ESTABLISHING AND RE-MEASURING THE INSTALLATION CONTROL REFERENCES OF EAST TOKAMAK

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FNAL, SEP. 2012

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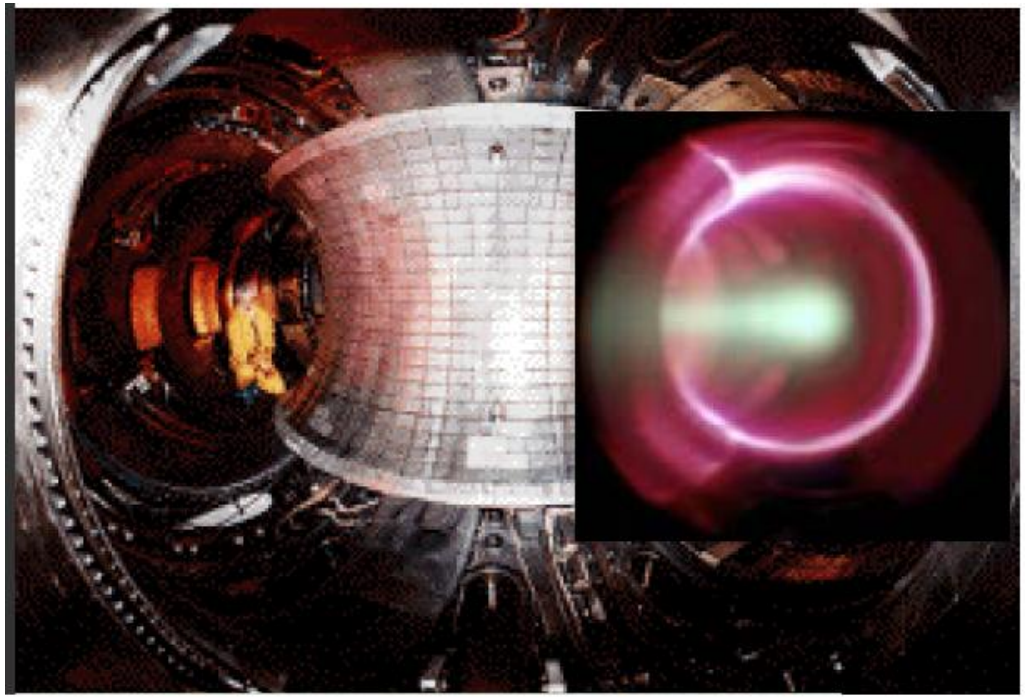
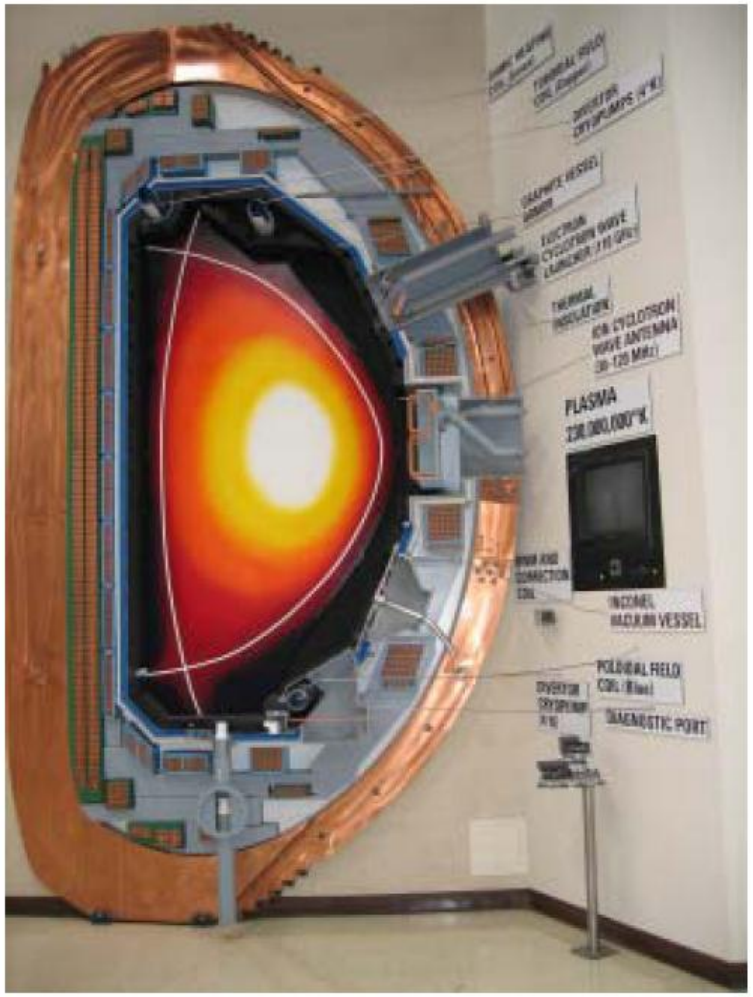
1. Brief introduction of EAST TOKAMAK.
2. Installation procedure of EAST.
3. Establishing control references.
4. Re-measuring the control references.
5. Conclusion

Brief introduction of EAST TOKAMAK

TOKAMAK is the controlled nuclear fusion experiment device. EAST is based on the 'tokamak' concept of magnetic confinement, in which the plasma is contained in a doughnut-shaped vacuum vessel. The fuel—a mixture of deuterium and tritium, two isotopes of hydrogen—is heated to temperatures in excess of 100 million℃, forming a hot plasma. Strong magnetic fields are used to keep the plasma away from the walls.



Limiter mode—early mode



Divertor mode—current mode

EAST—Experimental Advanced Superconducting Tokamak

It was constructed by Institute of Plasma Physics, Chinese Academy Science in 2005. IMP was in charge of the design the method of alignment, establishing and re-measuring the installation control reference for EAST assembling.

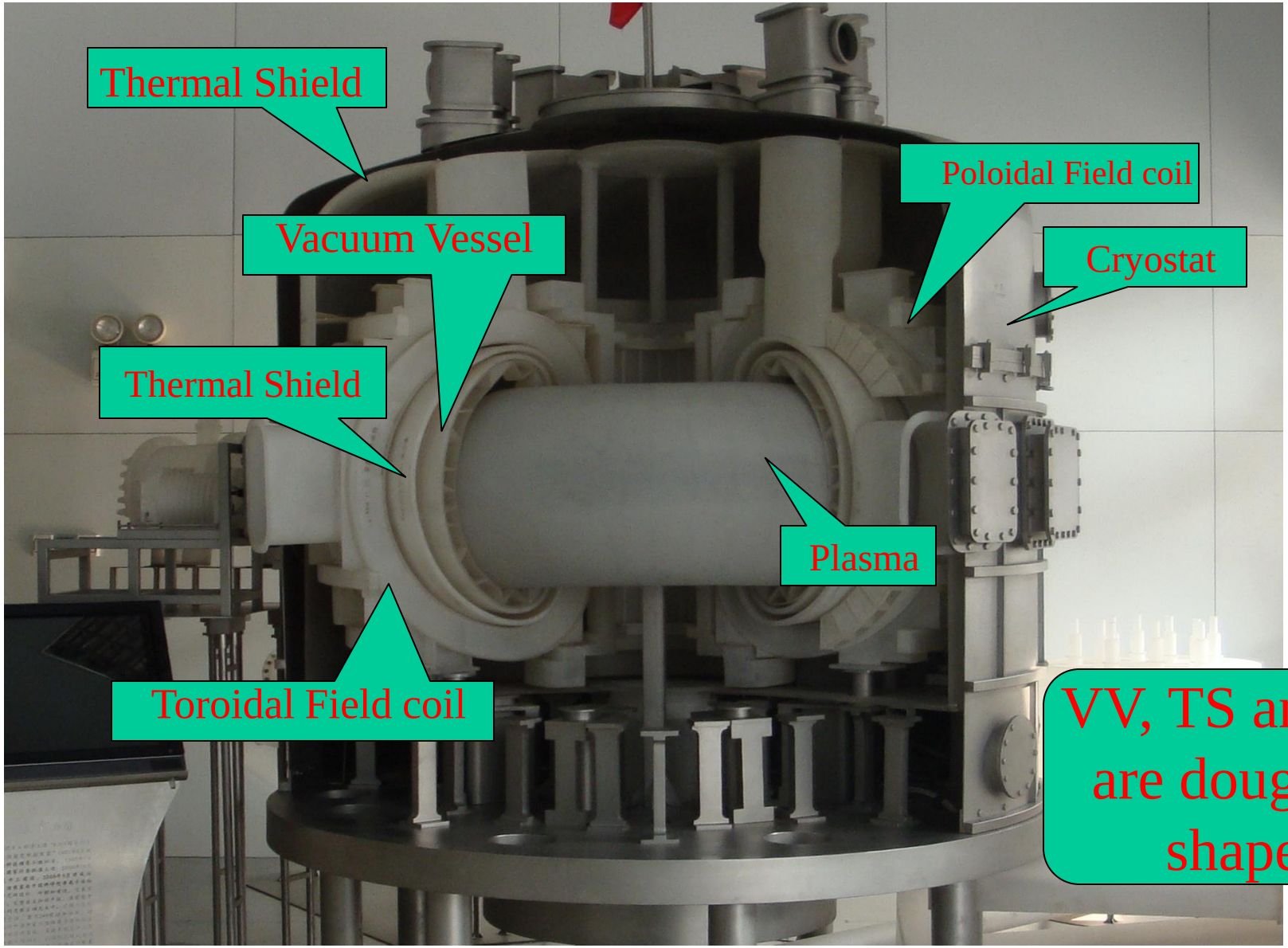
Features :

First fully supercon
-ducting TOKAMAK;
consists of 16 TF coils
(BT=3.5T);
14 PF coils($\Delta\Phi \geq 10$ VS).

Design goal:

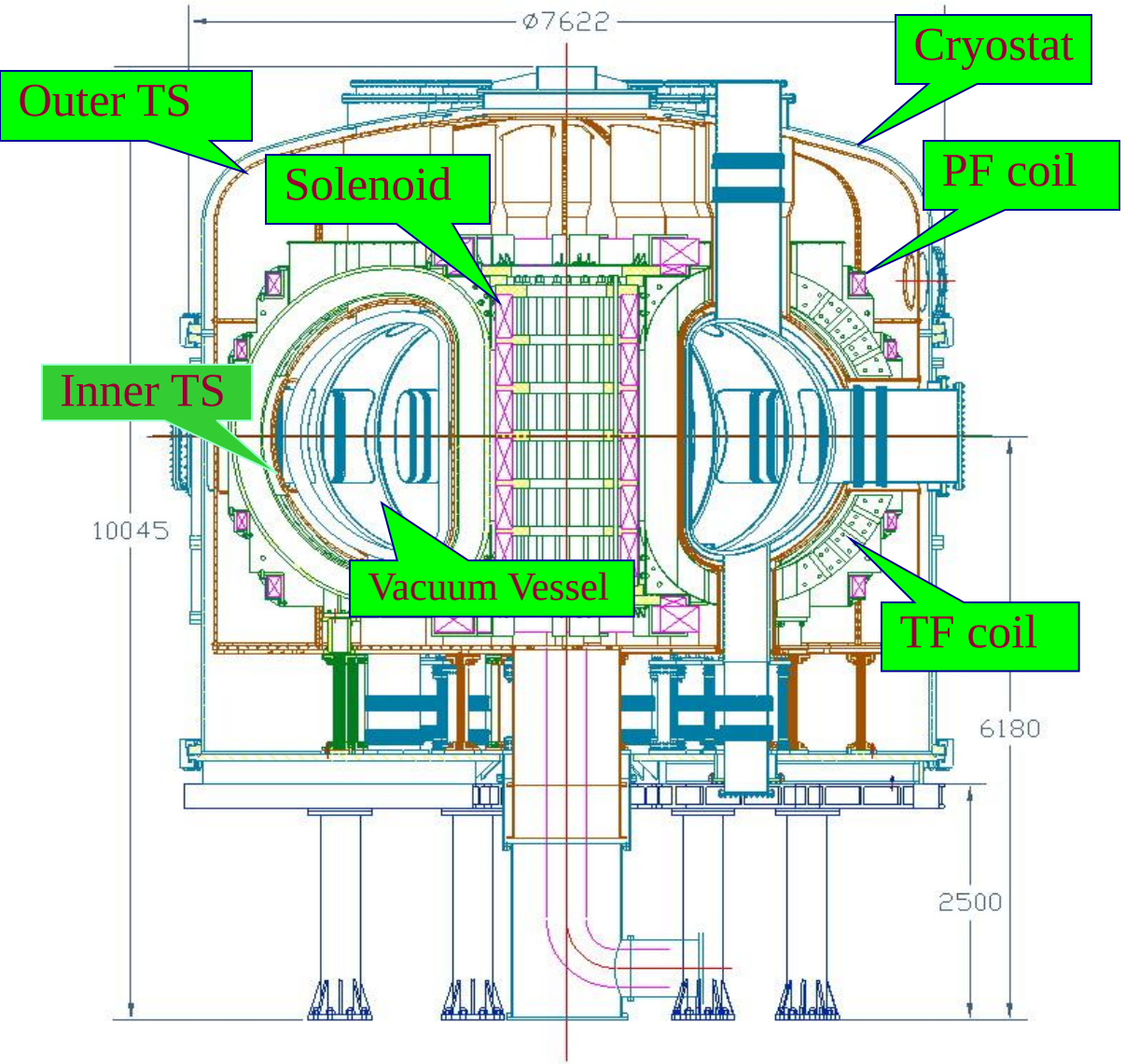
Produce ≥1 MA plasma current ,1000s of plasma duration and 100M ℃ of plasma temperature.

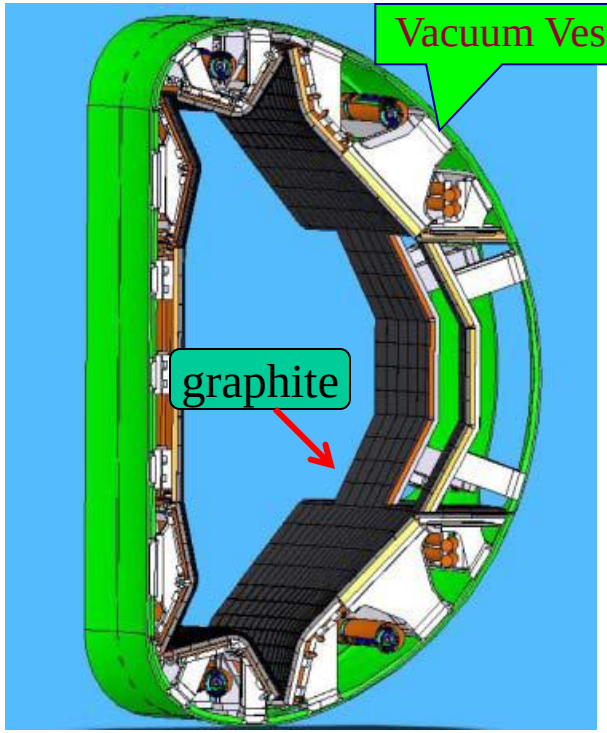
5 key components: Poloidal Field coils; Toroidal Field coils; Vacuum Vessel; Thermal radiation Shield; Cryostad Vessel



Assembly tolerance:

height ±0.5mm; verticality ±0.5mm; coaxiality±0.5mm; horizontal relative position±1.0mm; horizontal angle ±36″





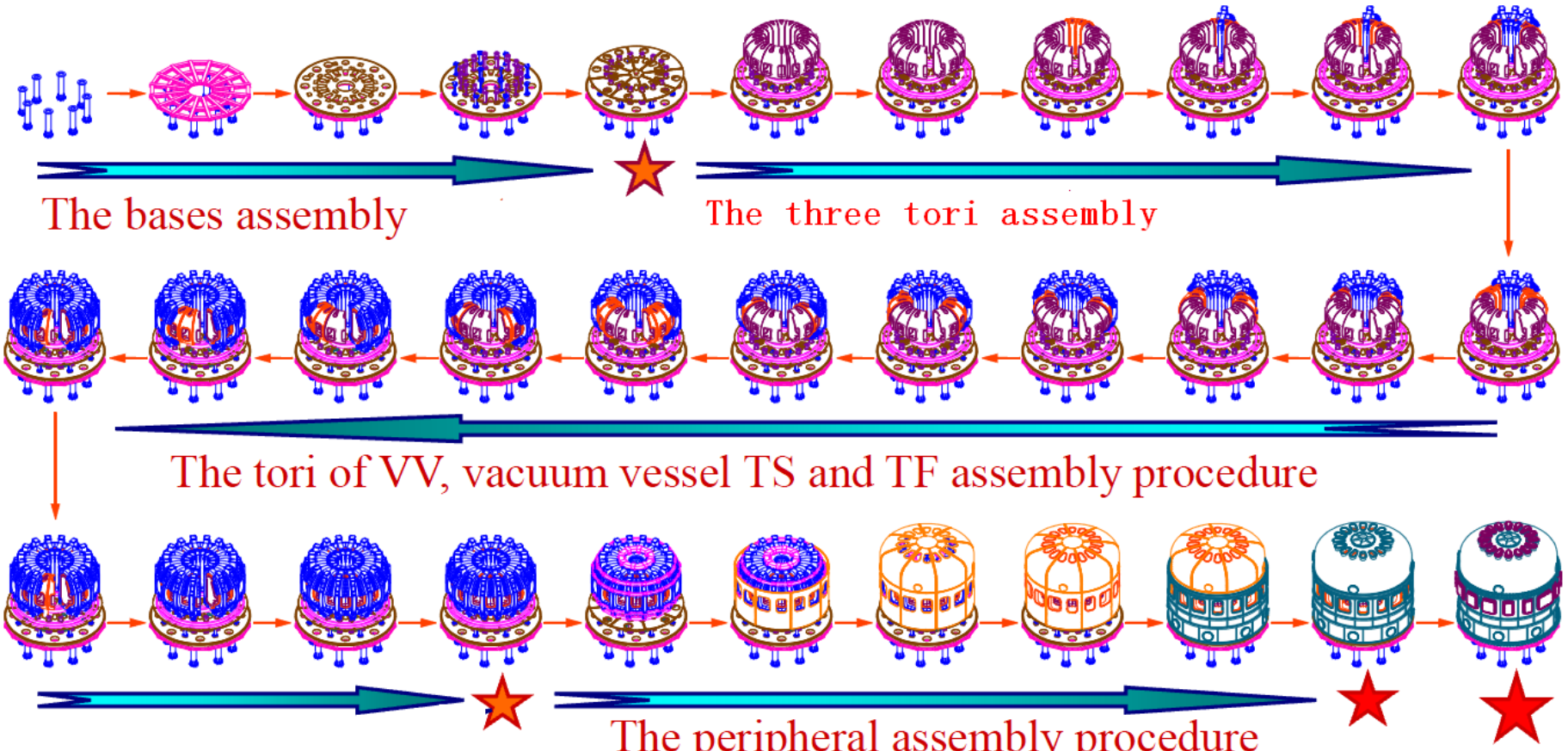
In-vessel components

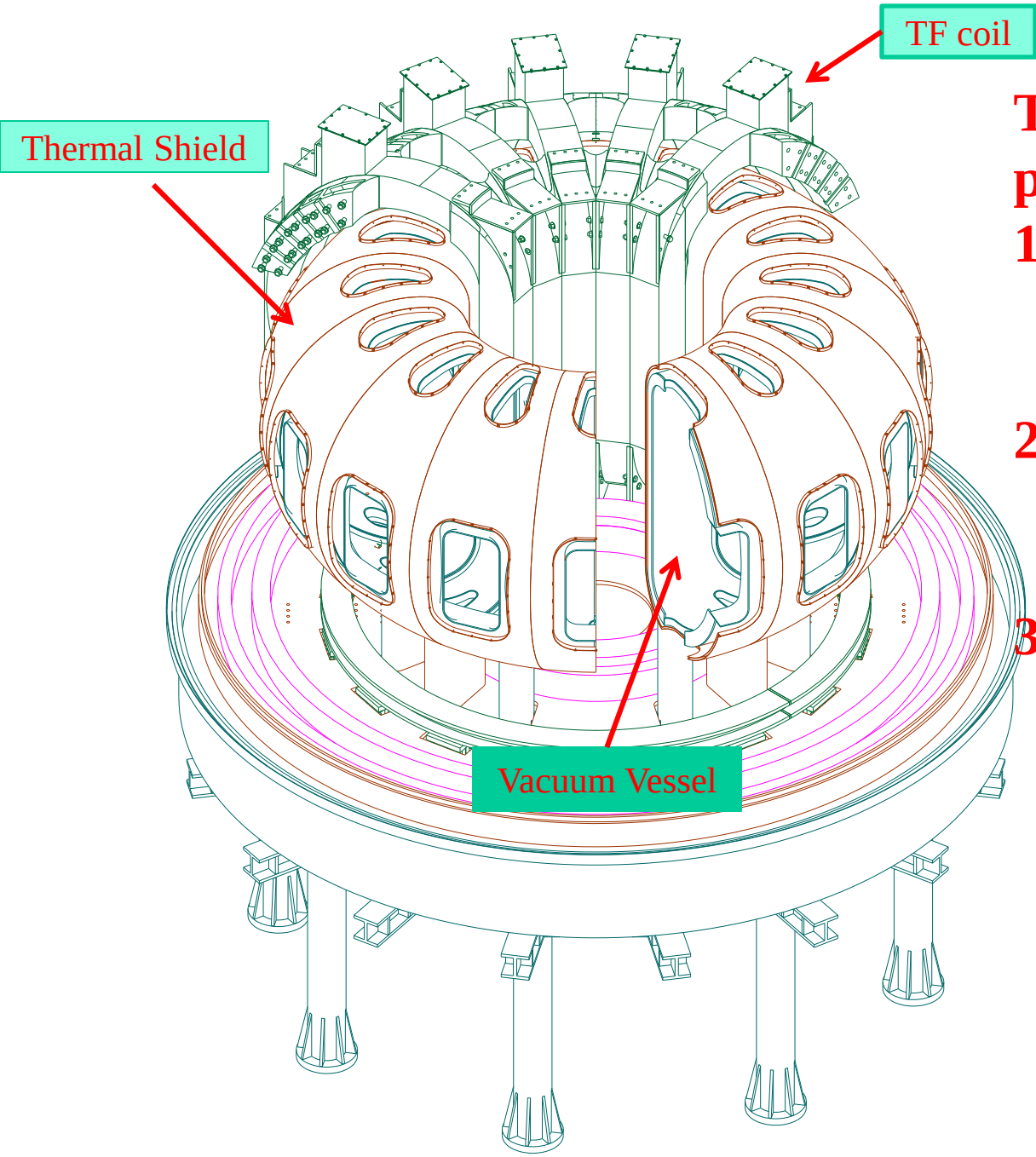
Total Height： 10m

Diameter： 7.6m

Total Weight： 360T

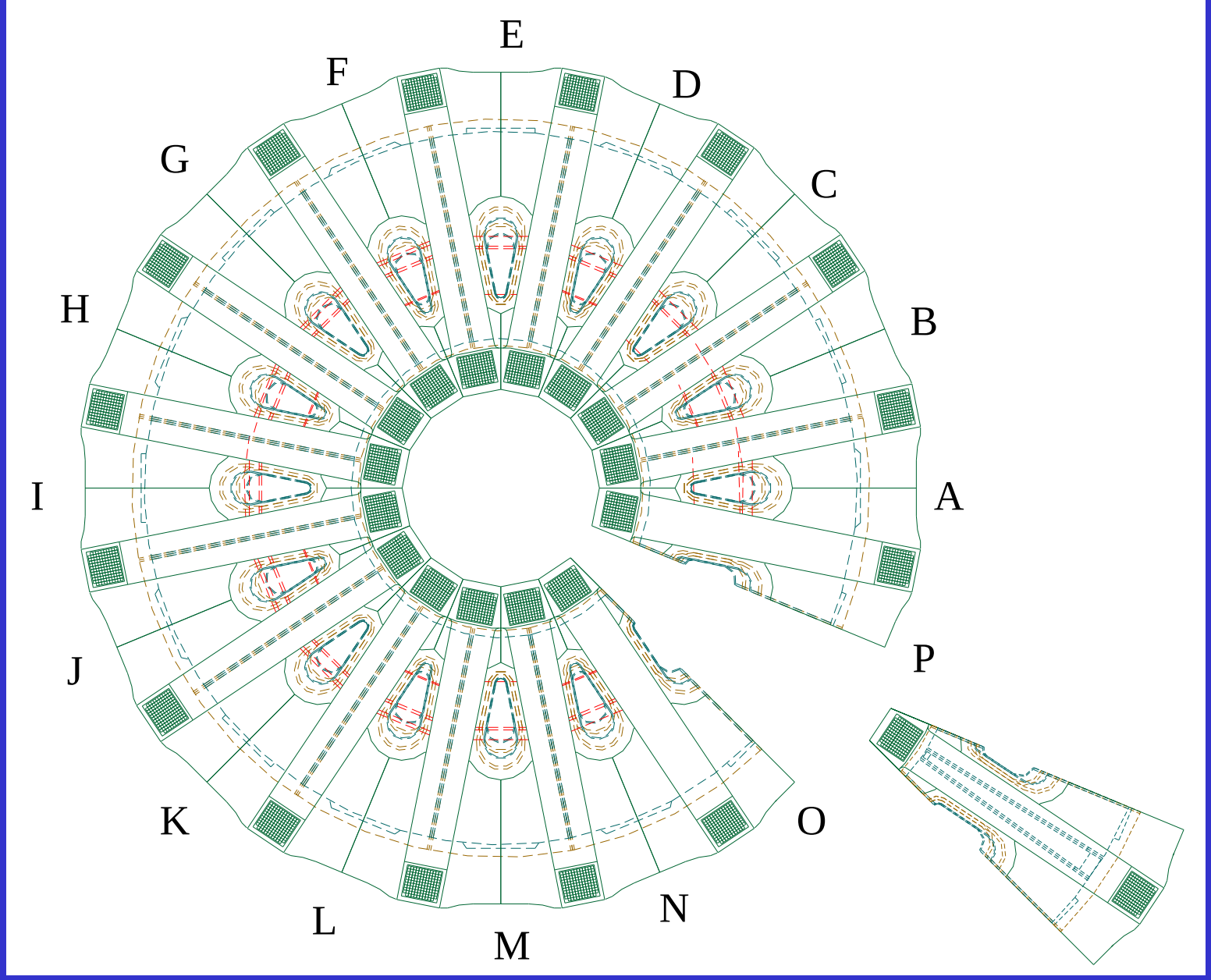
Installation Procedure





Three tori assembly procedure:

1. **15 segments of VV were assembled to C shape and welded.**
2. **15 segments of TS were assembled to C shape and welded.**
3. **15 segments of TF were assembled.**

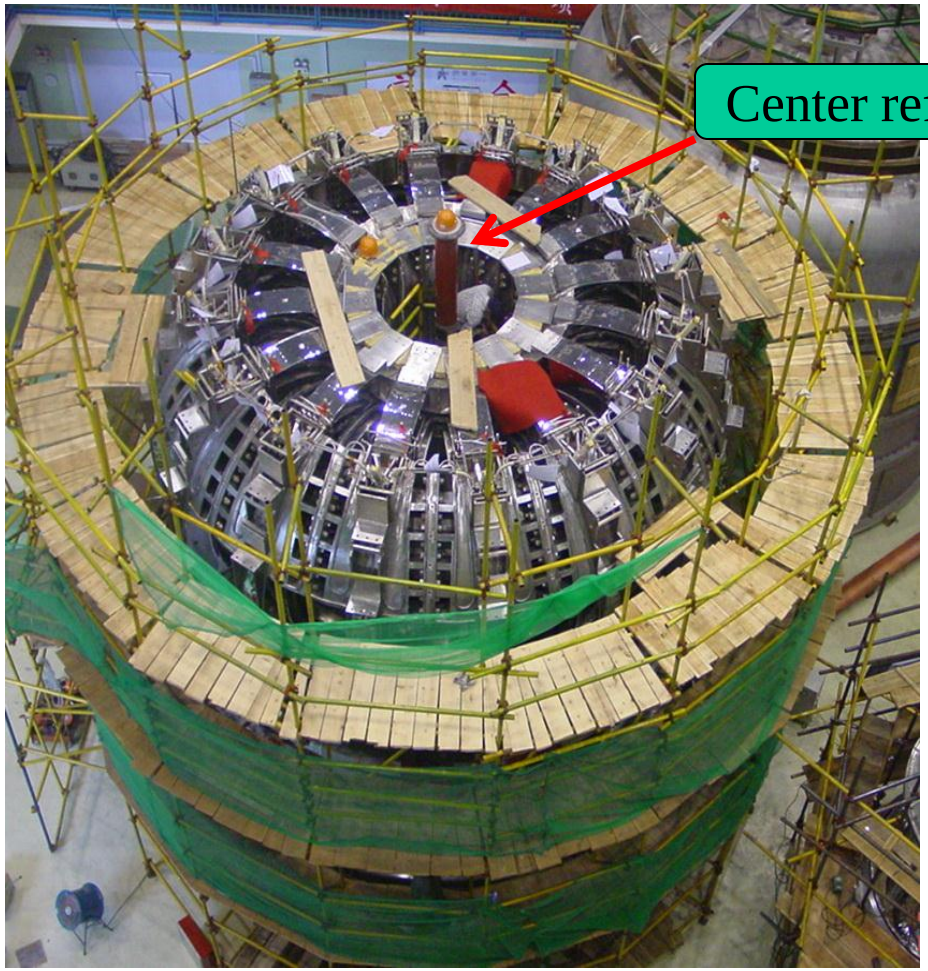


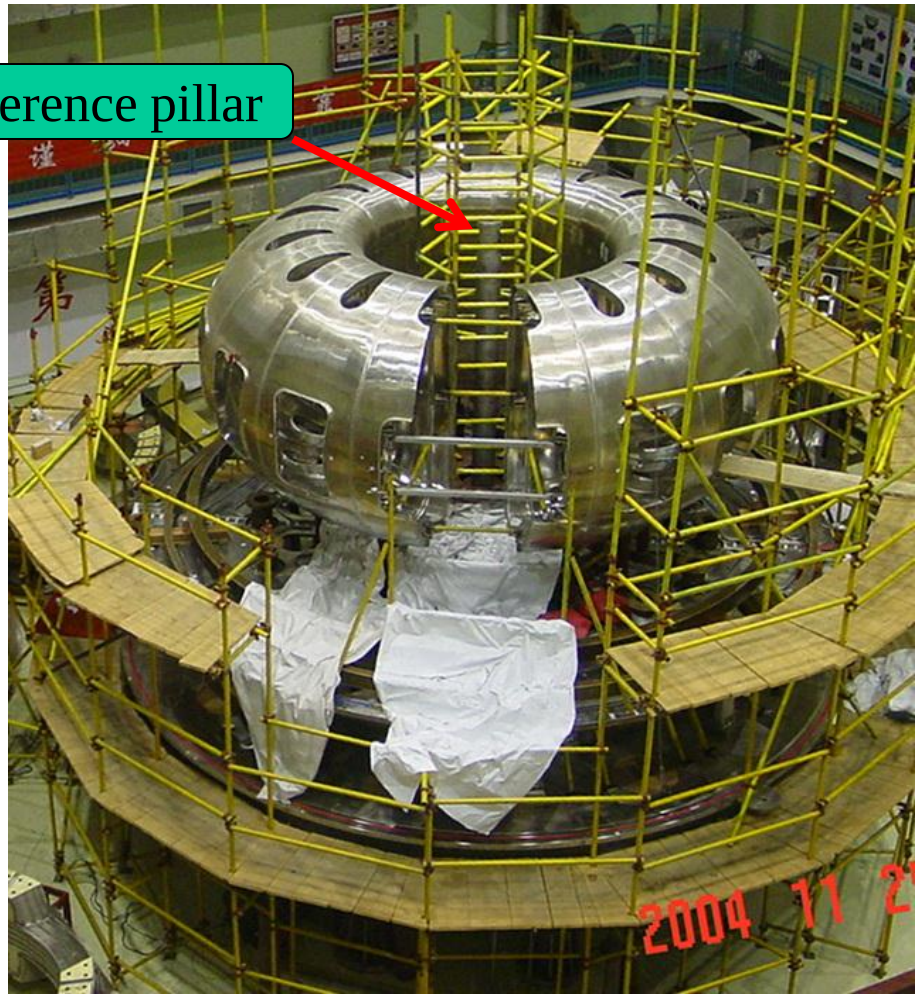
4. Put the last segment of VV, TS and TF together to form a component

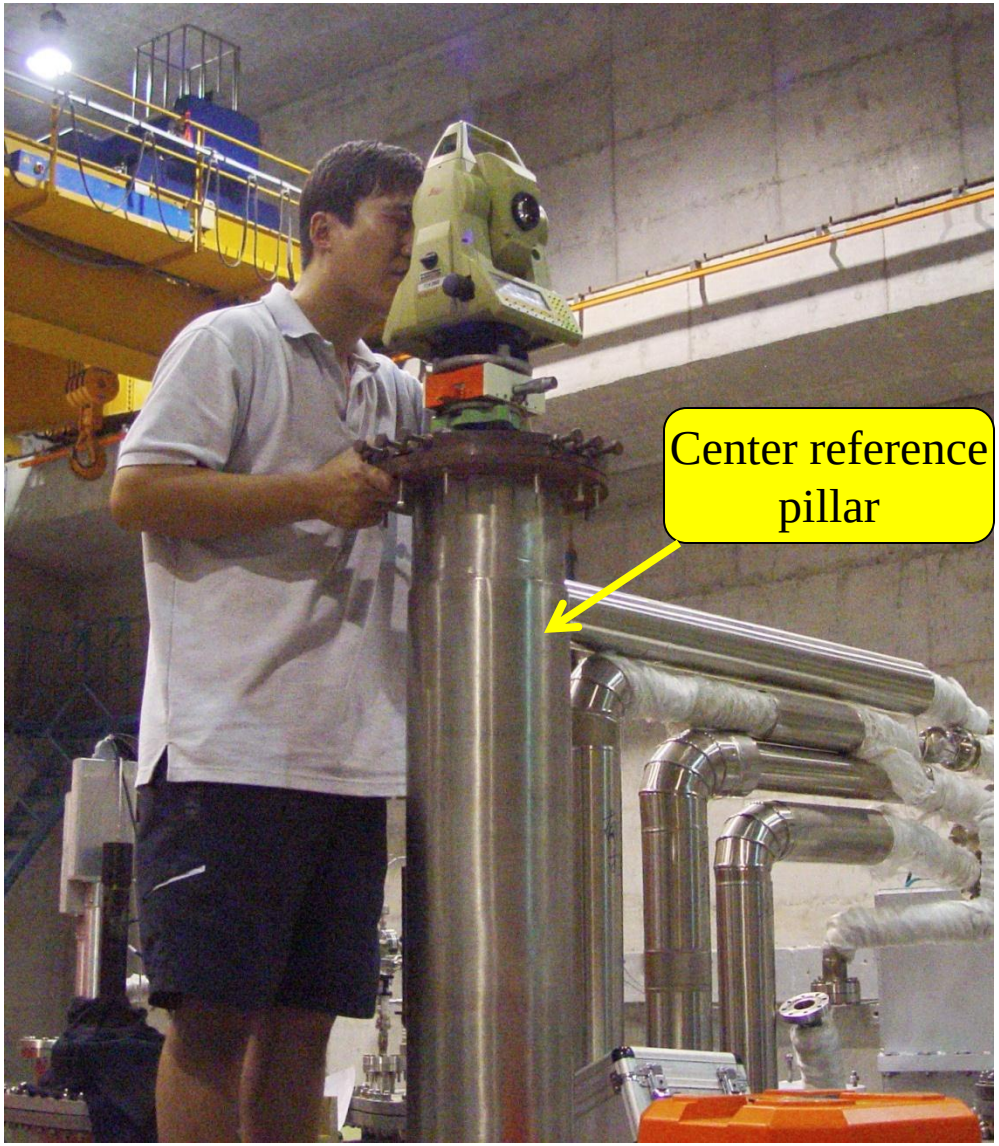
5. Insert the component into the gap.

Center reference pillar

1. To provide the platform for TCA2003 or TC402 total station to measure the angles of each segments of torus.
2. To controlling the radial dimension and coaxiality of three tori as a measuring reference.

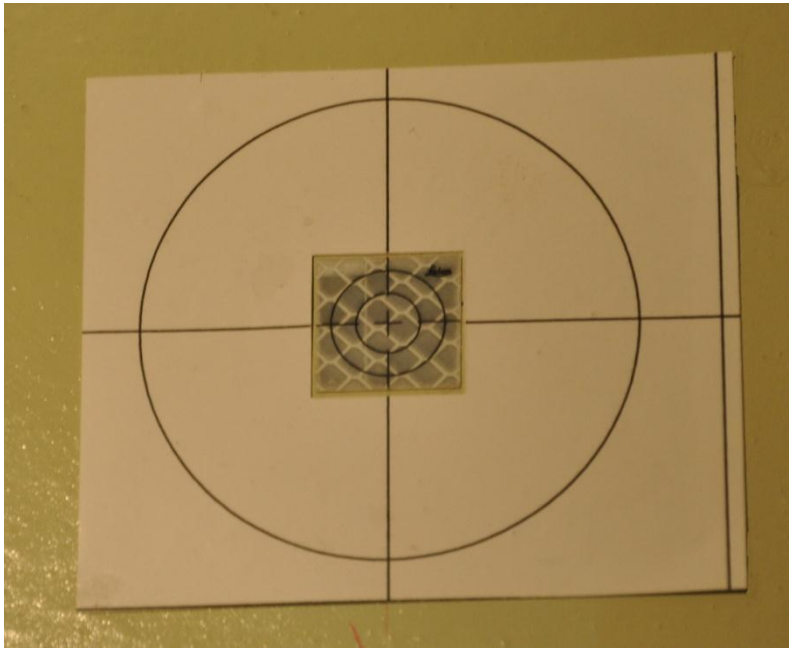






Aiming the targets on wall.

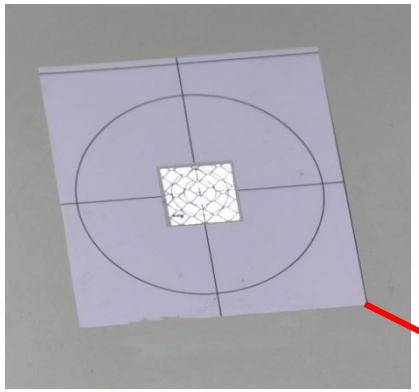
Orientation reference point



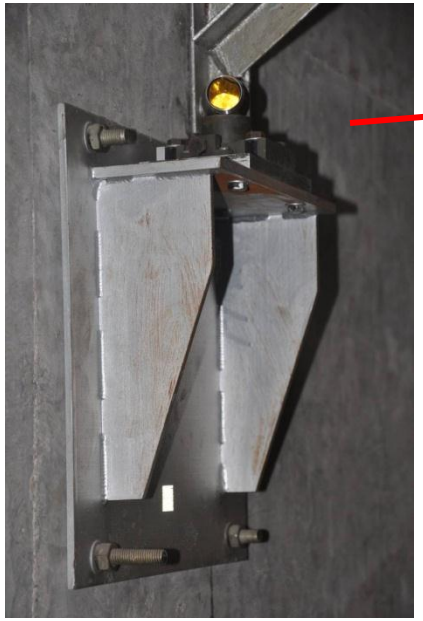
Angle reference point

Establish assembly control reference points

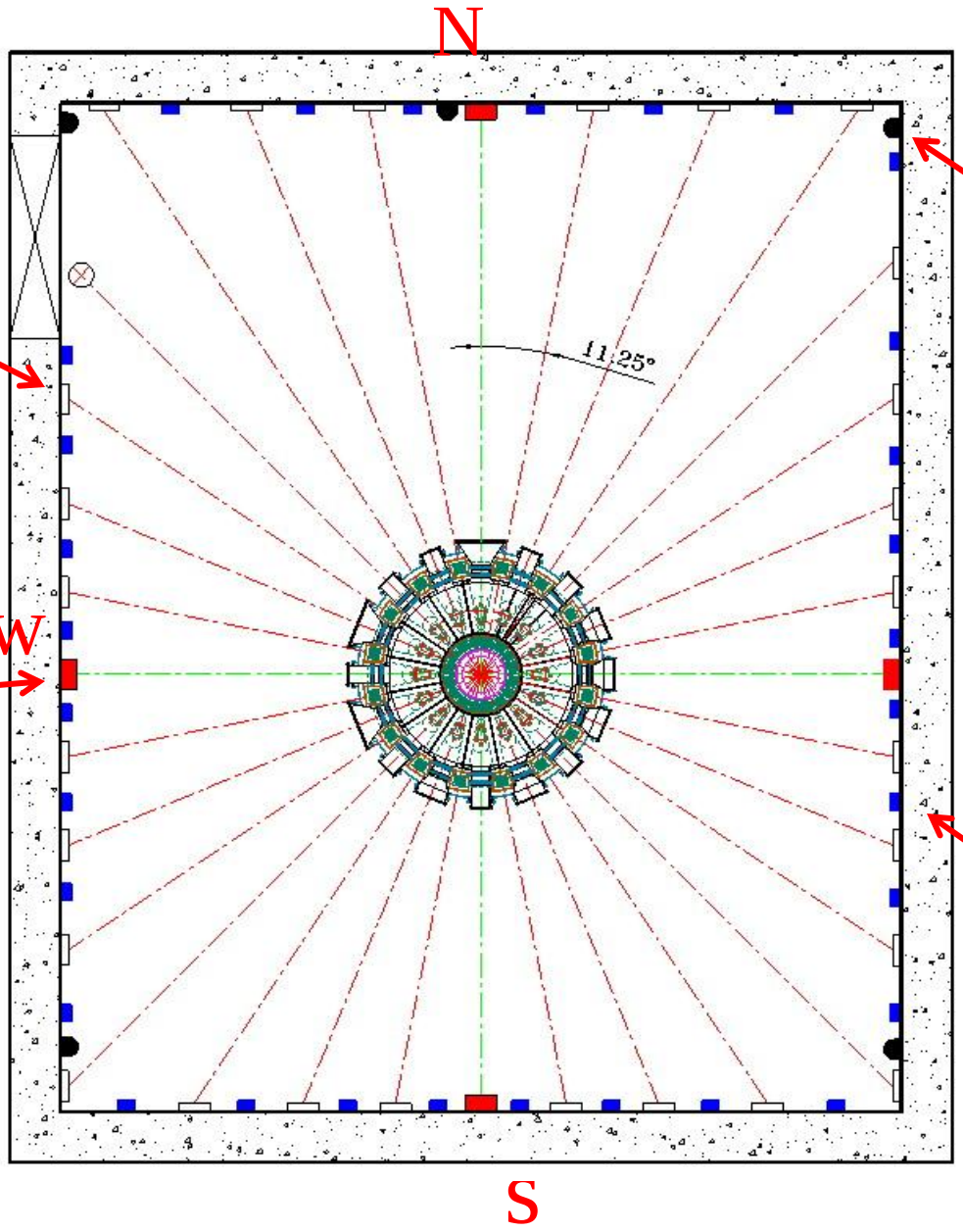
1. Distribution of control reference points
2. The instrumentation
3. Survey method and the result



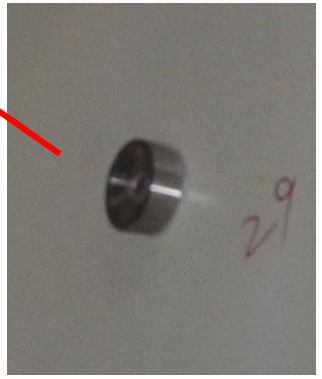
32 angle reference points



4 orientation control references



10 elevation references



31nests

Distribution of control reference points

Instrumentation:

- a. Leica TCA2003 total station.
- b. Leica DNA03 leveling
- c. Leica Wild Optical Plummets 1/200,000

- Accessory:
- Leica CCR1.5” SMR
- Zielmarken 20×20mm reflective sheet
- K&E CUBIC PRECISION measuring stand

Measuring method and accuracy analysis

1. For 4 orientation control points:

   Method: 6 observation sets of direction observation in rounds

   Accuracy analysis: (from Leica TPA1000 user's manual)

$$m_R = \sqrt{\frac{\sum v^2}{(N-1)(S-1)}} = \sqrt{\frac{28.84}{(4-1)(6-1)}} \quad m_R = 1.4''$$

- $m_M = m_R/\sqrt{S} = \pm 1.4''/\sqrt{6} = \pm 0.6''$
- $\boldsymbol{m_R}$ _Standard deviation of a single direction in both faces.
- $\boldsymbol{m_M}$—Standard deviation for an averaged direction from all sets.
- *v*—Correction number
- N—Target number
- S—Number of the observation set

Measuring method and accuracy analysis

2. For 32 angles direction control points:

   Method: 6 observation sets of direction observation in rounds

   Accuracy analysis:

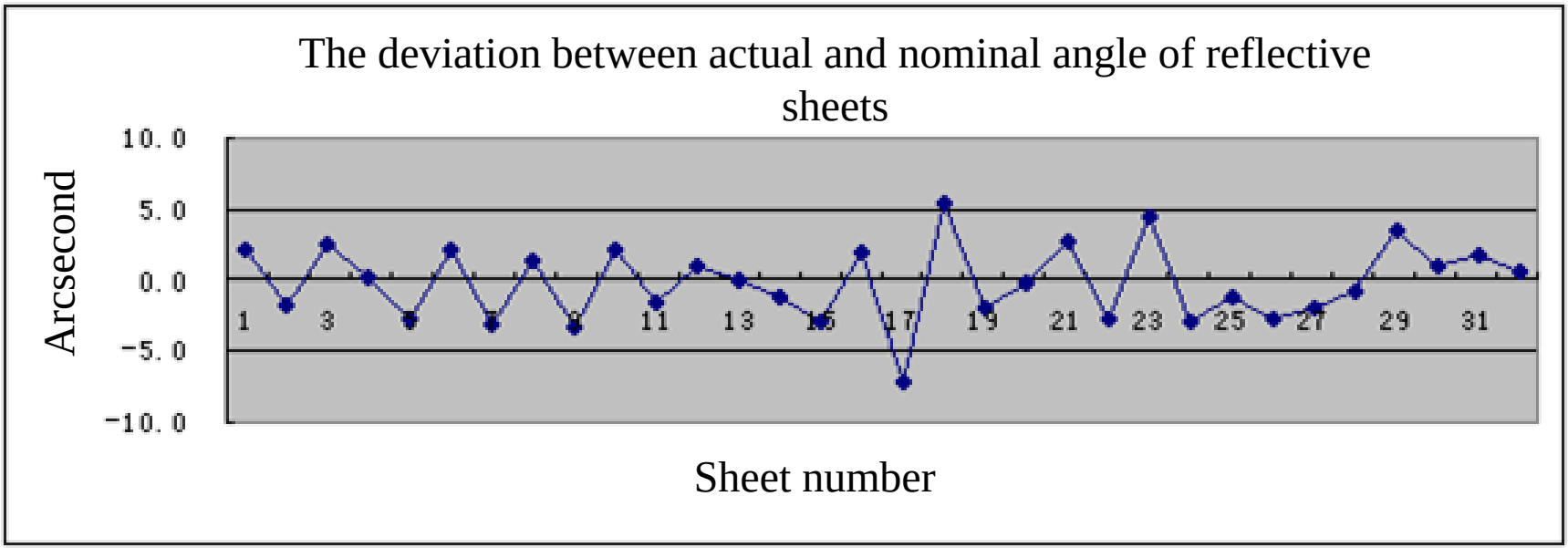
$$m_R = \sqrt{\frac{\sum v^2}{(\mathrm{N}-1)(\mathrm{S}-1)}} = \sqrt{\frac{243.24}{(32-1)(3-1)}} = \pm 2.0''$$

$$m_M = m_R/\sqrt{S} = 2.0''/\sqrt{3} = \pm 1.2''$$

- $\boldsymbol{m_R}$ _Standard deviation of a single direction in both faces.
- $\boldsymbol{m_M}$—Standard deviation for an averaged direction from all sets.
- v—Correction number
- N—Target number
- S—Number of the observation set

Measuring results

1. Angle deviation of the 32 angle control points:



2. Height errors of the elevation reference:

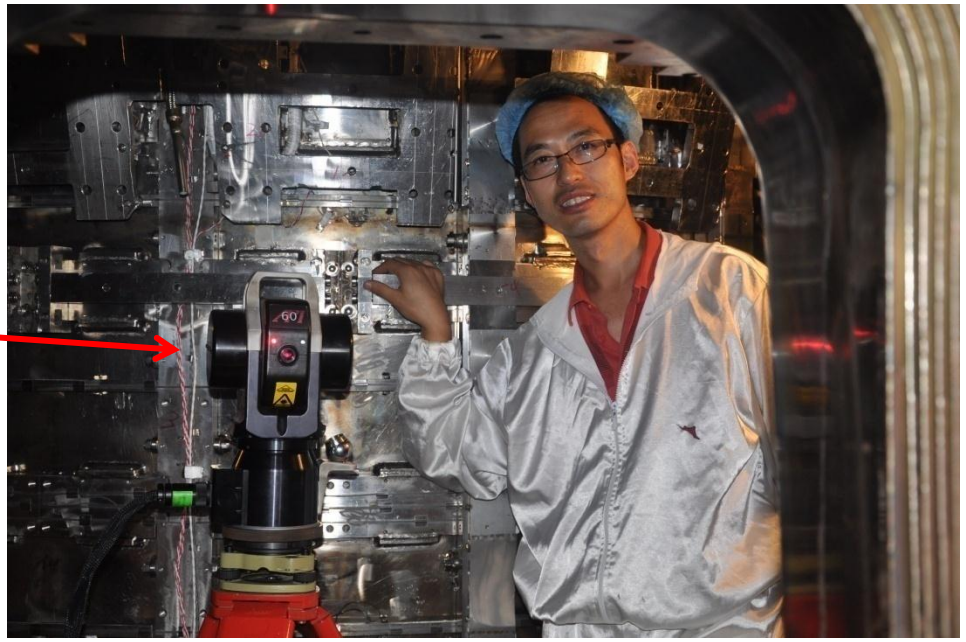
The closure error is ±0.05mm with 10 elevation reference points, after 2 sets of closed traverse leveling.

Re-measuring Installation Control References in 2011

- EAST assembly control references was established in 2003.
- EAST finished the installation work in 2005.
- First success discharge test finished on Sep. 2006.
- It passed the final acceptance by NDRC(National Development and Reform Committee) in 2007.
- Many yeas passed, the control references need to be re-measured and increase some control points, because they need the control references to replace in-vessel components every year.

Instrumentation and Software

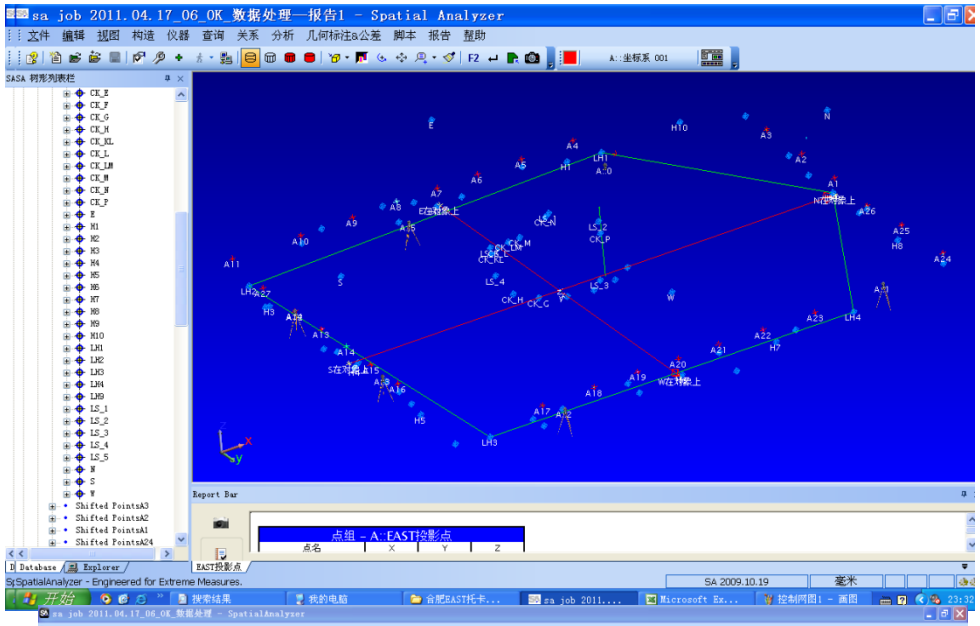
1） API T3 laser tracker

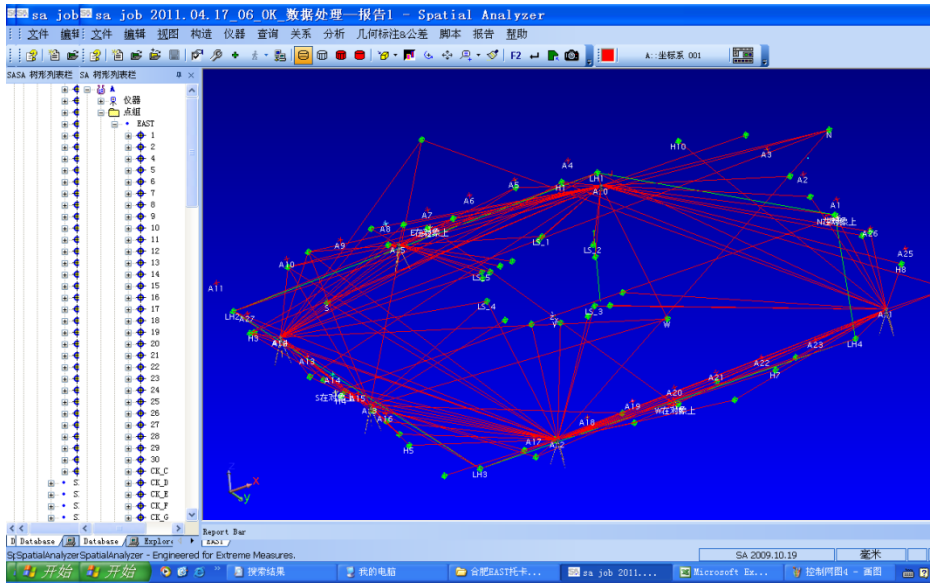


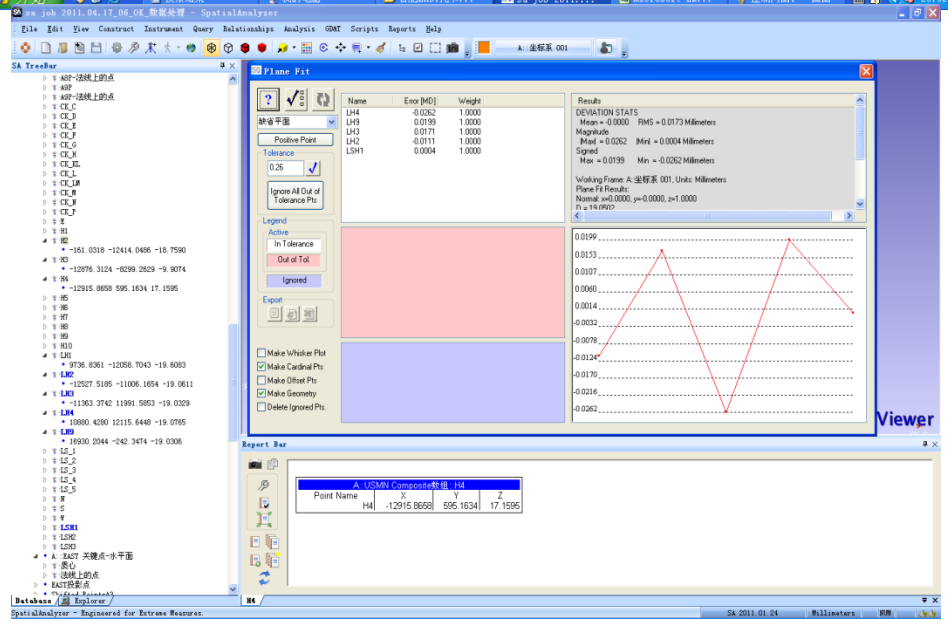
T3 tracker in vacuum vessel

2） Leica DNA03 leveling

3）SA--- Spatial Analyzer







2011年4月合肥EAST托卡马克超导装置分度点测量结果（柱坐标）

No.	R(mm)	Angle(deg)	Angle(deg)	Z(mm)	Norminal(deg)	角度偏差(deg)	角度偏差(sec)	分度序号
A1	16986.1605	0.0002	0.0002	953.6936	0	0.0002	0.72	32
A2	17324.7816	-11.251	348.749	1007.4302	348.75	-0.001	-3.6	31
A3	18407.8427	-22.4998	337.5002	952.2709	337.5	0.0002	0.72	30
A4	14982.9693	-56.2495	303.7505	1019.2471	303.75	0.0005	1.8	27
A5	13491.0925	-67.502	292.498	972.0644	292.5	-0.002	-7.2	26
A6	12710.8766	-78.7499	281.2501	980.2629	281.25	1E-04	0.36	25
A7	12482.4185	-90.0013	269.9987	971.635	270	-0.0013	-4.68	24
A8	12737.5834	-101.2509	258.7491	1018.6411	258.75	-0.0009	-3.24	23
A9	13529.7193	-112.5007	247.4993	979.8093	247.5	-0.0007	-2.52	22
A10	15046.5414	-123.7514	236.2486	961.7744	236.25	-0.0014	-5.04	21
A11	17725.9055	-135.0005	224.9995	985.323	225	-0.0005	-1.8	20
A12	14027.36	-157.5007	202.4993	924.0482	202.5	-0.0007	-2.52	18
A13	13227.8656	-168.7514	191.2486	1005.8381	191.25	-0.0014	-5.04	17
A14	12982.7057	179.997	179.9966	1027.5136	180	-0.0034	-10.8	16
A15	13253.7025	168.7505	168.7528	1022.328	168.75	0.0028	1.8	15
A16	14078.4205	157.4982	157.4982	1018.4162	157.5	-0.0018	-6.48	14
A17	14990.9367	123.7482	123.7482	1033.0445	123.75	-0.0018	-6.48	11
A18	13505.8698	112.4991	112.4991	1051.7137	112.5	-0.0009	-3.24	10
A19	12729.5711	101.2473	101.2469	1066.8222	101.25	-0.0031	-9.72	9
A20	12492.3512	90.0006	90.0006	1023.4312	90	0.0006	2.16	8
A21	12745.0316	78.7503	78.7503	1062.6104	78.75	0.0003	1.08	7
A22	13537.6814	67.501	67.501	997.4716	67.5	0.001	3.6	6

Sheet1 Sheet2 Sheet3 Sheet4 Sheet5

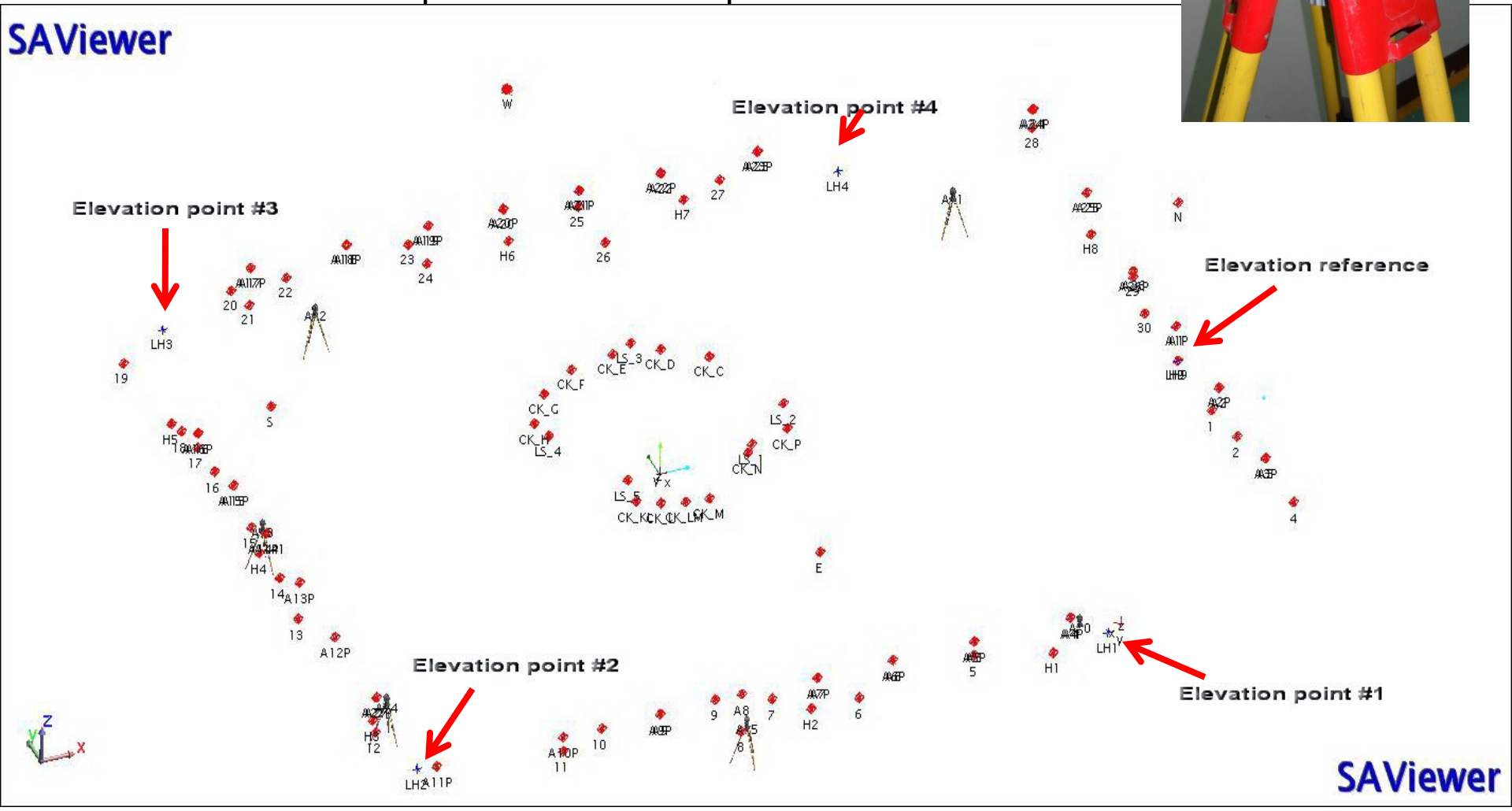
MEASURING METHOD

1) To create horizontal reference plane of the machine using DNA03 leveling for establish the coordinate
2) To measure all reference points and collect dada using T3 laser tracker.
3）Dada processing using SA
4） Giving measuring report

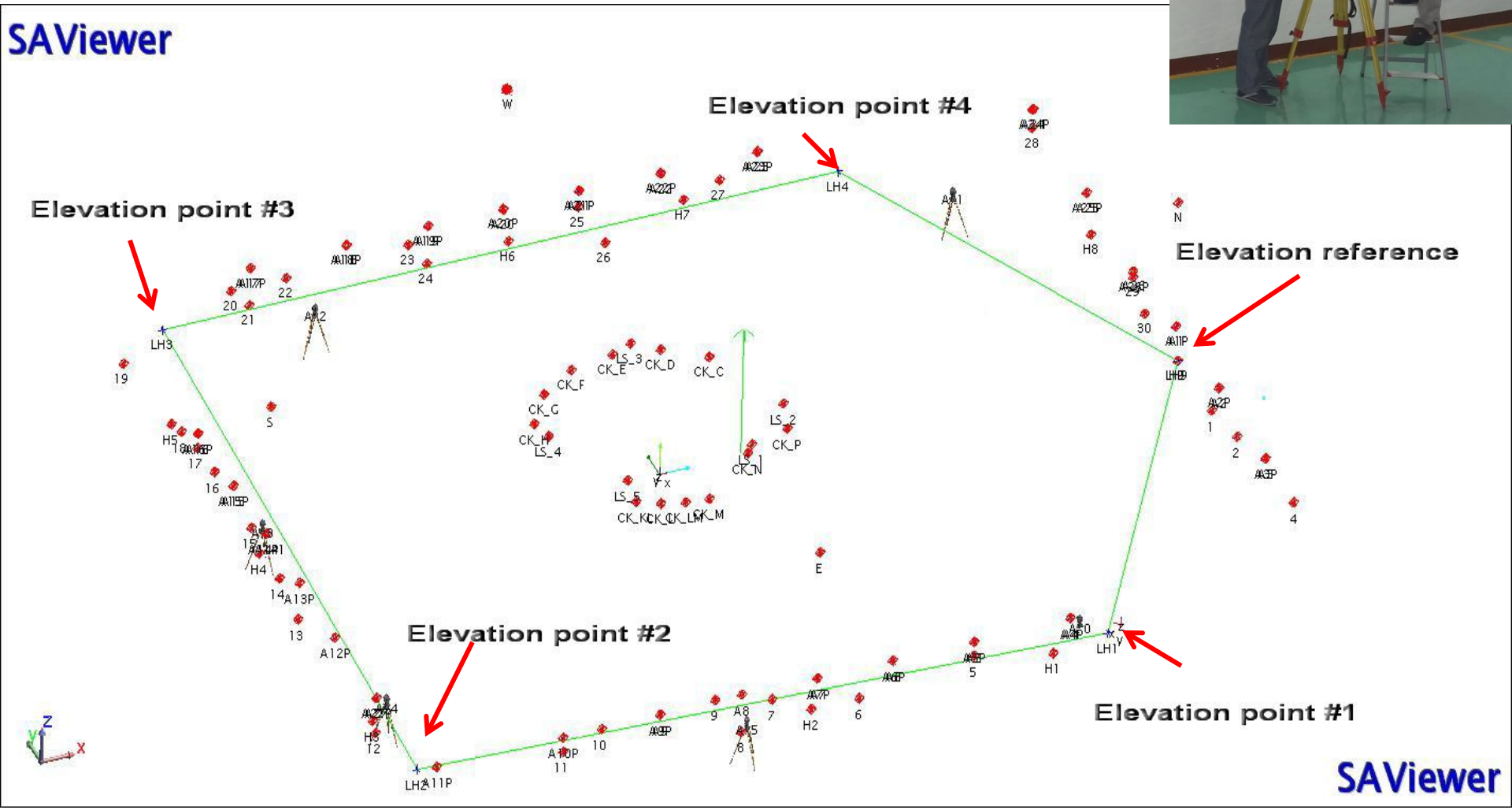
Method:

Creating horizontal reference plane

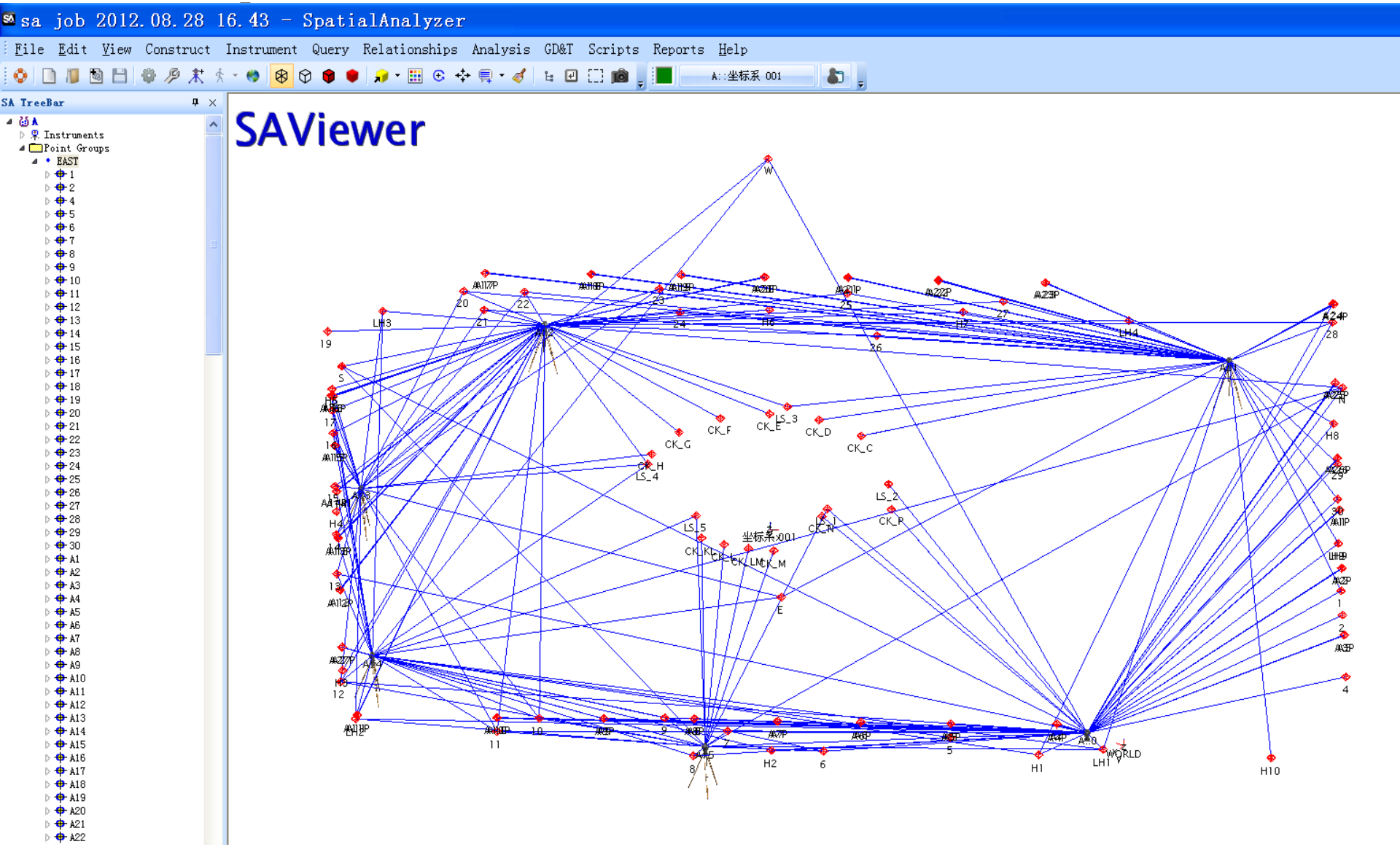
1. Place 4 height adjustable elevation points around the machine, together with the elevation reference point on north wall composed 5 elevation points.



2. Measure and adjust the 4 elevation points using DNA03 leveling, make sure the 5 control points have a same elevation. The closure error is controlled no more than 0.05mm after 2 observation sets .

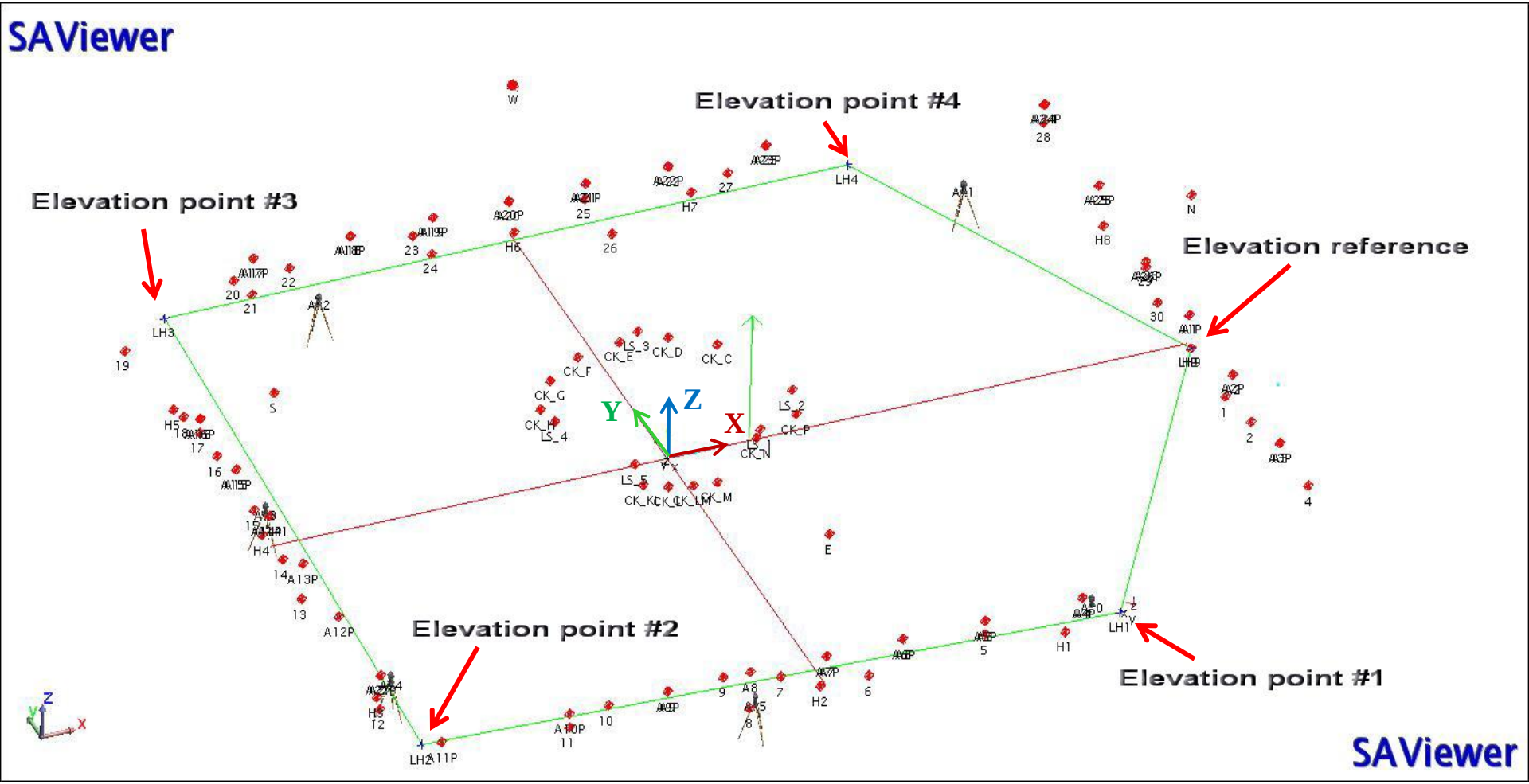


Data collection of all points using laser

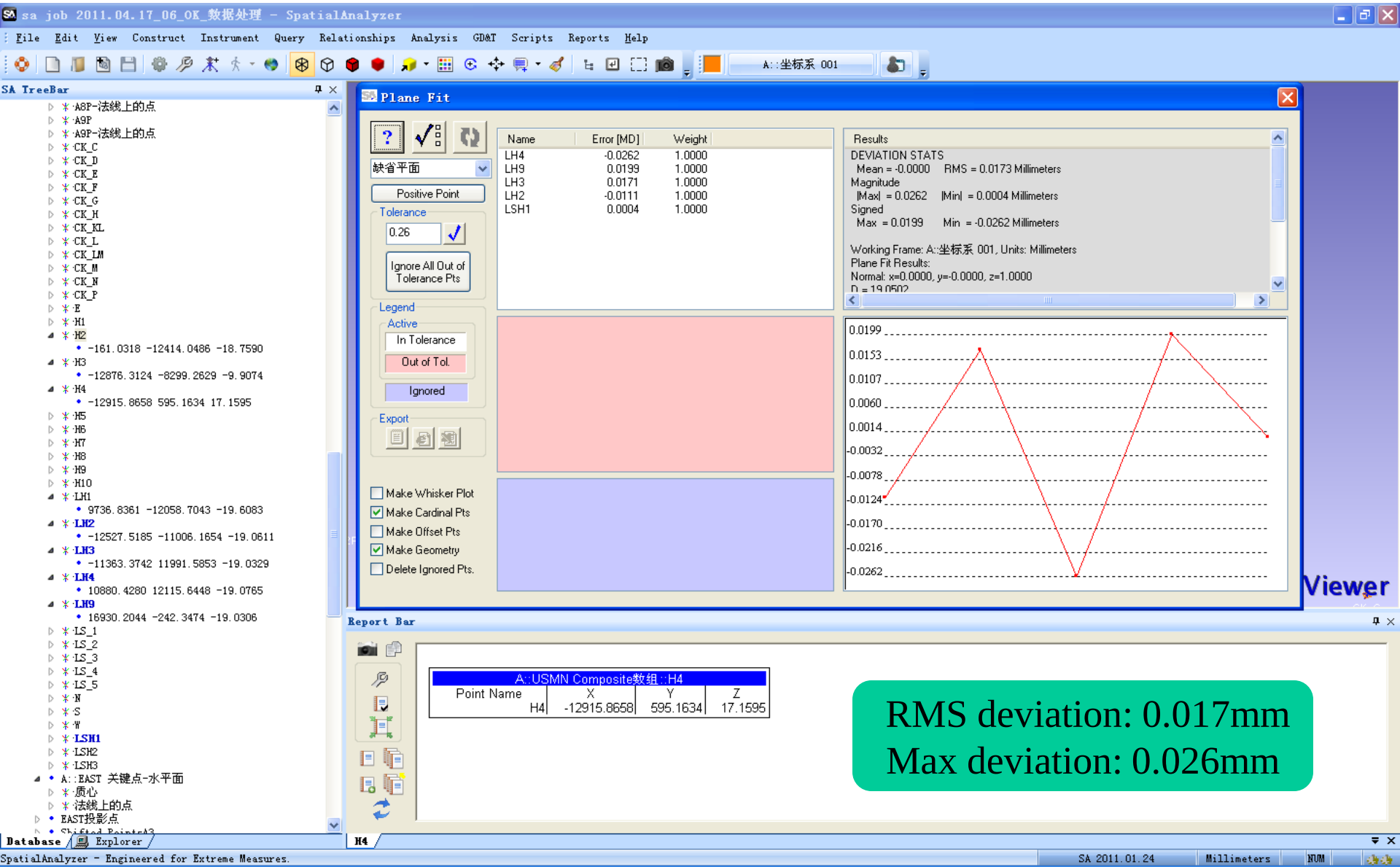


T3 laser tracker, 6 stations, 92 measured points.

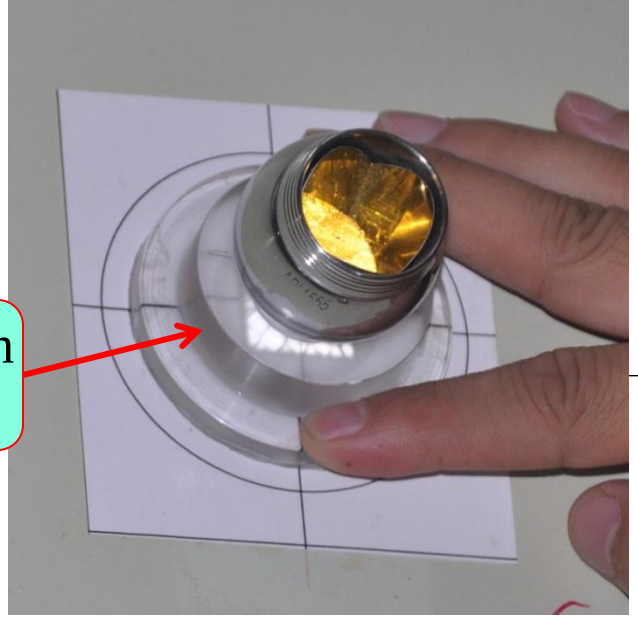
ESTABLISH COORDINATE FRAME: Using the 5 elevation points to fit a plane, the 4 orientation control points(ESWN) project to the plane and create two line, the point of intersection of two lines is the origin of coordinate frame, the normal of plane defines Z direction, the N direction defines X direction.



Result of best- fitted a plane with 5 elevation points



Data Treatment: using SA's Shift Point in Direction function to get the datum of reflective sheet.



Transparent nest with Cross-hair reticle

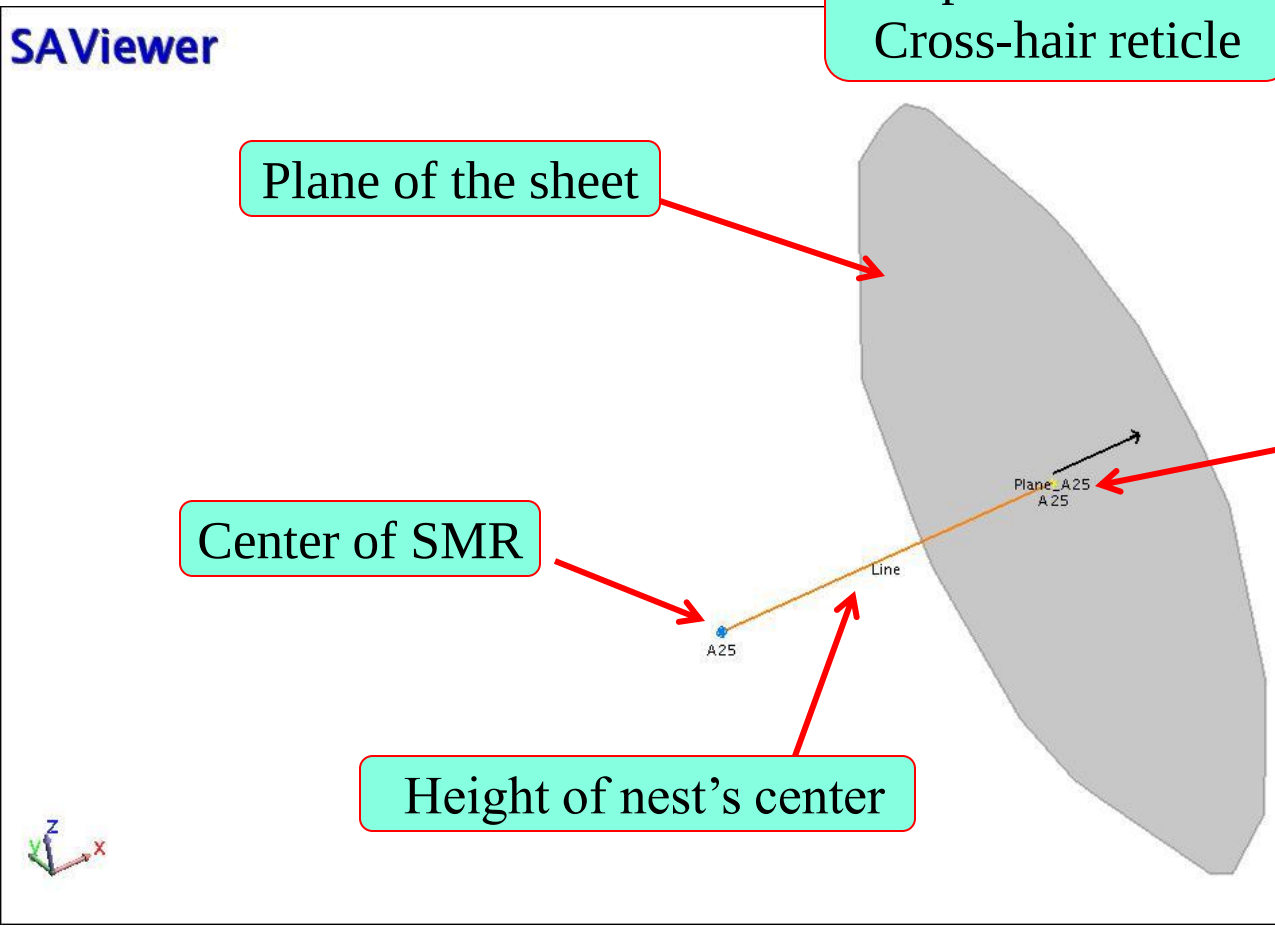
SAViewer

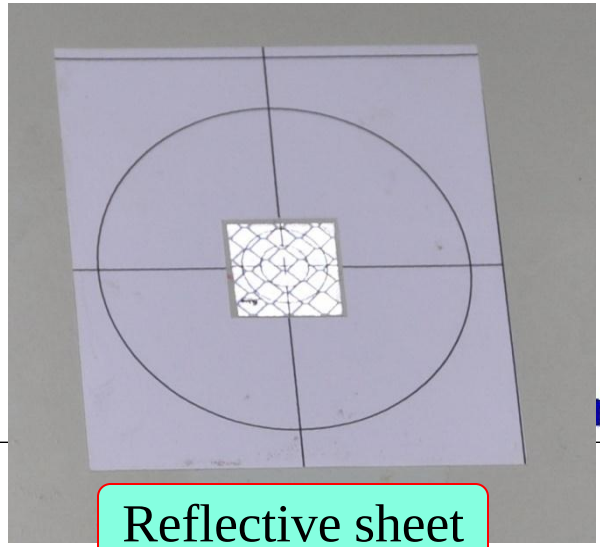
Plane of the sheet

Center of reflective sheet

Center of SMR

Height of nest's center





Reflective sheet

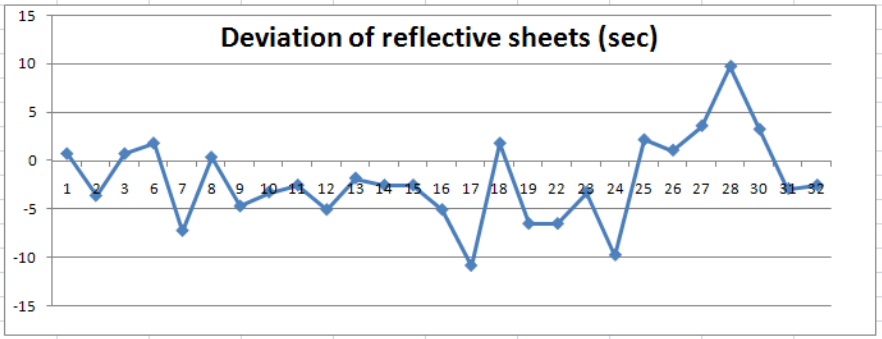
Adjust and measure the elevation point

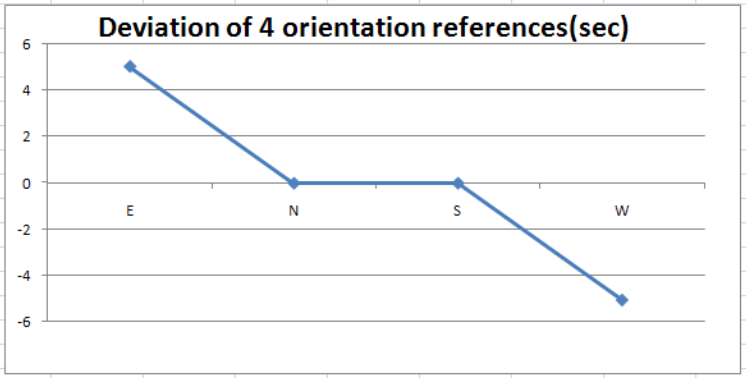
Adjust the reference in VV

Measuring results of angle control reference points

measuring results of reflective sheets of EAST, April 2011

No.	R(mm)	Angle(deg)	Z(mm)	Norminal(deg)	Arror(deg)	Arror(sec)	Sheet No.
A1	16986.16	0.0002	953.6936	0	0.0002	0.72	1
A2	17324.78	348.749	1007.43	348.75	-0.001	-3.6	2
A3	18407.84	337.5002	952.2709	337.5	0.0002	0.72	3
A4	14982.97	303.7505	1019.247	303.75	0.0005	1.8	6
A5	13491.09	292.498	972.0644	292.5	-0.002	-7.2	7
A6	12710.88	281.2501	980.2629	281.25	1E-04	0.36	8
A7	12482.42	269.9987	971.635	270	-0.0013	-4.68	9
A8	12737.58	258.7491	1018.641	258.75	-0.0009	-3.24	10
A9	13529.72	247.4993	979.8093	247.5	-0.0007	-2.52	11
A10	15046.54	236.2486	961.7744	236.25	-0.0014	-5.04	12
A11	17725.91	224.9995	985.323	225	-0.0005	-1.8	13
A27	15584.21	213.7493	967.4736	213.75	-0.0007	-2.52	14
A12	14027.36	202.4993	924.0482	202.5	-0.0007	-2.52	15
A13	13227.87	191.2486	1005.838	191.25	-0.0014	-5.04	16
A14	12982.71	179.9966	1027.514	180	-0.0034	-10.8	17
A15	13253.7	168.7528	1022.328	168.75	0.0028	1.8	18
A16	14078.42	157.4982	1018.416	157.5	-0.0018	-6.48	19
A17	14990.94	123.7482	1033.045	123.75	-0.0018	-6.48	22
A18	13505.87	112.4991	1051.714	112.5	-0.0009	-3.24	23
A19	12729.57	101.2469	1066.822	101.25	-0.0031	-9.72	24
A20	12492.35	90.0006	1023.431	90	0.0006	2.16	25
A21	12745.03	78.7503	1062.61	78.75	0.0003	1.08	26
A22	13537.68	67.501	997.4716	67.5	0.001	3.6	27
A23	15064.4	56.2527	964.7635	56.25	0.0027	9.72	28
A24	20382.13	33.7509	1115.134	33.75	0.0009	3.24	30
A25	18353.18	22.4992	1027.003	22.5	-0.0008	-2.88	31
A26	17307.75	11.2493	684.1627	11.25	-0.0007	-2.52	32
E	12412.67	270.0014	5057.332	270	0.0014	5.04	E
N	16924.34	0	4994.527	0	0	0	N
S	12905.99	180	5169.046	180	0	0	S
W	12437.32	89.9986	4957.669	90	-0.0014	-5.04	W





The deviation of reflective sheets is large than the initial result, it is du to using laser tracker we must handmade centering the sheets using the transparence nest. The 4 orientation references haven't the problems, so the two results are same.

CONCLUSION

The installation control references of EAST were established in 2003, eight years passed, the references points are measured using laser tracker and the results show us that the deviations of the reference points changed a little, they are all in the acceptable tolerance. That tests and verifies the accuracy of installation control references established in 2003, and also verifies that the foundation of machine hall is very stable.

EAST 2012 Experimental Campaign Highlights

Significant progress has been made on EAST during this new experimental campaign on many physics and technology fronts, with the following key advances:

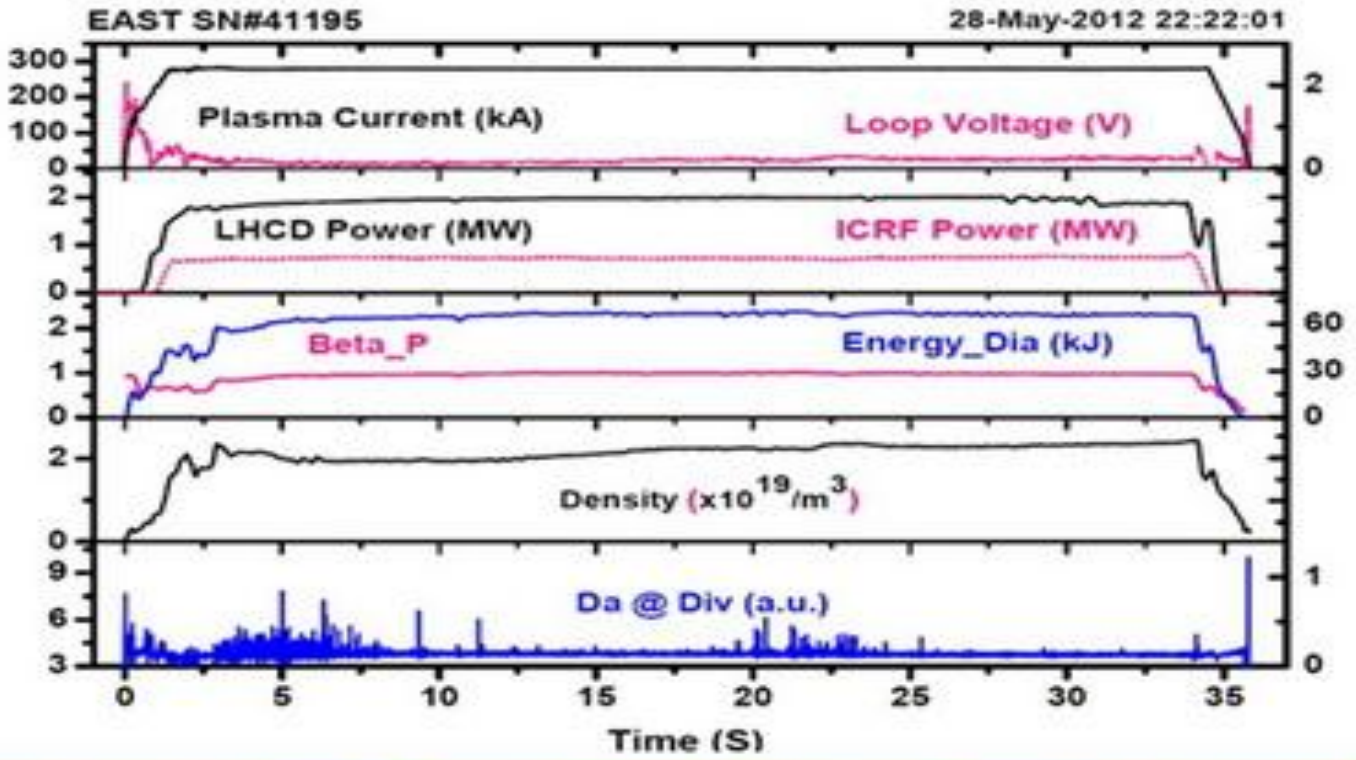
Breaked the World records

1. Achieved long pulse H-modes over **30 s** with LHCD and ICRH, facilitated by active lithium (Li) and cryopumping.
2. Achieved long pulse divertor plasma up to **411s**, which was fully driven by LHCD with active-cooled PFC and internal cryopump.
3. Achieved a long-pulse Enhanced (EDA) H-mode regime and further verified the role of zonal flows in the L-H transition by direct gas dynamic imaging.
4. Demonstrated change in edge magnetic topology induced by LHCD, which have potentially significant impacts on divertor and edge physics, such as power deposition, edge rotation and L-H transition, etc.
5. Observed a lower L-H transition power threshold for the ion drift direction away from the dominant divertor in the RF heated discharges in EAST, opposite to the previous observations in other tokamak.
6. Upgraded RF and LH systems to a total power of 8 MW, implemented more than 10 new diagnostics, and developed a new CW pellet injection system and supersonic molecule beam injection (SMBI) system for ELM mitigation and precise density feedback control.
7. Successfully demonstrated ELM control by LHW power modulation, SMBI, D_2 pellet and innovative Li pellet injection.

ASIPP

稳定重复的长脉冲H-mode运行

EAST

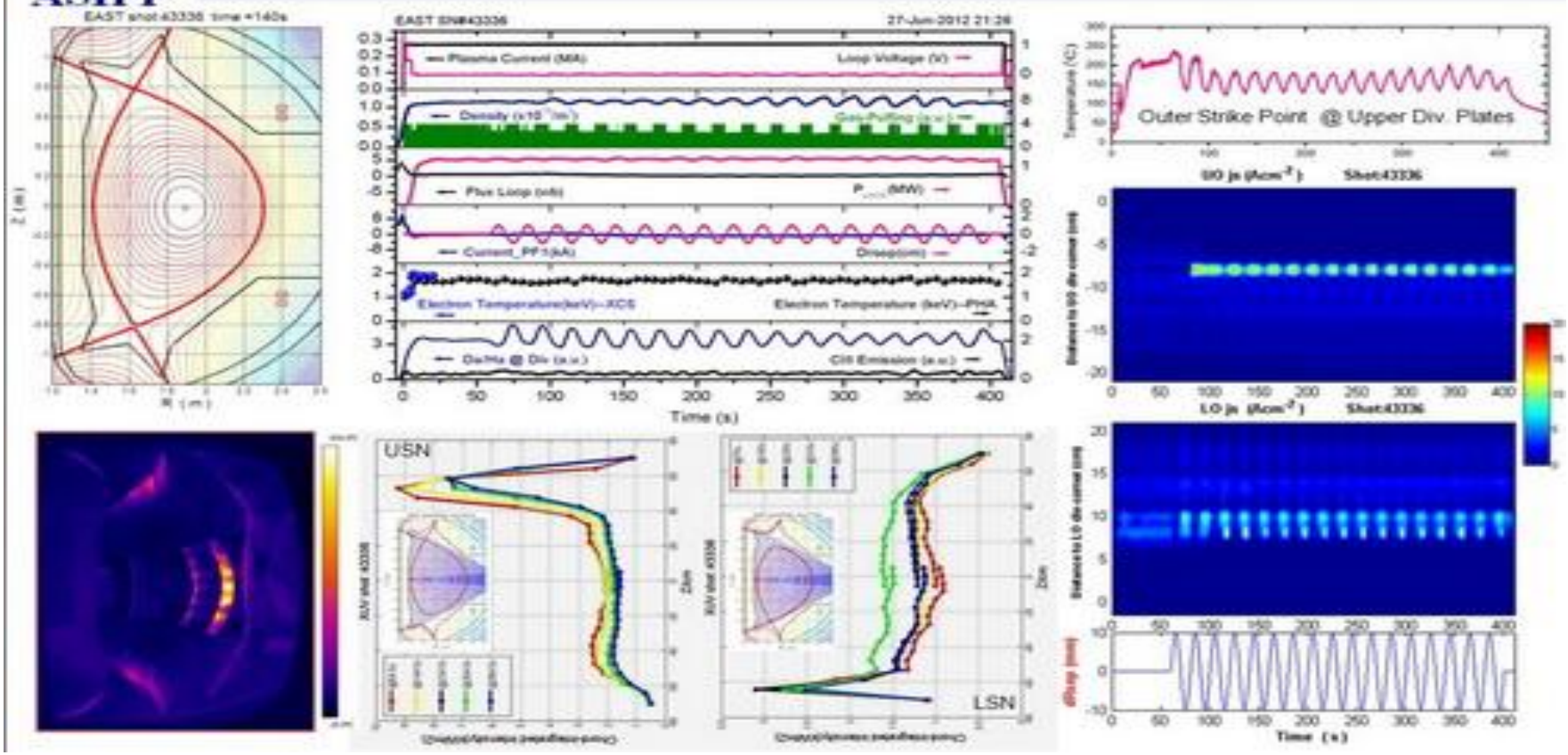


Ip~0.28MA/35s, ne~2.2, P_{LHCD}=1.8MW, P_{RF}=1.2MW, Bt=1.9T, H98(y,2)~0.8

Long pulse H-modes over 30 s with LHCD and ICRH.

The longest time of H-modes plasma discharge in the world up to now.

400秒偏滤器等离子体放电



Long pulse divertor plasma up to 411s,

T_e = 1.8 keV, B_t = 2.0 T.

The longest time of divertor discharge in the world up to now.

ACKNOWLEDGEMENT

We appreciate the trust and help that the colleagues of Institute of Plasma Physics gave to us, so we can have the opportunity to get and successfully finish the important task. We also appreciate the cooperated effort that IMP's colleagues made.

THANK YOU!!

FNAL, Sep. 2012