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PRELIMINARY DESIGN OF TOTEM T1 TELESCOPES MECHANICAL SUPPORT STRUCTURE

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Abstract

The present design of the TOTEM T1 telescopes mechanical support structure is described in detail in view of the Technical Design Report. Constraints, structural considerations, layout and operating sequences are described below, and will be used as a baseline for the final design.

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1. LAYOUT CONSTRAINTS

TOTEM T1 detector telescopes[1)] will be installed inside the CMS magnet gap[2)], between the CMS yokes spacer rings inner shape and the vacuum chamber, provided that the constraints imposed by CMS are respected as stated below.

1.1. Geometrical envelope

The TOTEM T1 telescopes are allowed to fit in the space between z=7500 mm and z=10500 mm from I.P., and between z=-7500 and z=-10500 mm from I.P., where z is the beam axis.

While in operating position, T1 must not interfere with CMS alignment beams as positioned in drawings CMS 5185-113 and CMS 5185-114, that require a cylindrical space of radius 40 mm.

The T1 inner envelope is defined by the vacuum chamber, whose inner shape is a cone pointing to I.P. with a vertex half angle of 13.61 mrad ($\eta = 4.9$). Taking into account of the contribution of

- Vacuum chamber thickness: 2.5 mm;
- Vacuum chamber mechanical and survey tolerances: 2.5 mm;
- Vacuum chamber gravity sag: 4 mm;
- Minimum clearance: 10 mm;

T1 inner envelope should be offset from the theoretical vacuum chamber inner shape by 19 mm.

Assuming as reasonable the following values

- T1 gravity sag: 1.5 mm;
- T1 mechanical tolerances: 2 mm

T1 offset from the theoretical vacuum chamber inner shape should be increased up to 22.5 mm.

T1 structure should be designed and manufactured to comply with the stability and accuracy requirements stated above.

T1 outer envelope is defined by the inner shape of CMS yokes spacer rings, as defined in drawing CMS 5185-125; T1 outer shape must stand at least 10 mm away from them. Also this envelope is a cone whose axis lies on the beam axis, with a vertex half angle of 99.12 mrad ($\eta = 3.0$).

1.2. Services

Cables, tubes and any other kind of service connected to the detector must come out upwards through 4 square windows positioned at z=+/- 10750 mm and +/- 45° respect to the vertical Y axis, whose cross-section is approximately 200 cm2 each.

1.3. Installation and removal

T1 can be fastened only to the outermost CMS yoke rings, that supports also the vacuum chamber, so that any unpredictable relative motion of CMS yokes due to the magnetic field in operation, or whatever other reason, couldn't result in any motion of T1 relative to the vacuum chamber.

T1 installation and removal should be easy and fast as possible, so that a change of configuration could be done in less than 48 hours. The operations should not require the access of people inside the gap.

T1 must be installed and removed without dismantling the vacuum chamber. The vacuum chamber is supported at z=10570 mm by means of 4 (2 horizontal and 2 vertical) 2 mm diameter wires: the horizontal wires can be temporarily removed during T1 installation.

The complete removal of T1 and all its components should be possible, not to interfere to any other CMS maintenance operation.

2. DETECTOR LAYOUT

T1 telescope is composed of 5 planes of cathode strip chambers (CSC) and 2 planes of RPC detectors, positioned as in fig. 1. Given the installation and removal requirements, the telescope is split approximately along detector YZ plane (vertical) in 2 independent halves, that will slide into operating position along rails (fig. 2). There are two rails on each side, parallel to the detector outer conical envelope generating lines lying on detector XZ plane (horizontal).

2.1. CSC detectors planes

Every CSC plane is made up of two half planes with 3 CSC each. 10 different types of CSC are foreseen:

- a slightly smaller CSC on each plane, shaped to allow the integration of the rails structure inside the detector envelope; the relevant layout is outlined in fig. 3;
- a couple of larger CSC on each plane, sized to meet the maximum acceptance allowed by T1 outer envelope; the relevant layout is outlined in fig. 4.

The two types of CSC on each plane are required to minimize the acceptance losses due to the shape of the rail framework.

In each half plane the 2 large-size chamber and 1 small-size chamber are doweled and secured to each other and to the global skeleton frame. The small CSC is neighbored by 2 large CSC. Detectors are overlapped to avoid loss of efficiency at the edge; overlap is foreseen also between chambers on the same plane in the two telescope halves, thus creating a constraint to T1 introduction and extraction sequences. In addition, there's a rotation of 3° around Z of each plane relative to the previous one, to distribute the material in CSC edges of different planes. Fig. 5 outlines a CSC half plane sub-assembly, where you can notice adjacent CSC overlap as well as the semi-annular housing (see skeleton frame description below).

2.2. RPC detectors

RPC detectors are also made in two halves, in order to allow T1 to be split as described and then introduced into the gap when the vacuum chamber is already in place.

They are integrated at T1 ends, external to the CSC volume, adjacent to the innermost and outermost CSC planes. RPC are centered and secured to T1 skeleton frame as the CSC planes.

As in the CSC planes, RPC layout is arranged so that, when T1 is in its operating position, the two halves overlap enough to avoid any loss of acceptance along T1 vertical split plane.

2.3. Services cross section

A preliminary estimate of the envelope of cables and tubes of half T1 proved that they could stay inside a 150 cm2 cross section. The services bundle section will of course increase up to that value, from the inner to the outer end of T1. That value meets the CMS requirements. Furthermore, a cable raceway of such dimension can be easily arranged in the detector dead space between the CSC outer edge and T1 conical outer envelope.

2.4. Electronics

A preliminary estimate of the number and dimensions of electronic cards required for the readout have been done, based on the performance of the actual CMS CFEB cards. A preliminary card arrangement has been found, where the cards are installed onto the shaped plates of the skeleton frame that connect the plane assemblies along Z. This way the cards can be easily accessed from outside, do not screen the particles and can be easily cooled, if necessary.

2.5. Mass estimate

A preliminary mass estimate of the full detector (the 2 halves) has been made. The calculation included electronics and services. The table below summarizes the breakdown of the individual contributions.

CSC PLANE	CSC	RPC	CABLES & TUBES	PCB	TOTAL MASS
[#]	[Kg]	[Kg]	[Kg]	[Kg]	[Kg]
1	26	80	8	5	119
2	30	0	24	9	63
3	32	0	42	13	87
4	35	0	64	19	118
5	37	80	70	19	206
TOTAL	160	160	208	65	593

The values above have been used as static loads for the structural simulation described in the following paragraph.

2.6. Cooling considerations

Even though a heat balance of the detector hasn't been done yet, nevertheless an effort has been done to arrange electronics layout so that heat drain could be simplified.

A cooling pipe could be easily integrated onto the metallic skeleton frame. The cards will be cooled by heat conduction through the metallic plates of the frame where they are attached to, that will be kept cool by the coolant circulation inside the pipe.

3. SUPPORTING FRAMEWORK

Generally speaking, T1 is made of two parts: a framework with the rails, that is fastened to CMS outermost yoke spacer ring, and a skeleton frame with the detectors on, that can slide on the rails.

3.1. Materials

As a general rule, the structure is made of radiation-hard, non-magnetic materials. Then all metallic parts are made of aluminum alloy AA 5754, where possible, or of AISI 316 stainless steel, where higher stiffness is required. Both alloys are commonly available on the market and relatively cheap.

Radiation hard CIBA glue Araldite 420 A/B is foreseen as structural adhesive to bond the components of the skeleton frame.

Sliders bushings are made of IGLIDUR X, a low-friction commercial polymer declared to withstand up to 10^5 Gy.

3.2. Rails supporting frame

A stainless steel welded framework made of 80x80x3 mm square pipes and 80x40x2 "C" profiles supports the rails, giving them the required stiffness to withstand the gravity load and fulfill the stability requirements of the detector.

Fig. 6 outlines the complete framework assembly, with the rails (red) and the interface plates (cyan) to CMS yokes spacer rings.

The frame is made of two trusses, one on each side of T1, and features at its outermost ends appropriate interface plates that cope with the outermost CMS yoke ring; then the frame works as a cantilever beam. The assembly is secured by means of 4 M16 screws on each plate; the relevant threaded holes have been foreseen on CMS yokes spacer rings from their design phase, and CMS collaboration confirmed that they are available for this task. Doweling to prevent motion of the structure is advisable and will be discussed with CMS during next design steps.

At the innermost end, the two trusses are joined through a push (upper) and a pull (lower) rod, that help the structure to limit the deformation given by the torque due to the offset of the detector center-of-gravity. Those rods will be fastened to the main structure, so that they can be fitted, during T1 introduction, after the rails framework innermost end passed through vacuum chamber support wire position (z=10570 mm), and removed, during T1 removal, before they pass through the same location.

To recover acceptance at detector outside edge, the rails have been integrated in the structure, as showed in the detail of fig. 6. That solution keeps the structure stiffness high enough but, being unsuitable a small production of stainless steel purpose-designed profiles, requires the assembling of a 80x40x3 mm "C" profile to a 80x40x3 mm square pipe through discontinuous welding. Given the accuracy specifications of the detector, that is not a trivial operation and special provisions will have to be made to meet the requirements.

The total weight of the rail frame is estimated to be 270 Kg, both sides considered; finite element structural simulations showed (see fig. 7 and 8) that the worst radial motion towards beam axis should be within the required 1.5 mm, taking into account of the CSC plane deformation too.

Truss layout is arranged so that alignment laser beam can pass through it. Given the laser beams layout, right side truss is different from left side truss, but negative-z trusses have the same layout as positive-z trusses.

T1 owes its shape to the rail framework, as the skeleton frame alone is not stiff enough. When outside the detector, an external skid, with an extension of the rails, is required (see fig. 9). Such a structure must be used for all detector assembling and transport, and will be aligned to the rail framework inside the gap before T1 introduction and extraction.

3.3. Rails and sliders

Commercial rails and sliders have been foreseen. IGLIDUR self-lubricating friction bushings have been selected, because of their high load capacity with an acceptable friction coefficient. As a matter of fact, that kind of bushing has a considerably larger contact area to the rails, compared to the traditional ball bushing. That allowed us to reduce to ϕ 20 mm the rail diameter. Furthermore, the self-aligning capability of such bushings, stated to be up to 0.5° of angular error, makes the rail integration onto their supporting frame less critical, being then the detector required geometrical accuracy the only actual constraint.

Given the center-of-gravity offset of the CSC planes respect to the rails plane, sliders should transfer to them both vertical action and torque. As the circular shape of the rail doesn't allow that, two rails have are foreseen; consequently, every detector half plane features a couple of sliders. The upper slider reacts both vertically and horizontally; the lower one instead reacts only horizontally, as it has an adjustment feature that allows a vertical run of ± 3 mm, and then an automatic compensation of rails misalignment. As a result, the upper rail gives T1 its shape and withstands the vertical load, while both rails together withstand the horizontal load, let's say the momentum, then limiting detector torsion around Z axis.

3.4. Skeleton frame

An aluminum skeleton frame has been foreseen in each half of T1, to house the planes, the services and the electronics. Such a structure integrates the sliders that run along the rails, and transfer the static load through them to the rails.

The assembly is made of aluminum 3 mm-thick sheets laser-cut to shape and bent to give them the appropriate stiffness; components are glued, doweled and riveted together, so that the required accuracy is ensured and any relative motion is prevented. Though the complete assembly has considerable overall dimensions, it is made of much smaller components with simple geometry, that can be easily manufactured and handled in most workshops.

The skeleton features 7 semi-annular housings (see fig. 10, in purple), essentially made of 2 faces kept at the required distance through axial spacers; CSC planes and RPC detector are installed in between the faces, doweled and screwed to them.

Every semi-annular housing features also a couple of sliders, to transfer the load to the rails.

The semi-annular housings are positioned along Z through spacer plates (see fig. 10, in gray). That solution makes it easier to meet CMS requirements, as spacers and sliders are installed on the housing and not directly on CSC or RPC detectors, being then their position more independent from CSC and RPC geometry and layout.

Spacer plates support also the electronics and for the services, providing also cooling capacity with the simple integration of a cooling pipe.

The skeleton frame has been designed to fulfil both negative and positive z layout constraints.

4. SEQUENCE OF OPERATIONS

Given the CMS constraints about T1 installation and removal, a preliminary study of the operations has been performed, to demonstrate that the proposed solution could meet the requirement. An animation has been produced to better explain the most critical phase, when T1 is introduced into the gap. Four frames have been extracted from the motion picture to make the explanation easier, and are reproduced in fig. 11a/b/c/d.

4.1. Installation and removal of the rails

The rail frame is the first element that must be introduced into the gap and, consequently, the last to be removed. It should be hanged on a crane, through eyebolts to be fitted on its outermost end, with a counterweight that should allow keeping it roughly horizontal. A large clearance, of around 100 mm, has been foreseen between the vacuum chamber and frame push/pull rods, so that the motion with the crane doesn't require a special accuracy.

The major obstacles to rail frame installation are the 4 vacuum chamber support wires at z = 10570 mm: the horizontal ones can be temporarily removed, but not the vertical ones. That's why the push and pull rod at frame innermost end must be installed only after frame edge has passed through that critical position. Temporary spacers must be fitted before, to keep the relative position of the two trusses, and removed after the rods have been installed.

Once the frame is in its final position, it will be aligned introducing the pins into the holes on the outermost CMS yoke ring, and then secured tightening the screws. Then the crane can be disengaged, taking care of a proper handling of the counterweight.

The removal of the rail frame follows the same sequence in reverse order.

4.2. T1 introduction and removal

Once the rail frame has been installed, T1 is ready to slide to its operating position inside the gap. As previously mentioned, T1 is made of two halves, so that it can be introduced when the vacuum chamber is already in place. Furthermore, given the overlap and the rotation of the CSC, the two halves cannot get inside the gap independently.

While outside, T1 rests on an appropriate framework, where extensions of the rails have been fitted. First at all, such a structure must be positioned so that the rail on the frame inside the gap and their extensions on the external framework are aligned.

Then the two halves can slide towards I.P. as long as their innermost edges are almost in contact (fig. 11a): at this point, the half that the layout study foresees as the closer to I.P. must advance a little (fig. 11b), while the other one stays in place. From now on, the two halves must move synchronously (fig. 11c).

The two halves now advance along Z axis together, as soon as the most advanced touches the reference blocks that have been fitted on the rails to determine the operating position. That half can now be secured on position, by means of lock rings on the outermost end of the rails. The other half must continue to slide as long as it touches its reference blocks too.

Then, it can be secured in the same way (fig. 11d). Now T1 is in position, and the external structure can be removed.
T1 removal follows the same sequence in reverse order.

4.3. Timing of the operations

A first study of the introduction/extraction timing has been carried out, to check whether the current solution can meet CMS timing requirements. Fig. 12a/b/c/d details in four main phases T1 installation:

a) Rail trusses are moved to the pit bottom and installed on CMS outermost yoke rings; the first operation is deemed to require 8 hours for both sides, taking into account also of alignment, shimming and doweling. Given the robustness of the structure, lowering into the pit with the crane can proceed at the maximum speed allowed by CERN safety rules.
b) The four T1 skids (one for each half of each telescope) are lowered into the pit. Given the fragileness of the equipment loaded on the skids, this operation must proceed very carefully, at low crane speed, and is deemed to require totally 4 hours.
c) The skids are shimmed and aligned, and everything is set to proceed with T1 introduction, in a time budget of 4 hours.
d) Telescopes are introduced into CMS cavity, aligned and connected to services; tests are performed to check main installation parameters. The foreseen time budget for this last task is 16 hours.

After the breakdown of operations reported above, the complete installation of both T1 telescopes can be completed in 32 hours, that means two working days with two 8-hours shifts or four working days with only one 8-hours shift. That gives confidence that the 48 hours limit specified by CMS can be respected, with a 16-hours allowance to face contingencies.

5. CONCLUSIONS

The major issues about T1 integration have been addressed, and the proposed structure proved to be able to meet all requirements. Relatively simple solutions to assemble it have been identified, and confirmed its feasibility. Assembling and dismantling sequences have been studied and showed that the installation and removal operations can be easy enough to be performed in compliance with the assigned time schedule. Generally speaking, there's flexibility enough to successfully face problems that, at the present stage of development, can be only estimated, as electronics layout and cooling, and services routing. The present solution can be considered a good baseline for the final design of the structure.

6. REFERENCES

(1) TOTEM Technical Proposal, CERN/LHCC 99-7
(2) CMS Technical Design Report, CERN/LHCC 97/010

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Fig.9	external skid, with rails extension, for detector handling outside CMS gap
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Fig.11a/b/c/d	T1 introduction sequence
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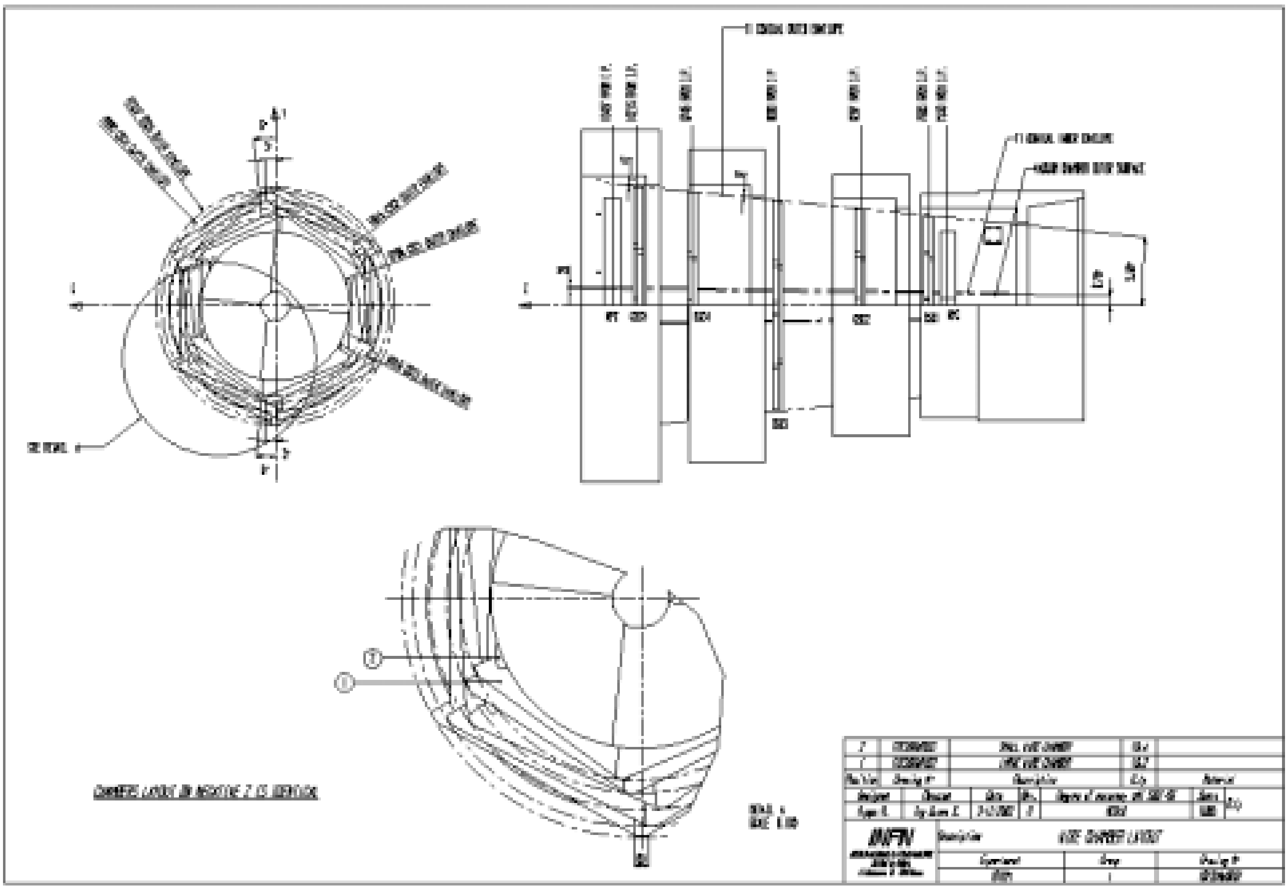

Fig.1: T1 detector layout

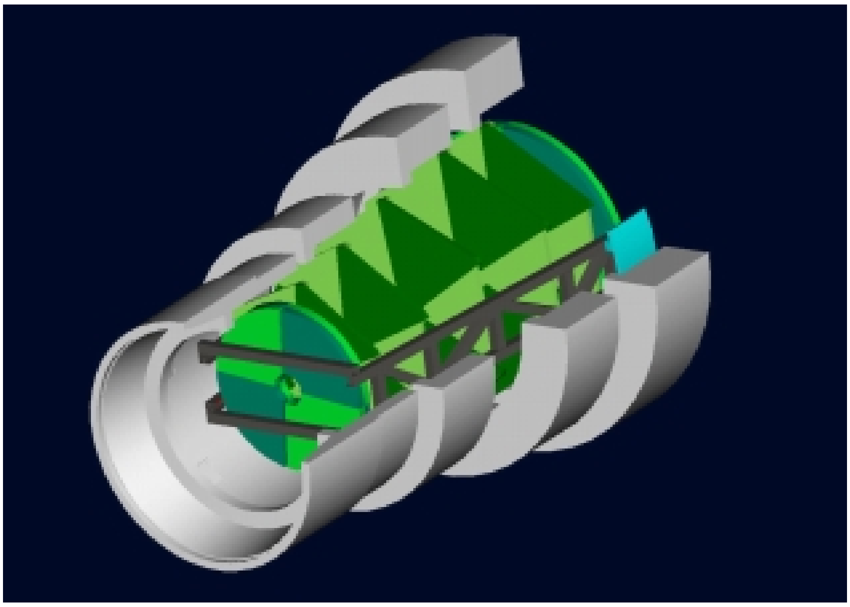

Fig. 2: T1 pictorial view

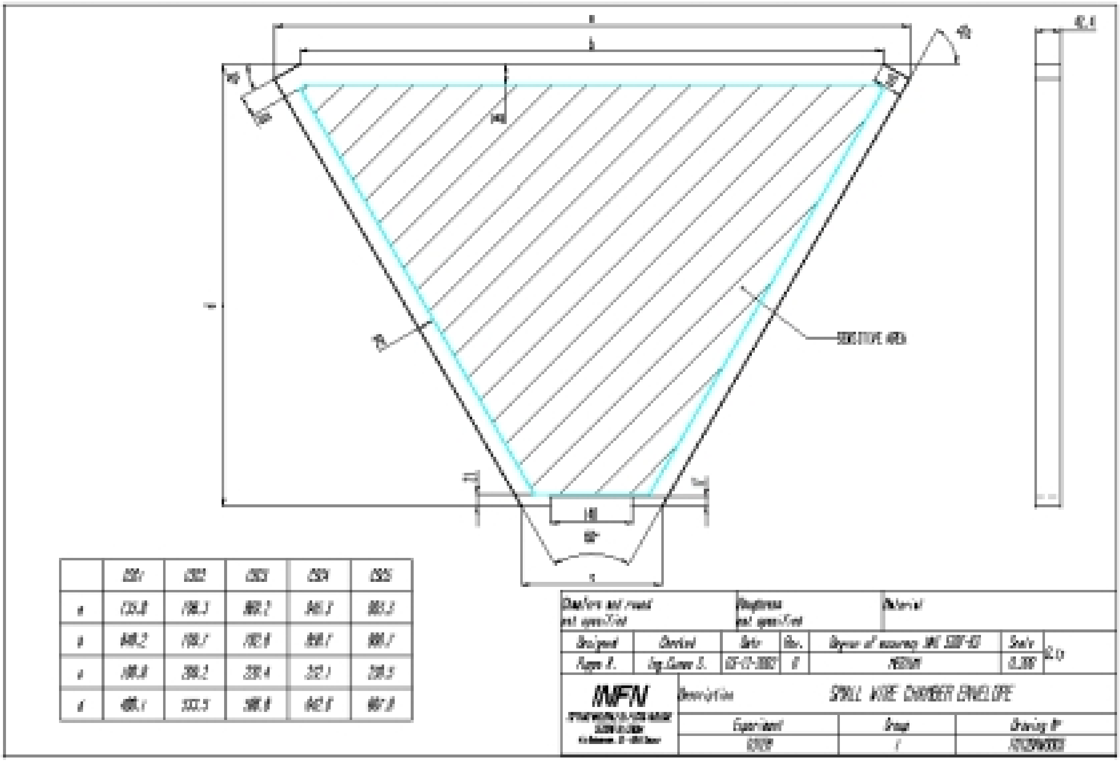

Fig. 3: small CSC layout

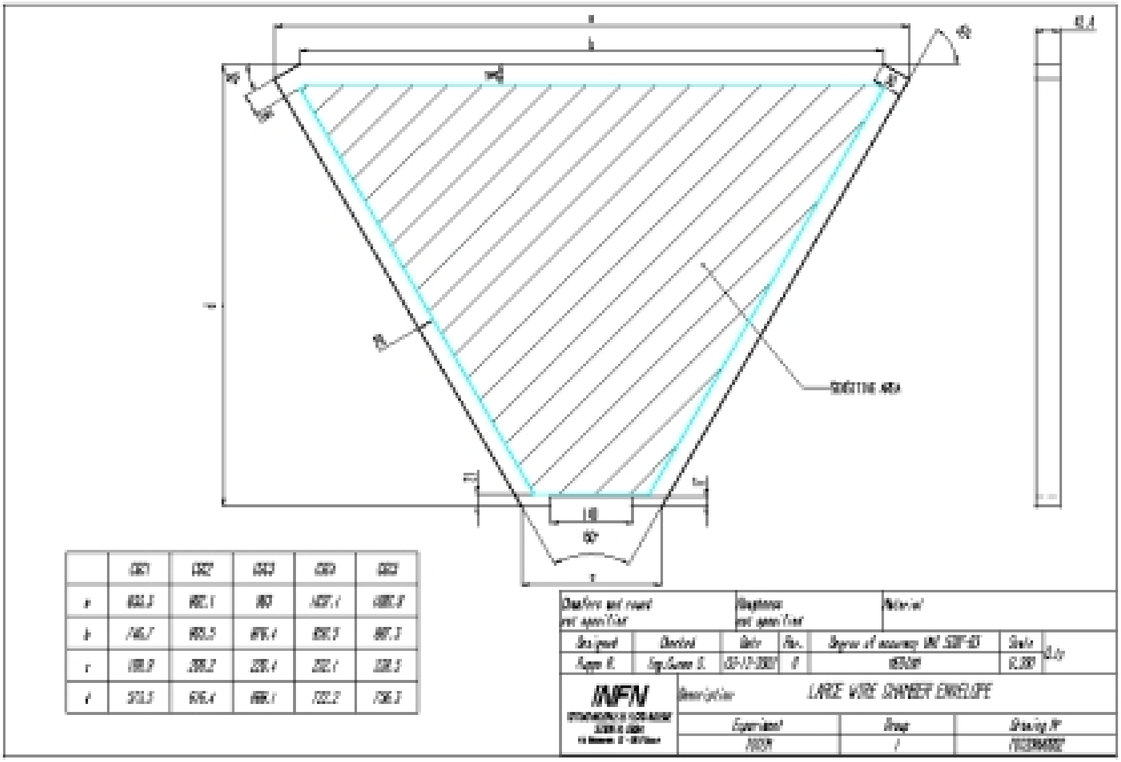

Fig. 4: large CSC layout

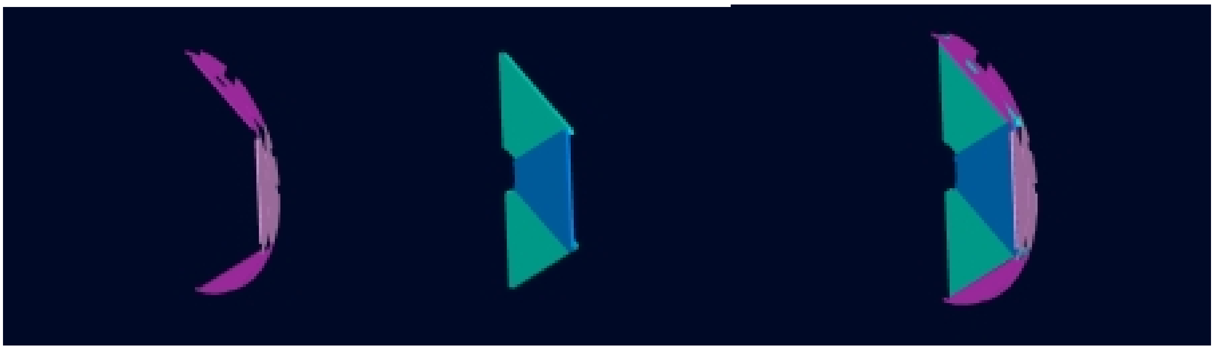

Fig. 5: pictorial view of a CSC half plane (semi-annular housing in purple)

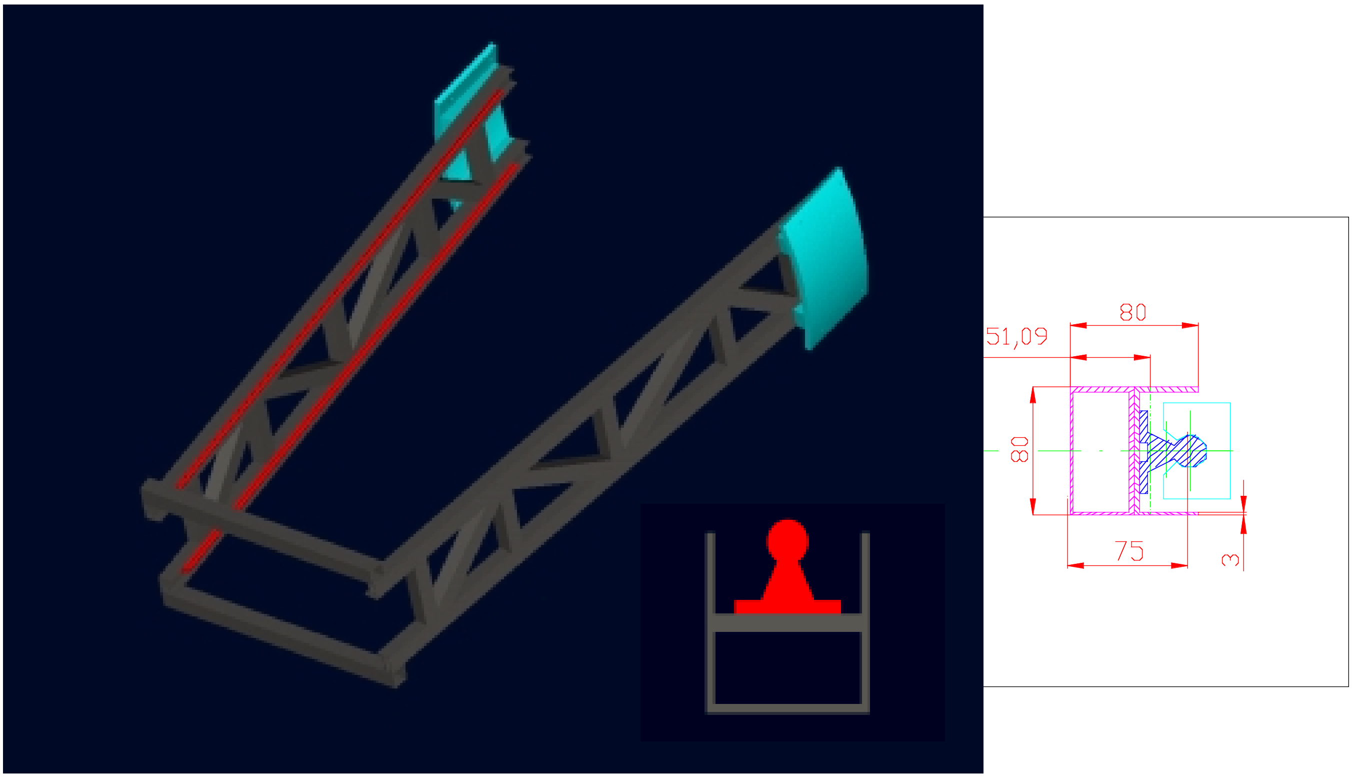

Fig. 6: rail framework assembly, with detail of the rail integration inside truss profile (interface plates in cyan, rails in red)

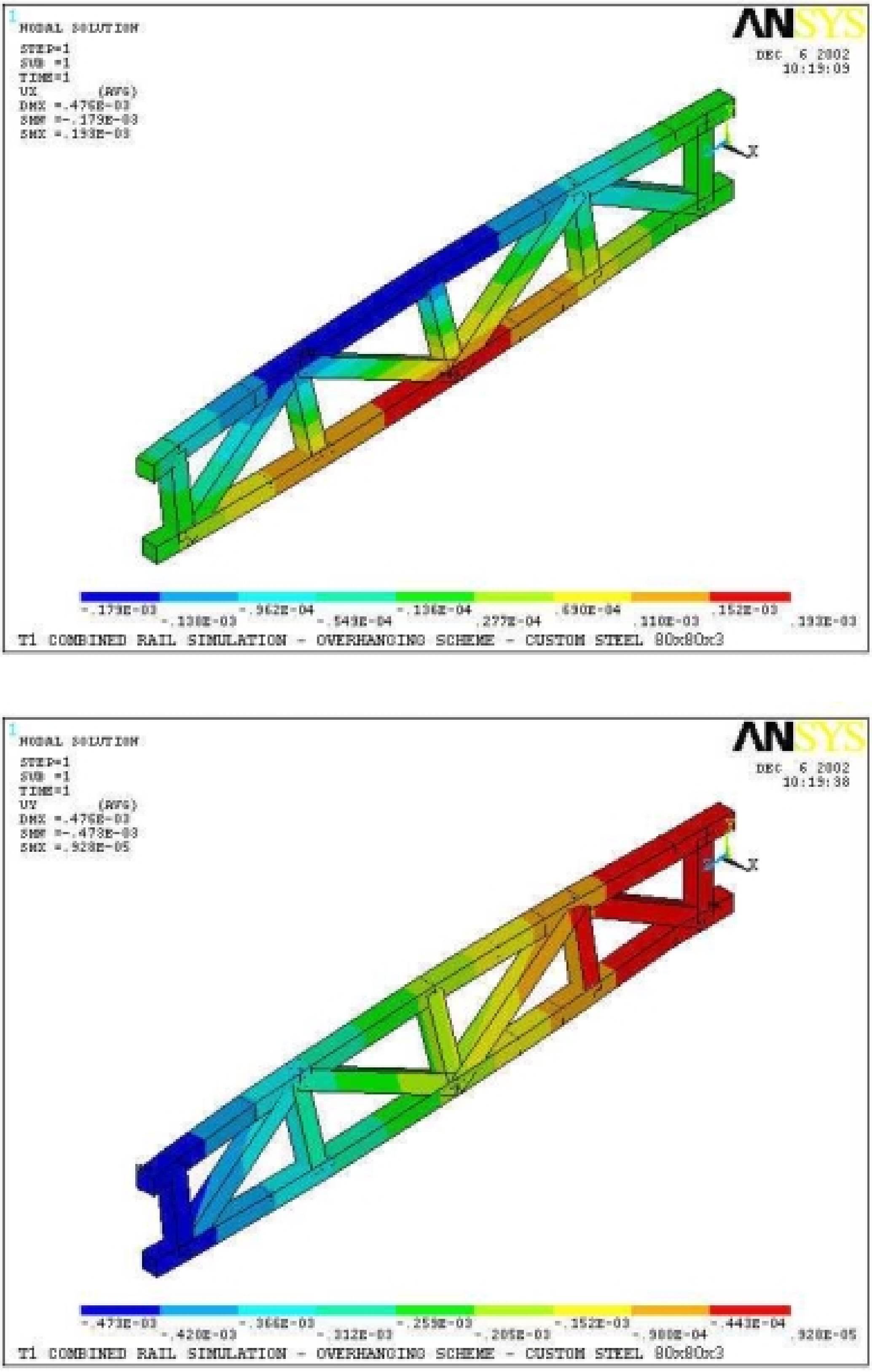

Fig. 7: horizontal (UX) and vertical (UY) deformation of the truss under load (displacements in [m])

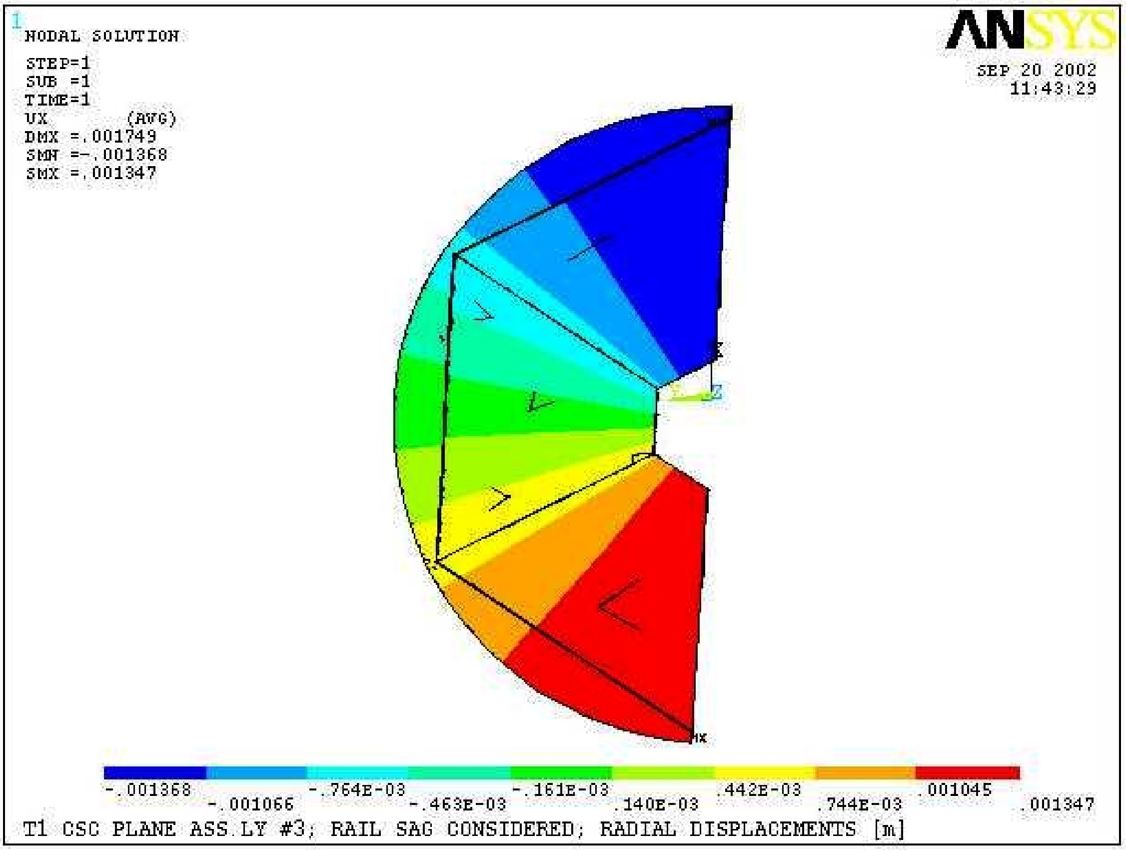

Fig. 8: radial motion of CSC plane #3 towards beam axis, truss deformation considered (displacements in [m])

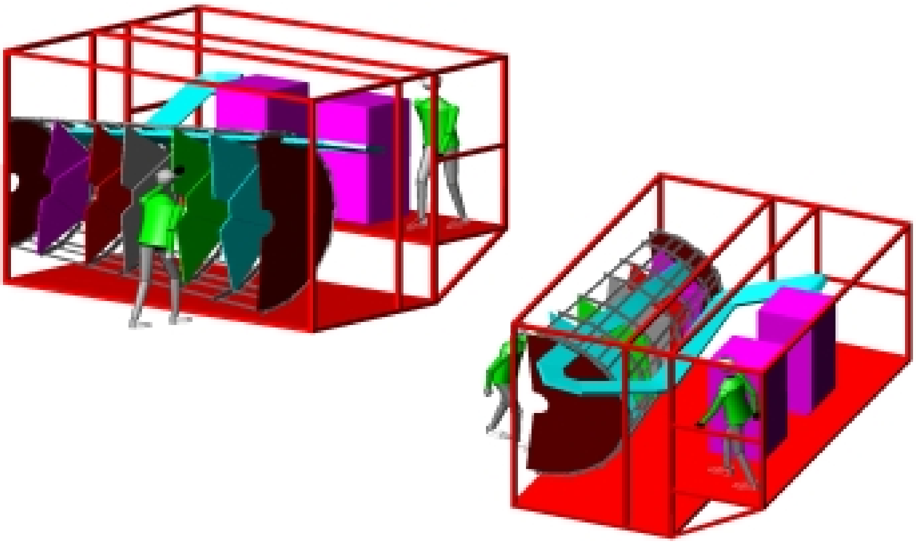

Fig. 9: external skid, with rails extension, for detector handling outside CMS gap

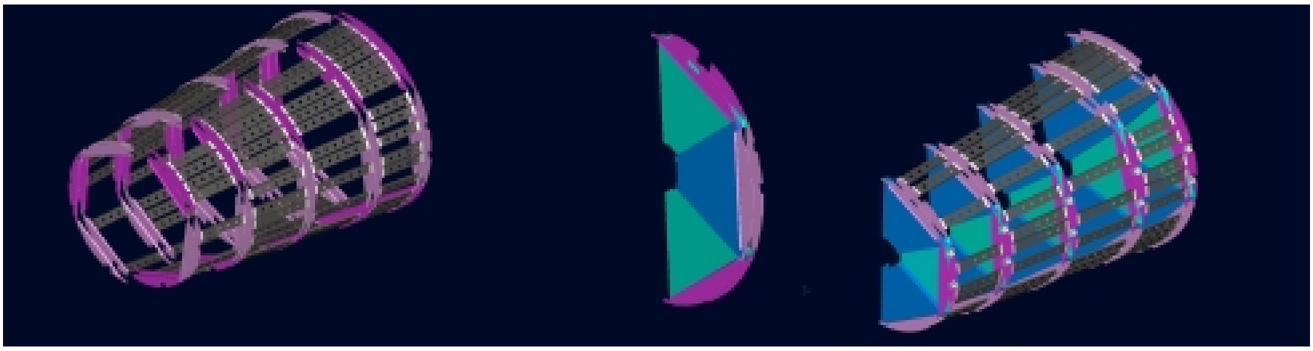

Fig. 10: skeleton frame concept: skeleton alone (left), a CSC plane inside the housing annulus (center), half T1 (right)

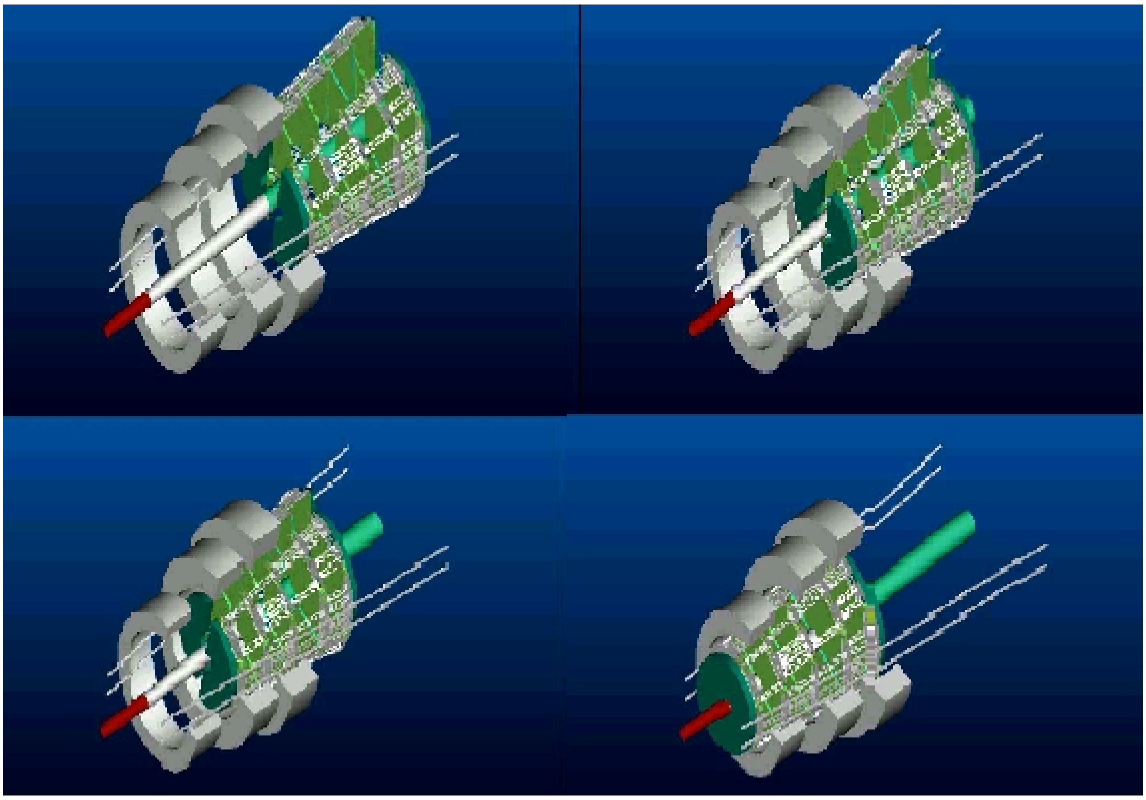

Fig. 11a/b/c/d: T1 introduction sequence

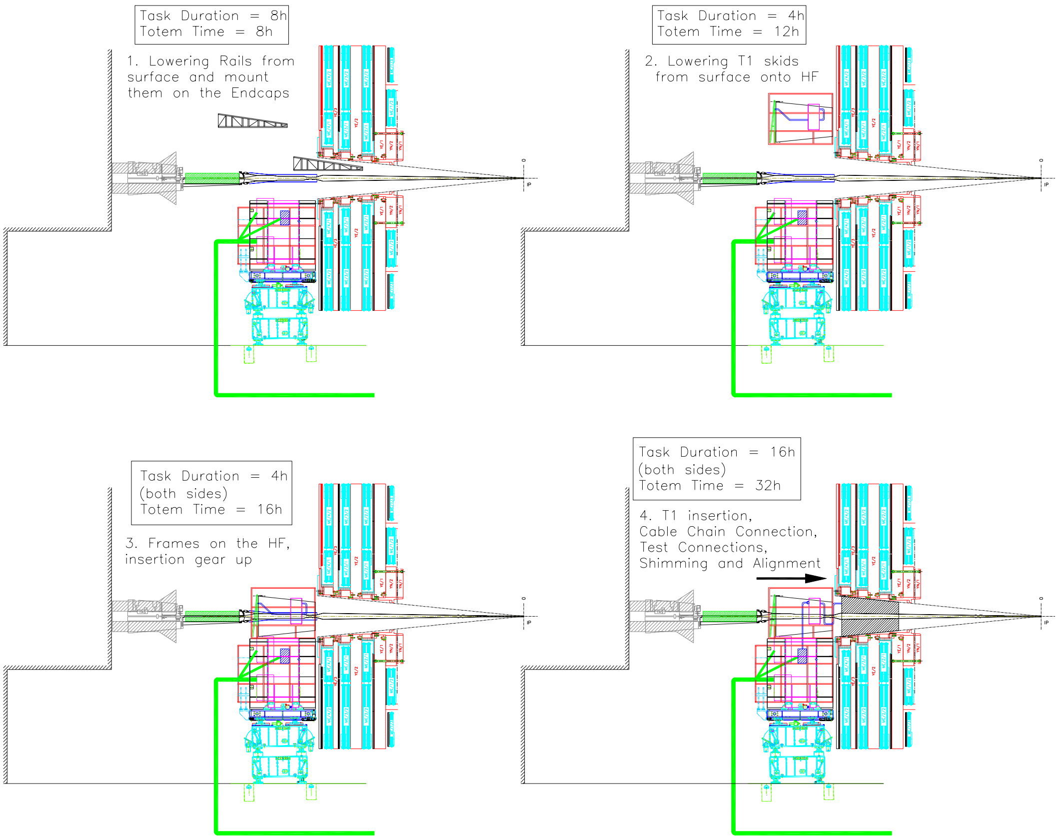

Fig. 12a/b/c/d: T1 introduction timing study