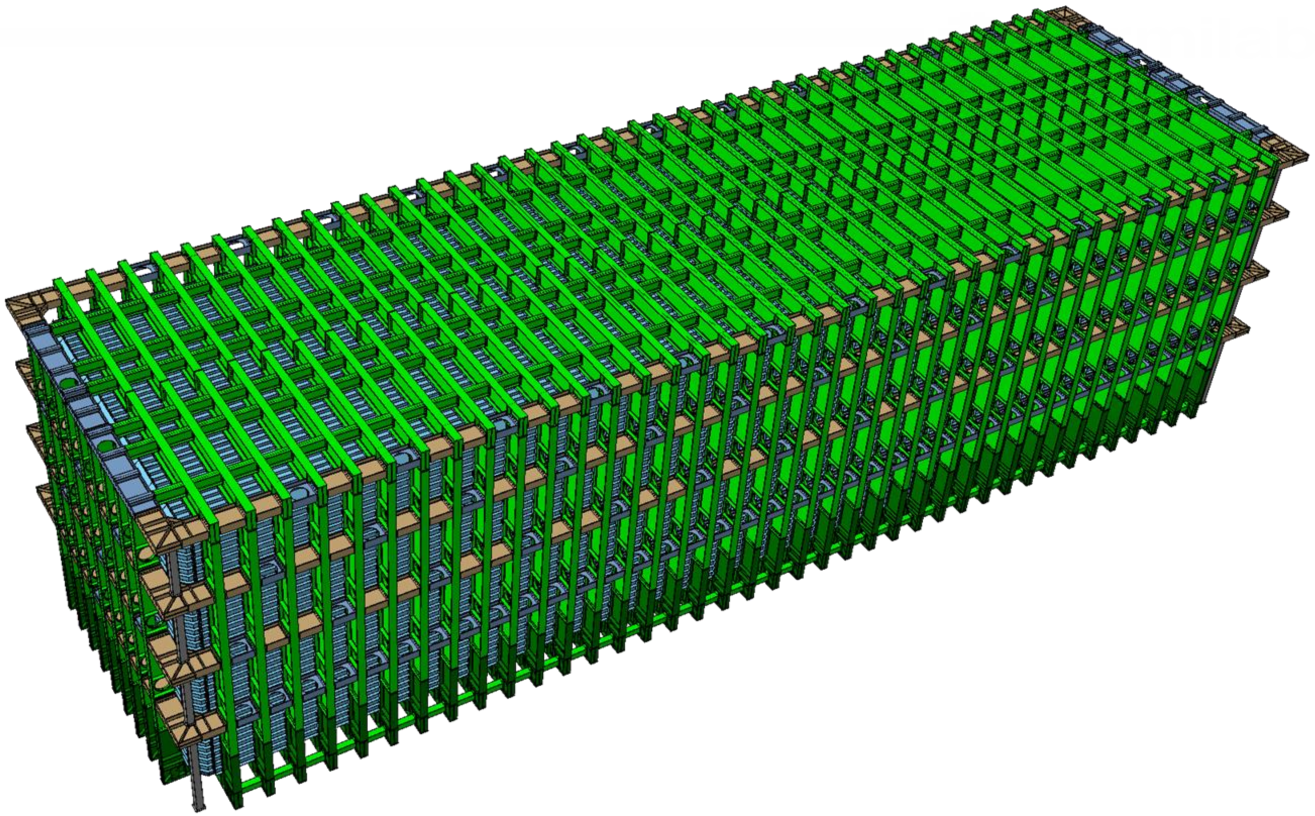


LBNF Design Engineering & Details

Andrea Catinaccio (CERN-EP-DT)

LBNF Cryostat, final design review

SURF, 21-22 August 2017

Outline

- Design revisions since the initial design review of May 2015
- Details of the new design features
- Assembly Process and CAD Models available
- Summary and Conclusions

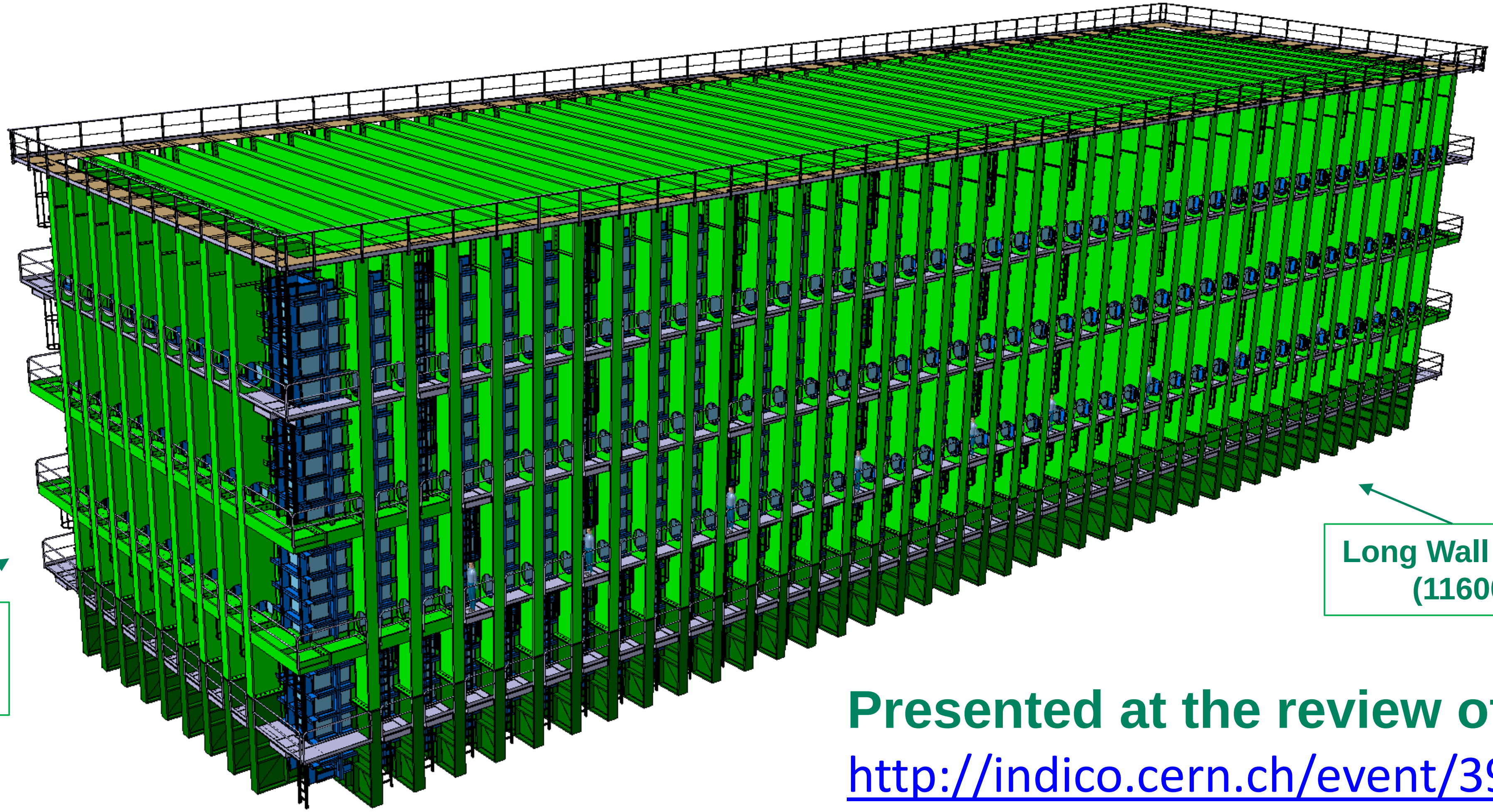
Who Am I and Where Have I Been?

Senior Mechanical Engineer (MSc)
CERN, Experimental Physics Department
Deputy Group Leader of the Detector Technologies Group (EP-DT)
https://ep-dep-dt.web.cern.ch/
Section Leader of the Engineering Office Section (EP-DT-EO).
https://ep-dep-dt.web.cern.ch/engineering-office

Coordinator of engineering design and structural analysis activities within EP-DT for the LBNF/DUNE Warm Cryostat project.

27 years of professional experience in space projects and large detector systems. At CERN since ‘94, experience includes 14 yrs as Project Engineer for the ATLAS LHC Inner Detector during design, construction, initial operations and further upgrade programmes .

Initial Design Concept



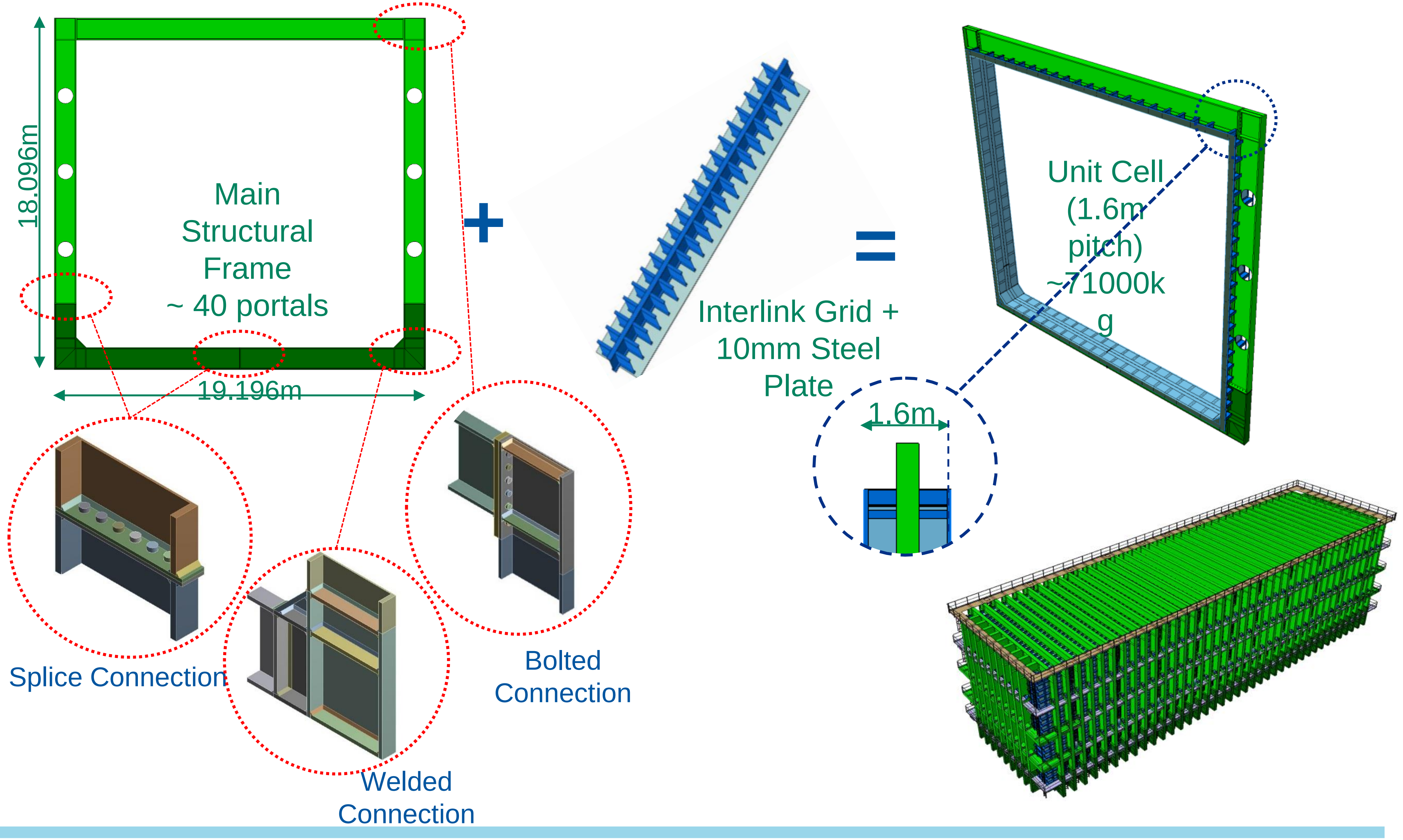
Short Wall
~27.7MN
(2800 T)

Long Wall ~114MN
(11600 T)

Presented at the review of May 2015

http://indico.cern.ch/event/395238/

Initial Design Concept main units



Initial Design Concept

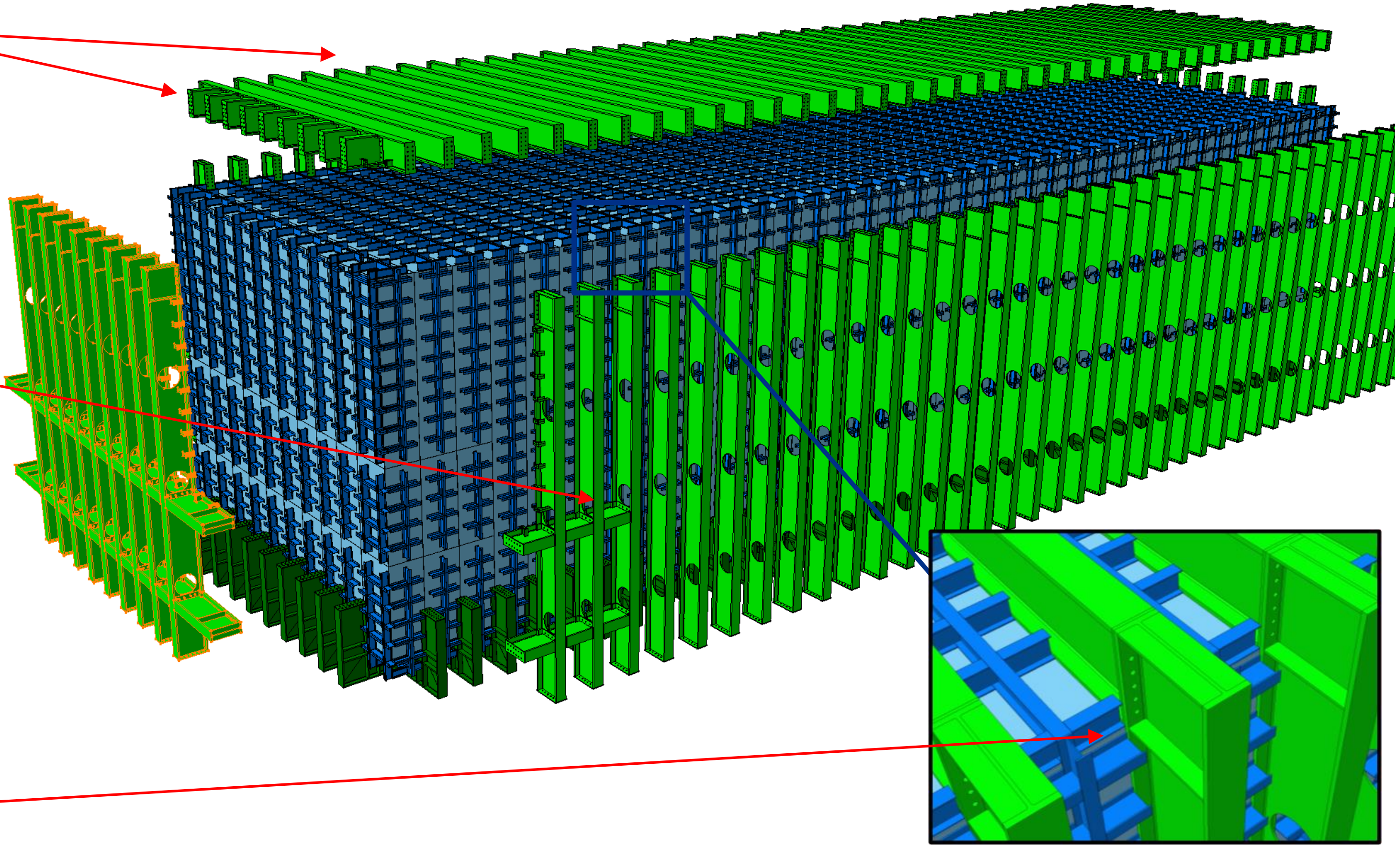
Since 2015, some improvements have been introduced:

High loads on first portals, from the end wall reactions, required to add longitudinal bracings through the roof and side walls (for strength and stability)

The grid reinforced membrane concept required a large number of connections with consequent manufacturing and installation work.

Butt bolted joints for the membrane grid came out to be very sensitive to manufacturing and assembly tolerances.

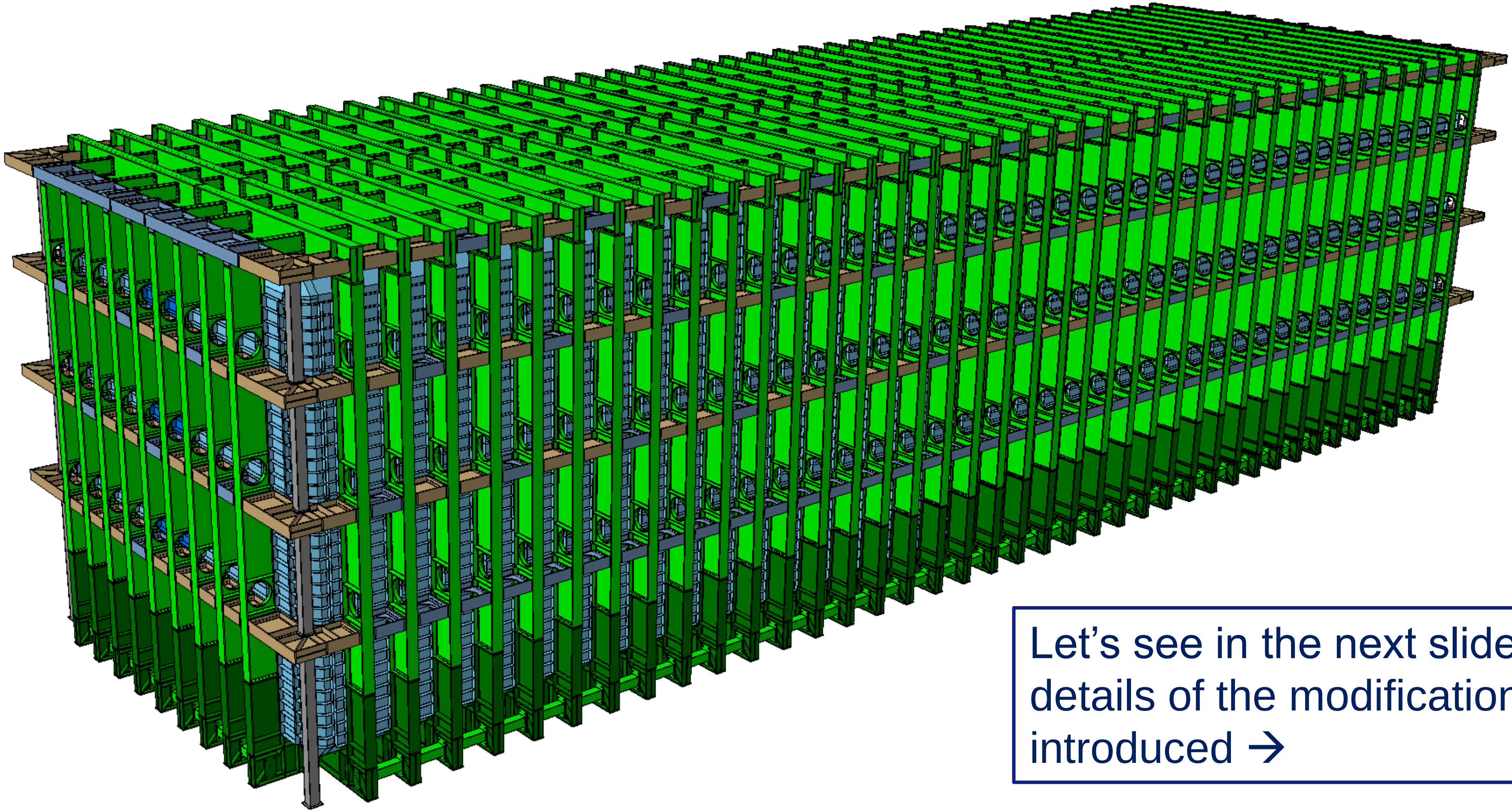
Their installation would also have required for LBNF access underneath the floor and adjustment work all around the cryostat.



more on next slides →

New Design of the warm structure

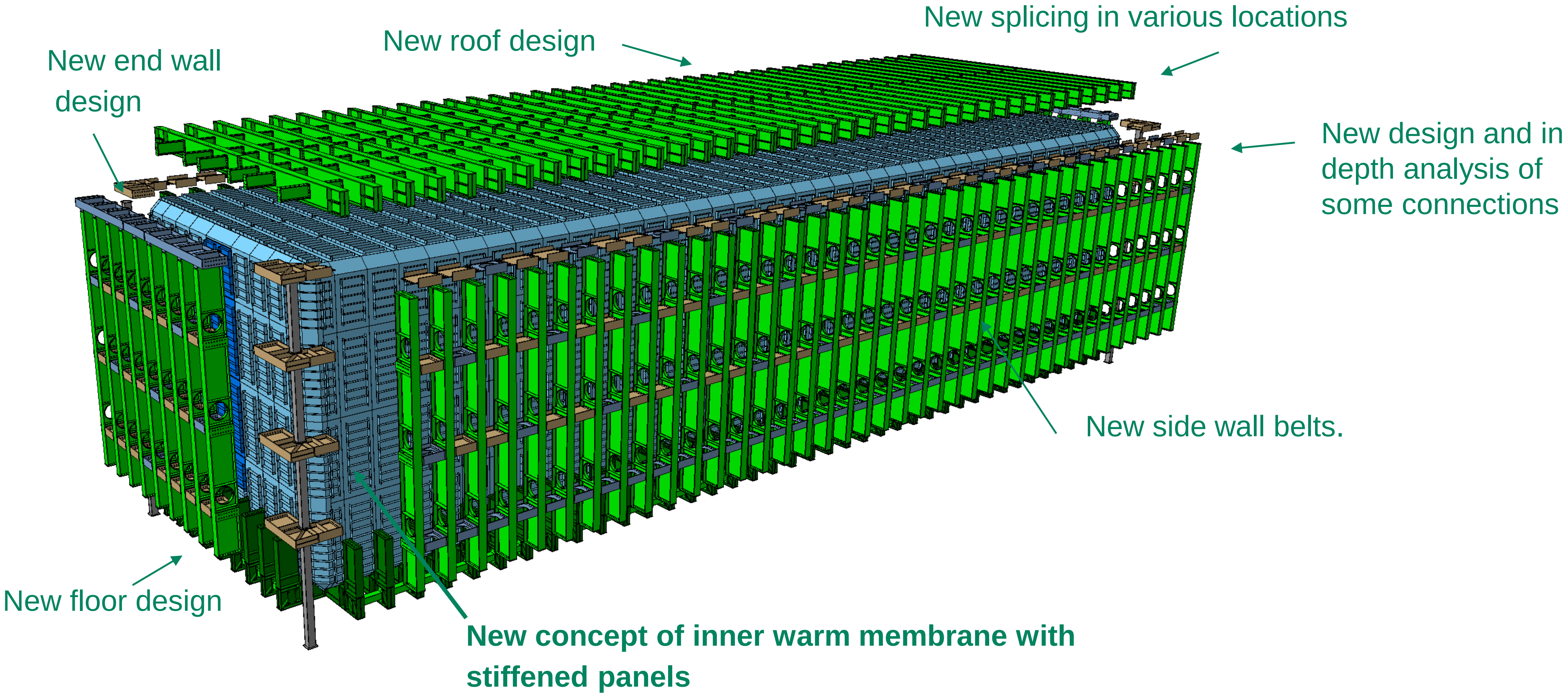
Stp files available: https://edms.cern.ch/document/1835609



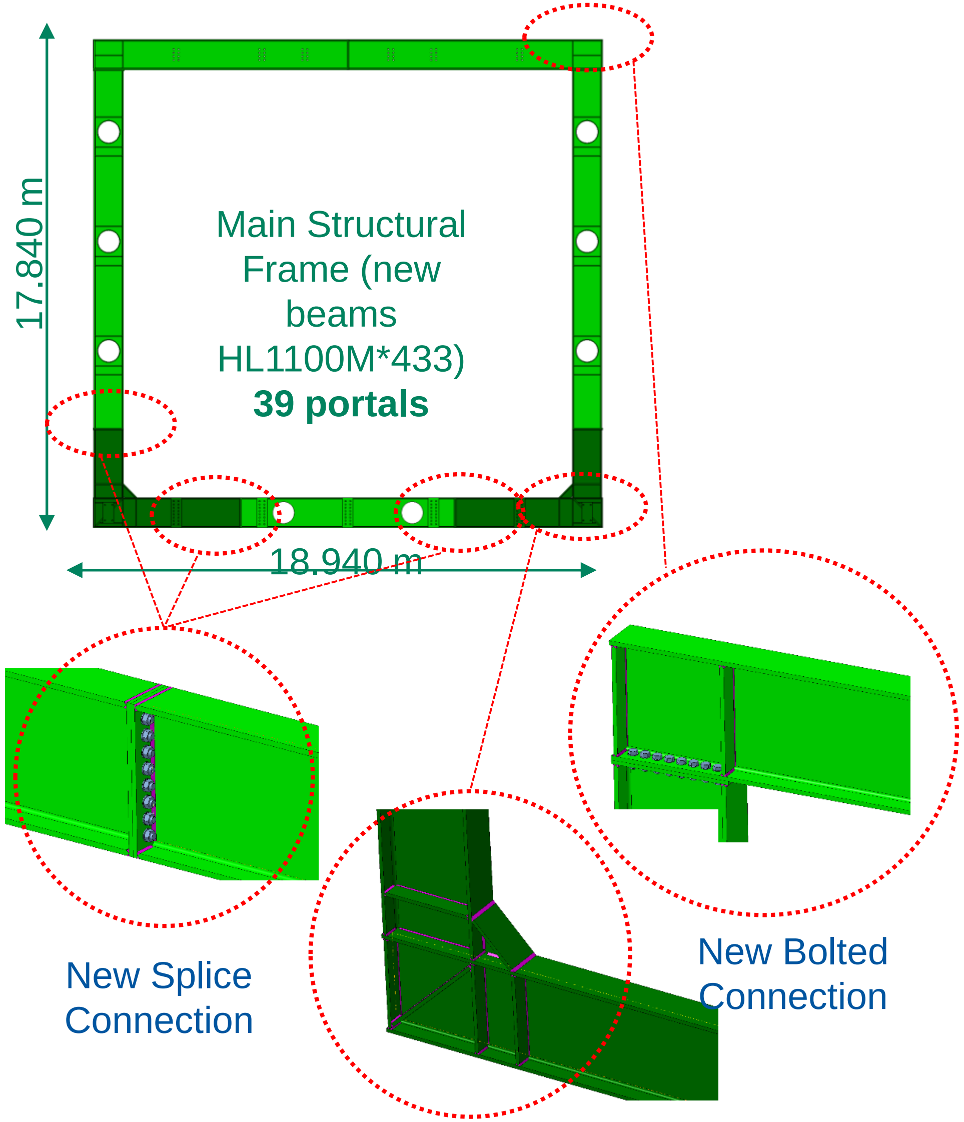
Let's see in the next slides all details of the modifications introduced →

Quick view of the new design revision

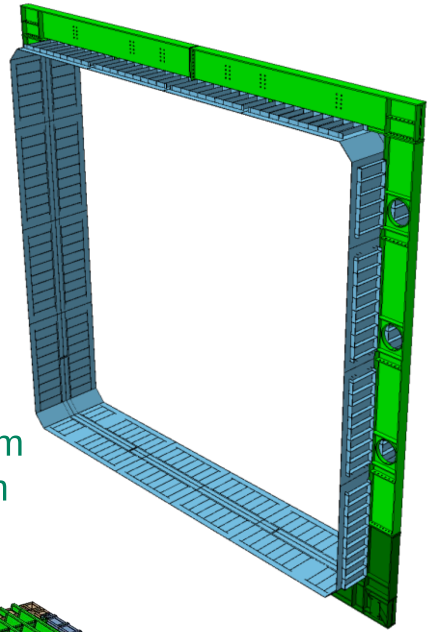
- Following various optimisations with structural analysis models made by EP/DT-EO



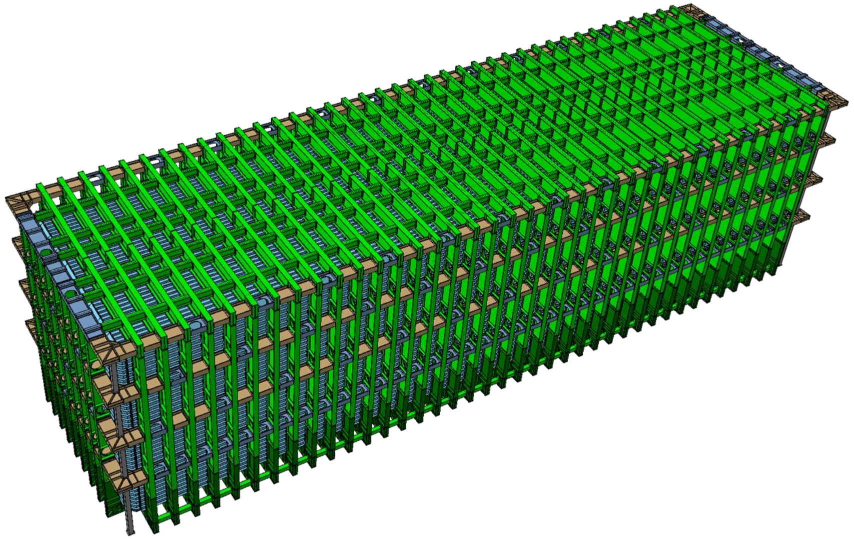
Revised Design of Basic Units



Unit Cell (1.6m pitch)



New Stiffened warm membrane 12 mm thick

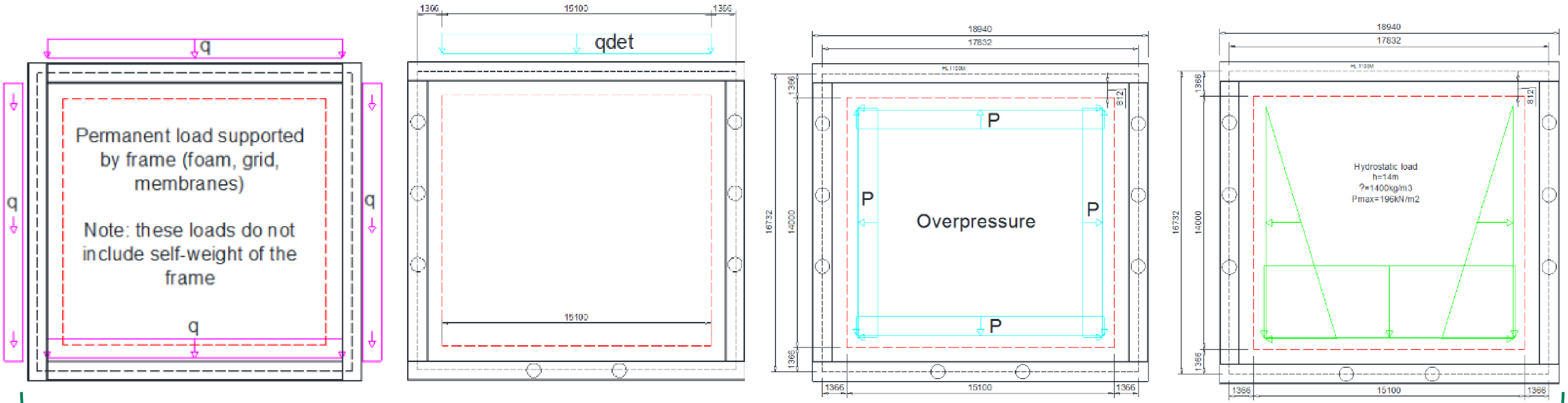


New in Loading and Materials

- Static head of LAr: 14m (~100% filling ratio, ρ=1400kg/m^3)
- Top pressure: 130mbar to 350mbar (valve opening)
- Weight of members:
  - Self-weight of composing members. Main beam members: HL1100M (433 kg/m)
  - Insulation plus inner corrugated membrane 105 kg/m2 (800 mm total thickness)
  - Stiffened warm membrane of 12 mm, 131 kg/m2
  - Detector weight (dry) 200 tons distributed on the roof
- In addition, new load cases with Seismic loads

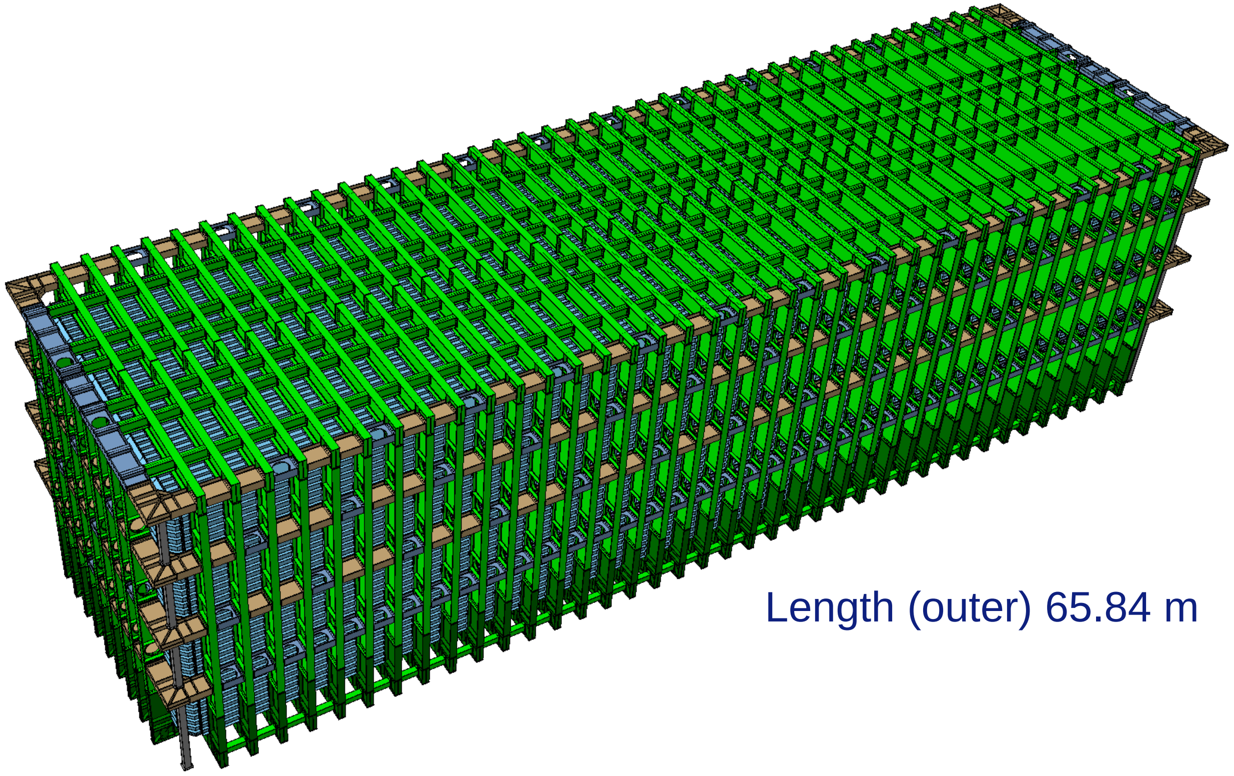
- Baseline Material: Grade S460ML (σy=440 MPa; UTS=540MPa) for main beams and membrane
- Bolt grades 10.9 – preloading quality EN14399

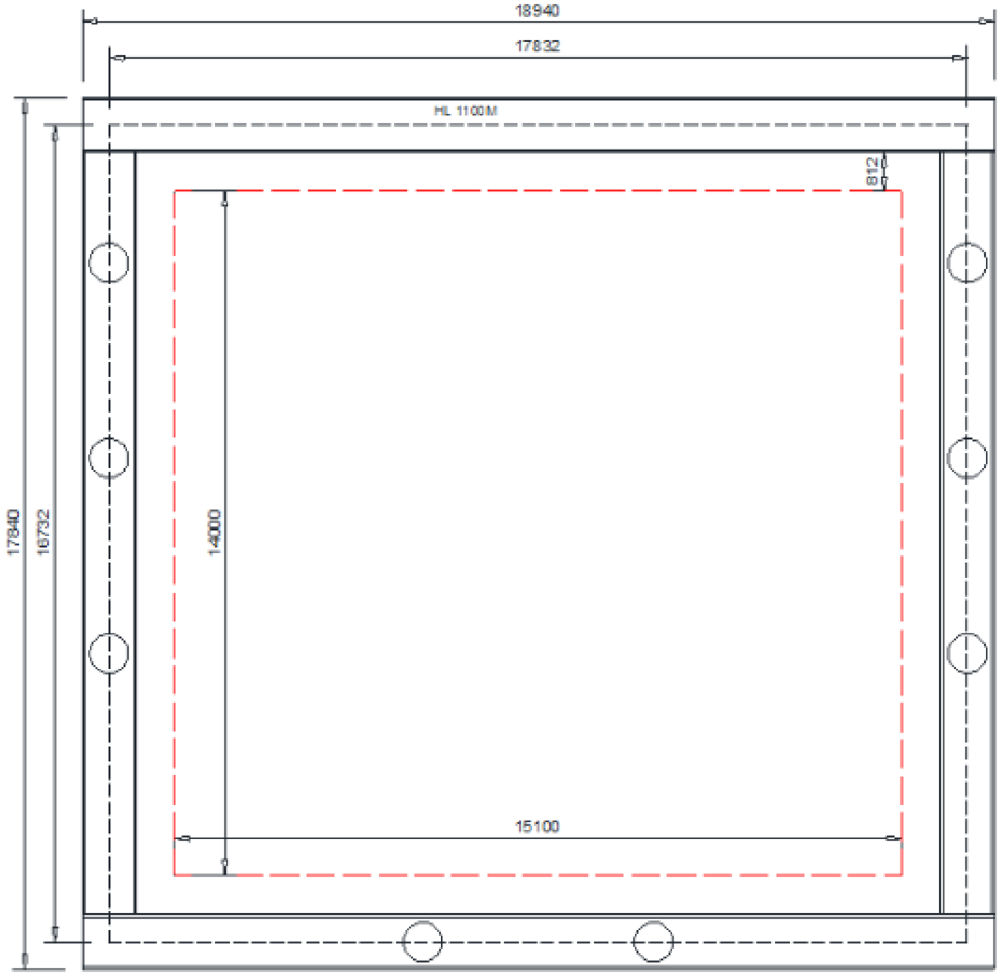
*New picture showing new HL1110M*433 beams and news dimensions of portals*



Loading corresponding to Unit Cell **(pitch 1.6m)**

New Main Beams and Portals

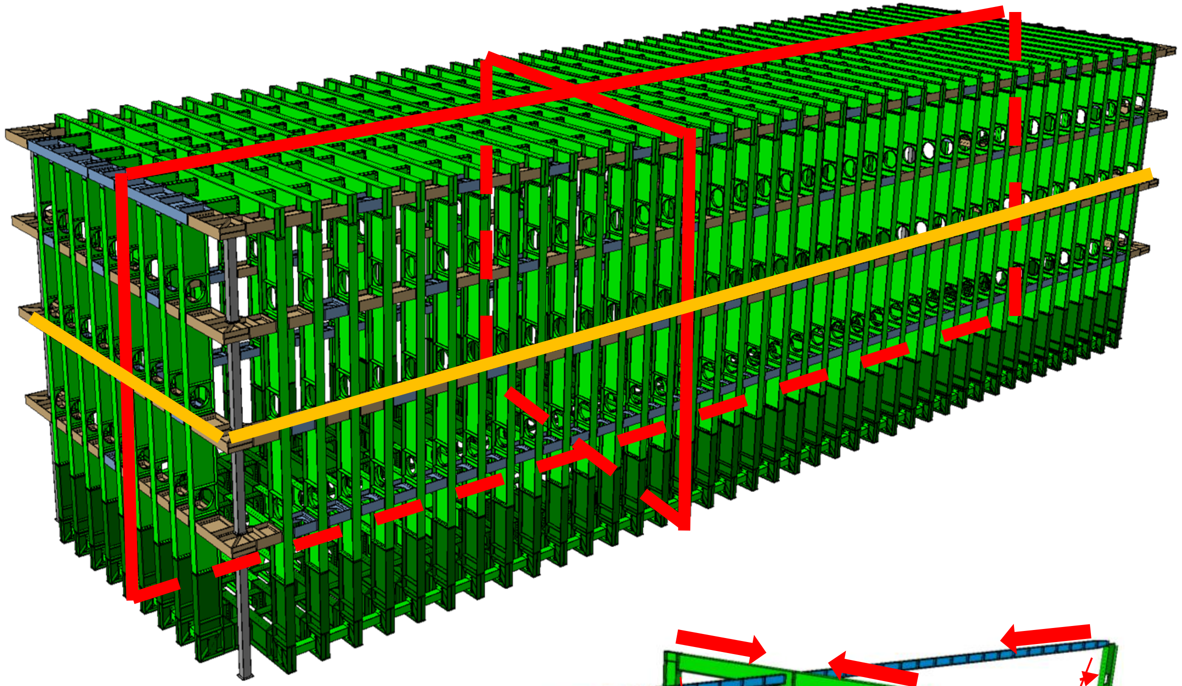




New HL1110M*433 lighter beams have been adopted

New dimensions of portals due to thinner insulation now 800 mm total

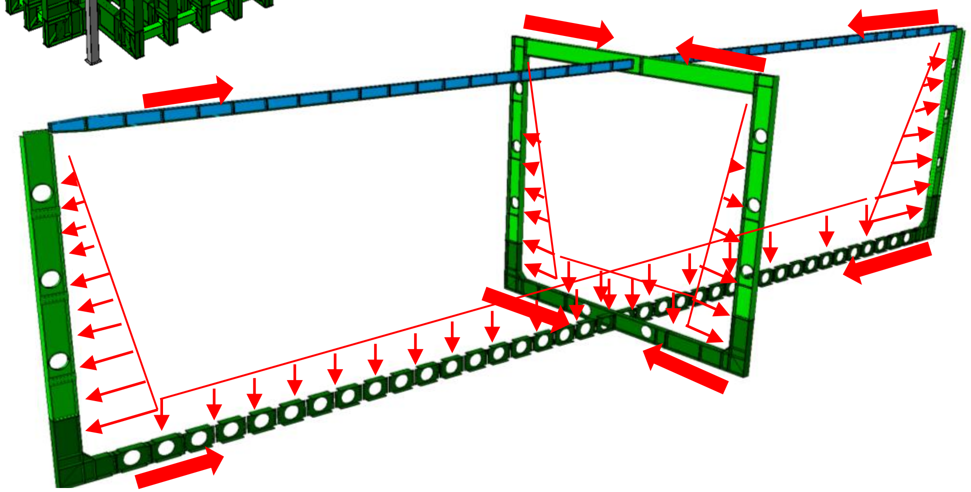
Improved bracing concept for the load carrying structure



- Outer independent load carrying structure

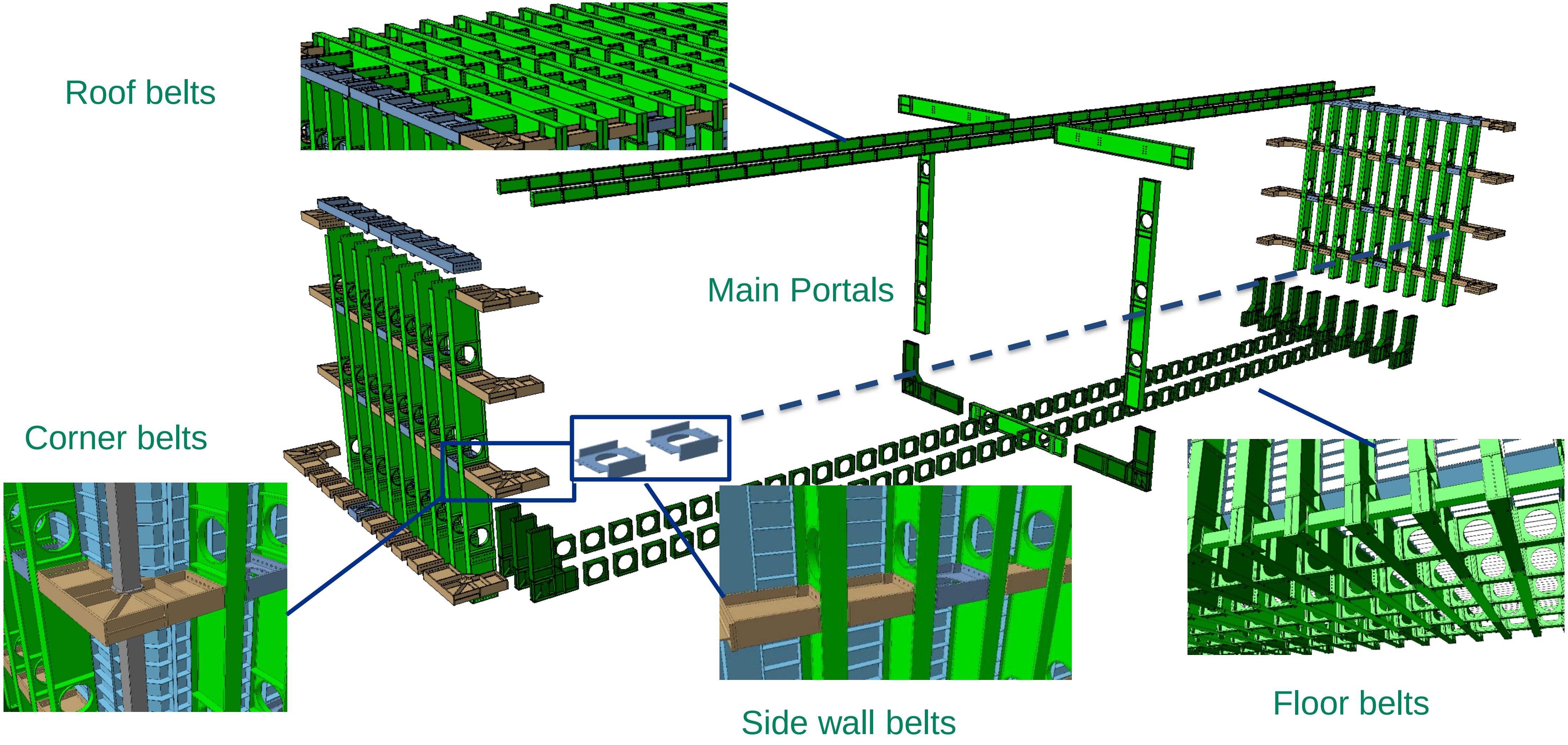
- Liner = warm membrane, independently sliding (beside frictional effects) on main outer structure

- Main long forces transiting through the belts (roof, floor and side walls).

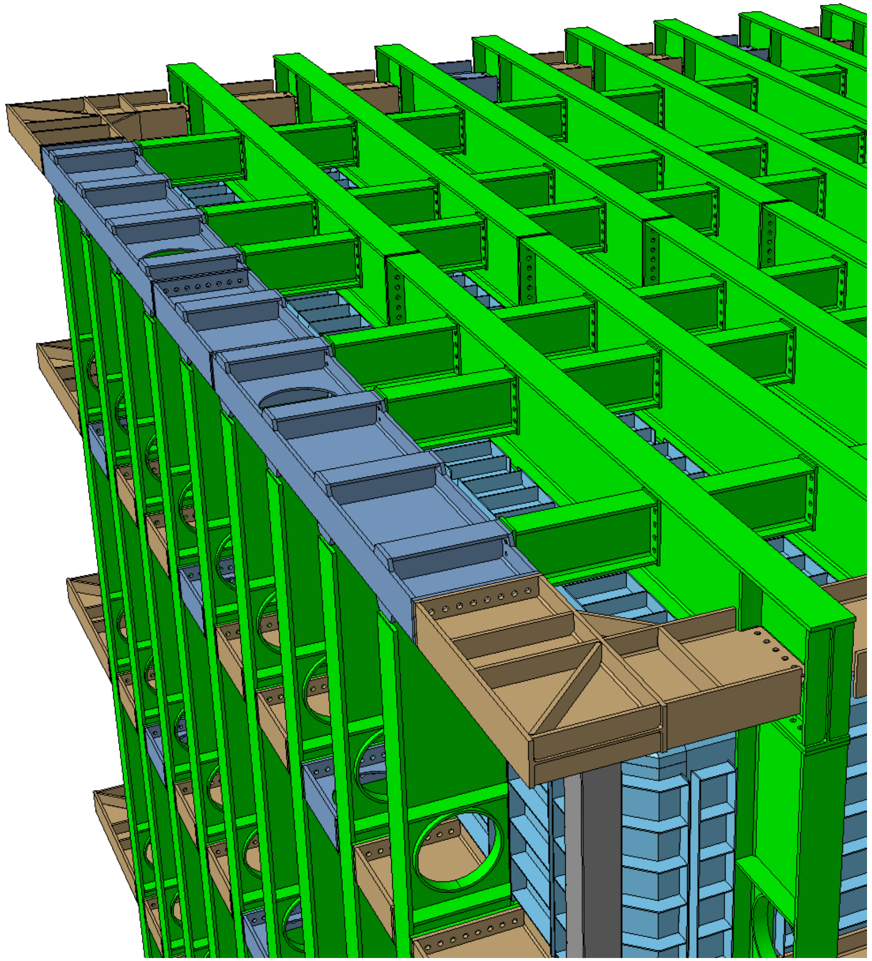


As presented at the end of 2016

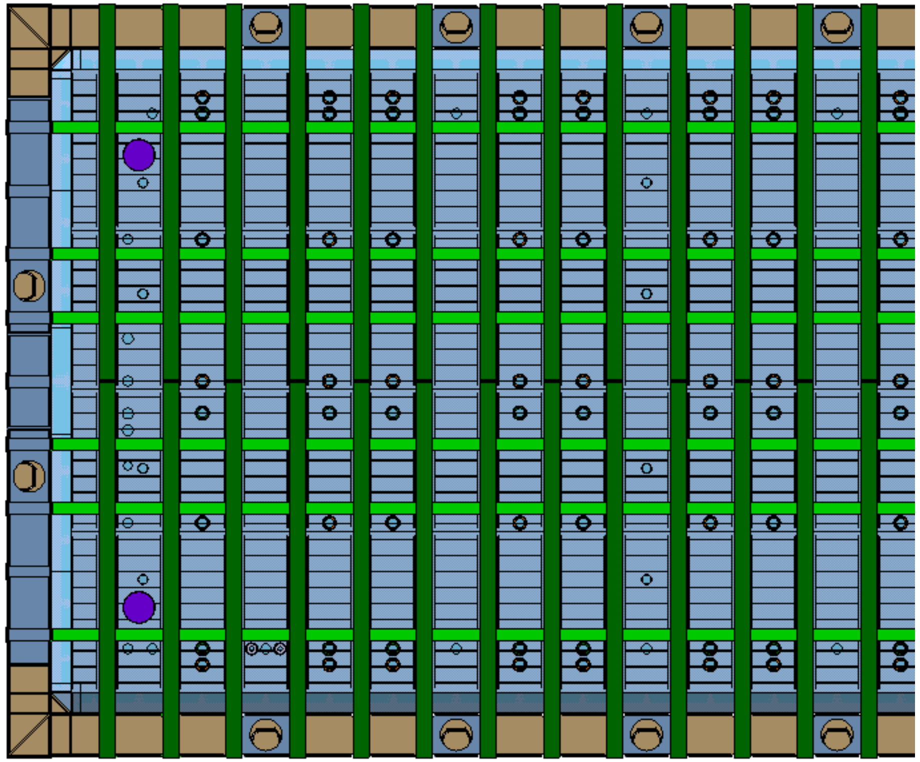
Details of bracing elements for the load carrying structure



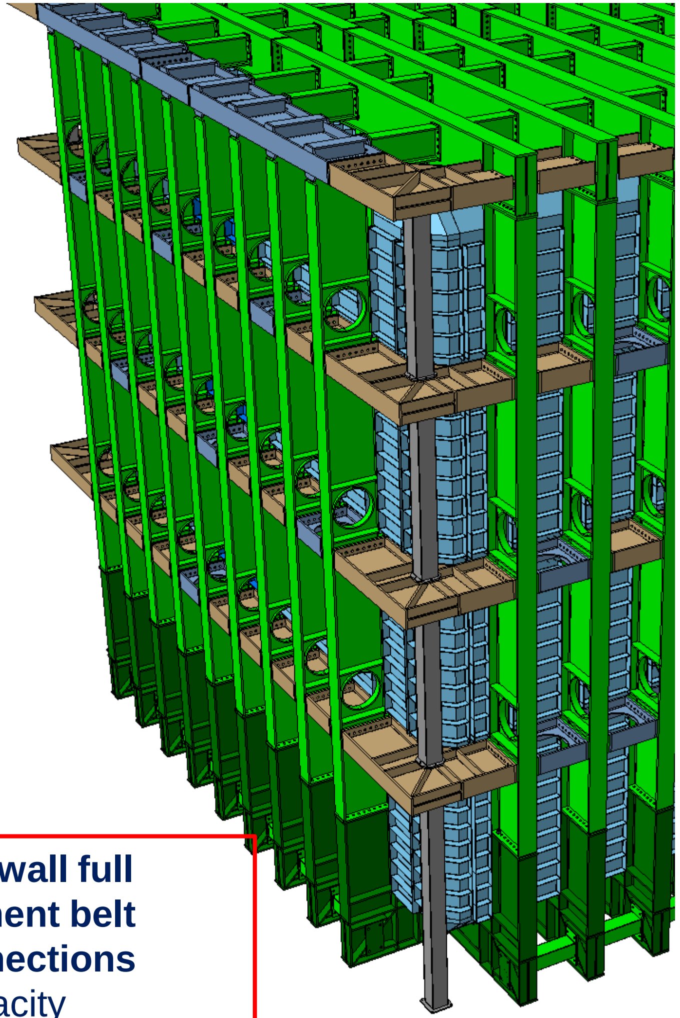
Details of the roof, belts and feedthroughs



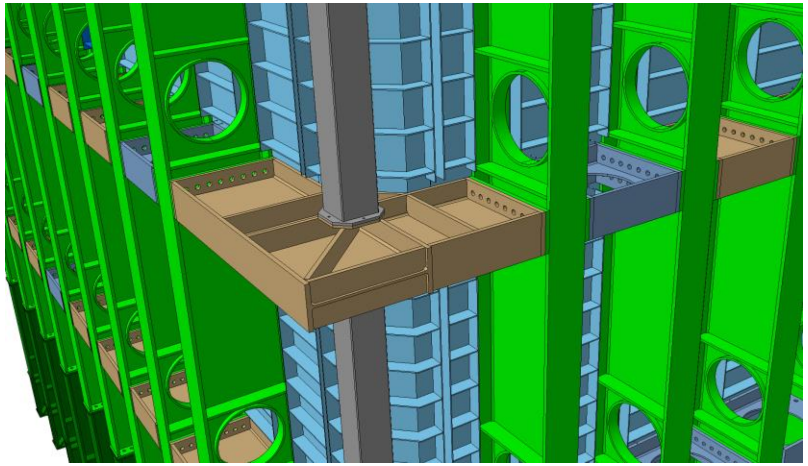
Roof belts profile and connection optimisation
New connection to the short wall and portals
Roof belts design compatible with ft’s pattern
New splices added for compatibility with crane/shaft



Side belts, Short Wall, Corners

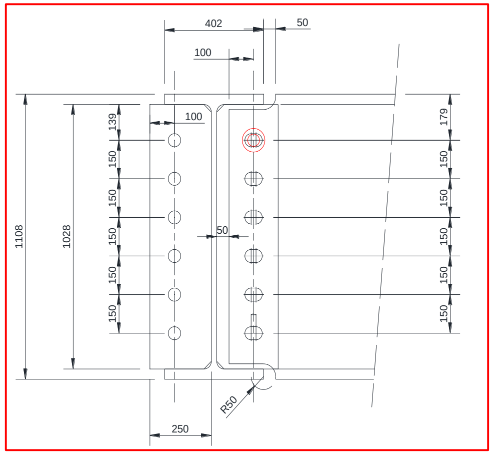


End wall full Moment belt connections
(capacity requirement)



Side belts optimisation, with full Moment and pinned connections
(more tolerance compliant)

Reinforced openings for access



Design of the Floor

Considering 3 points:

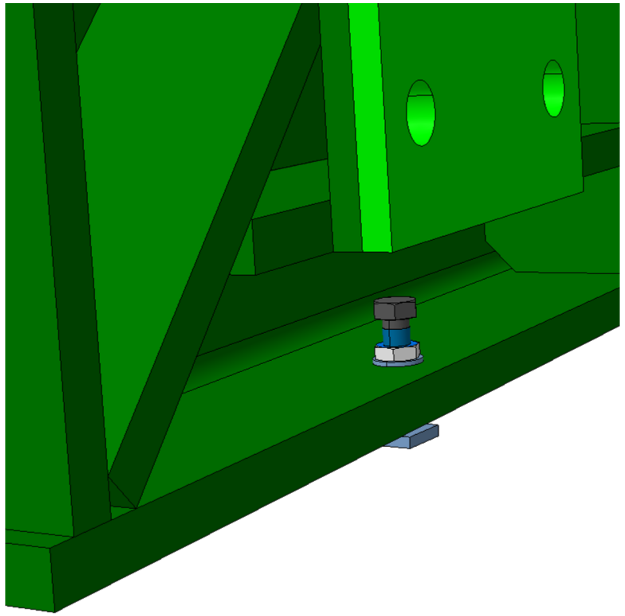
- rod diameter $r := 12\ mm$
- rod area $s := \pi \cdot r^2 = 452.389\ mm^2$
- load applied on rod $L := 10\ tonne$
- force on rod $F := L \cdot g = 98.067\ kN$
- Pressure at the bottom of rod $p := \frac{F}{s} = 216.775\ MPa$

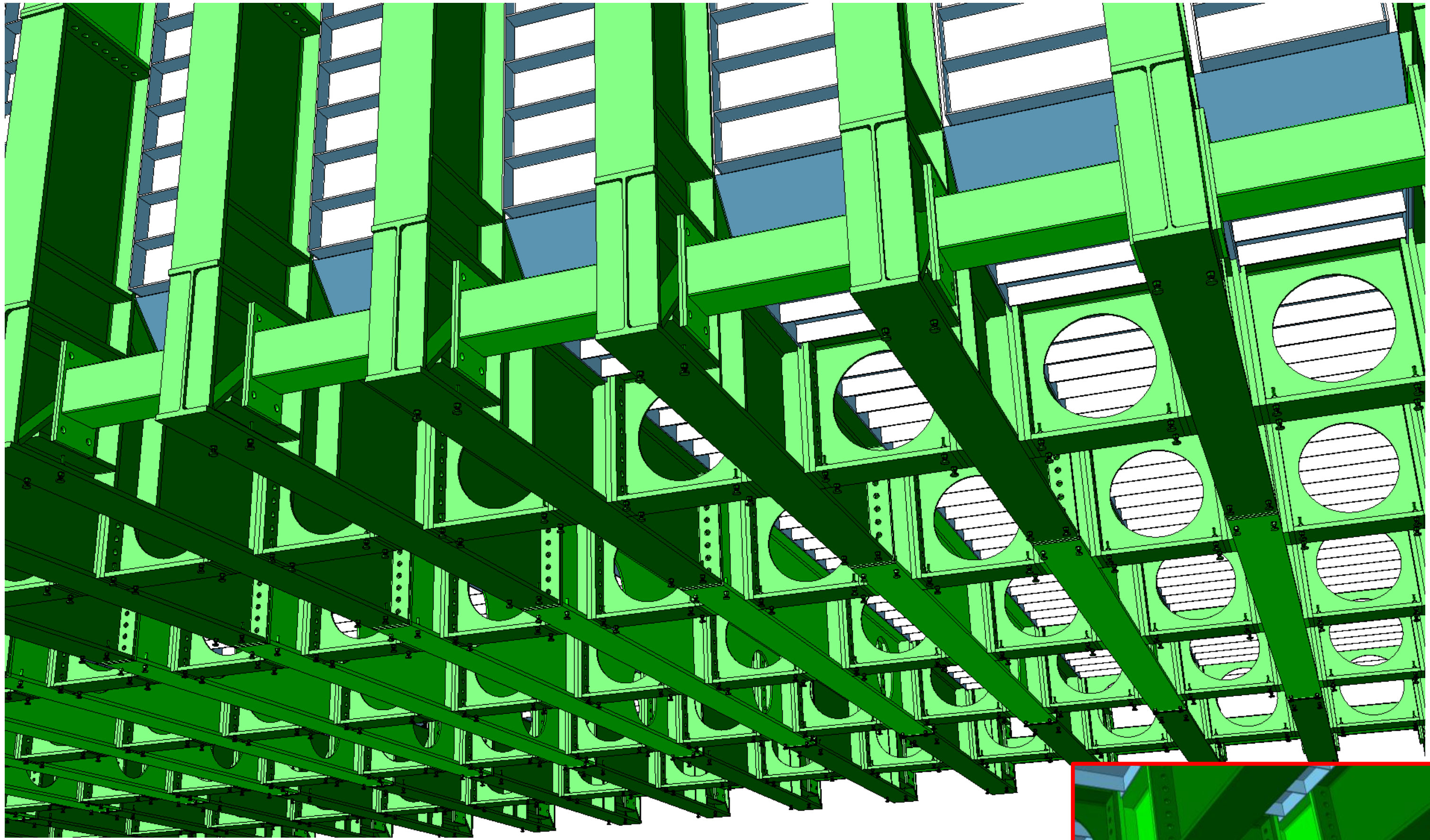
Conclusion: we need steel plate

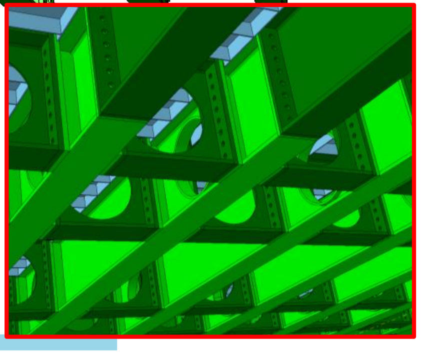
Considering that we have 3 beams and beams are aligned independently we may have 10 tonne per beam; and each beam is aligned with 3 points:

- load applied on rod $L := \frac{10}{3}\ tonne$
- force on rod $F := L \cdot g = 32.689\ kN$
- Pressure at the bottom of rod $p := \frac{F}{s} = 72.258\ MPa$

Conclusion: we need a good concrete







Adjusting assembly with bolts/jacks to the floor level, for later levelling by pouring concrete grout with formworks

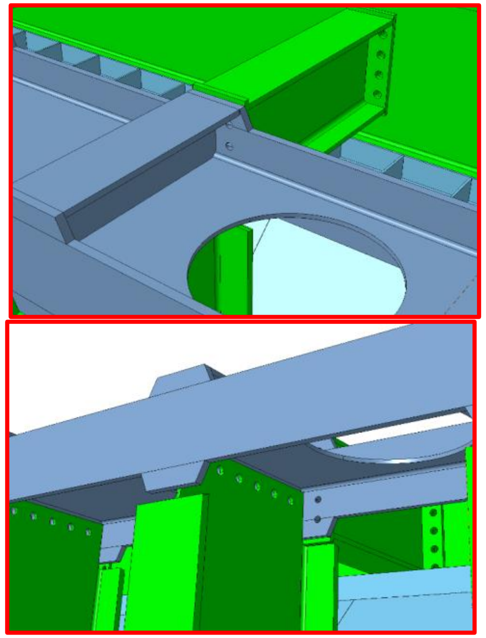
Access and ventilation openings below (and around) the cryostat

Design of additional splices

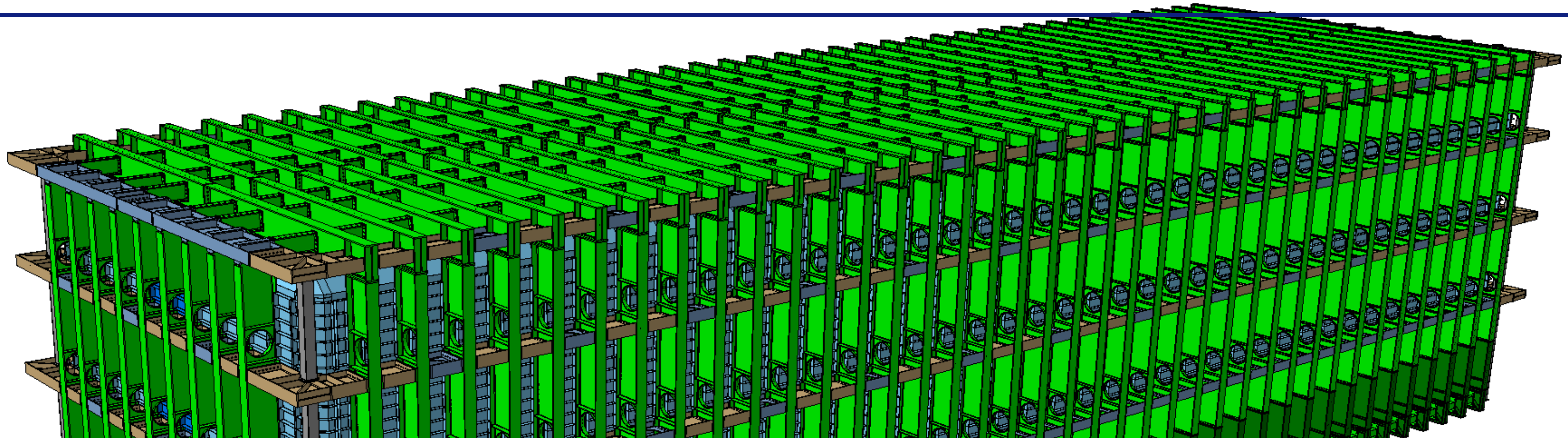
Main Structural Connections Details

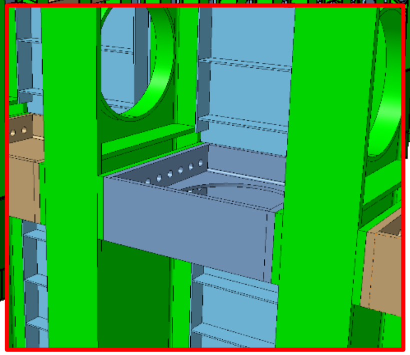
More comprehensive analysis of joints, not anymore designed to worst loading envelope but checked individually to assess individual safety margin

Main connections optimisation: moment and pinned connections for side belts, connection roof belts to short wall.

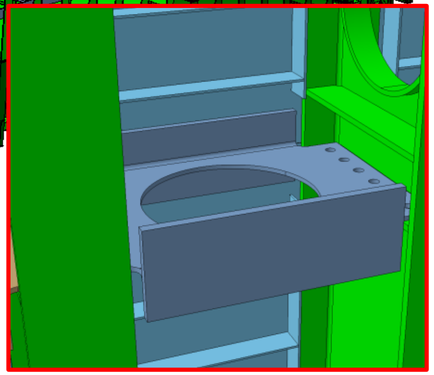


Connection- Roof belts to short wall girder

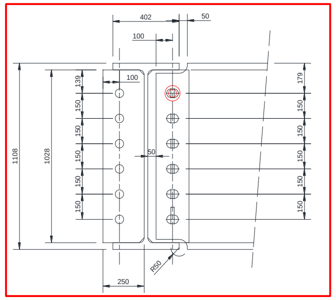




Connection5-BeltMomentConnection



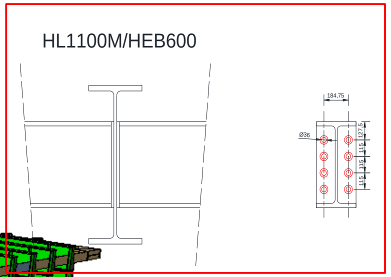
Connection10-BeltPinnedConnection

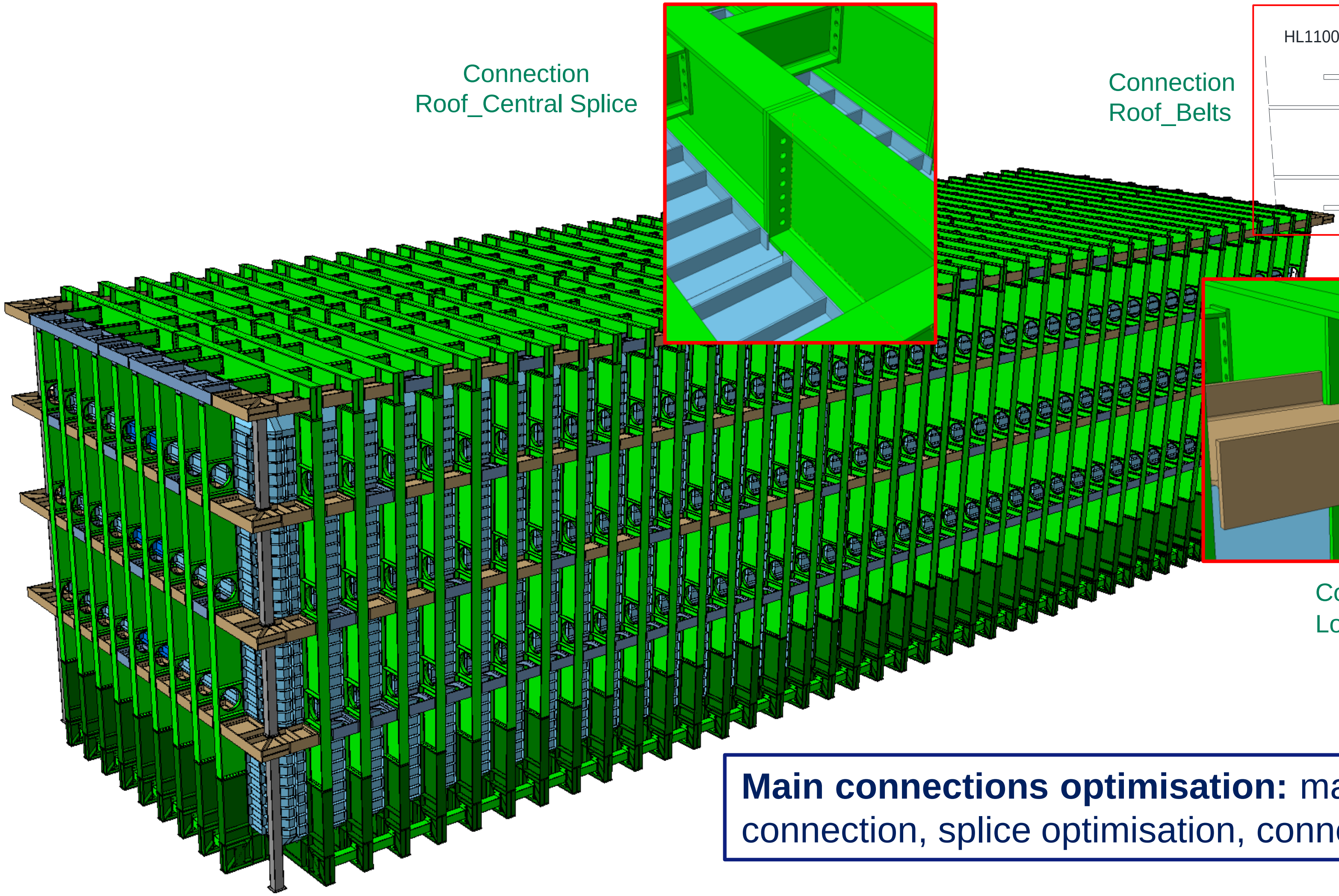


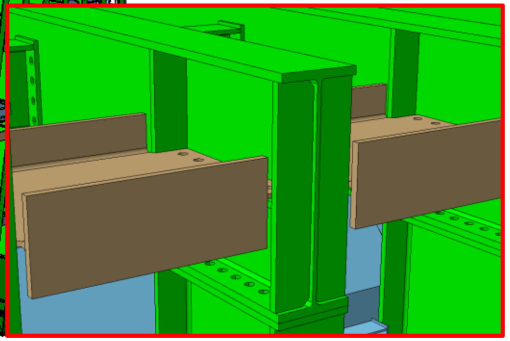
Main Structural Connections Details

Connection
Roof_Central Splice

Connection
Roof_Belts





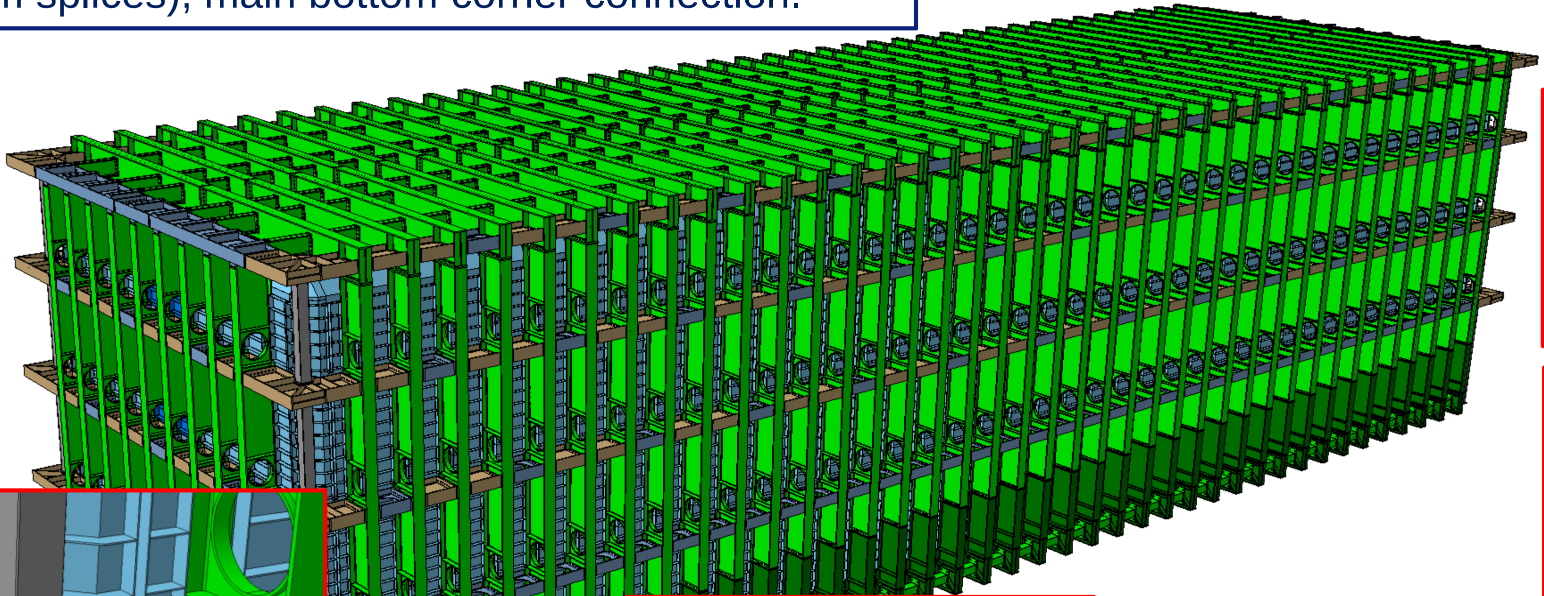


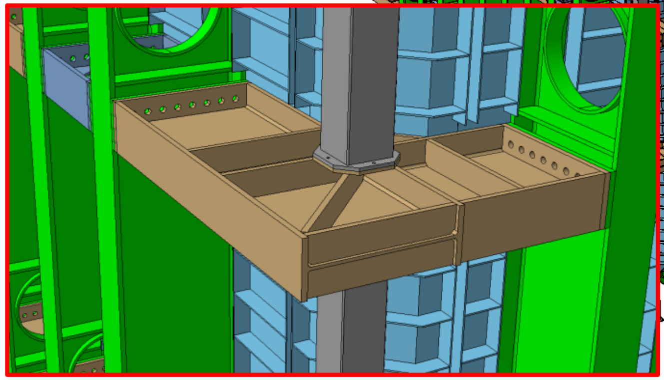
Connection Roof-Vertical
LongWallBeam

Main connections optimisation: main portal top connection, splice optimisation, connection edge roof belts

Main Structural Connections Details

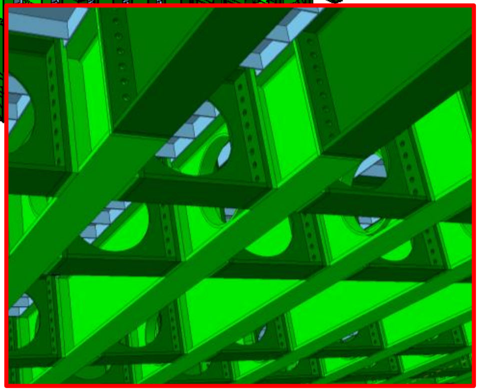
Main connections optimisation: new corner belts and pillar, moment floor belts, (vertical beam splices), main bottom corner connection.



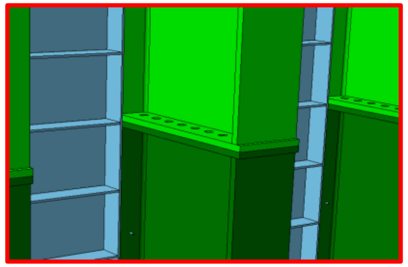


Connection welded corner

Moment connection floor belts

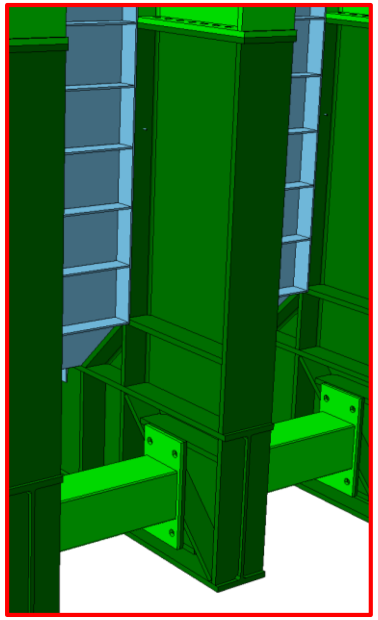


Splice vertical beam



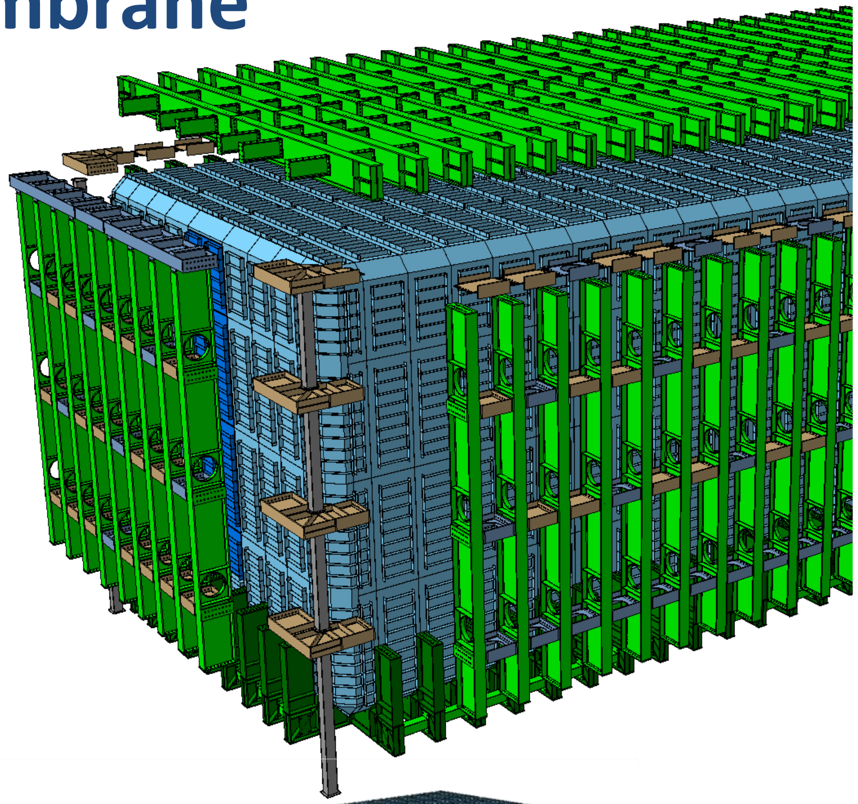
Moment corner welded connection

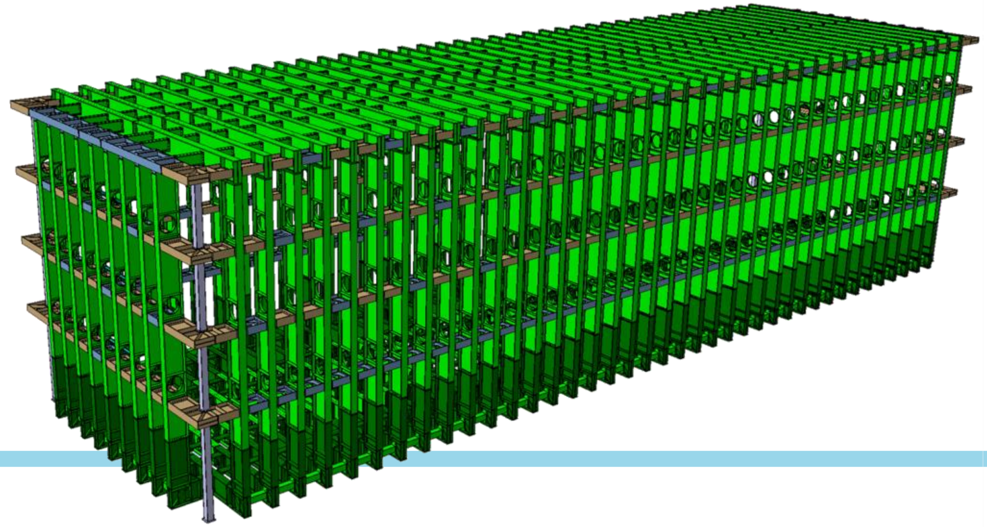
MN m connections

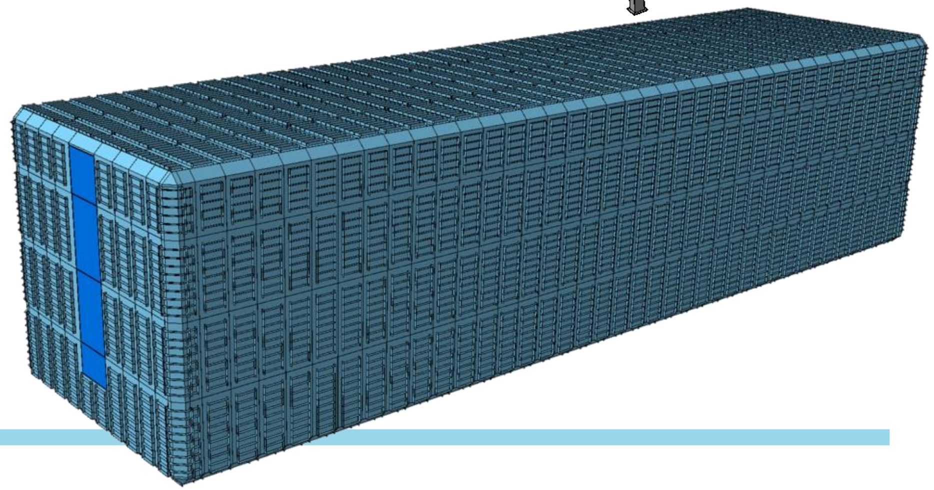


The new reinforced outer membrane

- “Independent” warm membrane, resting on main holding structure
- Allows good decoupling between membrane (liner) and main structure
- No need to participate to the global strength
- The old grid is replaced by stiffened panels (to withstand the pressure between portals)
- Allows for material saving, less bolting and welding in situ, and avoids difficult access (ref. floor)
- Beneficial to control cumulative welding shrinkage along the assembly process of membrane panels





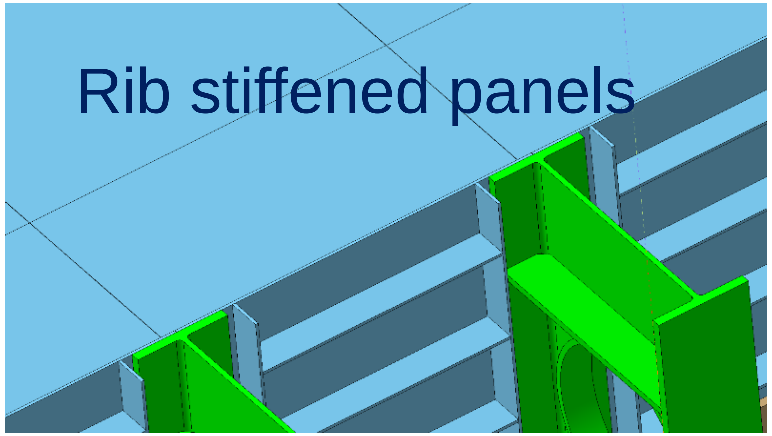


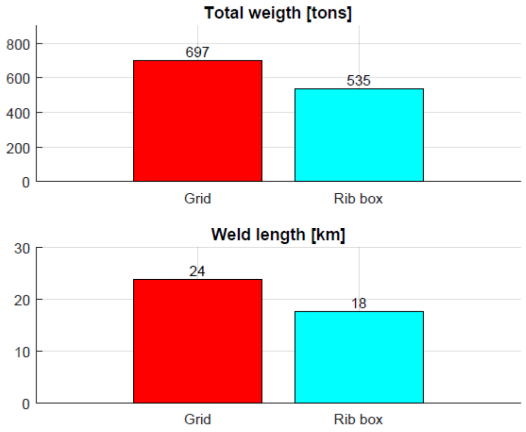
Design versions for the outer warm membrane

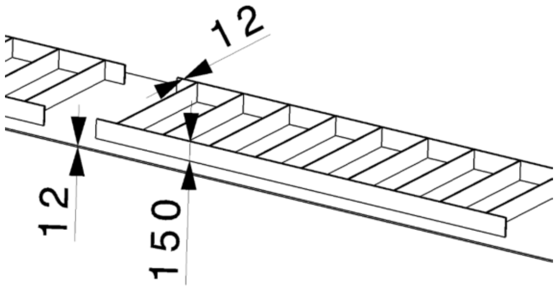
3 versions considered for the reinforcement of the outer warm membrane:

Rib stiffened panels – fin plate with stiffeners → retained as **baseline** for the main membrane and for the local door closing

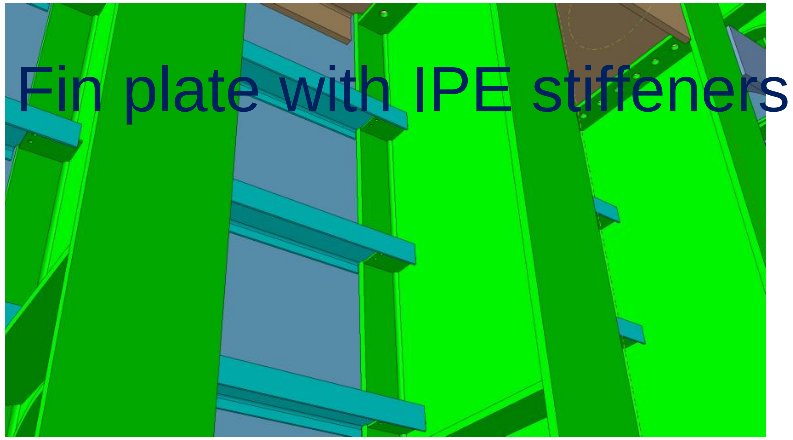
Metal sandwich: considered as option, but less explored in detail

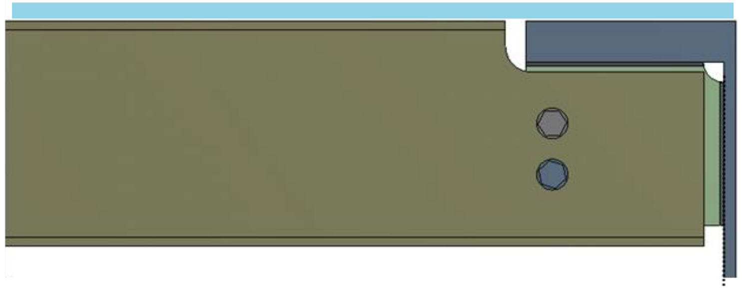






Saving in weld length with reinforced panels vs grid design



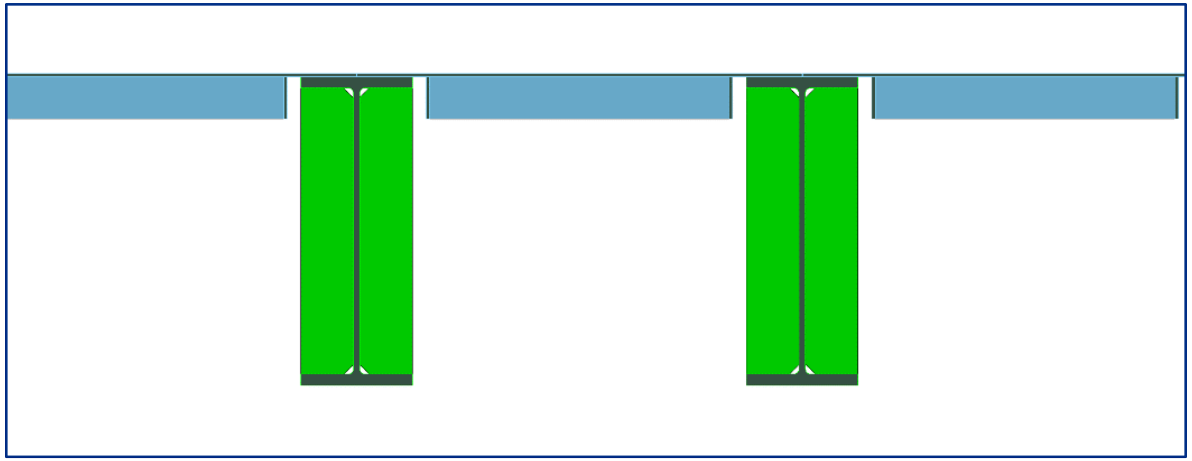


Rigid fin plate

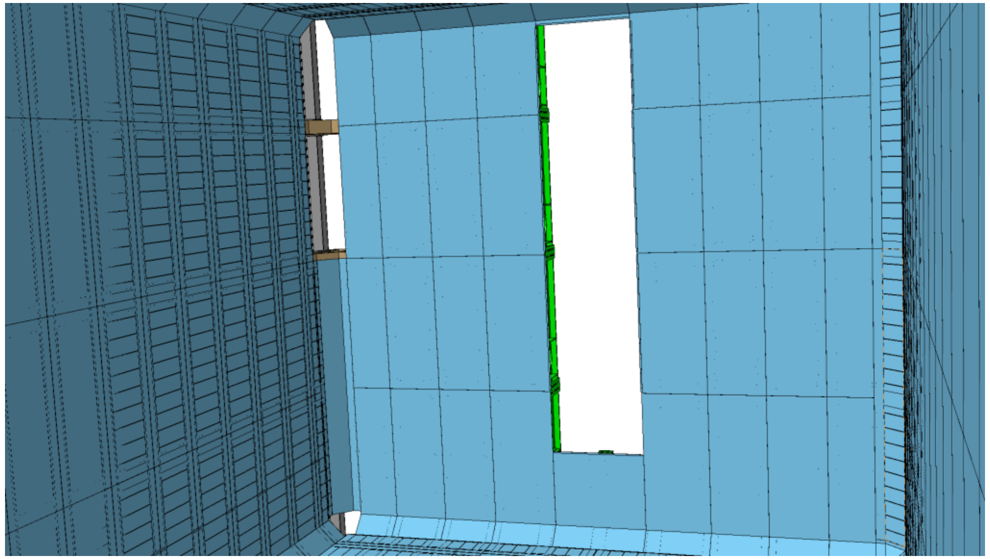
Metal sandwich option

+ manuf. deform, costs (TBV)
- more parts & inst. steps

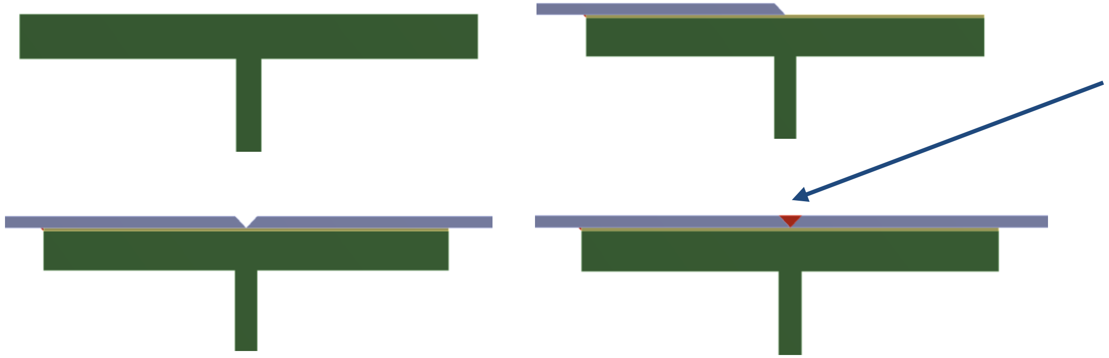
Welding outer membrane panels



Butt welding solution between reinforced panels, back plate to avoid weld contact to main beams



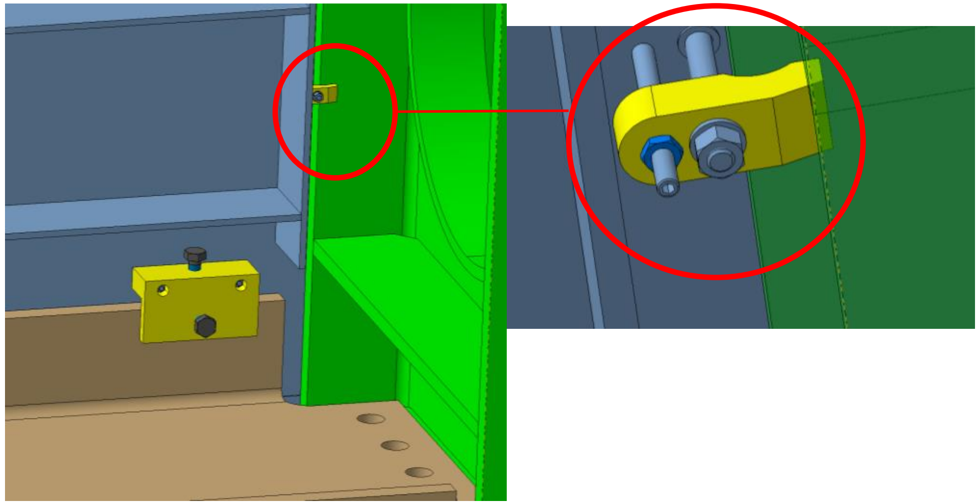
reinforced panel corners welding solution

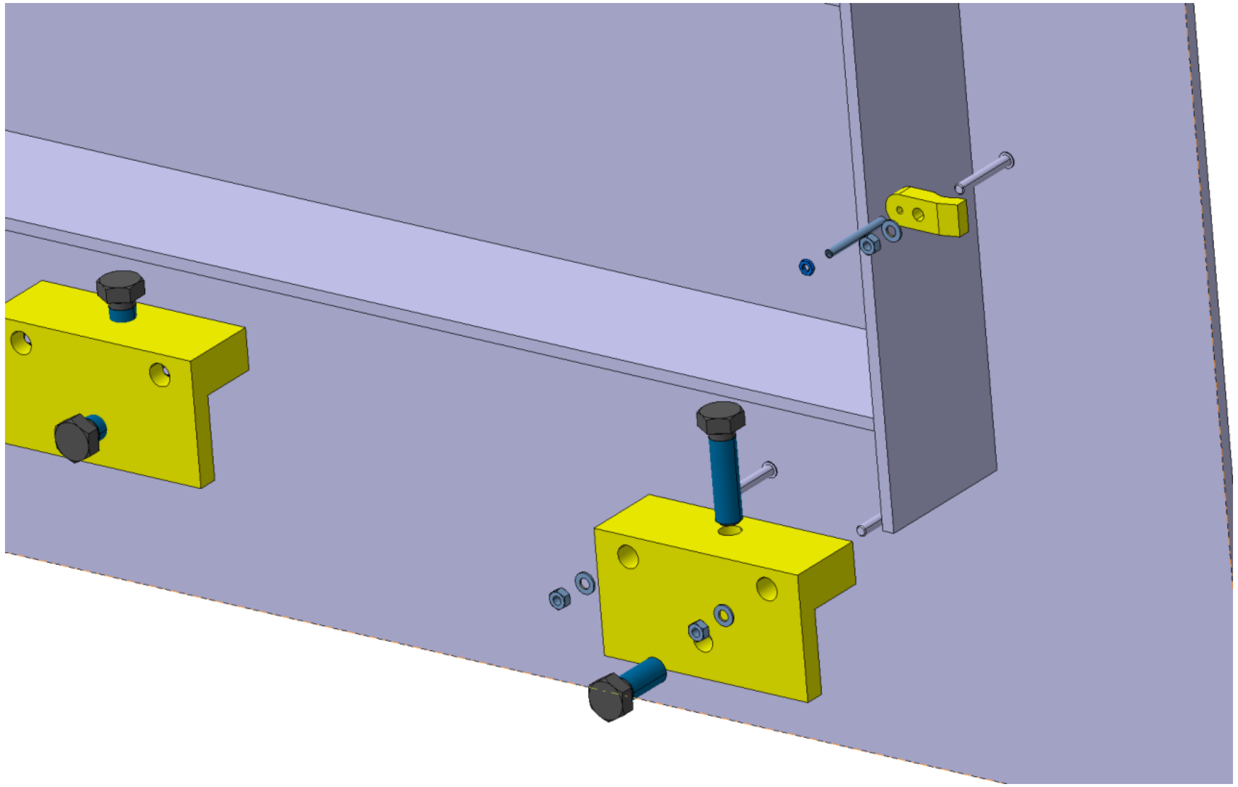


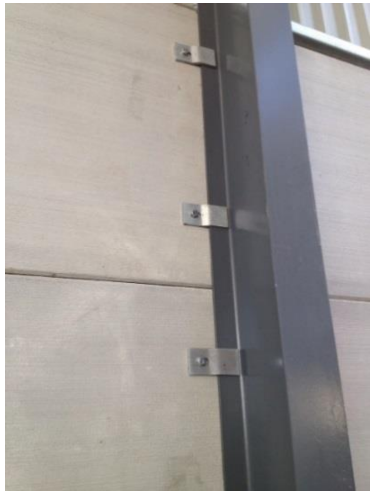
Welds here (mostly for tightness).

Partial penetration butt joint allowed → ref. material on calculations

Fixation brackets for the outer membrane

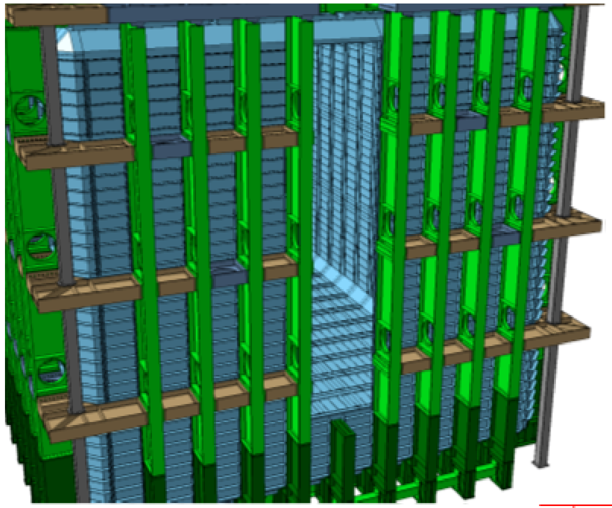


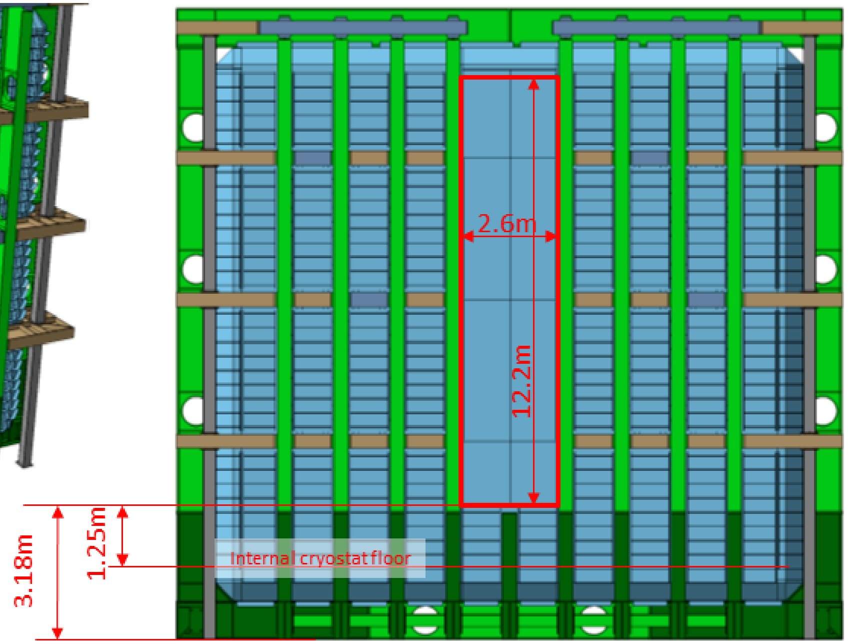




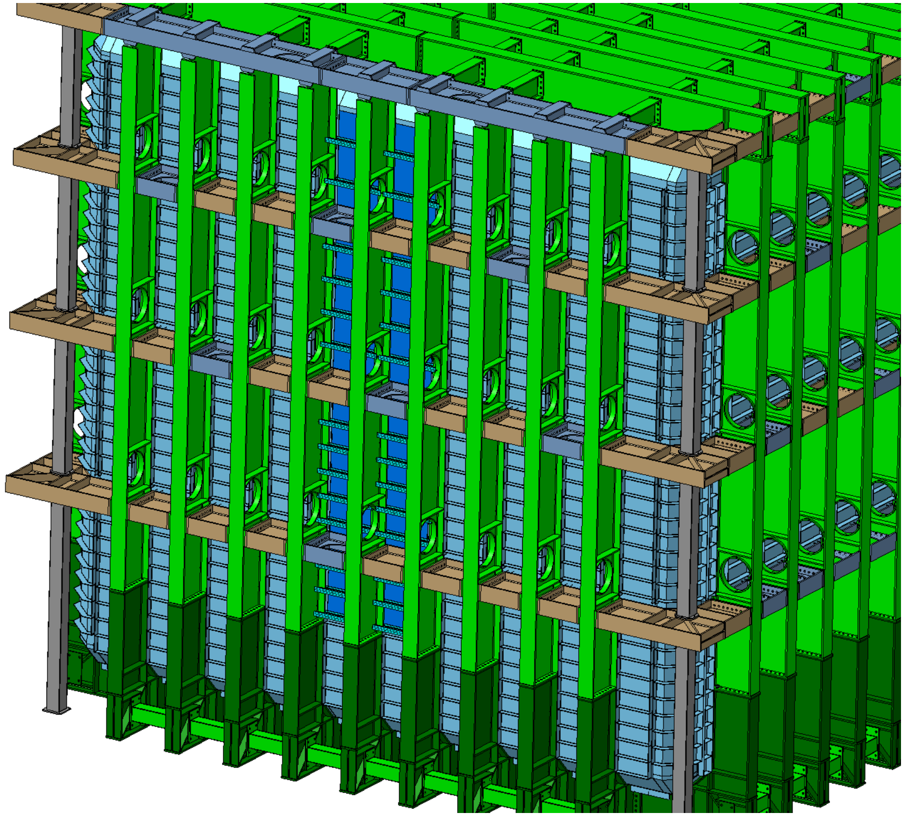
Holding brackets: maintain membrane against I-beams (side walls and roof), during assembly and filling, and allow for relative small displacements

Access Door Design





The gap (1.25 m) could be decreased by installing the central floor corner connection at the end of the mounting process. This would require a dedicated tool.

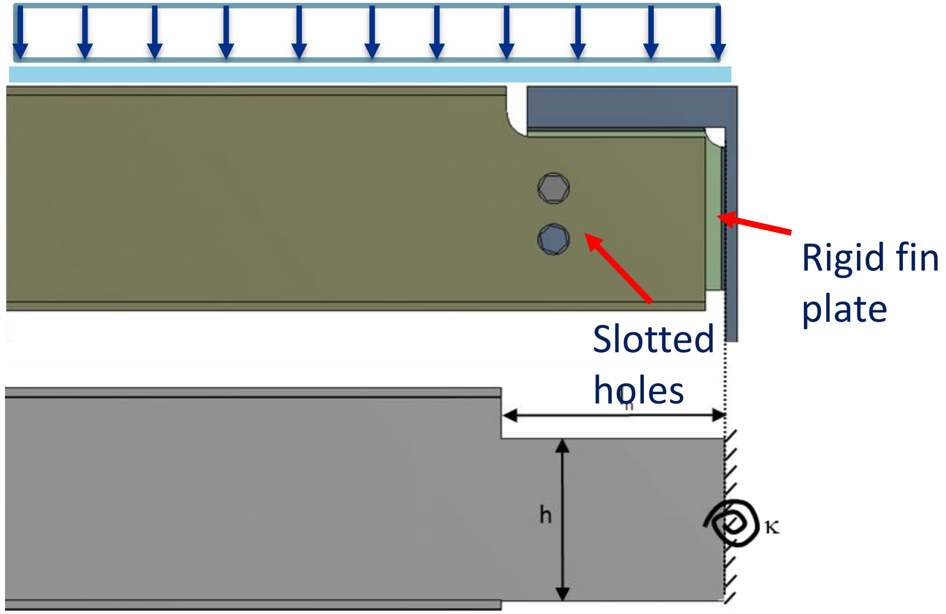


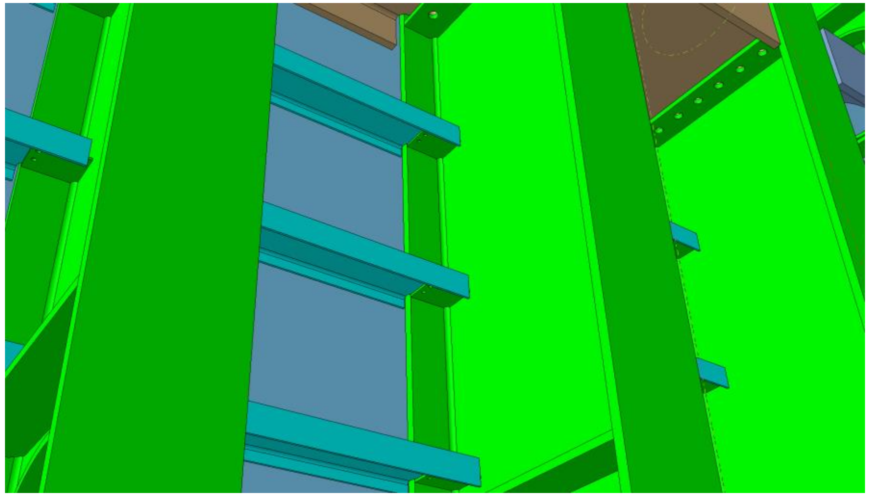
Closing: welding of warm plate and bolting external IPE reinforcement beams

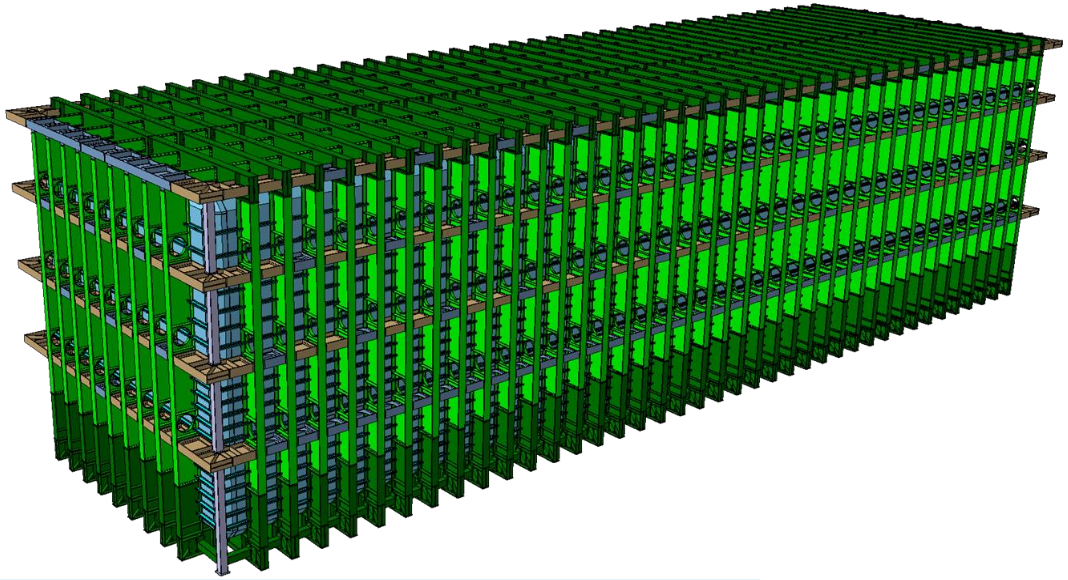
Access Door Design

Replacing rib stiffened panels with IPE220 beams, fin plate connection to main HLM profiles.

Allows closing with access from outside.





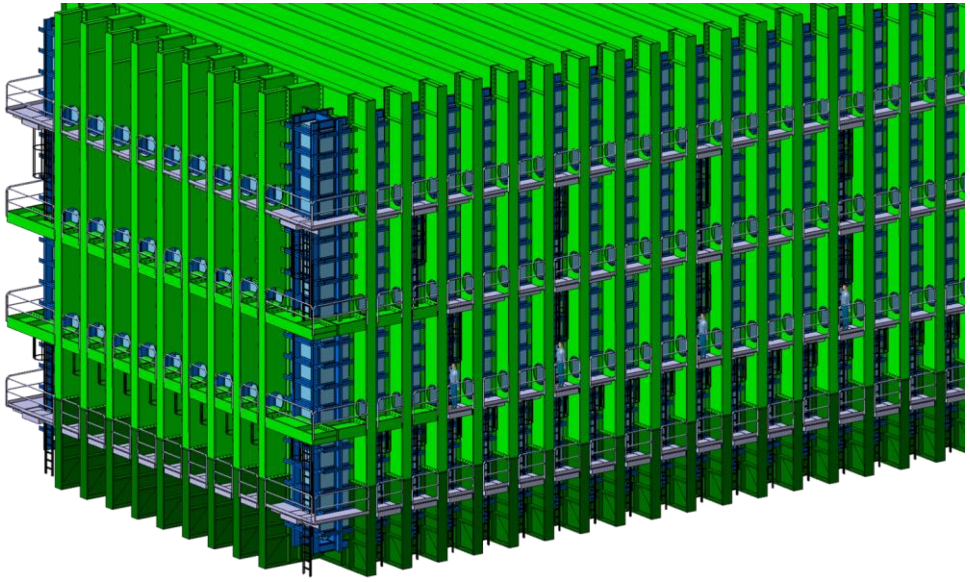


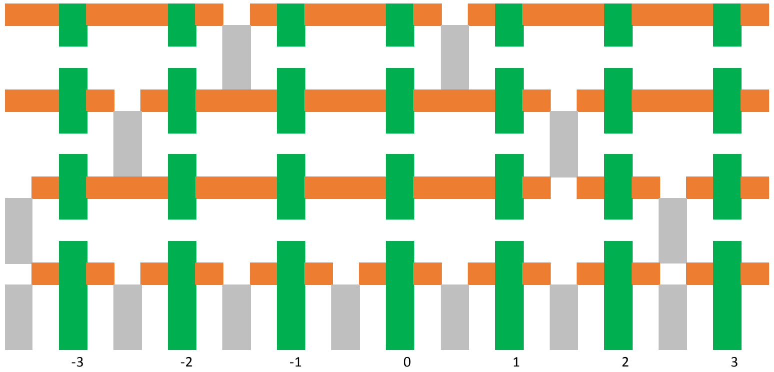
Potentially applicable to the entire cryostat.

Drawback: more work in situ for bolting.

External access to the warm structure

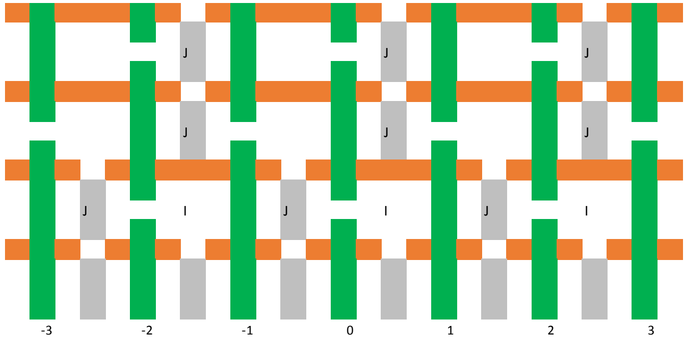
- Access at various levels and underneath through (reinforced) openings on the main beams and belts
- Hole size 800 mm ID





Baseline access pattern

Side wall access for initial assembly and later inspection



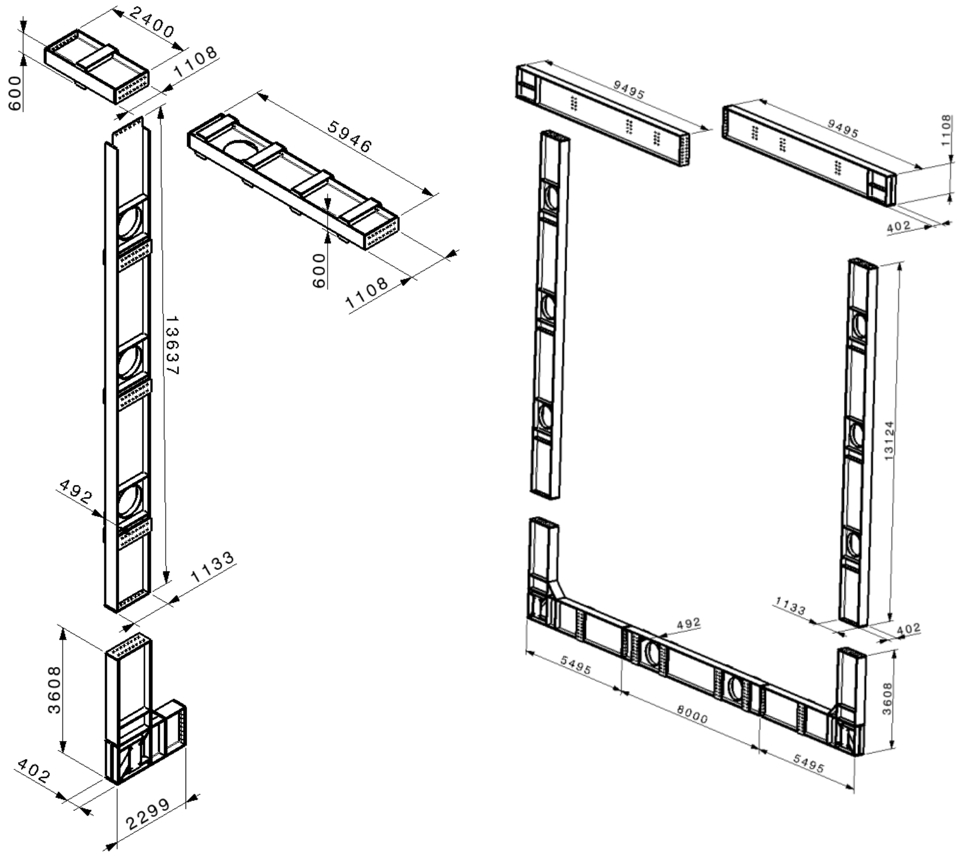
Alternative proposal in order to reduce the number of holes in vertical beams. Requires changing level.

Main Structural Assembly Elements

Severe constraints imposed by shaft size and crane capacity

Shaft dimensions (cage): 3.77 x 1.42 x 2.13 m (LxWxH)

Crane capacity: expected max 9.5 ton.



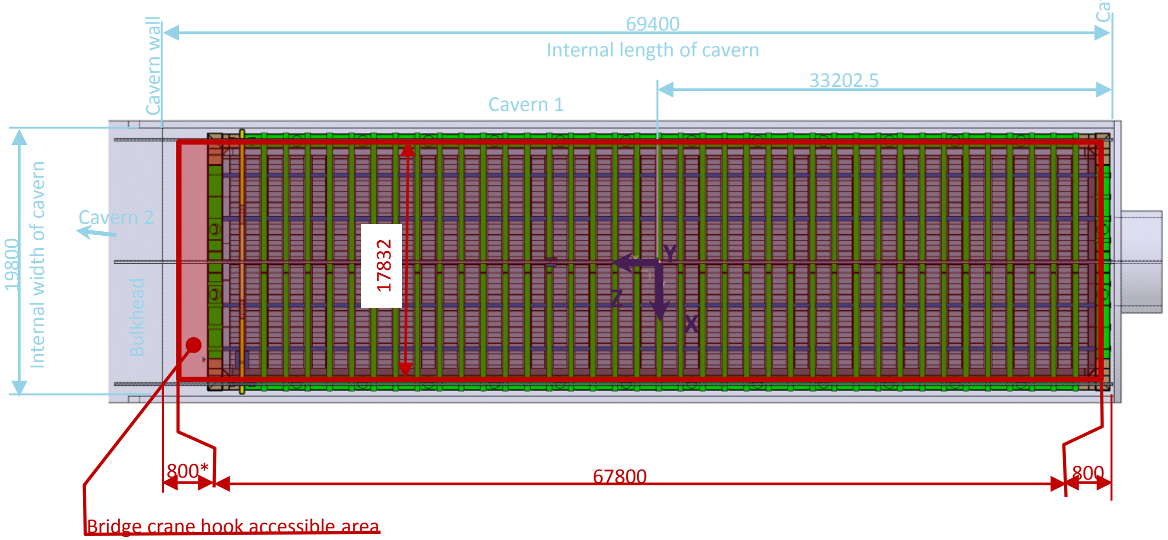
All assembly components designed to stay below 7 to 8 tons (9.5 ton for shaft crane capacity).

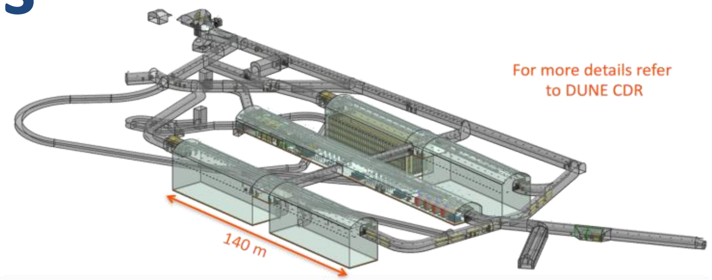
Component mass list at:

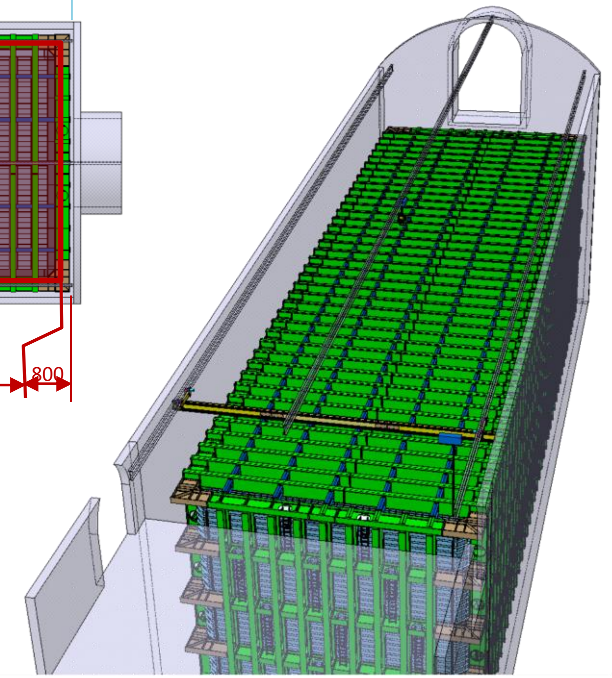
https://edms.cern.ch/document/1835609

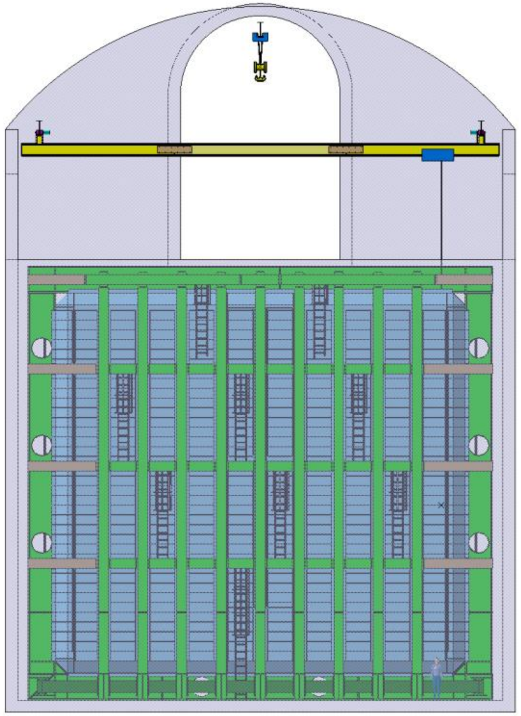
Assembly & Alignment Process

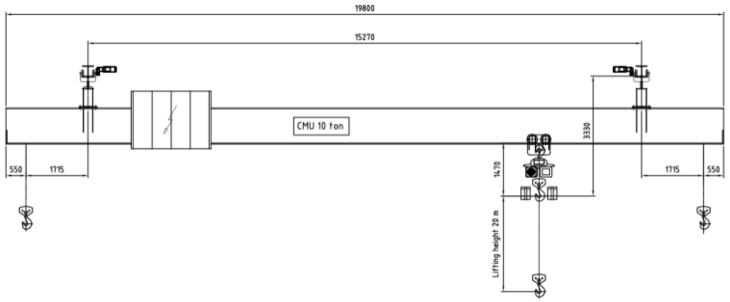
- Assembly procedure defined (see Christophe's talk)
- Basic Assembly tools defined only conceptually









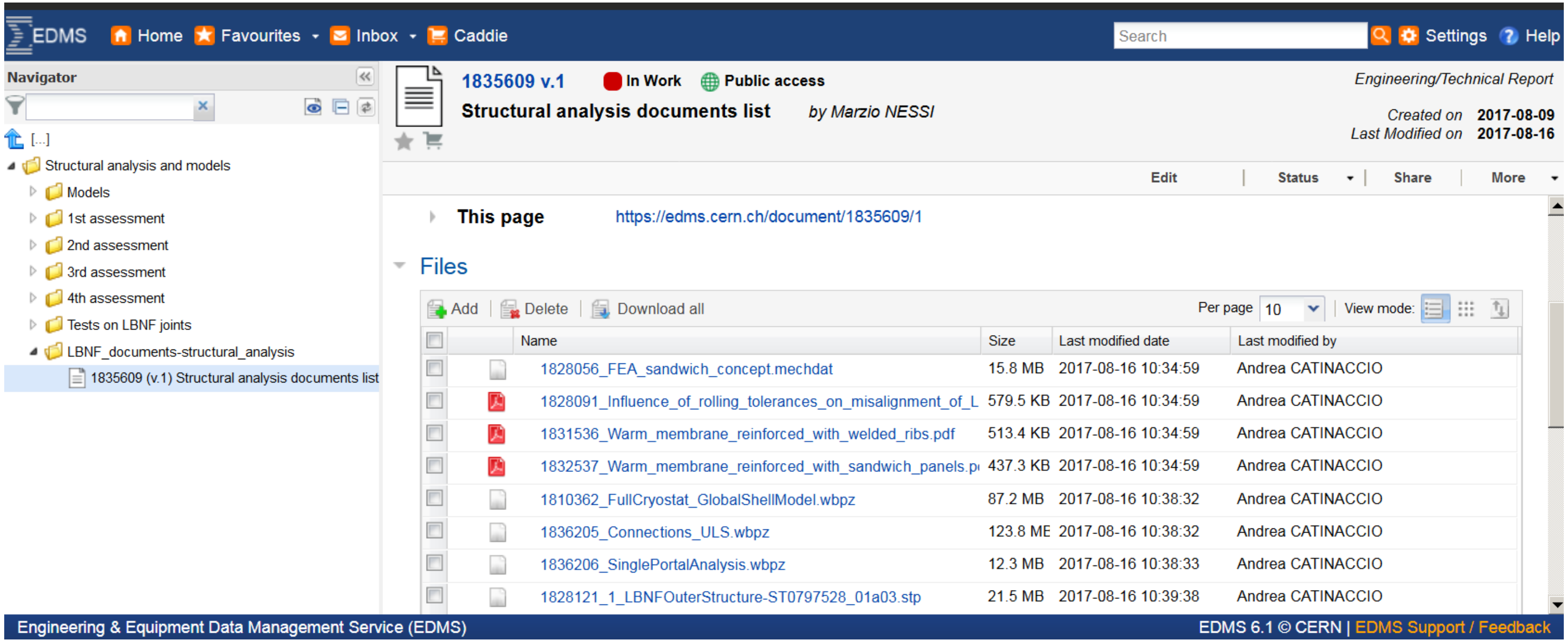


Some preliminary crane design by JL Grenard (Cern)

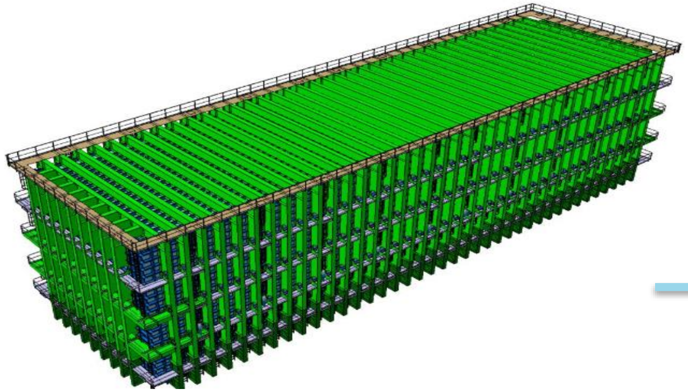
An overhead crane (under study) seems essential for realistic handling and to reduce assembly time

List of models and documentation

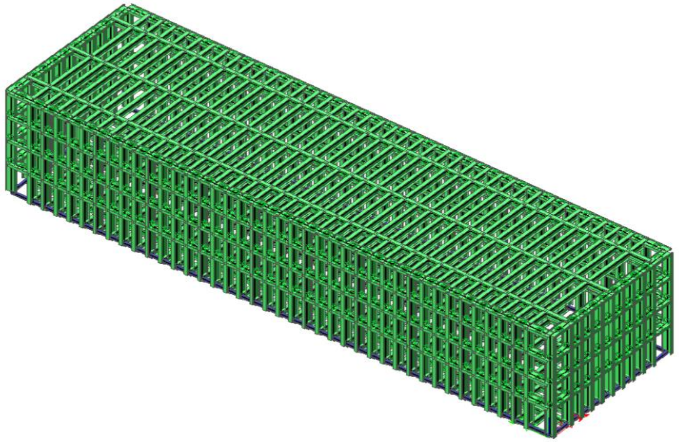
- Repository with component list detailing mass and dimensions: (new) EDMS https://edms.cern.ch/document/1835609.
- 3D model Stp file available there.



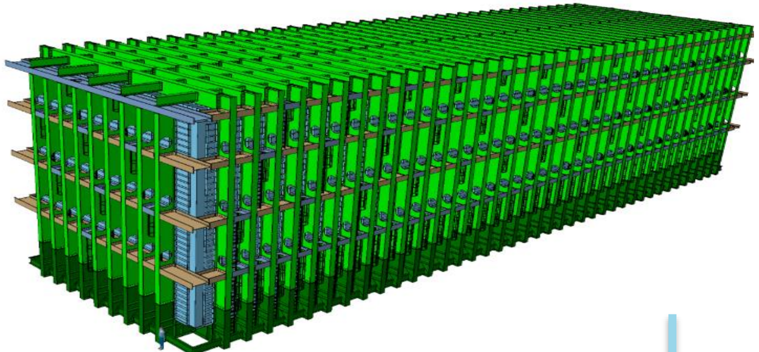
History of assessments and documentations



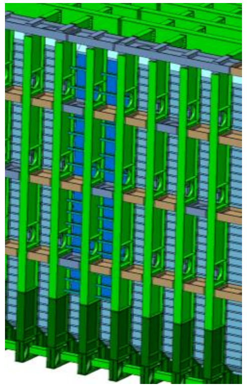
Assessment 1 : beams **HL1100*607**, grid IPE300 (Initial Design Review)



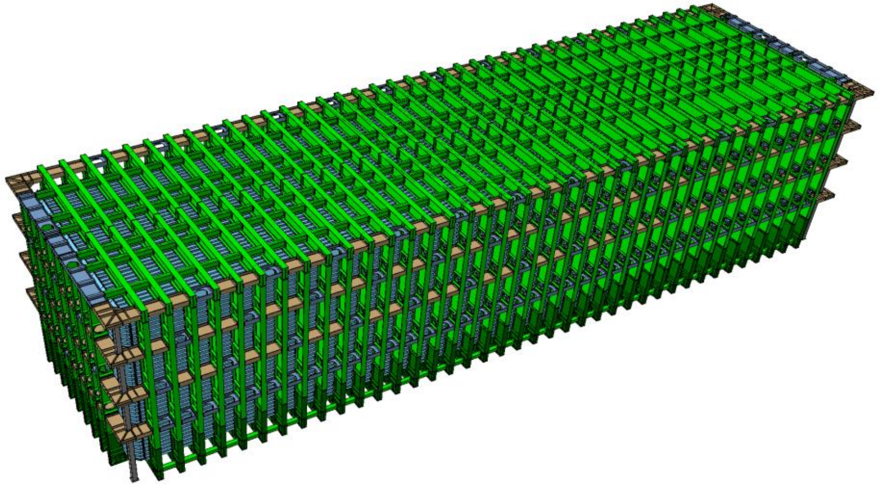
Assessment 2: modified roof, lighter beams HL1100M*433, belts IPE 300



Assessment 3: membrane reinforced with ribs



Assessment 4: roof belts modified for Ft’s, membrane supported by IPE 220 on the door – membrane with ribs



Documentation released for the Final Design Review

Summary and Conclusions

- The Outer Structure is conceived to hold the full load
- The warm membrane holds the pressure between the main portals and guarantees the tightness - baseline design reinforced with ribs
- An alternative warm membrane design is available for the door opening
- Access is guaranteed all around and underneath the cryostat (beam holes)
- The assembly sequence is available together with the conceptual design of basic installation tools
- An overhead crane results essential to speed up the assembly
- The new design allows to minimise the work in situ, access issues (ie floor), weight, cost, cavern size.