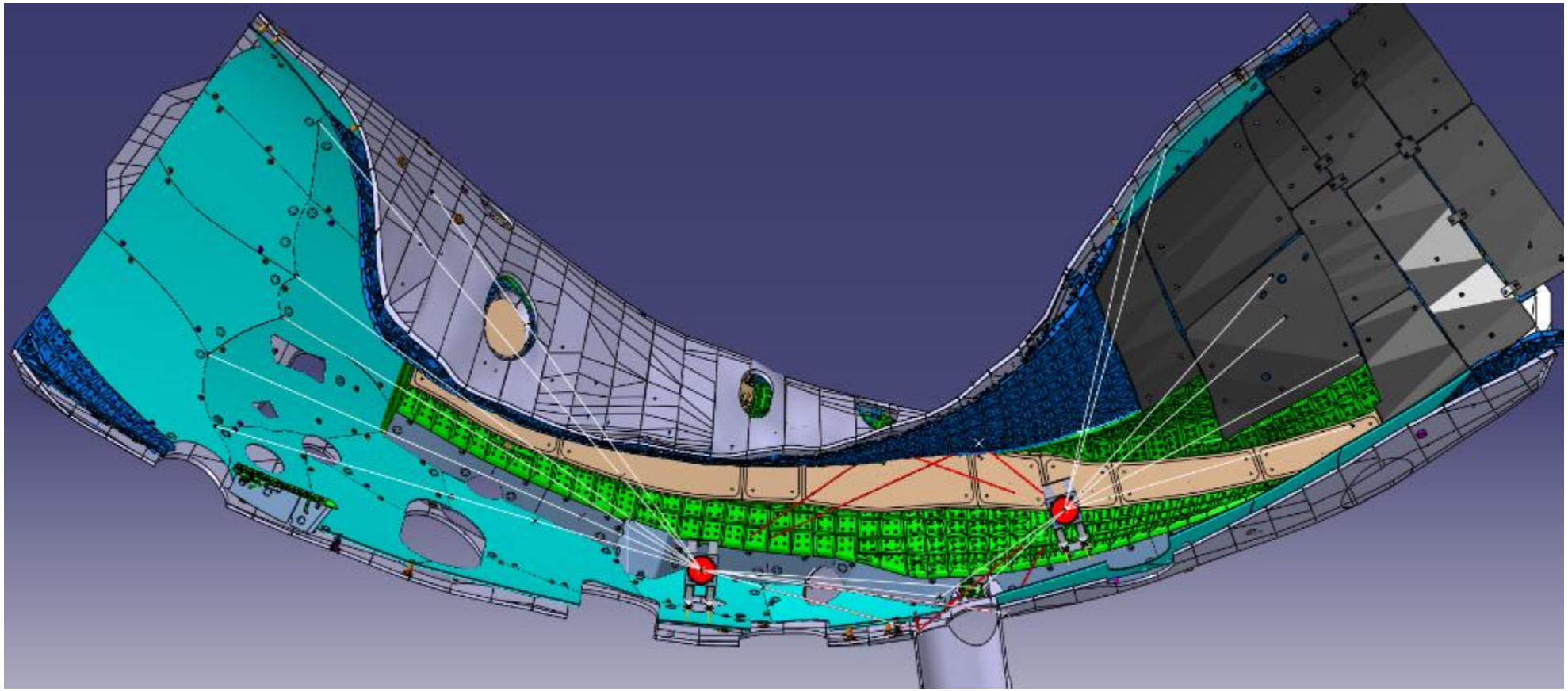
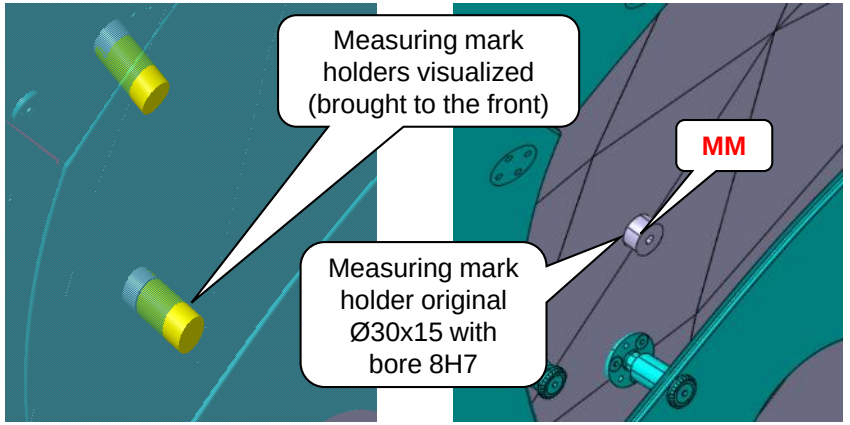
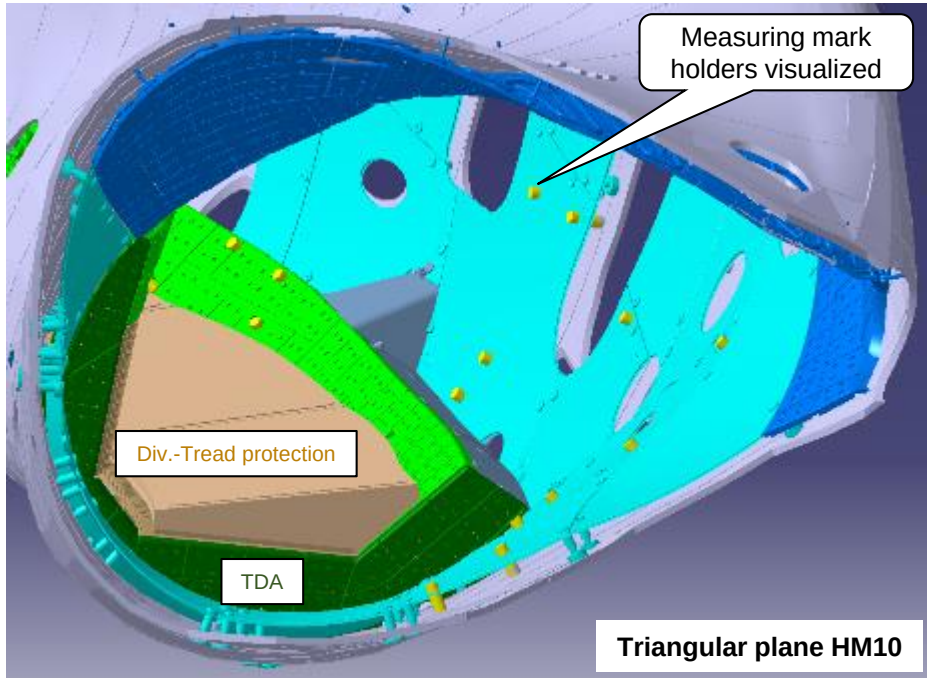
TKT – Draft concept for referenced measurements in the plasma vessel

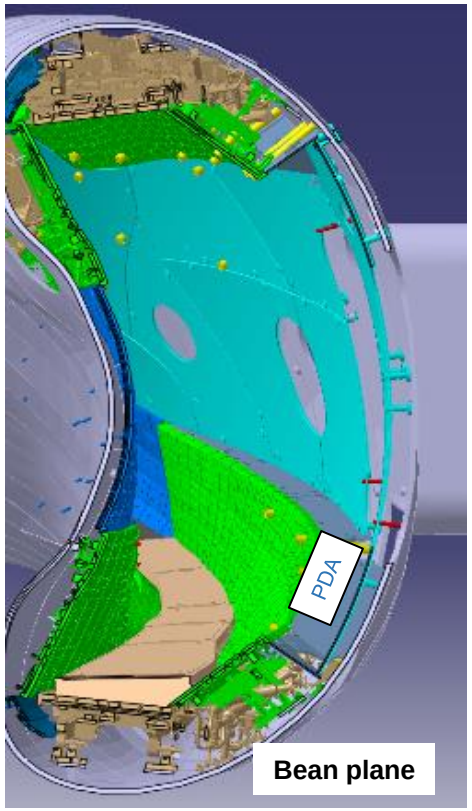


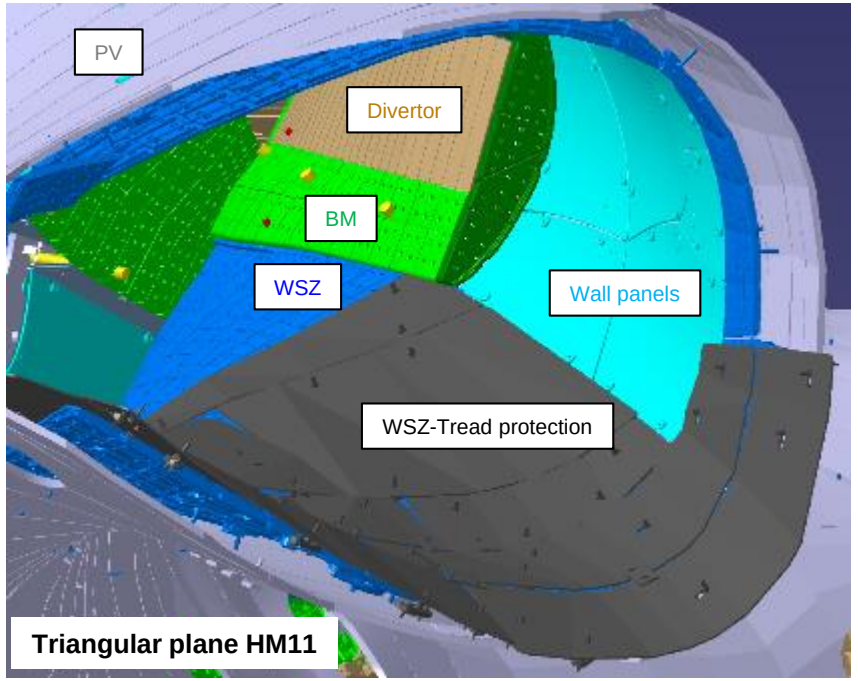
Current status reference system

- Referencing the PV to the torus hall coordinate system 2012 with approx. 80 to 113 measurement marks (MM) / module
- New referencing 2016 with approx. 46 to 56 MM / module → currently valid PV-Cosy
  Not all MM from 2012 were visible (built over) or had already been removed. In addition 28 new MM / module were also welded to the PV wall. Some of these 46 to 56 MM were also removed over time if they interfered with installation (not documented).
- The pictures show the position of the MM, which are all concealed and inaccessible behind the baffle modules, wall protection segments and wall panels. Access is only possible if components are dismantled.
- To clarify the position of the concealed MM, they have been visualized here with the yellow cylinders.





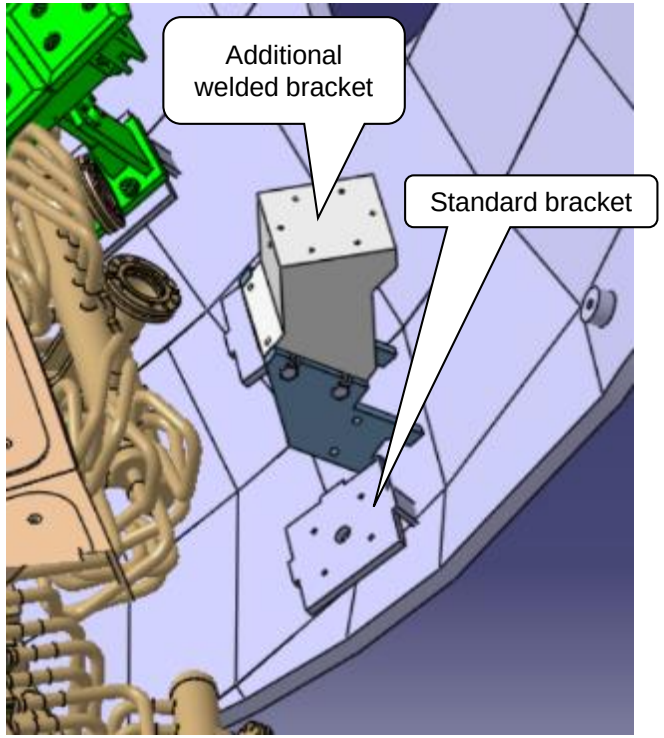




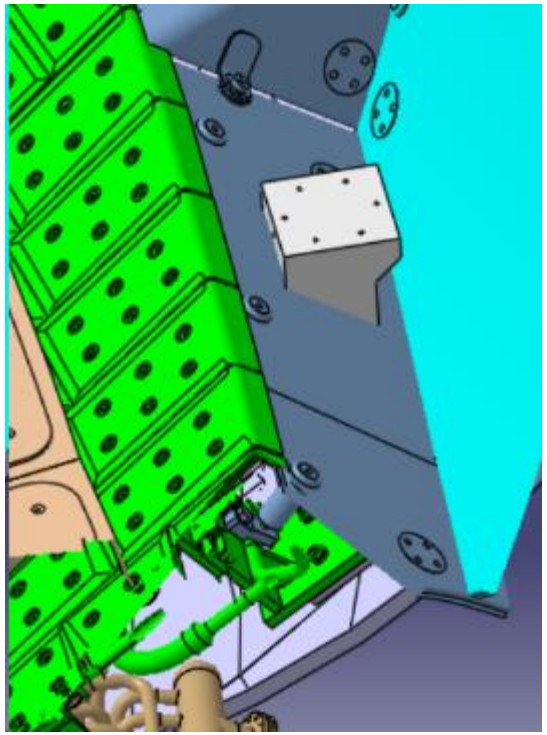
Current status mounting options for measuring devices

PV Modul 1

- During the build up phase of the W7-X, the PV standard brackets and additional brackets welded to the PV wall were used to attach the measuring devices (measurement arms, laser tracker). The divertor modules and baffle modules are now attached to the standard brackets. All additionally welded brackets have been removed.
- There is currently no way to mount measuring devices stably and securely in the PV *(IPP measuring devices see below).*
- In MP2.2, only unreferenced scans could be performed with the “HandySCAN700”. Targeted alignment of diagnostics with metrological support was no longer possible. *(Exception: Measurement of the flux surface diagnostic, where a special device for the API-LT was manufactured and positioned in the AEK10 Port. However, referencing was also only carried out using actual data from the baffle modules)*



Brackets can be used in the build-up phase of the W7-X



All brackets are now overbuilt or removed

FARO Measurement arm

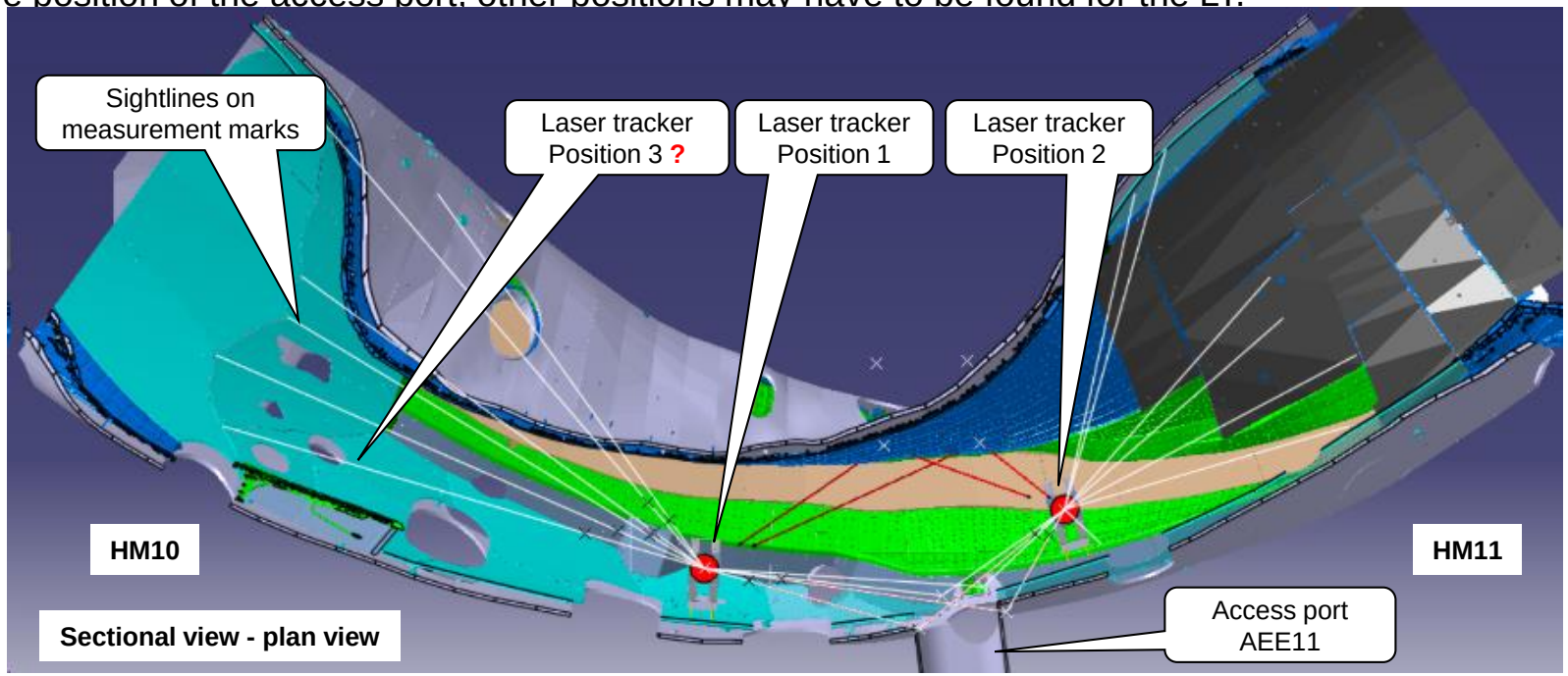
HandySCAN700

Lasertracker API

Laser tracker Leica AT901LR

Draft concept - Overview

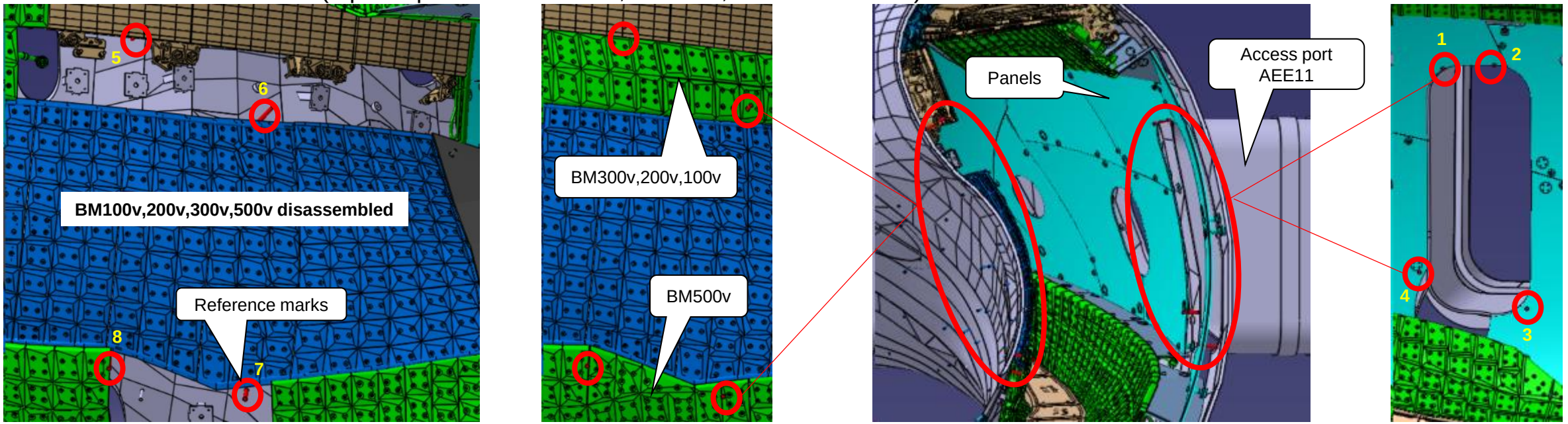
- The new measurement concept includes the positioning of new permanent measurement marks on the PV wall and the creation of mounting options on the wall panels for a laser tracker (LT) at 2 locations.
- From these 2 locatios, it should be possible to cover a variety of future measurement tasks *(no guarantee for all).* An additional 3rd position in the direction of module separation point 1/5 would be useful in order to be even more variable in the measurements.
  The use of a measuring arm is dispensed with in this concept, as a larger number of mounting options would have to be found for this (only small range). In addition, more measuring marks would have to be set, even in places that are unaccessible but for unreasonably large assembly efforts. (Note: At ASDEX in Garching, measurements in the PV are also carried out with a measuring arm. There is a visible reference system of measurement marks and mounting options are installed for the measuring arm). None of this is currently available in the W7-X, it was (knowingly) neglected to implement this in the design of the PG in such a way that it could be used permanently.
- The investigations carried out so far have only been carried out for PV Module 1, but must then also be carried out for modules 2 to 5. Depending on the position of the access port, other positions may have to be found for the LT.



Draft concept - Uncover existing reference marks

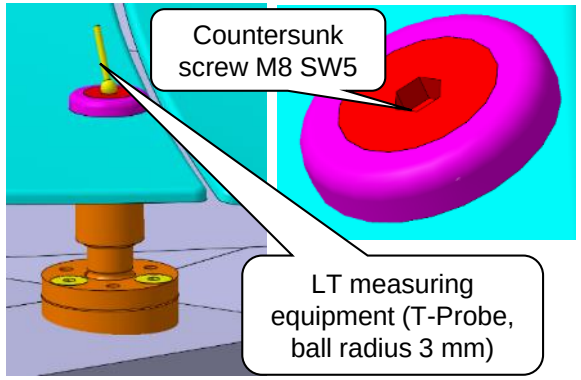
PV Modul 1

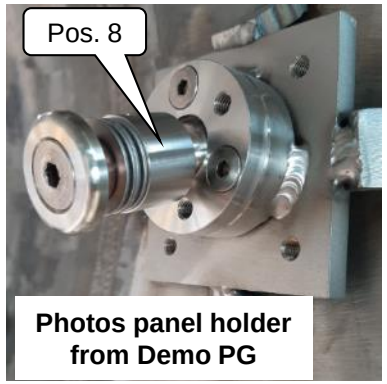
- During the new referencing in 2016, the torus hall cosy was transferred into the PV via the AEE11 access port using a laser tracker (LT). The LT was positioned outside the PV on the port flange and simultaneously had a view of measurement marks on the TH walls and a view into the PV. 8 measurement marks were set and measured in the PV, which then formed the basis for setting further measurement marks for the reference system in the PV.
- This process is very difficult to repeat nowadays (possibly only via detours with much effort), as the lines of sight to the measurement marks on the TH walls are usually blocked. Therefore, the best solution would be to first make the 8 reference marks in the PV accessible again. This is a one-off process that does not need to be repeated in the later MP phases.
- 4 reference marks (1 to 4) directly next to the port AEE11 are covered by the panels, but can be reached with the appropriate measuring equipment (T-probe), as the distance between the wall panel and the PV wall is large enough.
- 4 reference marks (5 to 8) on the opposite PV wall are covered by baffle modules. It is therefore essential to temporarily disassemble minimum 4 baffle modules (top: coupled BM100v/200v, BM300v, bottom: BM500v)

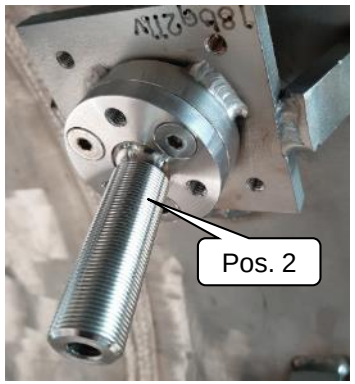


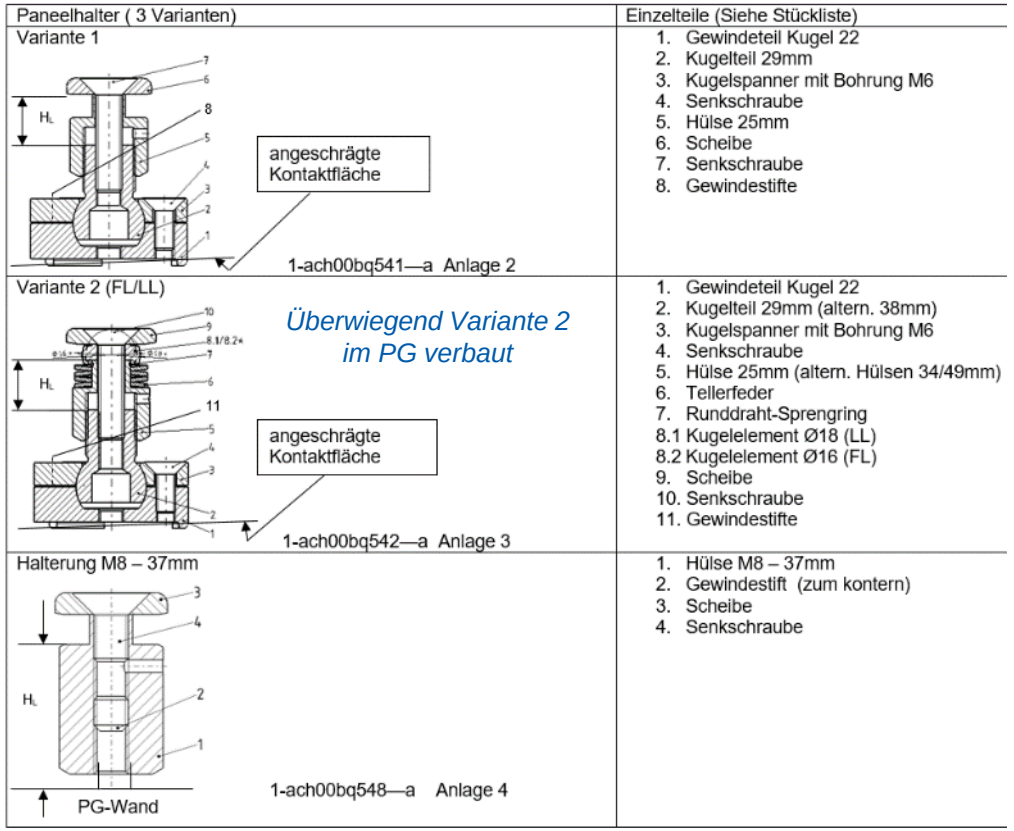
Draft concept - Generate new measurement marks

- The idea is to use the screw heads of the panel holders as a measuring mark. There are 3 variants of panel holders. According to work instruction 1-NEC-A0090.2, the ball parts are firmly clamped in place using a qualified tightening procedure and the M8 countersunk screws are tightened to a torque of 22 Nm. The holder can therefore initially be regarded as stable in position.
- The M8 countersunk screw has a SW5 hexagon socket. A self-centering measuring ball with a radius of 3 mm could be placed on this. As the hexagon socket of some screws has already been somewhat deformed by repeated tightening and loosening, these should be replaced with new screws beforehand if necessary.
- Disadvantage: When loosening panel holders if necessary, practical experience has shown that the threaded sleeve **Pos. 8** on the ball part **Pos. 2** twists. When refitting the panel and tightening the countersunk screw, the screw head will no longer have the same axial position as before and the reference coordinate would be incorrect. Deviations of several 1/10 mm are certainly to be expected. This in turn has an effect on the calibration accuracy of the continuous measuring processes for components to be aligned. These holders should then be “discarded”, i.e. no longer used as measuring marks in the future.
- In PV module 1 there are 39 panels, each with 4 panel holders, 1 of which is a fixed bearing that is also to be used as a measuring mark. The result is a well-distributed reference system of 30 to 40 points.





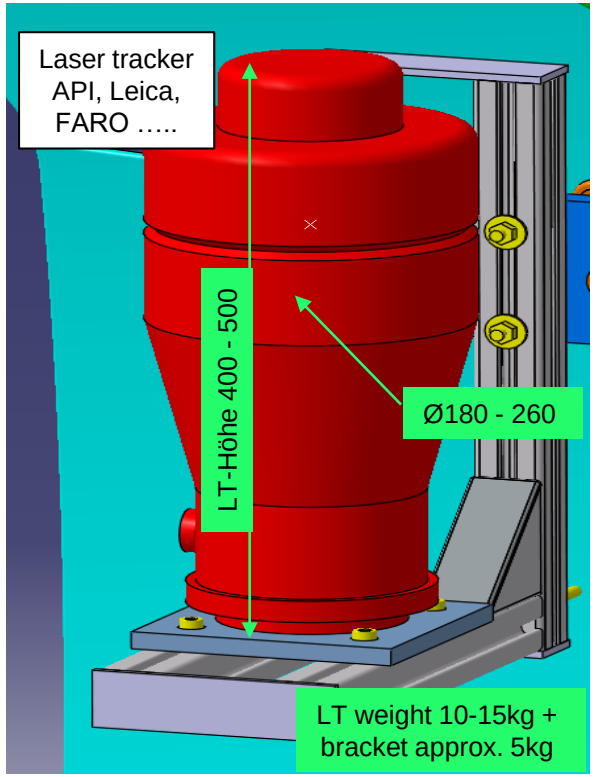


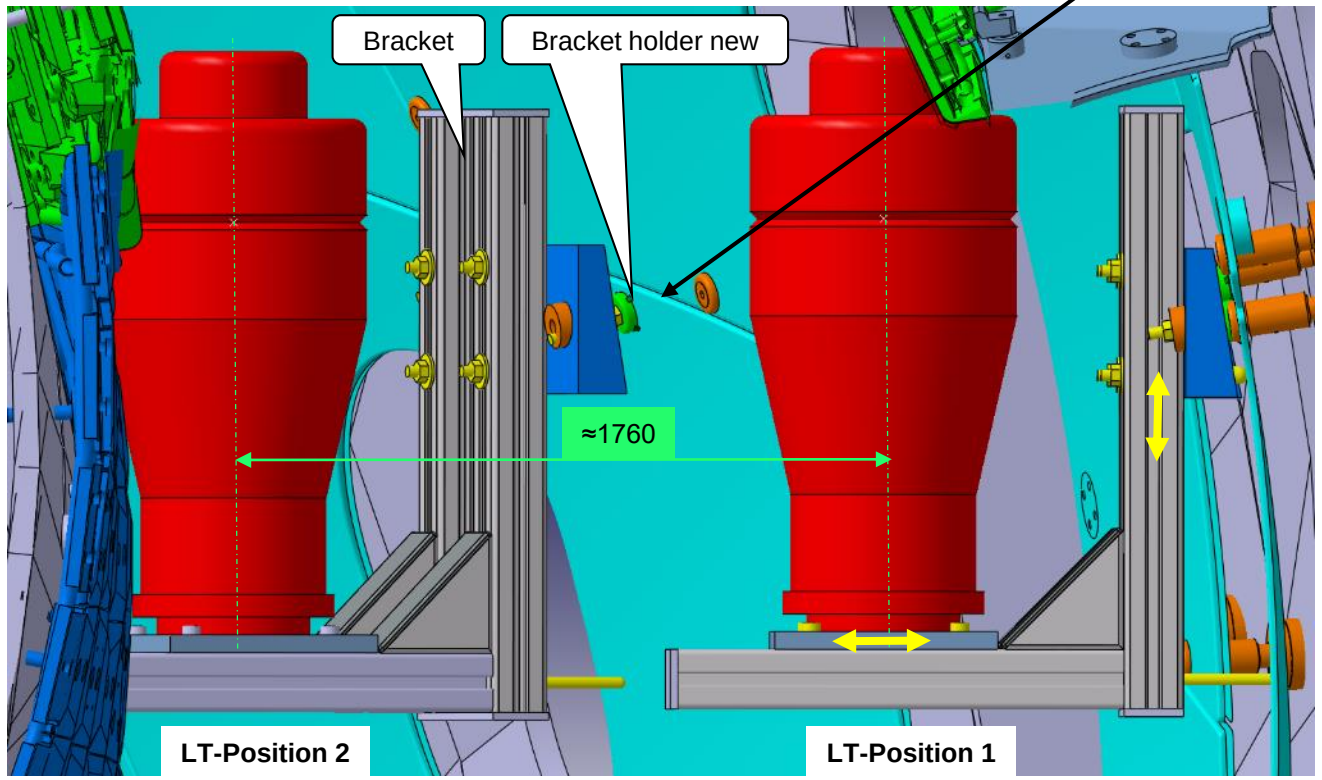


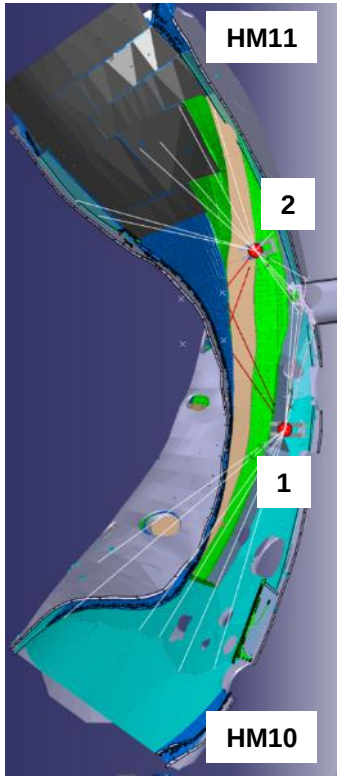
Draft concept – Laser tracker attachment to wall panels (1)

PV Modul 1

- In my opinion, the only way to keep the laser tracker in a stable position without having to keep dismantling components in the PV is to attach it to the wall panels using a bracket. To do this, a total of 4 (6) console brackets (washer Ø24x8) must be welded to 2 wall panels for the 2 (3) LT positions, where they then remain permanently and can be used again in each maintenance phase *(see also following page)*.
- Whether this is permissible from a thermal point of view would have to be checked conclusively. In the past, it has already been qualified that a fillet weld a=1-2mm can be welded on the 5mm sheets of the wall panels *(WPS 29F2KW from 2016).*
- Alternatively, it might be possible to construct a bracket (E5-ENG/DE) that is temporarily pushed into the 4 mm gap between 2 panels and locked *(feasibility rather unlikely)*.





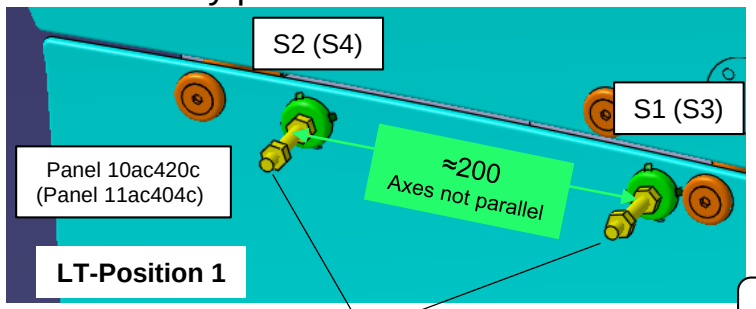


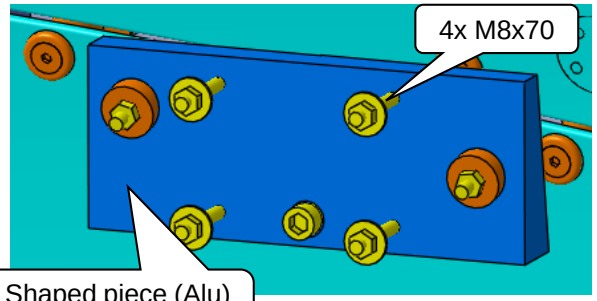
Draft concept – Laser tracker attachment to wall panels (2)

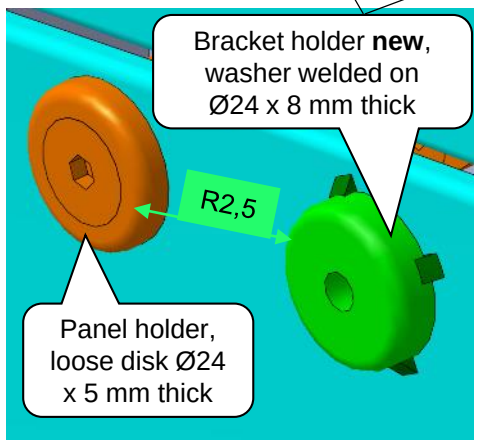
PV Modul 1

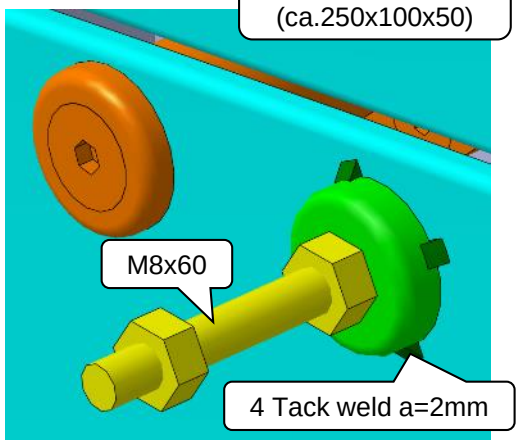
- The pictures show the arrangement of welded bracket holders (washers). The coordinates in the excel table can be used to determine whether the washers can be permanently welded on at these points.
- The shaped piece is a milled part for angle compensation so that the bracket made of ITEM profiles for the laser tracker is approximately perpendicular in the room.
- The support screws to the wall panel are intended to provide additional stability so that the rotational movements of the LT during the measuring process do not cause the bracket to move
- The horizontal and vertical adjustment options of the bracket allow the LT position to be corrected to a small extent, which may provide a better view of certain measurement marks.

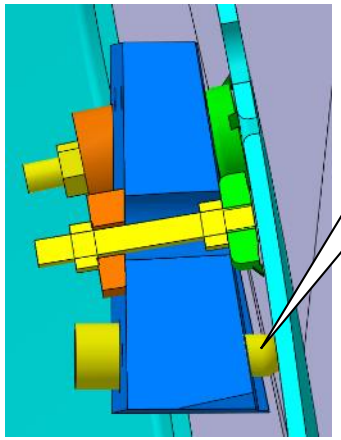
Koordinaten Scheibenposition M1			
	x	y	z
S1	6349,927	-508,862	332,506
S2	6362,780	-310,996	355,957
S3	6101,269	1319,646	340,375
S4	6029,193	1504,487	368,903

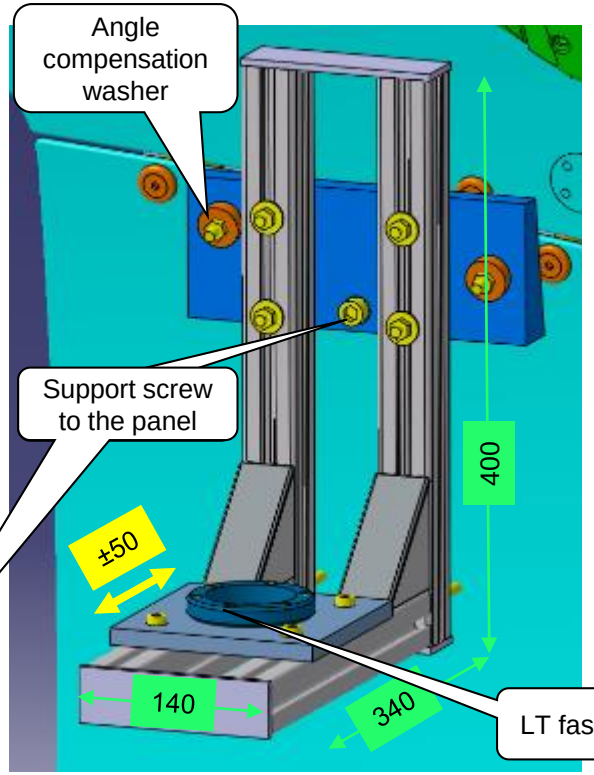


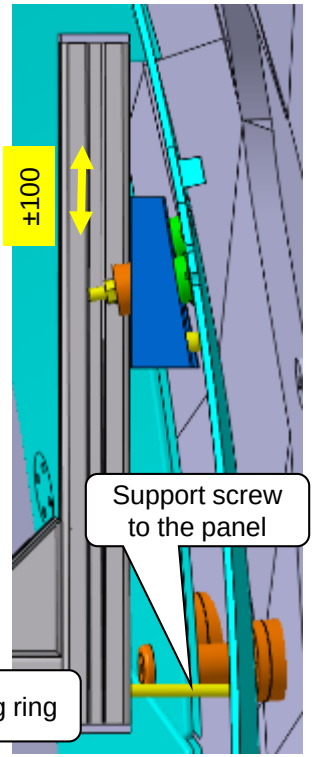






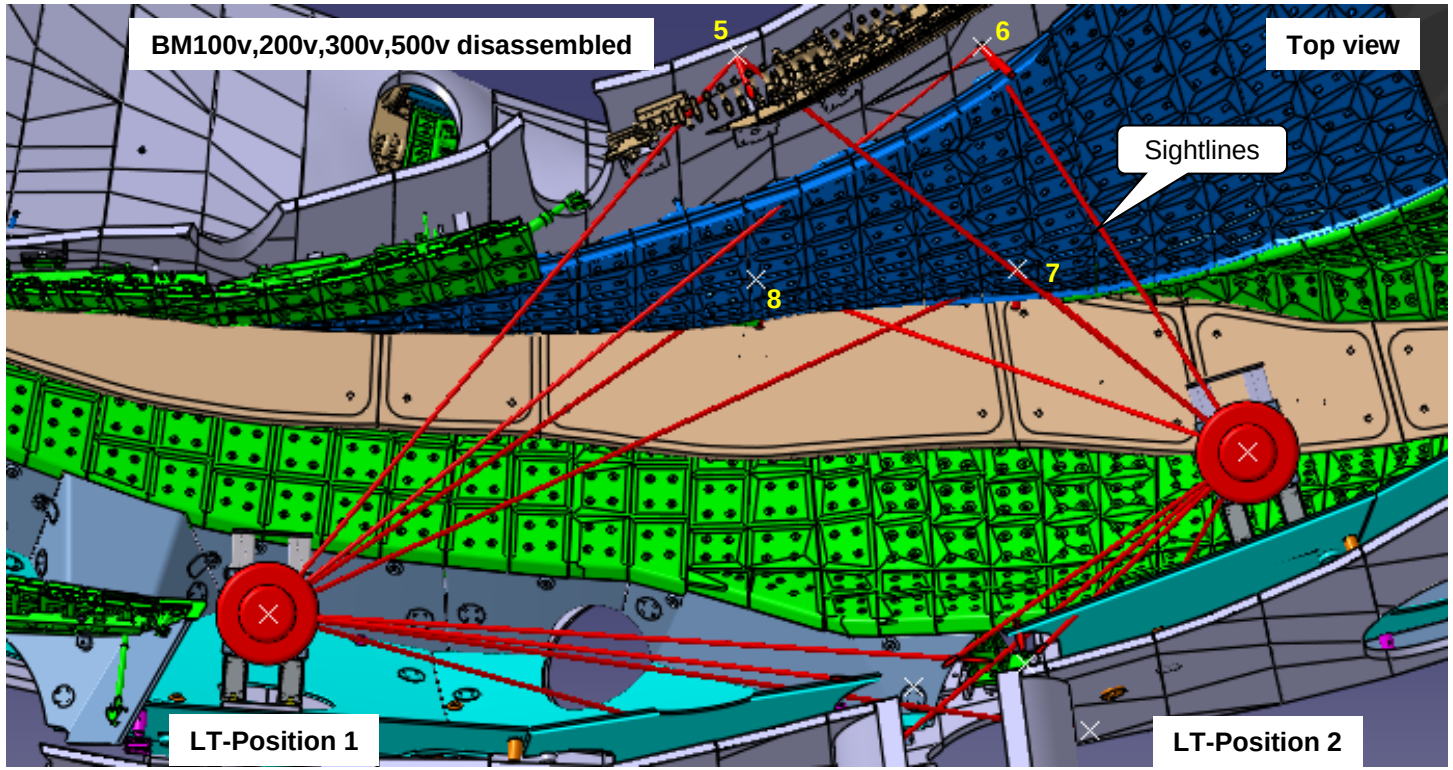


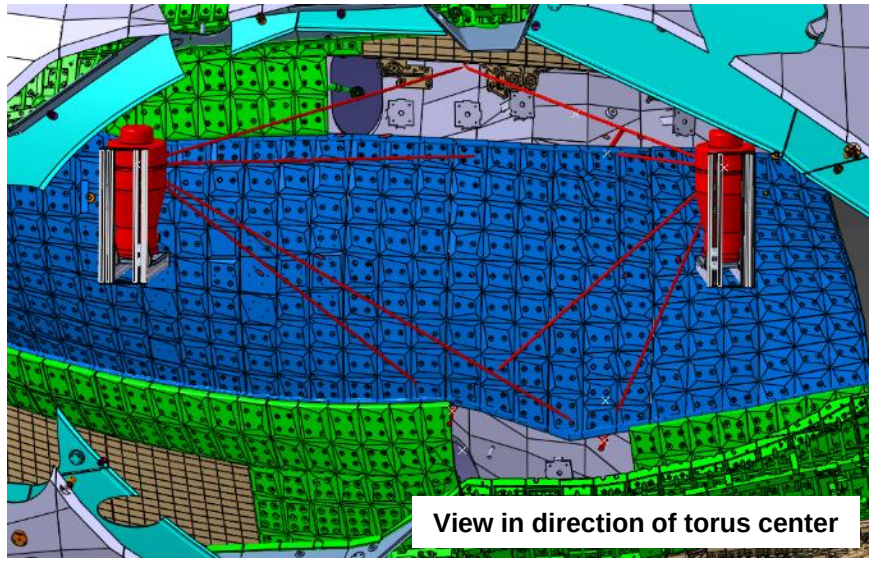


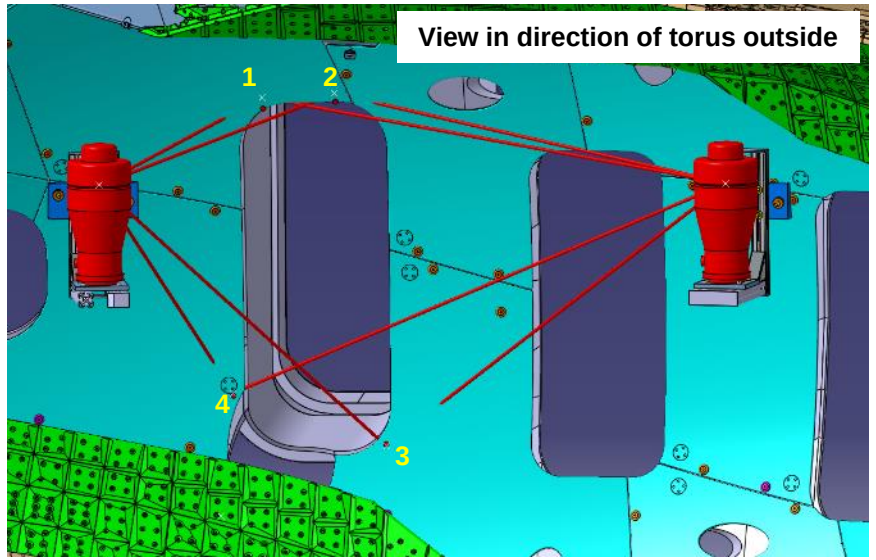


Draft concept - Sightlines laser tracker ↔ Measurement marks (1) PV Modul 1

- The sightlines to the 8 existing reference marks are shown here *(see also page 5)* in order to be able to set up the new reference system in the PV *(LT with T-probe required for this)*. The LT is used to measure in into the 8 referenz marks and then determine the actual position of the new measuring marks (screw heads of the panel holders).
- After measuring the actual position of the new reference points in the area of the baffle moduls, the 4 baffle modules are reinstalled. The 4 reference marks (Pos. 5 to 8), which are then covered again, are no longer required for further measurements.

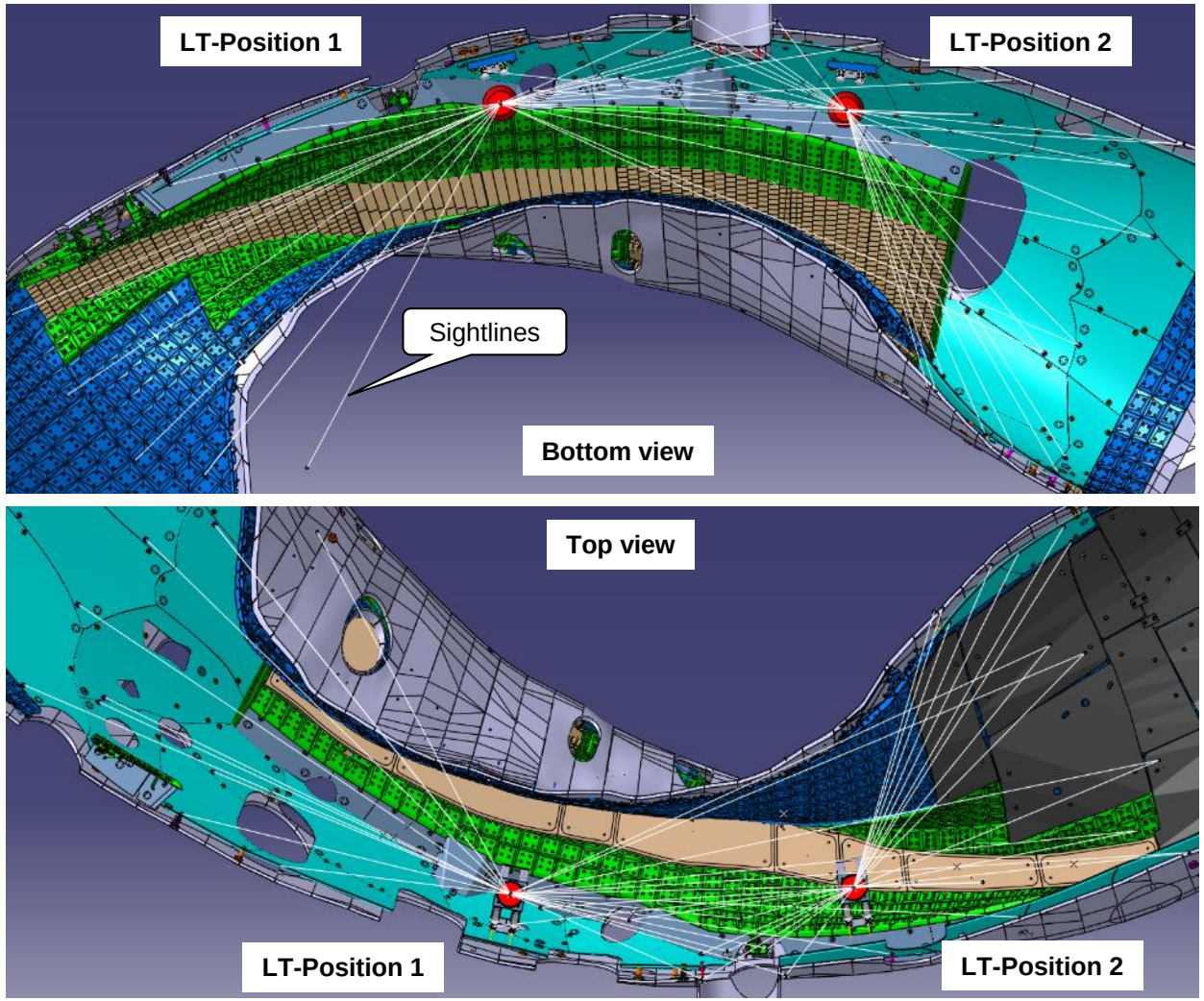






Draft concept - Sightlines laser tracker ↔ Measurement marks (2) PV Modul 1

- The sightlines on the measuring marks on the screw heads of panel holders are shown here (see also page 6). These measuring marks will be used later for referencing to align components in the PV or to determine their actual position.



Current situation regarding the laser tracker measuring system at IPP

- The measurement concept in the PV is based on the use of a laser tracker (LT) in conjunction with a so-called T-probe. The T-probe is a freely movable coordinate measuring machine for scanning and checking hidden points *(6 degrees of freedom)*. You can also measure with an LT without this device, but then you must have a direct and unobstructed view of the measurement marks, which is not always the case in the PV.

1. At IPP, we have the Leica LT AT901-LR (from 12/2009; 250k€) with the corresponding T-Probe. This LT is unsuitable for use in PV. With an overall height of 620mm and a dead weight of 22kg, the handling during transportation in the PV is very difficult and also dangerous for people. There is also a risk of the LT falling or bumping into the KiP, which could cause massive damages to the LT and the KiP.
   I would therefore generally rule out the use of this LT in the PV.
2. We also own the LT API Radian R50 from API (from 12/2011; 120k€). This LT is well suited for use in PV, height 430mm, weight 11kg. However, we do not have a T-Probe (called V-Probe by API) for this LT.
   My inquiry to API about the possibility of upgrading our old LT with a V-Probe was answered as not economically viable. The V-Probe has only been available since 2019. Alternatively, a new LT with V-Probe would have to be procured *(ca. 100k€)*.
3. An alternative to purchasing a new LT would be to borrow the LT from our measurement partner ITN Stralsund. ITN owns a Leica AT960 LT + T-Probe that is only a few years old. With an overall height of 480mm and a dead weight of 14kg, the LT can still be handled reasonably well in the PV *(should be tested in advance in the demo PG)*.
   ITN would always lend us the LT if required *(rental fee per month approx. 7500€, per week approx. 3000€)*.
   In order to save costs, the measurement jobs in the PV would then have to be bundled as much as possible during the maintenance phases. If we do not have measurement personnel available *(vacation, illness ...)*, ITN can also provide personnel.
4. If a decision is made to procure a new LT + T-Probe, a call for tenders must generally be launched *(API, Hexagon/Leica, FARO …)*.


AT901-LR


T-Probe


API R50


API V-Probe

AT960

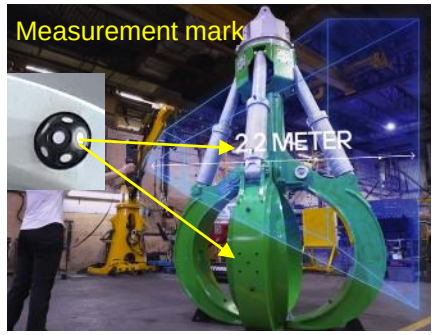

T-Probe


FARO
(Example)

Question: What are the measurement requirements in PV? (1)

1. Is there even a need for referenced measurements in PV? Is the effort described here to create the prerequisites justified?
   - In the query for the MP2.4 work packages *(as at 08.05.2024),* a total of 32 items from 12 plant operators are listed in the “Measurement in PV” column in the list from D. Behrendt. For some items, it is already clear from the description that this has nothing to do with measuring on the part of metrology (e.g. inspections, layer thickness measurements). The respective surveying task would therefore have to be precisely defined by each PRO in order to be able to estimate the scope more accurately.
2. Should you continue to measure with the HandySCAN700 in the PV?
   - In the last maintenance phases, only unreferenced scans could be carried out with the “HandySCAN700”. The method is a feasible solution for documenting the actual position of components (not for aligning components with active metrological support). However, it always has the disadvantage that a best fit on CAD models must be based on components that have already been mounted and measured, which means that their measurement errors are also transferred, ultimately resulting in a measurement accuracy of several millimeters. Furthermore, several graphite tiles usually have to be dismantled for each measurement and a grid with measurement markers installed. The measurement area is then always kept very localized.

3. From time to time, DE has asked whether Metrologie has a simple, fast and accurate scanning system that does not require a lot of referencing and can be used to scan larger areas inside and outside the PV. Is there still a need for this?
   - During my visit to the “Control” trade fair in Stuttgart in April, company Creaform introduced me to another variant of the 3D HandySCAN, namely the HandySCAN MAX or MAX/Elite. *(Price, depending on equipment, 45-80k€)* Here, large areas can be scanned with high accuracy and speed, whereby the temporary setting of measurement marks is also necessary, but at greater distances from each other. *(The technical data sheet “Elite” says e.g.: Volumetric accuracy 0.1mm+0. .015mm/m; working distance 0.3-2.5m; partial size range 1-15m; measuring capabilities at distance 0.5m >> pin 2.5mm / bore 3.5mm / step 0.04mm / wall 2.0mm)* An extensive demonstration of the product in the IPP is offered by Creaform.
   - In addition, Creaform's “Go!SCAN 3D”, for example, is the most user-friendly variant that can be used to scan without prior setup. Whether this meets our requirements needs to be tested/demonstrated.



Question: What are the measurement requirements in PV? (2)

4. An interesting possibility for referenced measurements in combination of laser tracker and hand scanner is offered by the company Leica. The laser tracker AT960, already mentioned in point 3 on page 11, offers the possibility to combine the measuring system with a Leica “T-Scan 5”.
   - If a referenced scan of components is required within the PG, the LT would be used to calibrate the new reference system *(see page 6)* and then the scan would be carried out with the T-Scan.
   - This would also work outside the PV, with measurement in into the W7-X reference system on the torus hall walls.
   - ITN has given the tip that the T-Scan could also be borrowed from Hexagon/Leica *(still to be explored)*. It could work like this:
     LT AT960 + T-Probe at ITN and borrow the T-Scan from Hexagon/Leica if necessary, if we don't want to buy these devices new *(estimated acquisition costs are over 300k€)*. The disadvantage is that we are then not flexible, measurements cannot be carried out ad hoc.

T-Scan 5

AT960

Time estimate for realization of measuring concept

Zeitschätzung für Umsetzung Vermessungskonzept „Referenzierte Vermessungen im Plasmagefäß“ *Stand 09/2024*			
Schritt Nr.	**Arbeitsschritt**	**Aufwand je PG-Modul**	**Zusammenfassung für 5 PG-Module**
1	Bestimmung der Ist-Position des PG Referenzsystem in Bezug auf das TH-Referenzsystems anhand der fest installierten Messmarken *(Scheiben)* am Rand des Zugangsstutzens *(Kann gleich nach dem Öffnen jedes Zugangsstutzen durchgeführt werden, das betreffende Modul ist dann für 1 AT blockiert)*	8h	∑40h = 5 Arbeitstage
2	Entleeren KKLB1, B6 oben/unten, KKL4c (Paneele) = 16h Demontieren ca. 79 Kacheln von BM1v, 2v, 3v, 5v, 9v = 24h Demontieren BM1v+2v, 3v, 5v, 9v = 24h	64h	∑600h = 75 Arbeitstage
3	Positionieren von 6 Konsolenhaltern nach Stichmaßen und mit Wasserwaage Evakuieren der Paneele zum Schweißen *(Wasser abpumpen)* = 3Tage *(1Tag Arbeitsaufwand, Rest Abpumpzeit)* Formieren der Paneele *(KKL4c/Modul)*, inkl. Schweißen = 16h He-Lecktest der Paneele nach Schweißen *(abpumpen, SN ansprühen)* = 16h	56h	
4	Zeitschätzung Bestimmen des neuen PG-Referenzsystems mit Lasertracker *(Es muss zwingend direkt hintereinander in allen 5 PG-Modulen gemessen werden)*	16h	∑80h = 10 Arbeitstage
5	Montieren BM1v+2v, 3v, 5v, 9v = 40h (BM müssen referenziert eingemessen werden) He-Lecktest der BM nach Wiedermontage = 16h (abpumpen, SN ansprühen) Montieren ca. 79 Kacheln von BM1v, 2v, 3v, 5v, 9v = 32h Befüllen KKLB1, B6 oben/unten, KKL4c (Paneele) = 32h	120h	∑600h = 75 Arbeitstage
			∑1320h = 165 Arbeitstage