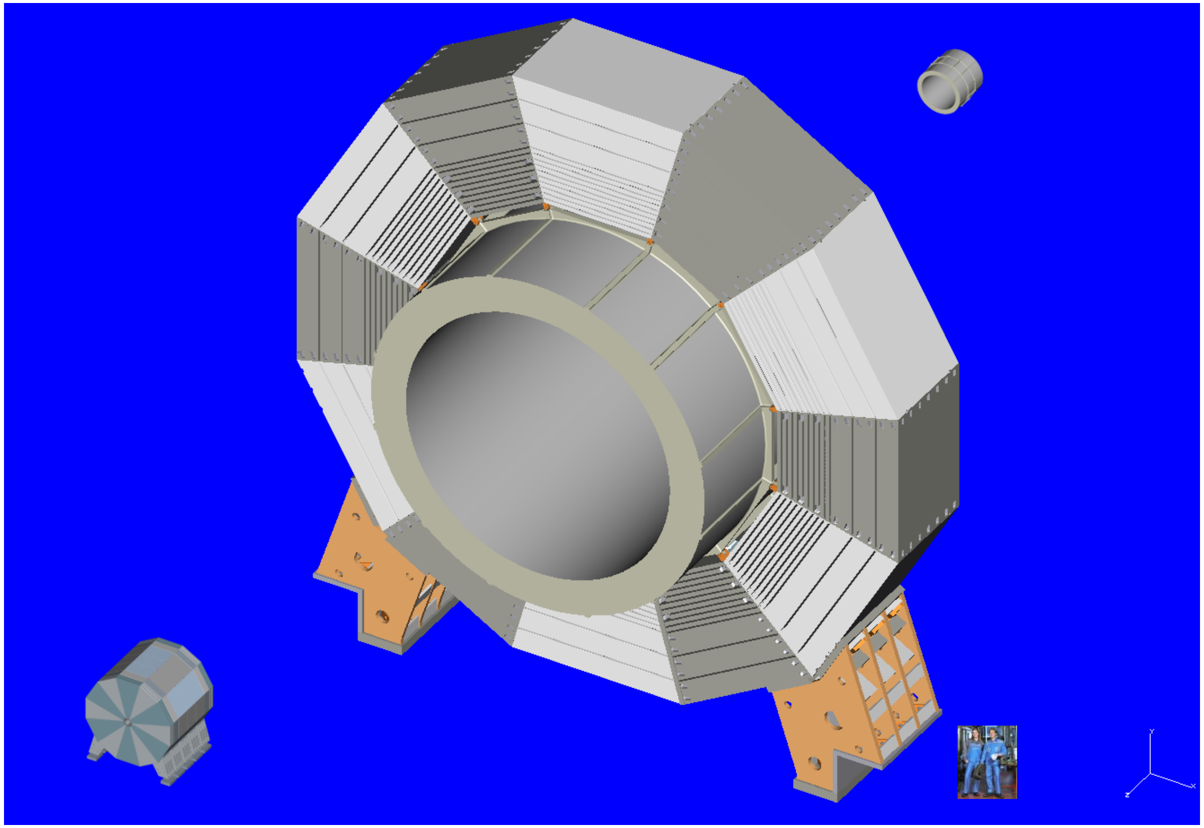
E-JADE is a Marie Sklodowska-Curie Research and Innovation Staff Exchange (RISE) action, funded by the EU under Horizon2020

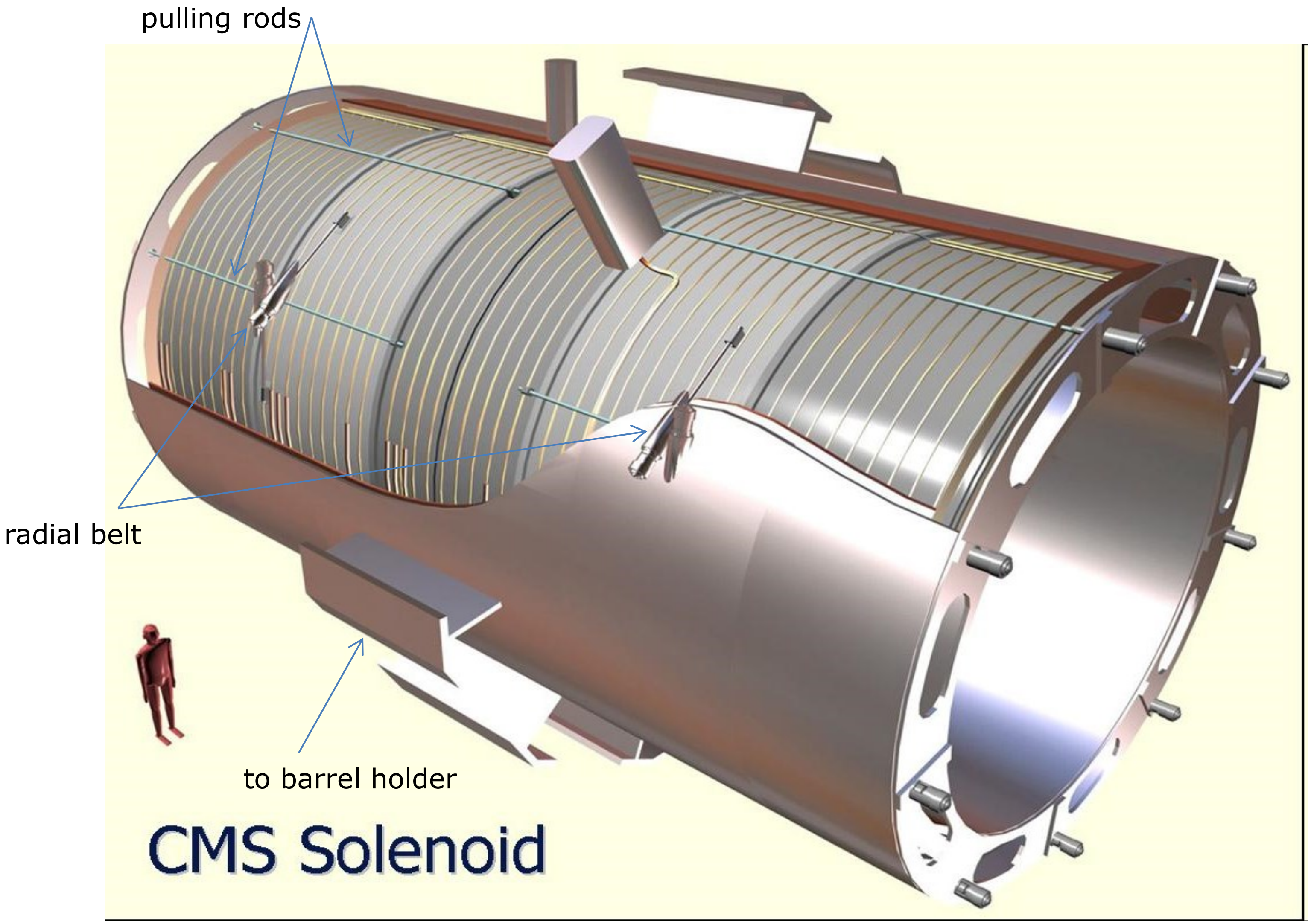
E-JADE

Cryostat Integration / Structural Analysis / Transfer Forces



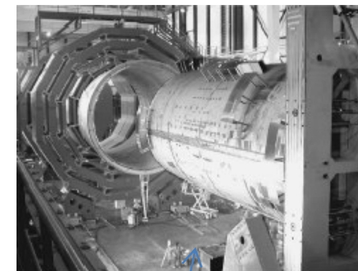
Richard Stromhagen / DESY-Hamburg / - ILD Integration Workshop 28. Sept. 2017 / KEK

CERN CMS Solenoid schematic



Insertion of outer vac-tank / CMS

5 segment, 2600 lg. sheet thickness: 30 ~2600lg, 40 and 60 mm



to need jig
and scaffolding
for on-site
installation

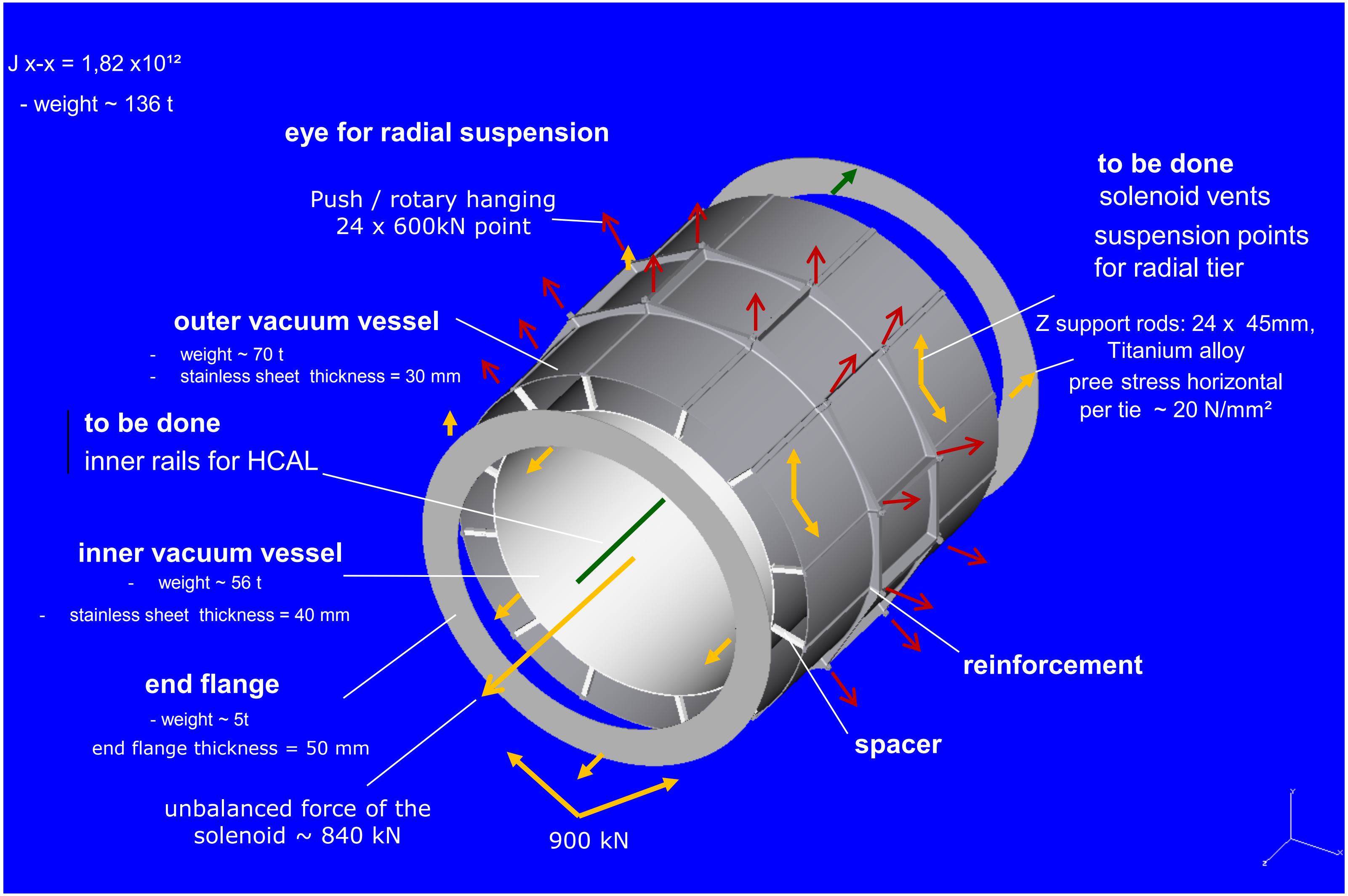
CMS Cryostat with inner-, outer vacuum vessel and end flange

E-JADE is a Marie Sklodowska-Curie Research and Innovation Staff Exchange (RISE) action, funded by the EU under Horizon2020

E-JADE

Cryostat structure proposal / all-welded
Radial positions system of the solenoid

effective section modul over ledge

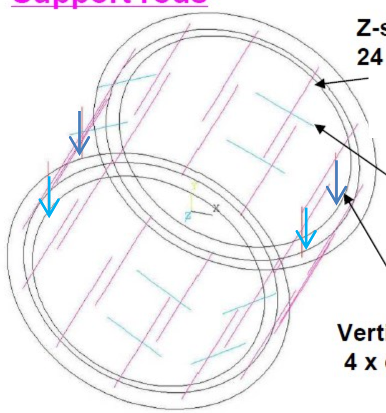


Reactions of the cold mass supporting system / Force (on left Fig.)

min. comparison material stress:
Titanium Alloying > 300 N/mm²

tensile strength stainless steel > 500 N/mm²

Support rods

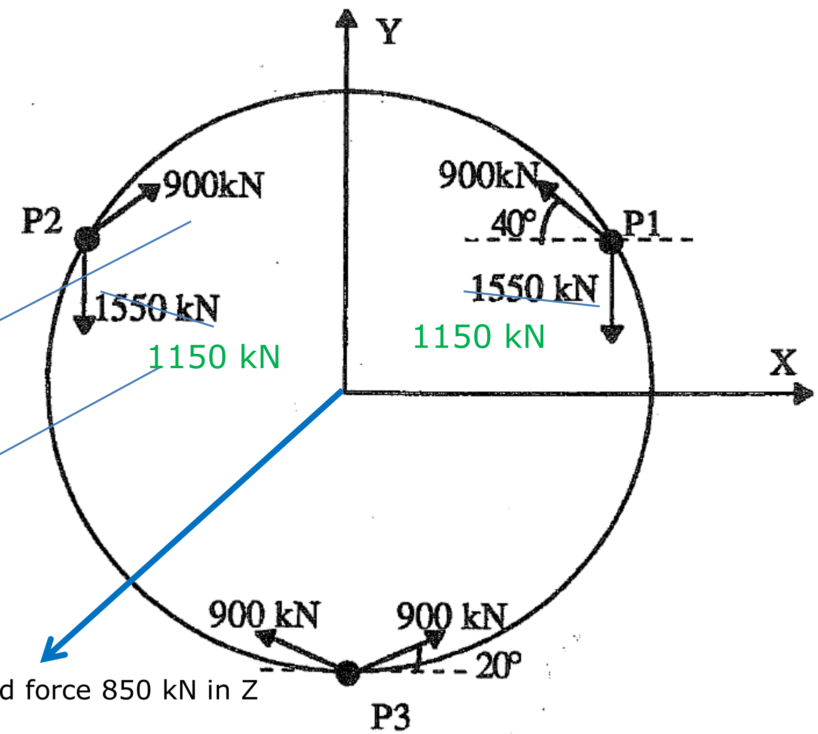


Z-support rods:
24 x dia.45mm, Titanium alloy
~ 36 kN per rods
stress ~ 22 N/mm²

Radial support rods:
8 x dia.35mm, Ti-alloy
stress ~ 117 N/mm²

Vertical support rods:
4 x dia.60mm, Ti-alloy 3
stress 210 N/mm²

Fig. KEK Hiroshi Yamaoka

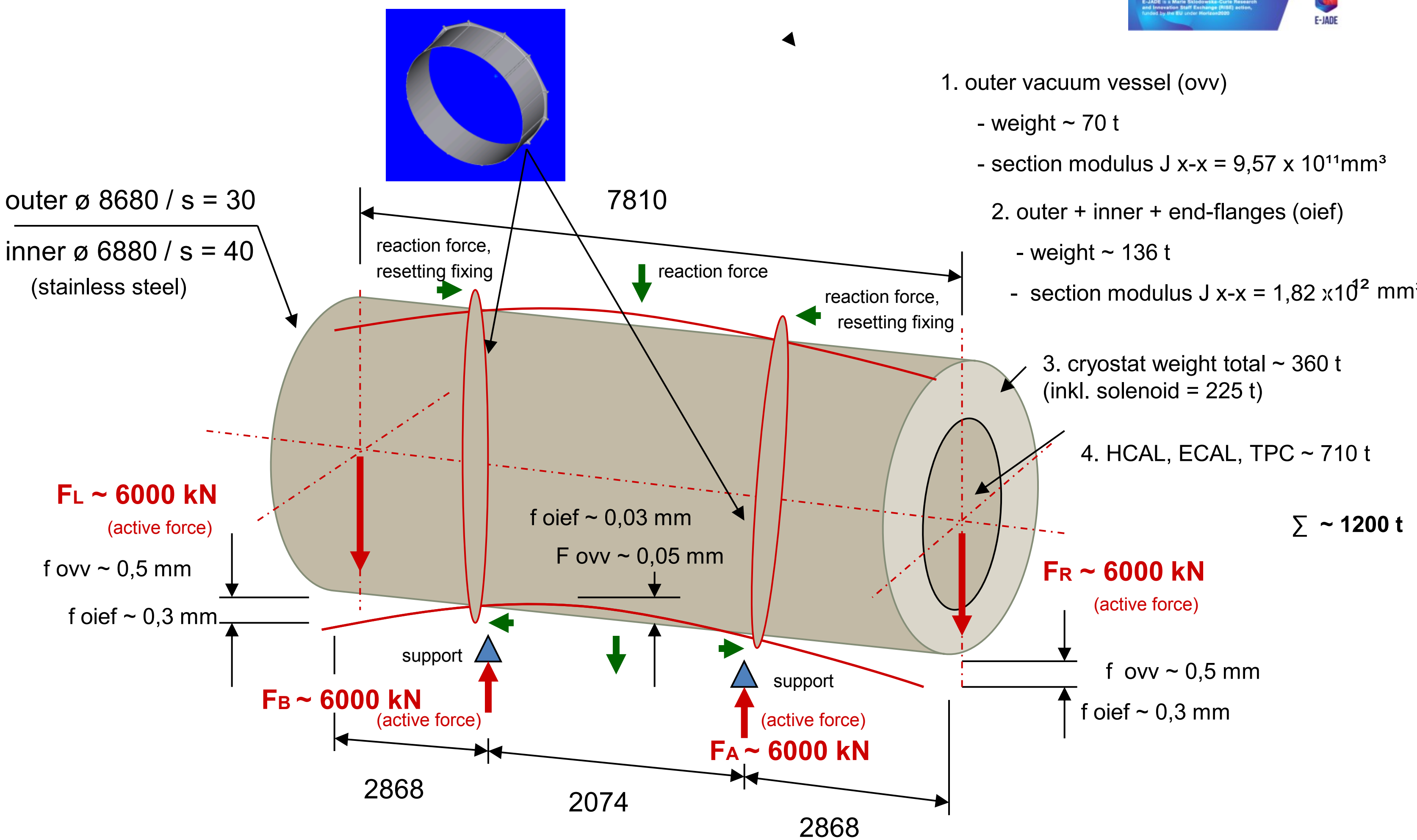


CMS TDR 1 / Page71

Fig. 9.2: Reactions of the cold mass supporting system.

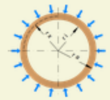
min. safety factor all rods > 2,

Cryostat: applied and resulting forces, deflection line



Loading case Cryostat / Vacuum / elastic deformation

External Pressure 2 bar = Safety factor 2



Belastungsart:

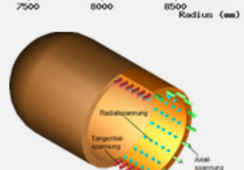
- Innendruckbelastung
- (●) Außendruckbelastung

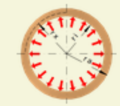
Eingabewerte:

Radius Außenwand - r_a (mm)	8680
Radius Innenwand - r_i (mm)	6880
Radius an Stelle x - r_x (mm)	7780
Elastizitätsmodul - E (N/mm²)	220000
Querdehnungszahl - ν (-)	0.3
Belastungsdruck - p (N/mm²) / 1 bar = 0,1 N/mm² Überdruck = positiven Wert eingeben. Unterdruck = negativen Wert eingeben.	2

tangential stress
radial stress
axial stress
Deformation
distortion

Radius	6880.0 mm Innenwand	7780.0 mm Radius x	8680.0 mm Außenwand
Elastizitätsmodul - E (N/mm²)		220000.0	
Querdehnungszahl - ν (-)		0.300	
Außendruckbelastung - p a (N/mm²)		2.00	
Tangentialspannung - σ t (N/mm²)	-10.8	-9.59	-8.76
Radialspannung - σ r (N/mm²)	-0	-1.17	-2.00
Axialspannung - σ t (N/mm²)		-5.38	
Vergleichsspannung GEH σ v (N/mm²)	9.32	7.29	5.85
Radialverformung - Δ r (mm)	-0.336	-0.327	-0.322
Beuldruck - p kr (N/mm²) - Sicherheit = 3		227.0	





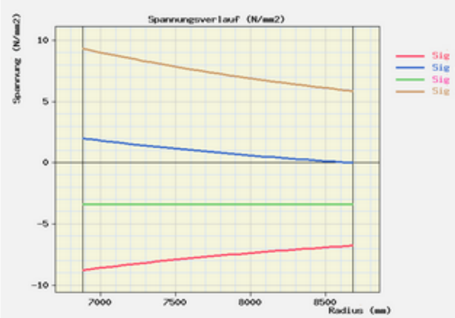
Belastungsart:

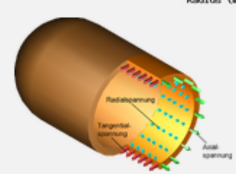
- (●) Innendruckbelastung
- Außendruckbelastung

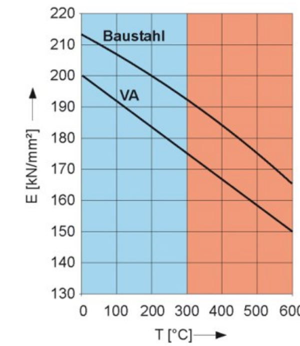
Eingabewerte:

Radius Außenwand - r_a (mm)	8680
Radius Innenwand - r_i (mm)	6880
Radius an Stelle x - r_x (mm)	7780
Elastizitätsmodul - E (N/mm²)	220000
Querdehnungszahl - ν (-)	0.3
Belastungsdruck - p (N/mm²) / 1 bar = 0,1 N/mm² Überdruck = positiven Wert eingeben. Unterdruck = negativen Wert eingeben.	-2

Radius	6880.0 mm Innenwand	7780.0 mm Radius x	8680.0 mm Außenwand
Elastizitätsmodul - E (N/mm²)		220000.0	
Querdehnungszahl - ν (-)		0.300	
Innendruckbelastung - p i (N/mm²)		-2.00	
Tangentialspannung - σ t (N/mm²)	-8.76	-7.59	-6.76
Radialspannung - σ r (N/mm²)	2.00	0.827	-0
Axialspannung - σ t (N/mm²)		-3.38	
Vergleichsspannung GEH σ v (N/mm²)	9.32	7.29	5.85
Radialverformung - Δ r (mm)	-0.293	-0.277	-0.267

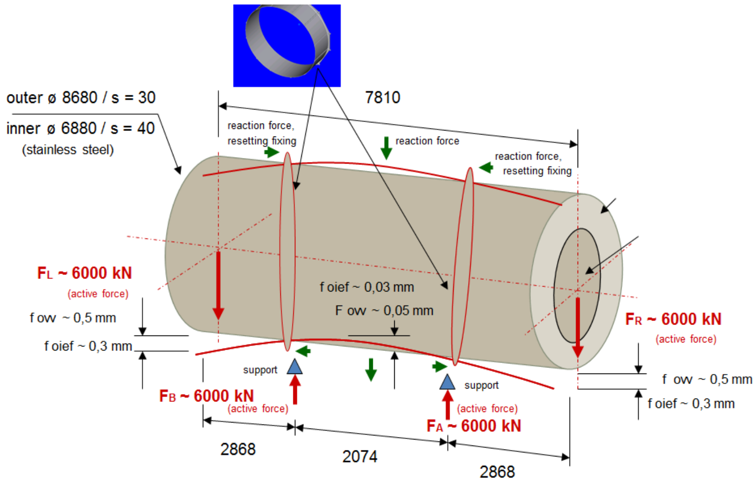


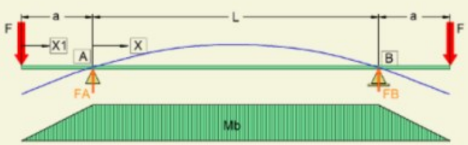




Ref. Stress ~ 6 N/mm²
Deformation ~ 0,3 mm

Cryostat: applied and resulting forces, deflection line cal. with pc





Eingabewerte:

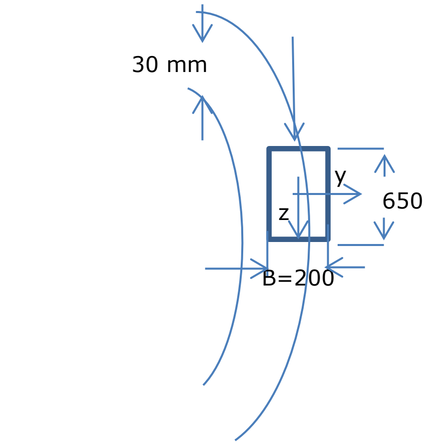
Belastung - F (N)	6000000
Länge - L - (mm)	7810
Kraftabstand - a - (mm)	2864
E-Modul - E - (N/mm²)	220000
Trägheitsmoment - I - (mm⁴)	3668239688000
Widerstandsmoment - W (mm³)	947865552
Berechnungspunkt X - (mm)	3905
Berechnungspunkt X1 - (mm)	0

Ergebnisse:

Auflagerkraft - F (N)	
Koordinate x = 0 mm [FA]	6000000.0
Koordinate x = 7810 mm [FB]	6000000.0
Biegemoment - M (Nmm)	
Koordinate x1 = 0 mm	0
Koordinate x = 0.0 mm [A]	-17184000000.0
Koordinate x = 3905 mm	-17184000000.0
Koordinate x = 7810 mm [B]	-17184000000.0
Max. Biegemoment bei x = 0 mm	-17184000000.0
Biegespannung - σ_b (N/mm²)	
Koordinate x1 = 0 mm	0
Koordinate x = 0.0 mm [A]	18.1
Koordinate x = 3905 mm	18.1
Koordinate x = 7810 mm [B]	18.1
Max. Biegespannung bei x = 0 mm	18.1
Durchbiegung - f (mm)	
Koordinate x1 = 0 mm	0.296
Koordinate x = 0.0 mm [A]	0
Koordinate x = 3905 mm	-0.162
Koordinate x = 7810 mm [B]	0
Max. Durchbiegung bei x1 = 0 mm	0.296
Max. Durchbiegung bei x = 3905.0 mm	-0.162
Neigung - tan α	
Koordinate x1 = 0.0 mm	-0.000114
Koordinate x = 0.0 mm [A]	-0.0000832

Max. defl. 0,3 mm

Hanger Solenoid / 225 T / 4 lifting strut, per 562 kN, rating material



$\Sigma M\uparrow = 0$

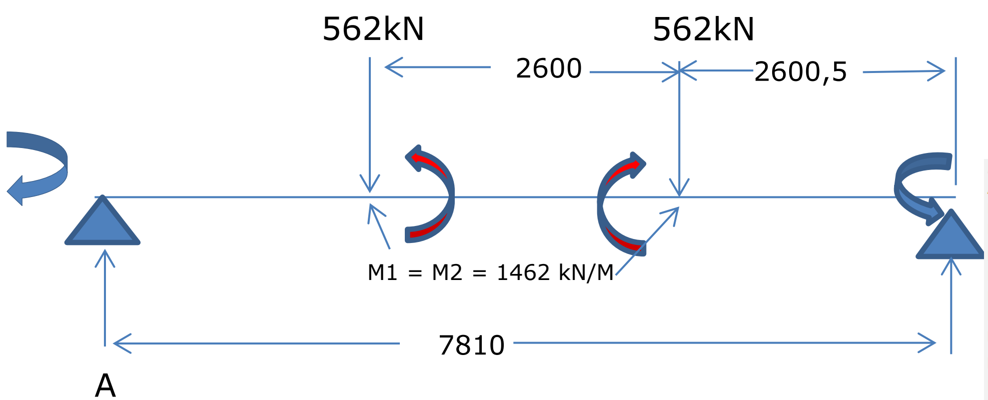
Mmax = 562kN x 2,6005 = 1462 kN/m

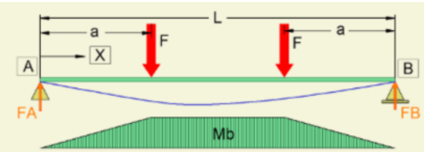
562kN x 7810 – 562kN x 2600,5 – 562kN x 5210 = 0

δ = Mmax/ Wy

Wy = B x H² /6

Iy = B x H³ / 12





Eingabewerte:

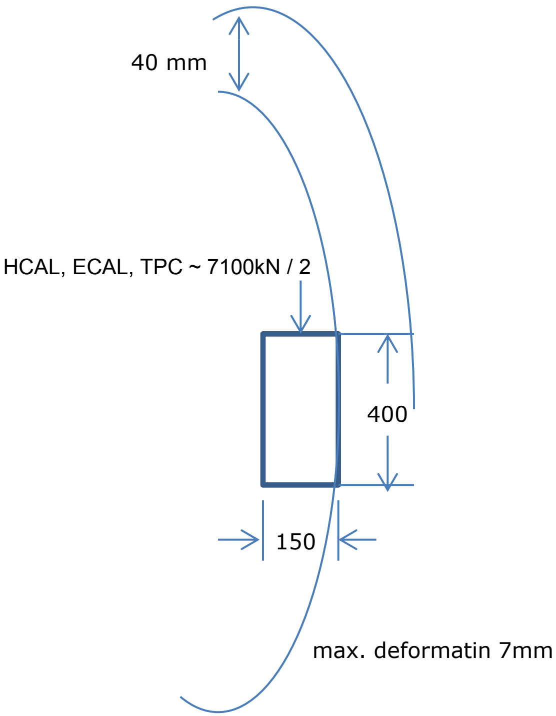
Belastung - F (N)	562000
Länge - L - (mm)	7810
Kraftabstand - a - (mm)	2600
E-Modul - E - (N/mm²)	220000
Trägheitsmoment - I - (mm⁴)	4577083333
Widerstandsmoment - W (mm³)	14083333
Berechnungspunkt X - (mm)	2600

Ergebnisse:

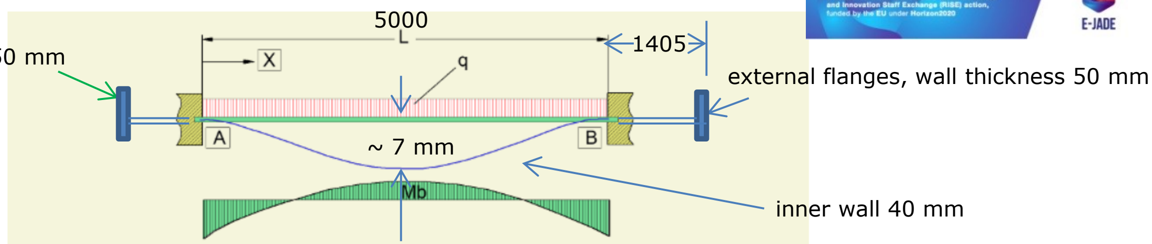
Auflagerkraft - F (N)	
Koordinate x = 0 mm [FA]	562000.0
Koordinate x = 7810 mm [FB]	562000.0
Biegemoment - M (Nmm)	
Koordinate x = 0.0 mm [A]	0
Koordinate x = 2600 mm	1461200000.0
Koordinate x = 7810 mm [B]	0
Max. Biegemoment bei x = 2600.0 mm	1461200000.0
Biegespannung - σ_b (N/mm²)	
Koordinate x = 0.0 mm [A]	0
Koordinate x = 2600 mm	103.8
Koordinate x = 7810 mm [B]	0
Max. Biegespannung bei x = 2600.0 mm	103.8
Durchbiegung - f (mm)	
Koordinate x = 0.0 mm [A]	0
Koordinate x = 2600 mm	8.19
Koordinate x = 7810 mm [B]	0
Max. Durchbiegung bei x = 3905.0 mm	9.43

Max. defl. ~ 10 mm

Hanger HCAL, ECAL, TPC, / 710 t constant load, rating material



Rough sketch



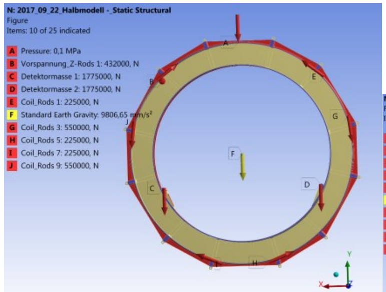
Eingabewerte:

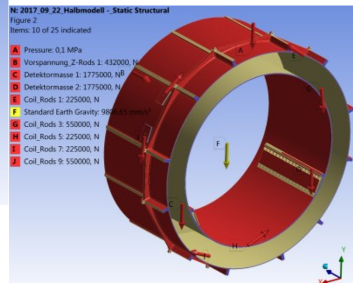
Streckenlast - q - (N/mm)	710
Länge - L - (mm)	5000
E-Modul - E - (N/mm²)	210000
Trägheitsmoment - I - (mm^4)	800000000
Widerstandsmoment - W (mm^3)	4000000
Berechnungspunkt X - (mm)	2500

Auflagerkraft - F (N)	
Koordinate x = 0 mm [FA]	1775000.0
Koordinate x = 5000 mm [FB]	1775000.0
Biegemoment - M (Nmm)	
Koordinate x = 0.0 mm [A]	-1479166666.7
Koordinate x = 2500 mm	739583333.3
Koordinate x = 5000 mm [B]	-1479166666.7
max. Biegemoment bei x = 0 und 5000 mm	-1479166666.7
Biegespannung - σ_b (N/mm²)	
Koordinate x = 0.0 mm [A]	369.8
Koordinate x = 2500 mm	184.9
Koordinate x = 5000 mm [B]	369.8
max. Biegespannung bei x = 0 und 5000 mm	369.8
Durchbiegung - f (mm)	
Koordinate x = 0.0 mm [A]	0
Koordinate x = 2500 mm	6.88
Koordinate x = 5000 mm [B]	0
Max. Durchbiegung bei x = 2500.0 mm	6.88
Neigung - tan α	
Koordinate x = 0.0 mm [A]	0
Koordinate x = 5000 mm [B]	0

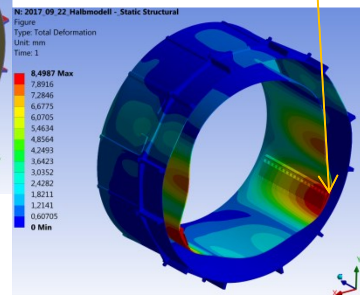
Defl. ~ 7 mm

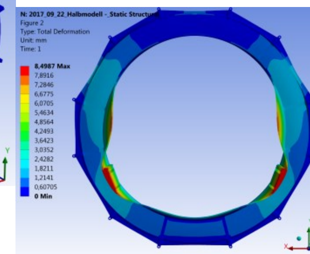
Max. deflection including all loads (vacuum, preloads, temperature), thickness outer 30 / inner 40 mm

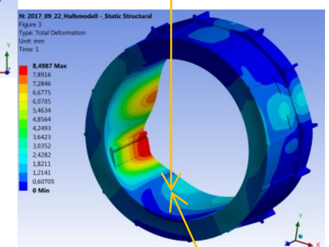




~ 9 mm

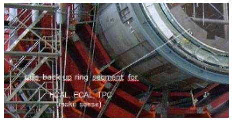






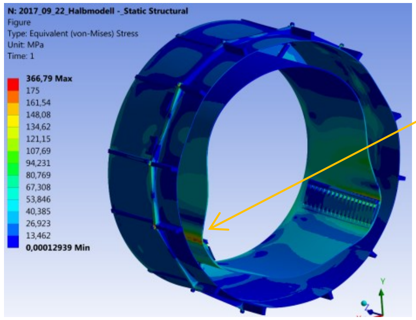
Martin Lemke

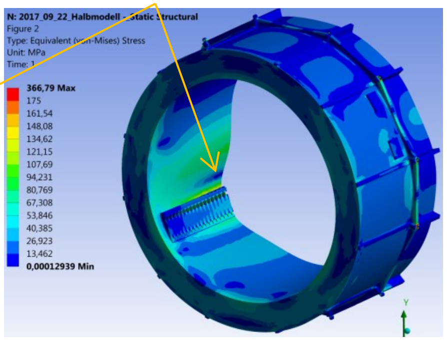
in fact, the deformation due to structural elements could be small.

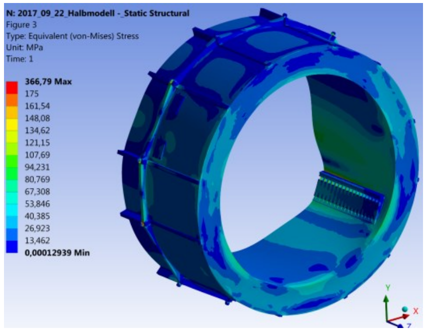


Max. stress including all loads (vacuum, preloads, temperature), thickness other 30 / inner 40 mm

δ ~ 180 N/mm²



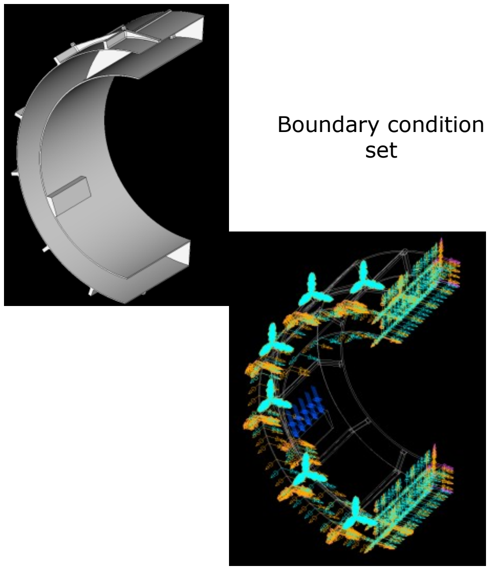




In fact, the stress caused by constructive elements could be small.

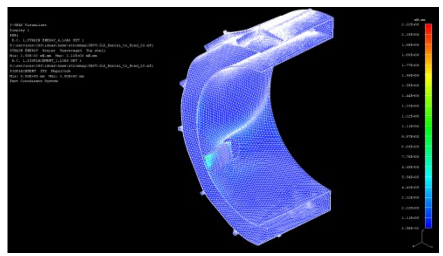
Deformation: 40 mm thinkness construktions suggestion force load ledge

(with CAD IDEAS)

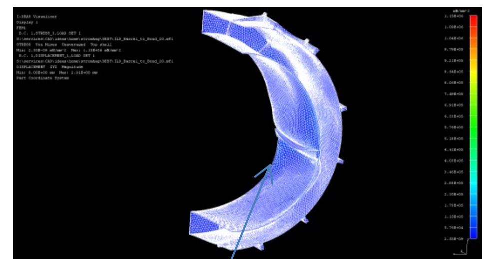


Boundary condition set

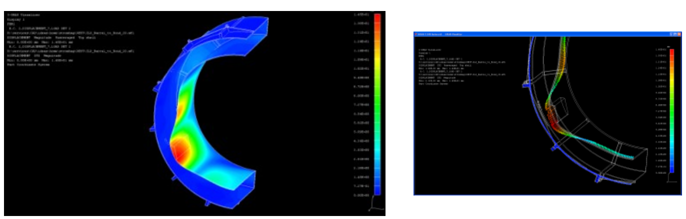
Deformation ~ 6 mm



Deformation 3 mm



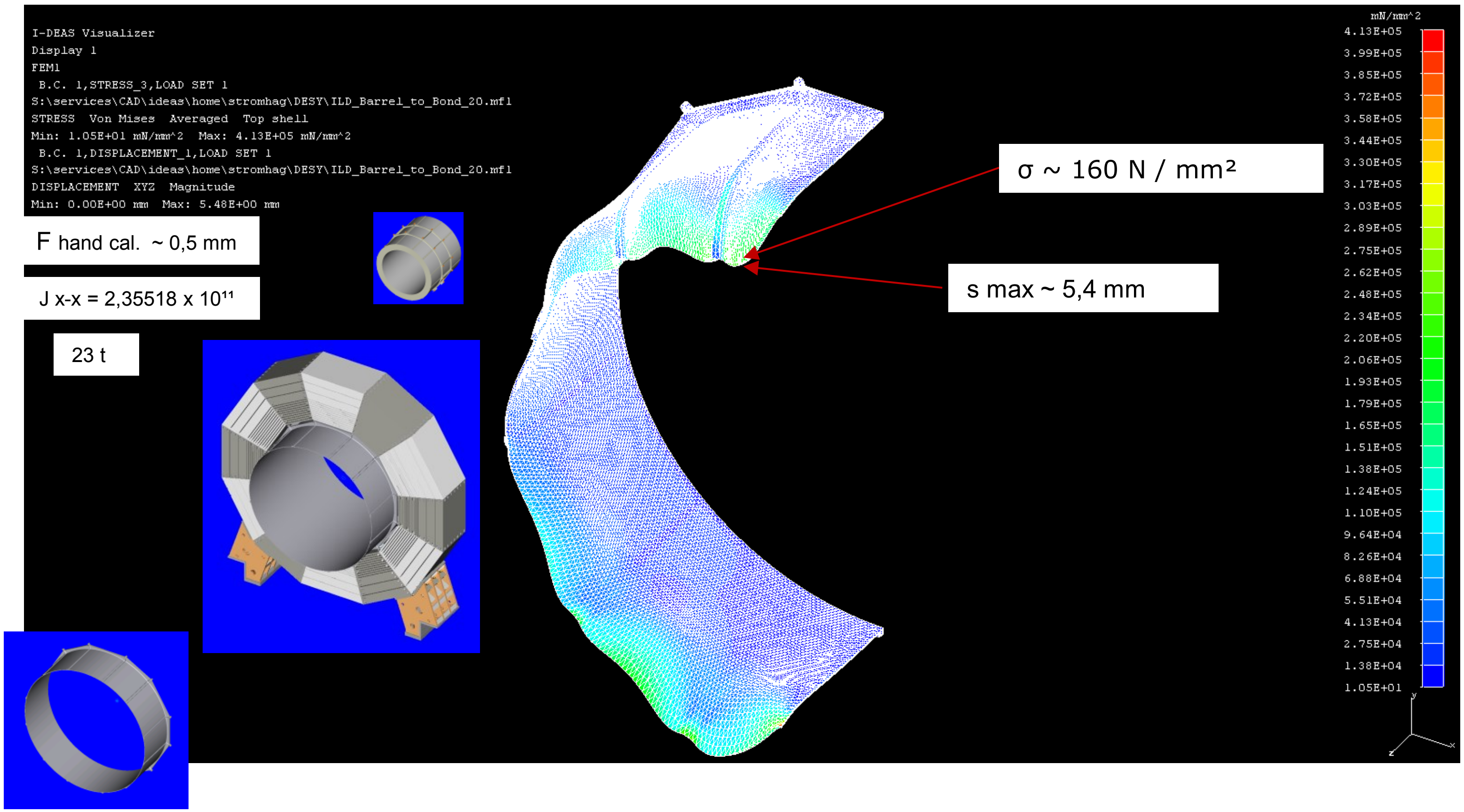
Deformation in Z ~ 2mm



ILD cryostat FEM simulation

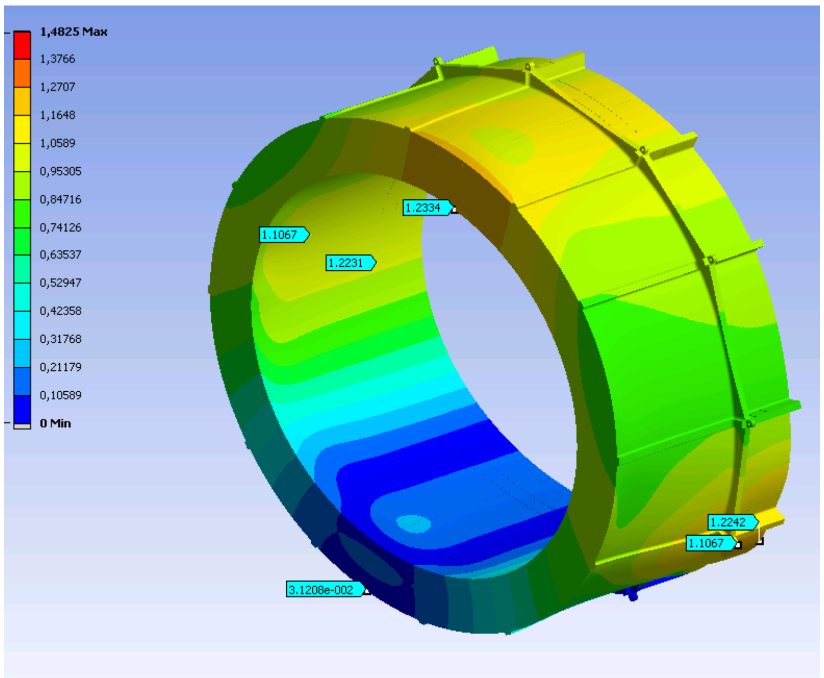
only end half part 2868 mm lg. / F = 3000 kN constant off-circumference

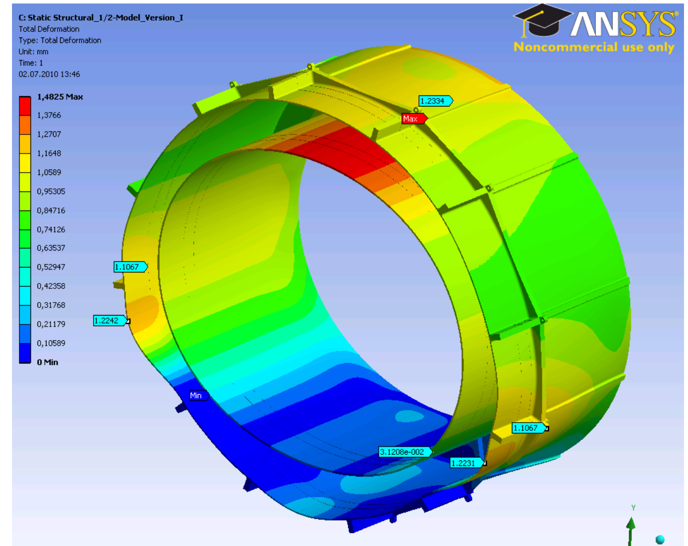
CAD IDEAS

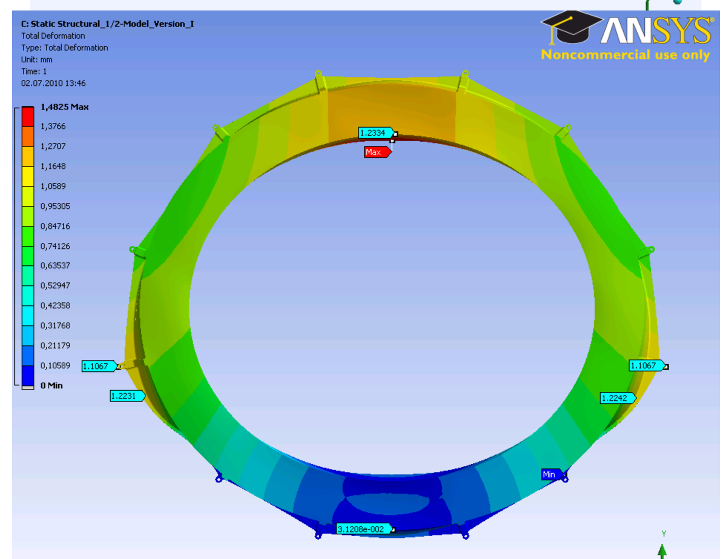


ILD Cryostat total deformation

max. ~ 2mm

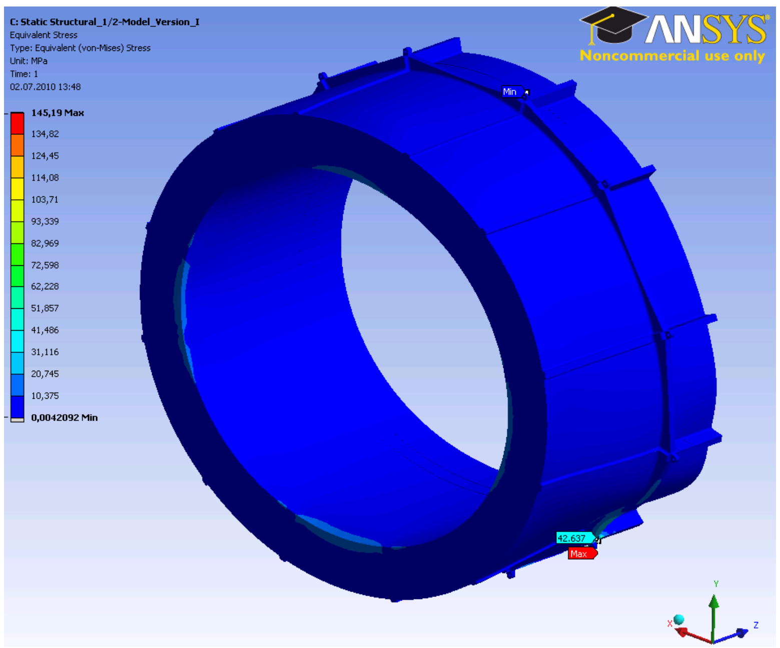


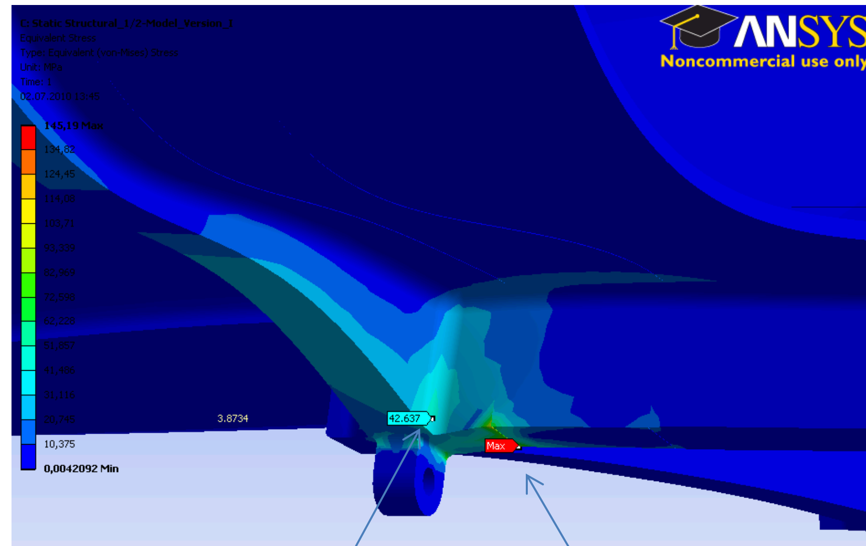




M. Lemke

ILD Cryostat total stress



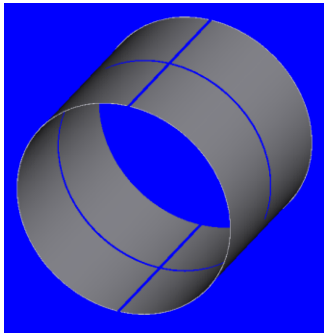


max. ~ 110 N/mm²
(as an exception)

normal max. 43N/mm²

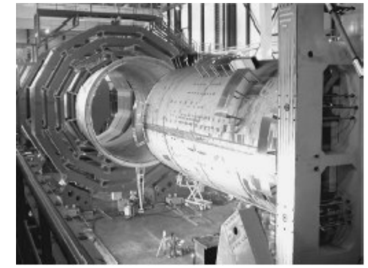
M. Lemke

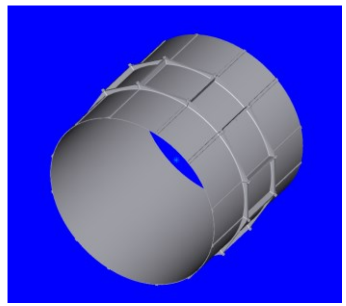
ILD cryostat production flow suggestion / assembly cryostat



Outer-, s=30mm; and inner-, s = 40 mm
- vacuum vessel

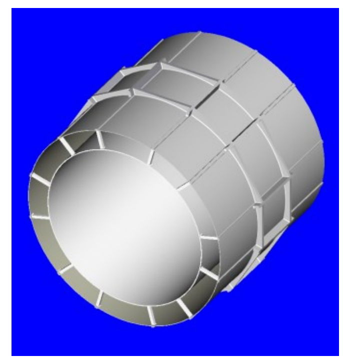
-sheet 4 or 8 (max. 13610 mm x 3905 mm,)
segment rolled and welded





outer vacuum vessel

- prepared edge lined up and welded
- rotation symmetrical pilot hole diameter (ø 40 mm)
- outer reinforcements clamped to barrel and held in place by outer support
- aligned axis of ovv and barrel
- fixed ovv and welded brackets to the central barrel



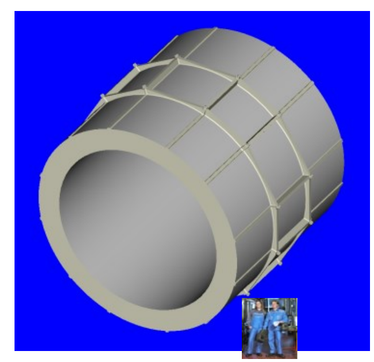
to be done

assembly cryostat to ovv

- solenoid completion and fixture

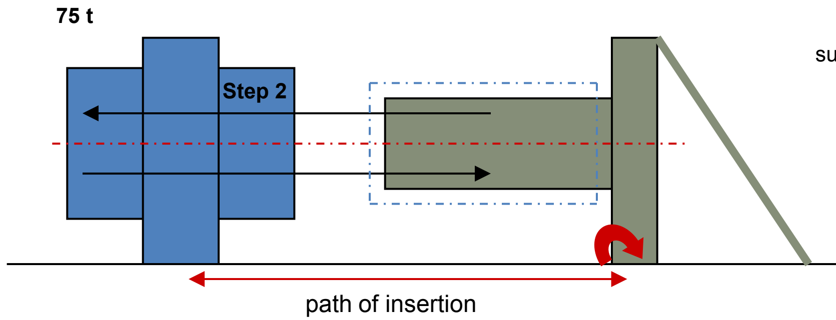
inner vacuum vessel

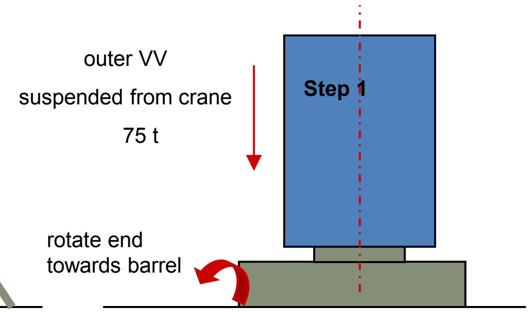
- sheet 4 or 8 rolled and outside scaffold
- aligned and welded
- lodge inner in outer vv, align rims and weld
- welding of end plate



Assembly completion of solenoid and vacuum vessel (CMS)

1. outer vacuum vessel (75 tons) with barrel after installation on turn table, primary alignment



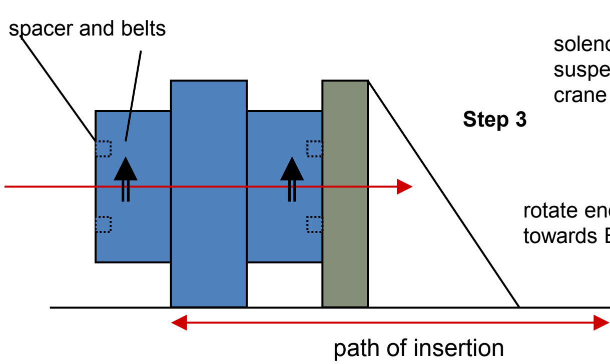


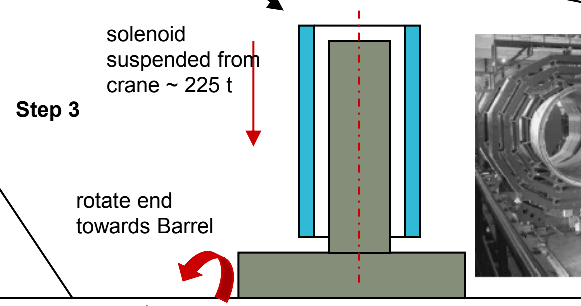
2. assembly and completion of the solenoid (~ 225 t)

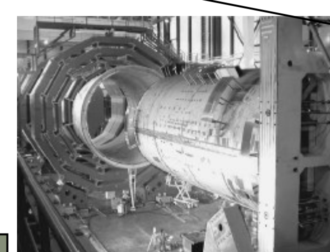
- rotate inner vacuum vessel into horizontal position => weld radial tiers and end flange

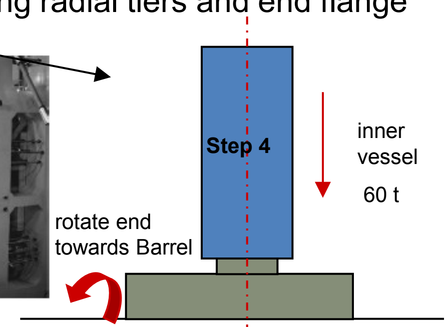
- vertical assembly of the inner vacuum vessel
- rotation of the Inner vacuum vessel in horizontal position

- welding radial tiers and end flange

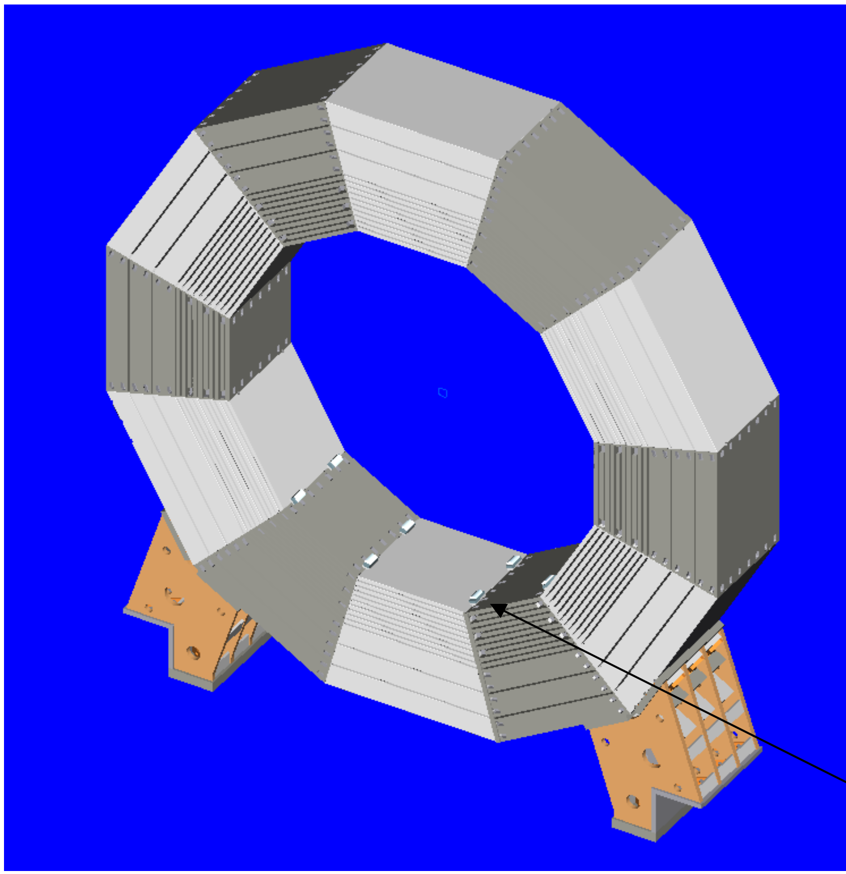


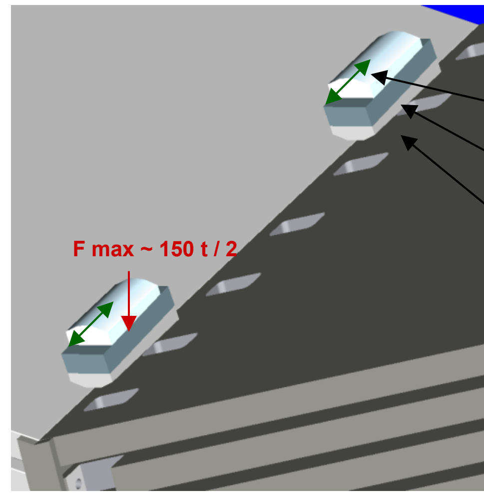






Cryostat integration in central barrel ILD first step





adjustment distance

integral key, slope 3deg

hardened plate

allowable pressure

S235JR (St37) R_{mN} ~ 360 N/mm²

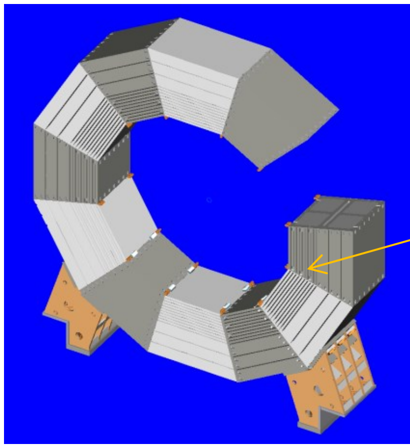
yield point $R_{p0,2N}$ ~ 235 N/mm²

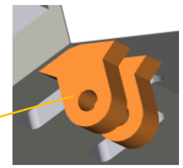
σ_{dB} ~ F / A ~ 75 000 0 N / 8 x 500 (mm) ~ 188 N/mm²

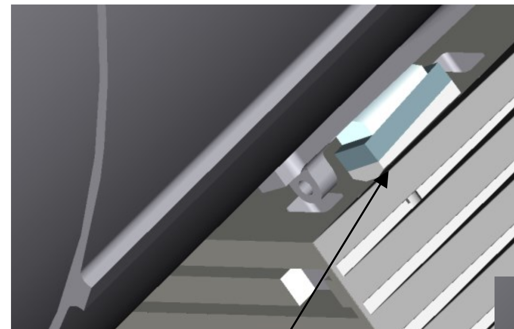
without preparatory work, full yield settling ~ 0,8 mm

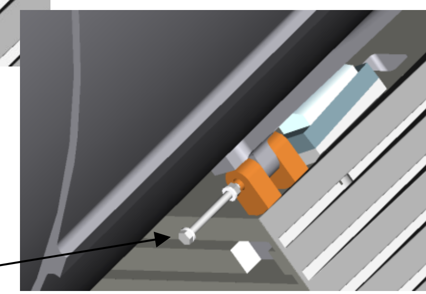
Installation of "jacking up to line" keys with hardened plate to primary alignment (integral key ~ 3deg), shown in position (8 units)

Second step: Push outer vacuum vessel to central barrel

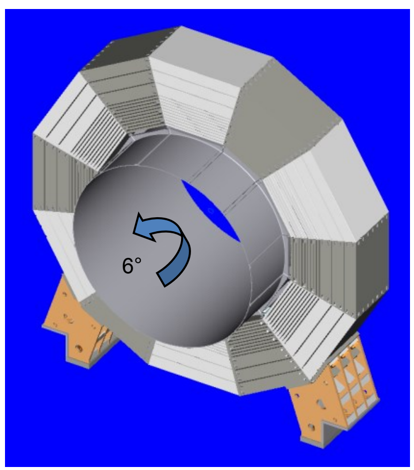








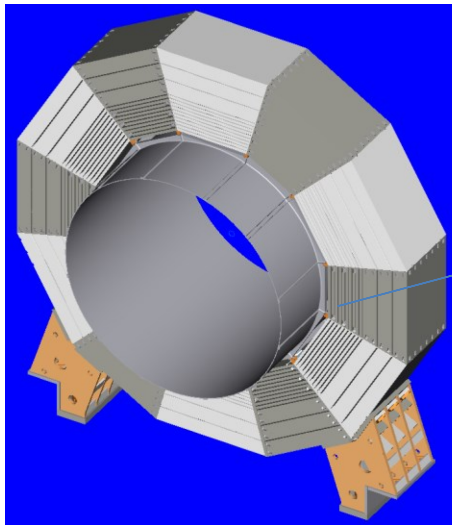
- after primary alignment
- tack weld each bracket to barrel individually,
- from point to point to fit and tack
- fit screw between barrel and ovv
- all bracket to barrel tack welding
- remove circular 6° ovv from barrel
- all bracket end welding
  (alternative: welding without removal of ovv)

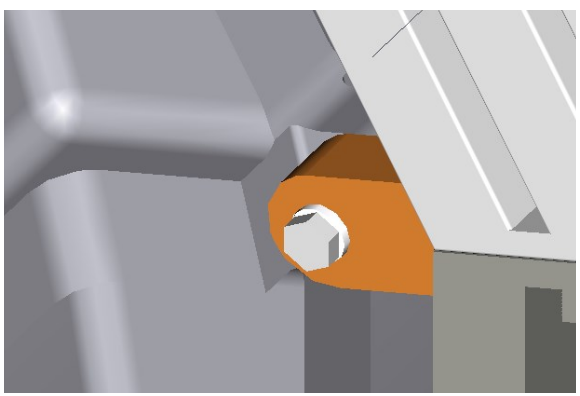


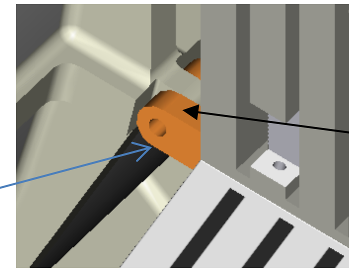
Drilling of Dowels Holes / 24 Suspension Bolds

E-JADE is a Marie Sklodowska-Curie Research and Innovation Staff Exchange (RISE) action, funded by the EU under Horizon2020

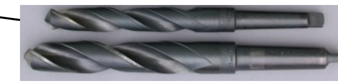
E-JADE







Assembly boring of ø 50H¹² mm
Bearing case in combination with Cryostat ear

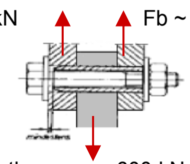


friction bold DIN 1481

fix with friction bolt DIN 1481 - ø 50 x 240 lg.
hexagon head bolts with large head (HV)
DIN 6914 – M30 x 300 comply with washers and nuts

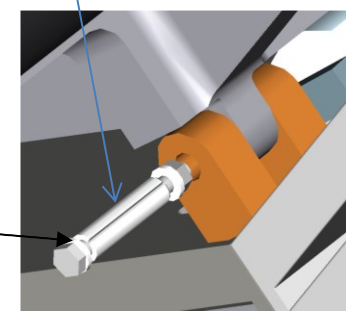
Fa ~ 300 kN

Fb ~ 300 k N



Fr theory ~ 600 kN
Fr applied under 600 kN!
Surface pressure 65 N/mm²

friction bold DIN 1481
shearing force max ~ 1685 kN
Account: 20 friction bold to lift 1200 t



shear stress factor ~ 2,5 (1,2 is ok)
surface pressure 125 N / mm²

S235JR ~ 235 N/mm² > 125 N/mm²

pressure factor ~ 1,8 (1,2 is ok)

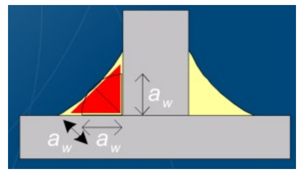
tightening screw condition:
hydraulically operated in sequence for 24 bold
DIN 6914 – M30 x 300
M ~ 1650 Nm, Fv ~ 350 kN

Cryostat integration in central barrel
welding bearing case

account to data sheet DVS 0705 / DIN 18800

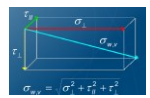
weld seam: aw ~ 35 mm,

l = 80 mm, Aw = 2800 mm²



steel: S235JRG2
Rm ~ 360 N/mm²
Re ~ 215 N/mm²

σ_{II} ~ 18 N/mm²
$\sigma_{\perp}$ ~ 32 N/mm²
τ_{II} ~ 32 N/mm²
$\tau_{\perp}$ ~ 32 N/mm²
σ_{exist} ~ 48 N/mm² < σ_w ~ 207 N/mm² (St37)
(factor ~ 4)



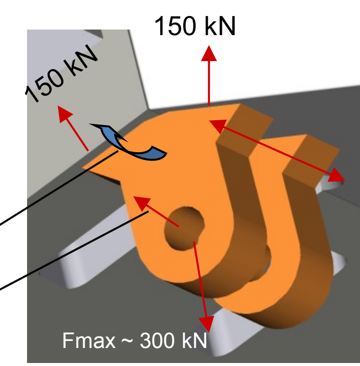
stress reference value

M bending moment ~ 19 kNm

F axial ~ 150 kN

σ normal stress ~ 152 N/mm² < $\sigma_{tol.}$ ~ 195 N/mm²

DVS 0705



Conclusion

- Performed detailed study
    - plant dimensioning load and variable geometric
    - stability of Cryostat / force
    - plant discussion optimal material strengths
    - safety factor
    - Instruktion report

A lot of studies need to be performed:
- design of cryostat supporting system,
- all geometrical parameters,
- finish cryostat constructions concept
- cryostat quench scenarios
- cabling concept
- power supply connection design
- cryostat safety instruction sheet
- scaffolding
- gas-, cables-, water-, power-connection
- escape rotes
- safety periphery and risk assessment analyse
- collaboration with other interacting group