- First field cage was built
- Stable operation was demonstrated
- Careful survey showed misalignment of axis
- Improved field cage is under construction

<u>Endplate:</u>
- Strut-based space-frame endplate is designed
- Fulfills almost all the requirements:
  Material budget of 8.6 % X_0,
  Thin enough (d < 10 cm),
  Static deflection of 190 µm (overpressure) + 430 µm (load)

<u>Mounting issues</u> are being looked at.