

TPS Survey & Alignment: Girder Settlement, Realignment, and Network Strategies

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TPS installation and alignment timeline

Civil Infrastructure Engineering

- Feb 2010: Groundbreaking
- Jun 2012: The 1.5 m thick foundation all areas is completed

Control Network Establishment

- Establish control network on ground
- Monitor control point
- Provide construction layout for contractors

Pedestal alignment

- Apr 2013: Begin rebar installation, alignment, and grouting
- Oct 2013: We Completed the installation of pedestal
- The control points is adjusted by position of pedestals.

Equipment Foundation Installation

- Oct 2013: Begin to Align the plinth (Booster, Linac areas)
- May 2014: Air condition system operating
- May 2014: Re-establish the control points

Component Alignment & Fine-Tuning

- Begin to align girders, Linac, and BPMs etc.
- Aug 2014: Completed Girder fine-tuning
- Sep 2014: all components installation is completed
- Oct 2014: Beam commissioning
- Dec 2014: Official operation



2010.02

Groundbreaking



2012.06

1.5 m Foundation Completed



2013.04

Pedestal Installation Begins



2013.10

Lattice Position Confirmed



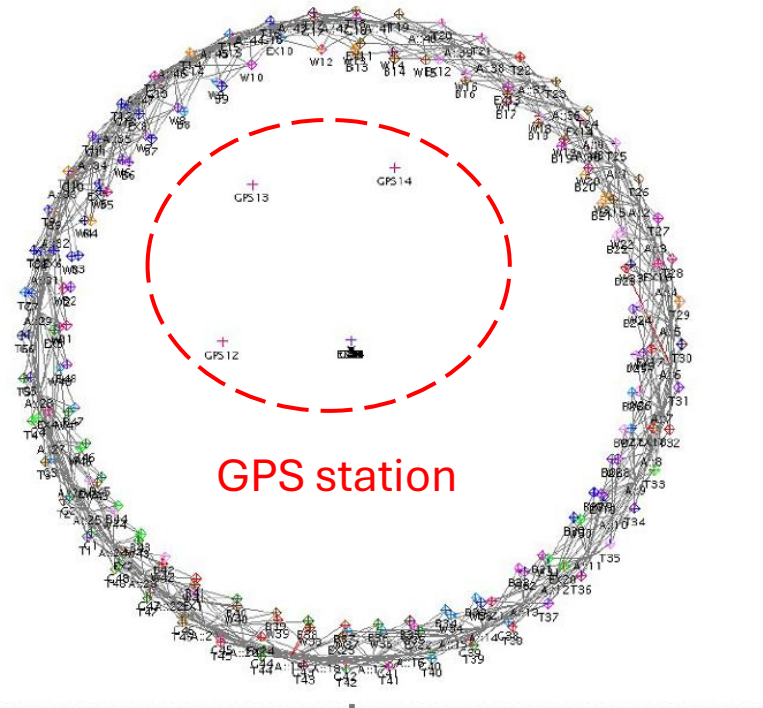
2014.05 - 08

All components installation completed

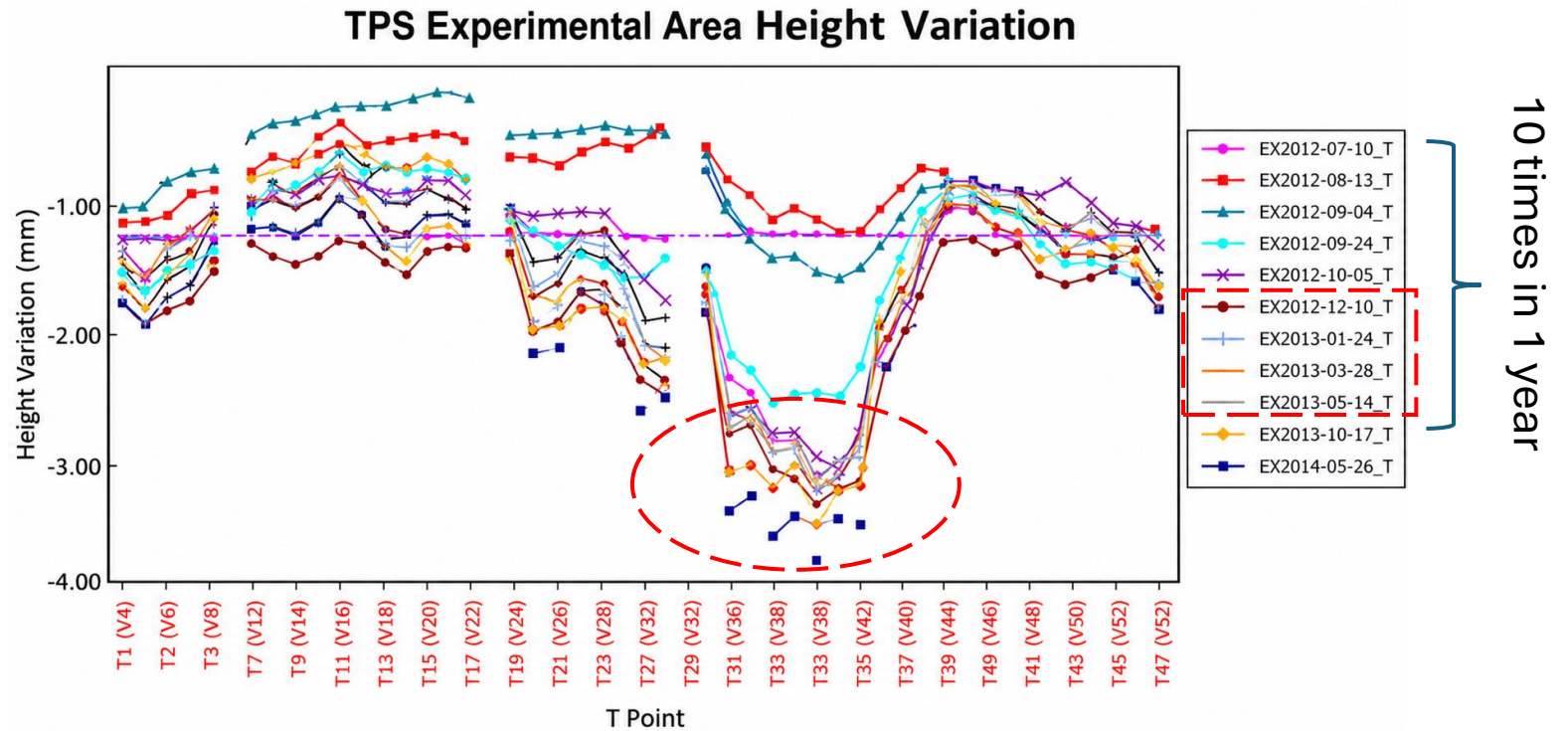
2015 ~

Official Operation & Monitoring

Ground Variation During Construction



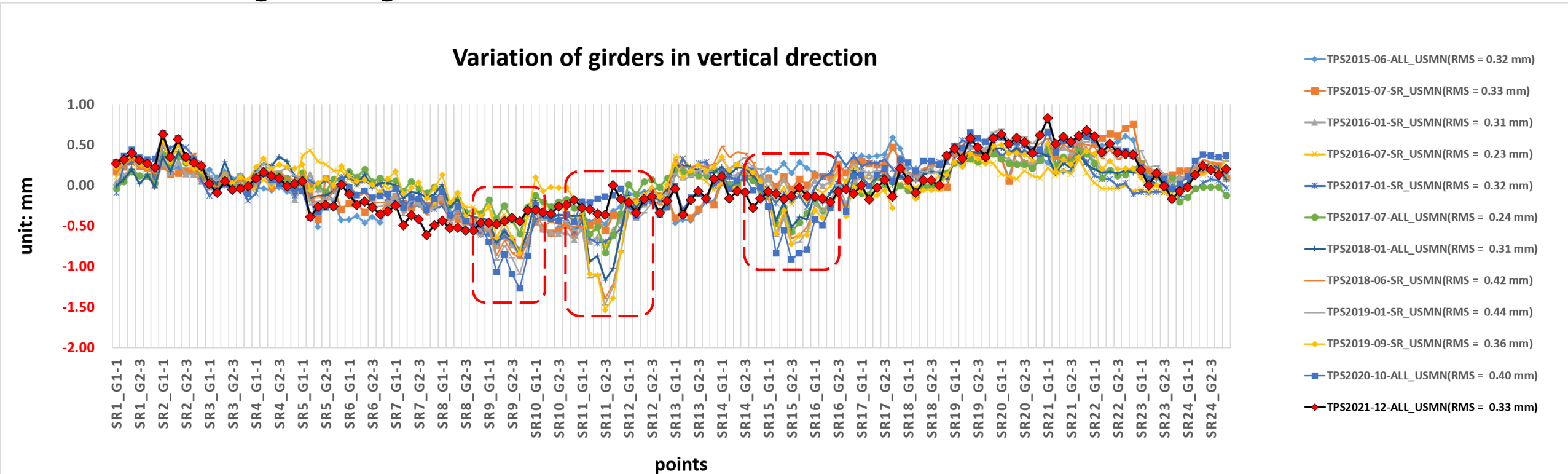
Foundation
control network



1. Because the TPS foundation was constructed in six separate area, the degree of settlement stability varied across regions.
2. October 2013: ground deformation tended to be stable, and we started to install rebars.

Historical Settlement Monitoring and Realignment (2020–2021)

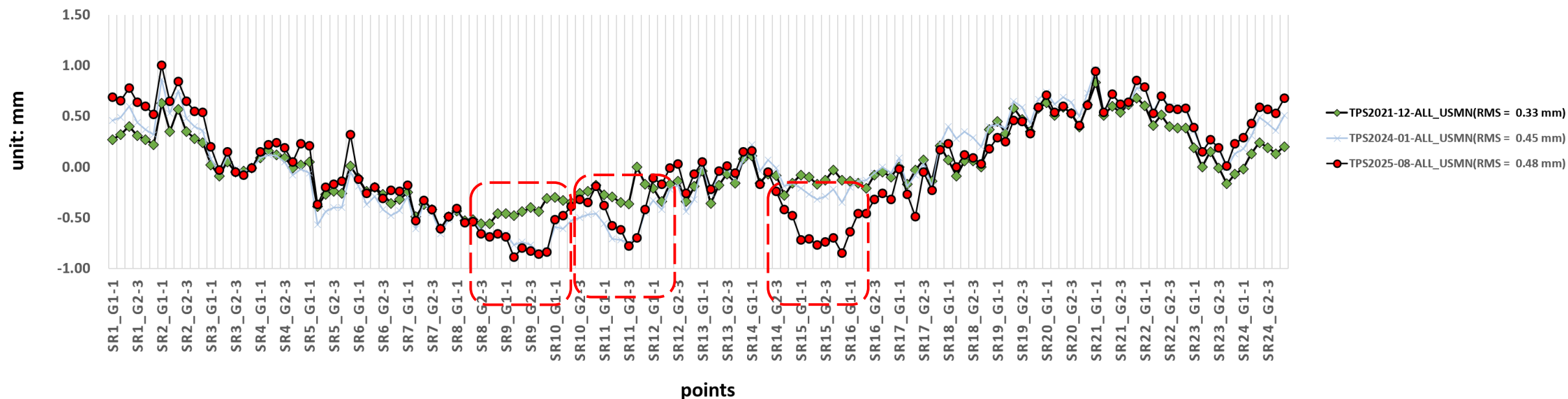
- Observation: In the beginning of operation, we built the control points at least once per year to monitor variations.
- 2020 Realignment: We first started to adjust Section 11, which exhibited the maximum settlement (> 1.5 mm)
- Results: The operator and beamlines users maintained normal functionality.
- 2021 Realignment: Localized smoothing adjustments were completed for Sections 8–10 and 15–16 during the long shutdown.



Recent settlement

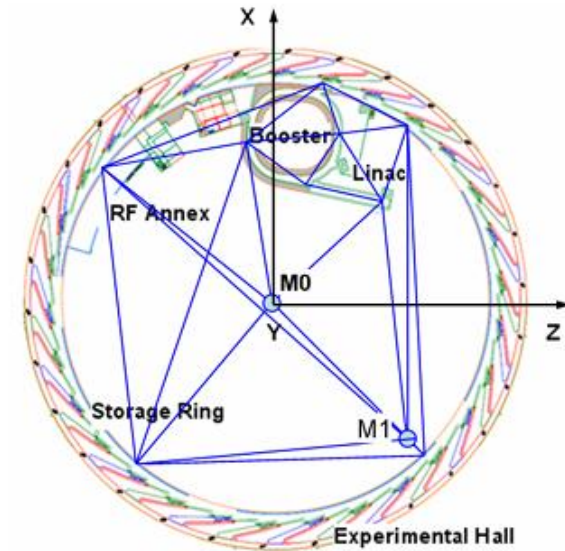
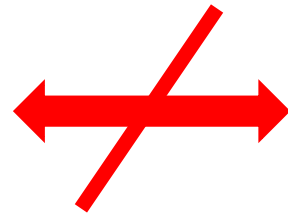
- Based on our latest data, we can see that Sections 9, 11, and 15 are still continuous settlement
- As shown in the chart, the overall RMS error in these areas currently ranges from about 0.45 to 0.48 millimeters.
- If the settlement expands further and begins to affect beam quality, we will perform another realignment

Variation of girders in vertical drection



Building Design and the site's topographic limit

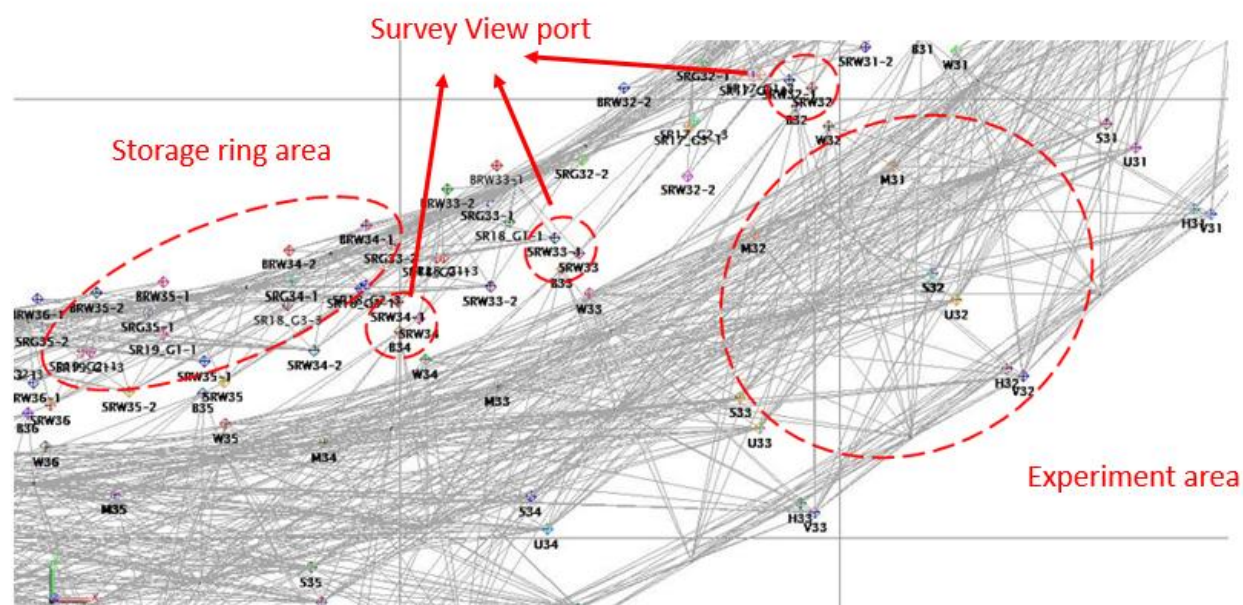
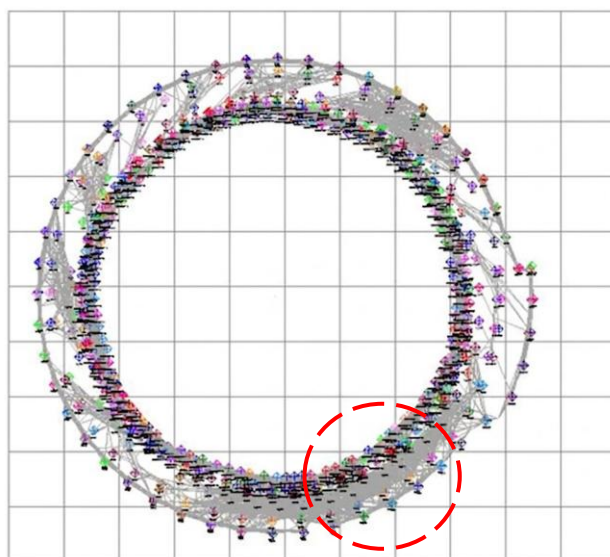
- TPS is built on a slope, and to mitigate earthquake impacts and consider costs, we adopted a semi-underground design, with part of the structure exposed above ground
- This design blocks the observations directly across the storage ring.
- To get good control network, we increase the number of survey stations to make sure most control points are measured at least four times.
- For the connection between the storage ring and experiment area, we used 'view ports' to link those, and it also can expand our control network.



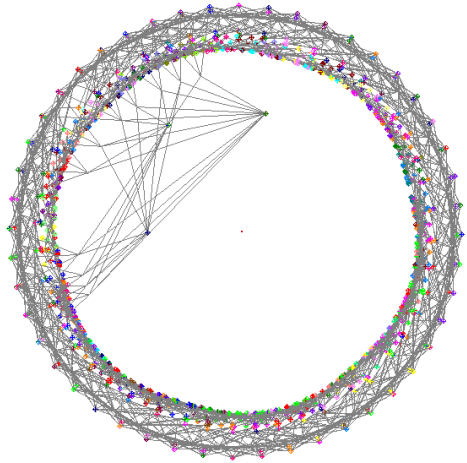
NSLS II Preliminary Design Report

Challenges of The Control Network

- In the past, we mainly relied on 'survey view ports' located on the wall between the storage ring and beamline to link the control networks together. “
- However, as the project progressed, more and more shielding hutches for the beamline stations were constructed and commissioned.
- As a result, a lot of the lines of sight through these view ports have dropped. The connections have become sparser. This reduces our relative linking accuracy between two areas.

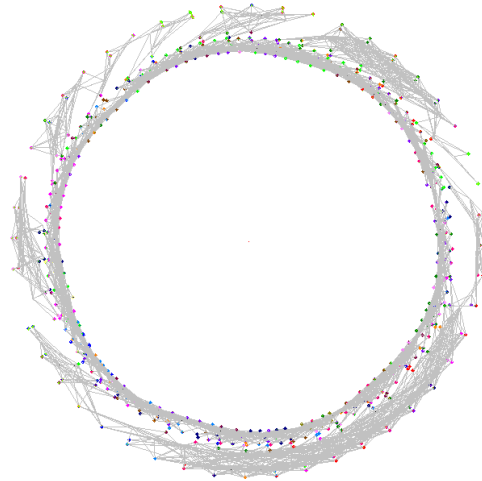


Evolution of the Survey Network Over the Years



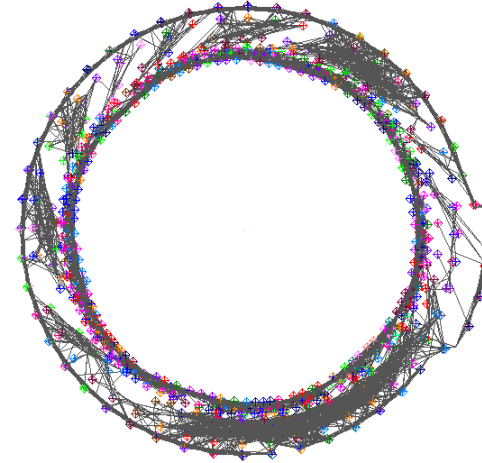
2015.06

In beginning, we had 47 view ports available to connect the storage ring with the experimental hall.



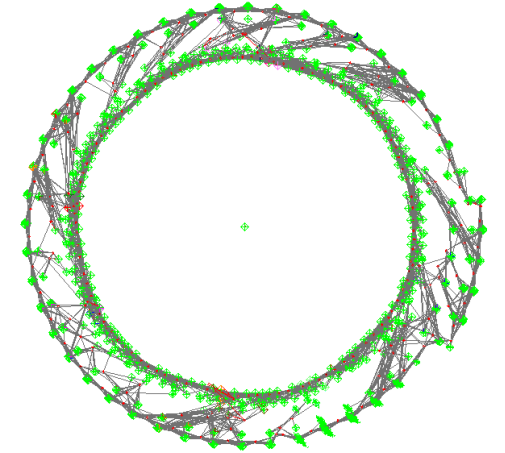
2018.12

We had 32 view ports available to connect the storage ring with the experimental hall.



2019.10

We started adding walkway networks in the outer areaTo strengthen the geometry of network

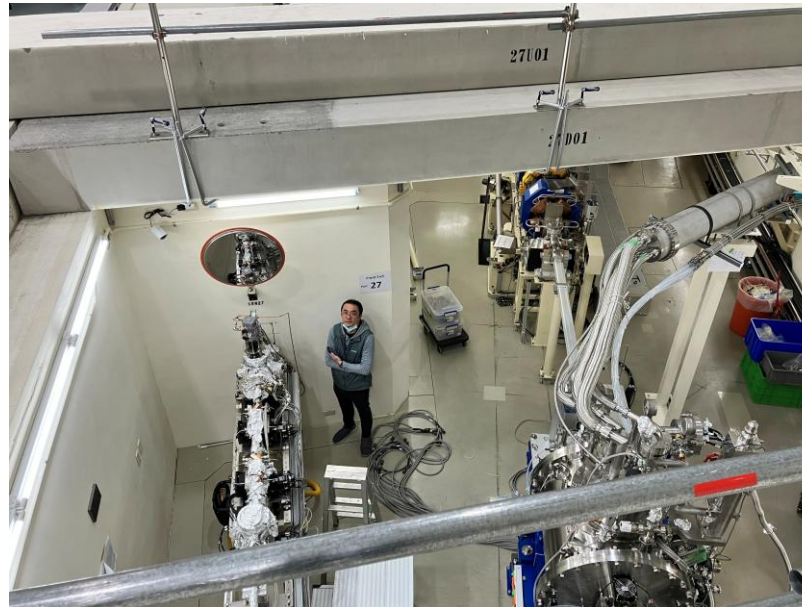


2025.08

As more beamline hutches were completed, the number of usable view ports dropped down to just 17.

Direct Observation via Ceiling blocks Removal

- **New method:** Utilize overhead cranes to remove storage ring ceiling blocks
- **Purpose:** Directly measure control points both in the storage ring and experiment area to replace view ports.
- **Validation:** Verify the relative position from experiment area to storage ring.
- **Survey Advantage:** View ports only allow single-point sight into the storage ring; the new upper station can observe up to 10 points in the storage ring and experimental area.



Optimal Setup Locations & Survey Benefits

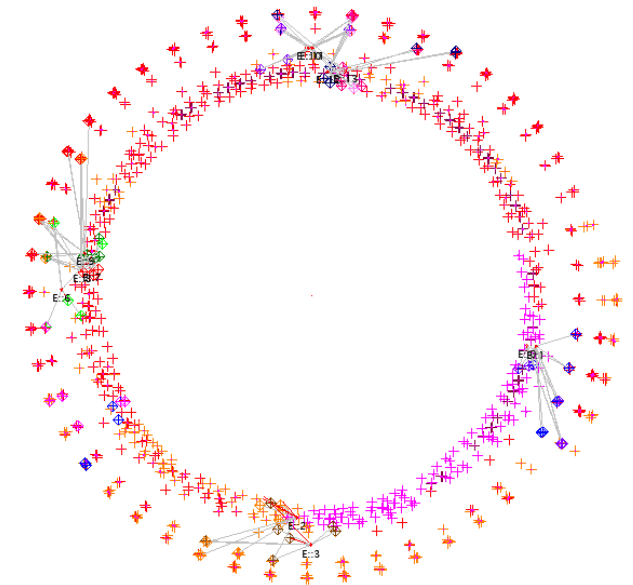
- Site Survey: A Laser tracker must be stationed in specific areas to maximize control points.
- Setup Option 1: Areas on the sky bridge connecting walkway
- Setup Option 2: Edge locations along the opened ceiling blocks.
- Both locations provide direct sightlines to get more control points inside the storage ring



Setup Option 1



Setup Option 2



Measurement on 2026.01

Verify the relative position from experiment area to storage ring.

Connecting Station B
Measure date 2026.01
Fitting the newest data 2025.08

Name	On	dX	dY	dZ
B11	X	0.43	0.68	0.13
BRW14-2		0.87	1.64	0.32
H12	X	0.15	-0.24	0.21
H14	X	-0.25	0.34	0.41
U12	X	0.34	-0.9	-0.47
U14	X	-0.42	-0.26	-0.28
U14-1	X	-0.43	-0.3	-0.1
W12	X	0.19	0.68	0.11

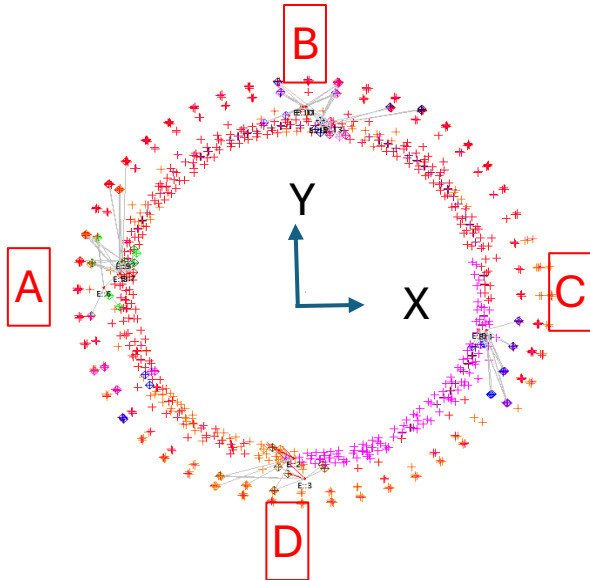
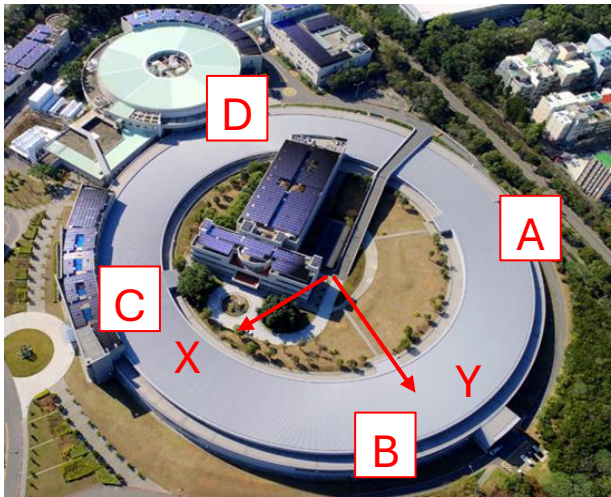
Connecting Station B-2
Measure date 2026.09
Fitting data 2025.08

Name	On	dX	dY	dZ
H14	X	0.09	0.04	0.10
SRG13-2		-0.23	0.01	0.36
SRG14-1		-0.26	0.05	0.33
SRW14		-0.12	0.01	0.44
U13	X	-0.01	-0.01	0.00
U14	X	-0.04	-0.01	-0.01
U14-1	X	0.00	0.04	-0.04
V14	X	-0.04	-0.05	0.01
V14-4	X	0.01	-0.01	-0.07

Connecting Station B
Measure date 2026.01
Fitting data 2024.01

Name	On	dX	dY	dZ
H12	X	0.05	-0.09	-0.01
H14	X	-0.06	-0.14	-0.1
BRW14-2		0.17	0.75	-0.21
B11	X	0.03	0.02	-0.04
W12	X	-0.06	0	-0.03
U14-1	X	-0.03	0.09	0.01
U14	X	0.01	0.07	0.08
U12	X	0.08	0.06	0.09

- 1. **Fitting Jan 2026 data with Aug 2025 network:** The maximum deviation in Area B reached 1.6 mm in the Y-direction (cross-seasonal comparison).
- 2. **Re-do the test in Sep 2026 (similar season to Aug 2025):** The deviation was significantly reduced to around 0.3 mm, proving seasonal thermal effects.
- 3. **Fitting Jan 2026 data with Jan 2024 network (same season):** Maximum deviation was reduced to 0.7 mm in the Y-direction.



Checking difference in Other Areas (Area A, C, and D)

Case1: Connecting Station A
Measure date 2026.01
Fitting data 2025.08

Name	On	dX	dY	dZ
B48	X	-0.11	0.05	-0.14
BRW2-2		-0.21	0.18	-0.53
M48	X	0.05	0.04	0.22
U3	X	0.05	-0.05	0.02
U48	X	0.04	0.03	-0.04
U3-1	X	-0.03	-0.07	-0.06

Case2: Connecting Station A
Measure date 2026.01
Fitting data 2024.01

Name	On	dX	dY	dZ
BRW2-2		-0.12	-0.18	-0.07
M48	X	-0.23	0.02	0.15
U48	X	0.15	0.05	-0.06
B48	X	0.02	0.02	-0.06
U3	X	0.09	-0.03	0.06
U3-1	X	-0.03	-0.06	-0.1

Case1: Connecting Station C

Name	On	dX	dY	dZ
SRG27-1		0.56	-0.08	0.94
SRW27		0.32	-0.3	0.81
SRW27-1		0.37	-0.33	0.87
U27	X	0.02	-0.02	0
U28-1	X	-0.02	-0.13	-0.01
V29	X	0.06	0.08	0.1
V29-2	X	-0.05	0.07	-0.1

Case2: Connecting Station C

Name	On	dX	dY	dZ
SRW27-1		0.03	-0.3	-0.11
SRG27-1		0.29	-0.09	-0.23
SRW27		-0.04	-0.25	-0.04
U28-1	X	-0.08	-0.03	-0.01
V29-2	X	-0.01	0.06	-0.1
V29	X	0.04	0.03	0.1
U27	X	0.04	-0.07	0

Case1: Connecting Station D

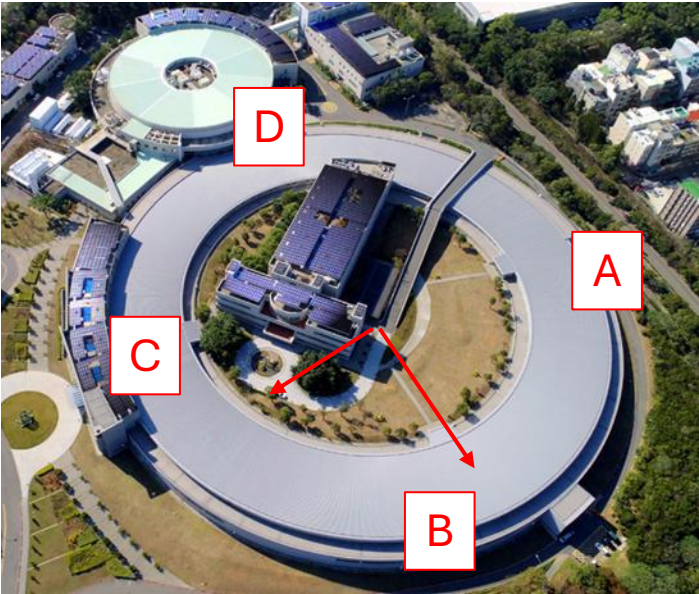
Name	On	dX	dY	dZ
B36	X	-0.05	-0.07	0.03
BRW38-2		-0.12	-0.15	-0.12
M37	X	-0.14	0.14	-0.07
U38	X	-0.07	0.18	0.07
U40	X	-0.01	-0.03	0.09
U40-1	X	0	-0.09	-0.13
W36	X	0.1	-0.03	-0.05
W38	X	0.17	-0.11	0.06

Case2: Connecting Station D

Name	On	dX	dY	dZ
M37	X	-0.18	0.06	0.1
BRW38-2		0.02	-0.49	0.09
W36	X	-0.14	-0.04	-0.06
B36	X	-0.18	-0.13	-0.07
U38	X	0	0.17	0.02
W38	X	0.09	-0.13	0.11
U40	X	0.19	0.06	0.03
U40-1	X	0.22	-0.07	-0.13

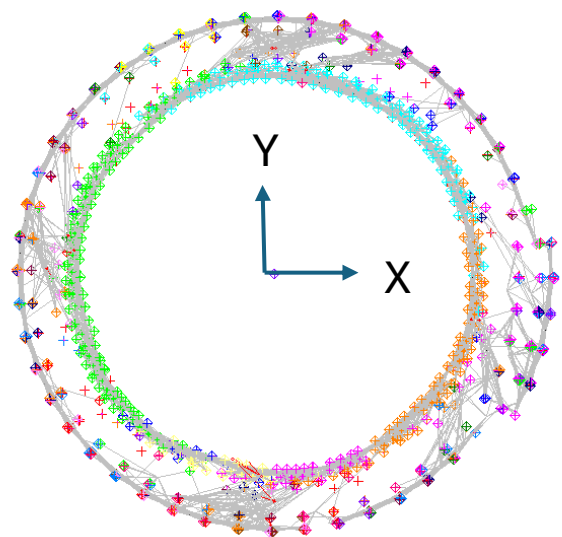
Measurement Results & Environmental Impact Summary

- **Area B:** Large seasonal temperature swings cause serious thermal expansion in open ground areas (max horizontal displacement: **1.6 mm**; vertical: **~0.5 mm**).
- **Same-Season Remeasurement:** Comparing Sep 2026 with Aug 2025 (similar temperatures), Area B's horizontal and vertical variations were down to **~0.3 mm**.
- **Area D:** Buried in the deepest underground level, Area D is least affected by ambient temperatures, with winter-summer variations staying **< 0.3 mm** in both horizontal and vertical directions.
- **Areas A & C:** Winter-summer elevation variations are **~0.5 mm** in Area A and **~1 mm** in Area C. Area C is bigger than Area A, because its measured area is narrower, causing bigger Abbe errors.



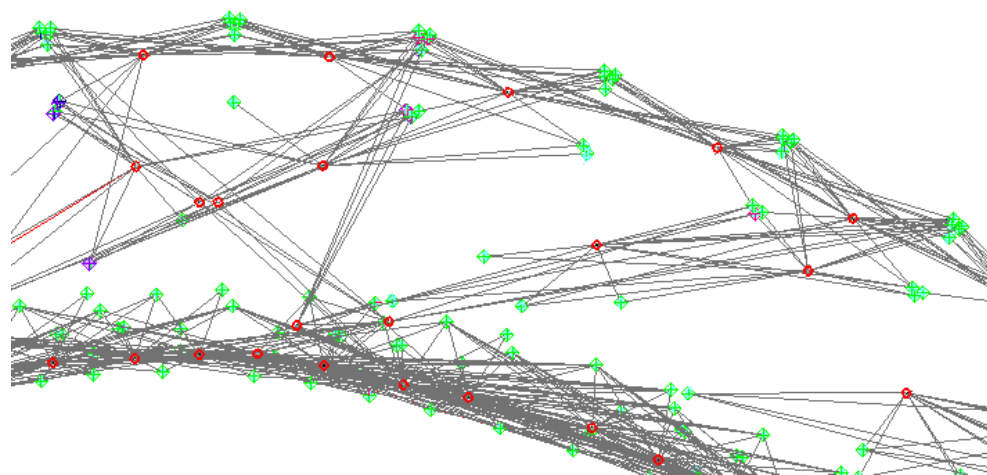
Area C	On	dX	dY	dZ
SRG27-1		0.56	-0.08	0.94
SRW27		0.32	-0.3	0.81
SRW27-1		0.37	-0.33	0.87
U27	X	0.02	-0.02	0
U28-1	X	-0.02	-0.13	-0.01
V29	X	0.06	0.08	0.1
V29-2	X	-0.05	0.07	-0.1

Network Analysis using Spatial Analyzer (SA)

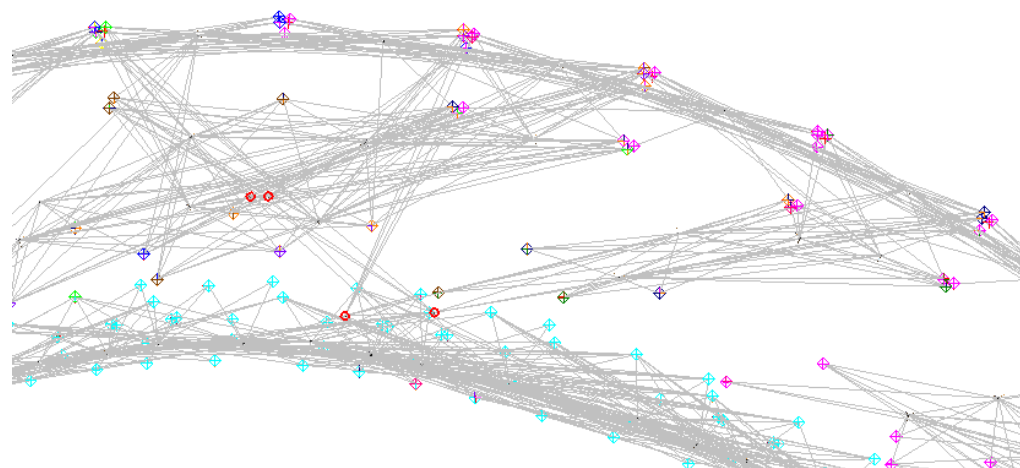


Merge two control networks
2024.01(processed) and
2026.01

The two ways are not much different(compared to the unprocessed 2024.01 network), especially in the vertical direction. We use the second one for further discussion, because it contains more survey data and is closer to the January 2024 network.



2024.01 delete connecting stations



2024.01 only delete connecting points

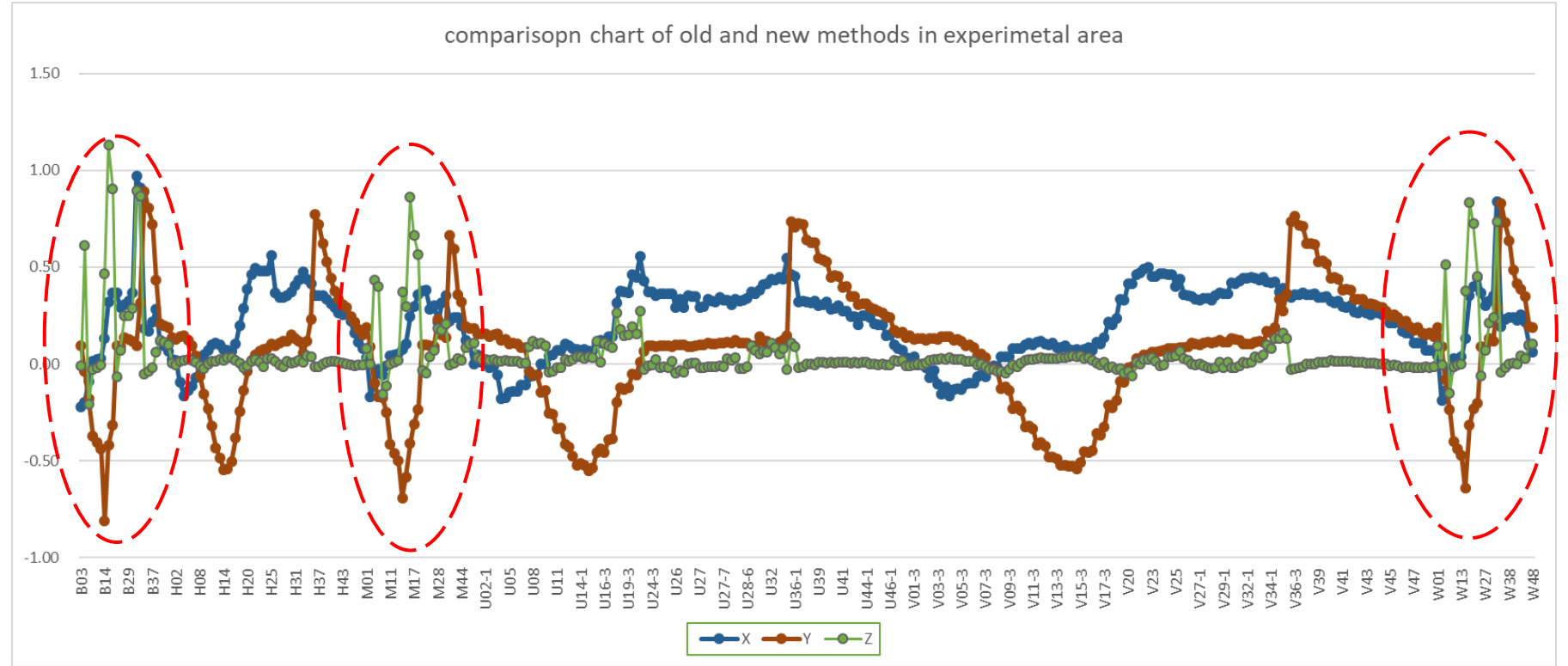
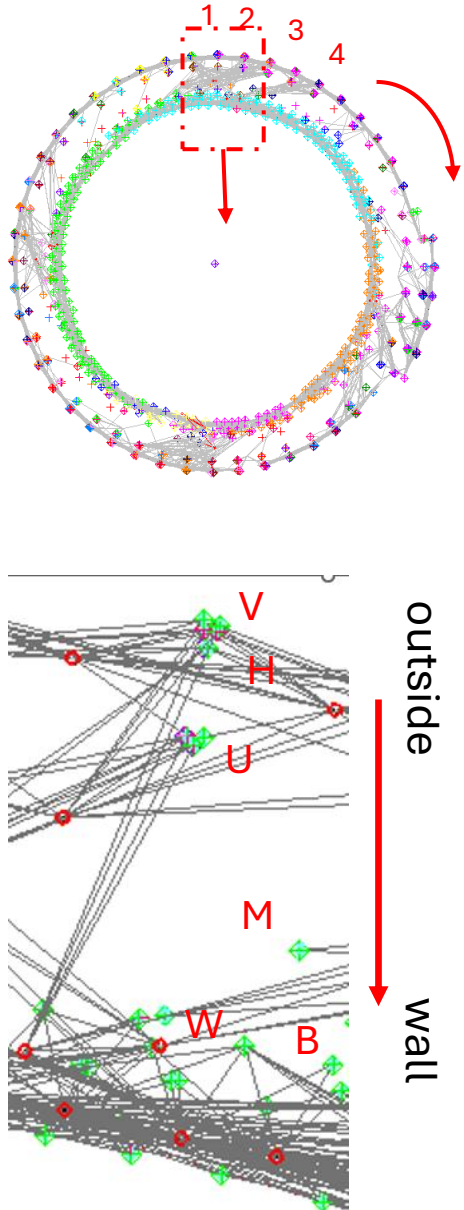
CASE 1: delete
connecting stations

Peak value
Max 1.7 mm, the second
one is ~1.1 mm
STDEV X:0.32 mm
STDEV Y:0.28 mm
STDEV Z:0.10 mm

CASE 2: only delete
connecting points

Peak value
Max 1.1 mm
STDEV X:0.19 mm
STDEV Y:0.22 mm
STDEV Z:0.11 mm

Control Point Comparison Between Old and New Methods



Naming Convention: From outside to inside, the letter is labeled **V, H, U, M, W, and B**, and the trailing numbers represent sector positions along the ring

- Regions with larger height difference (dZ) are close to the storage ring.
- Main reason: The January 2024 and January 2026 were not measured at the same time. It cause major variation.
- Computing network, fragmented local networks exhibit higher difference. (B, M, W)

Summary and Future Strategies

Summary

- **Network result:** Direct measurements via opened ceiling blocks, the deviations is within 1 mm compared to the conventional view-port method.
- **Feasibility:** Direct measurement is confirmed as a possible method instead of the view-port.
- **The difference in reference between areas is verified :** Cross-seasonal surveys revealed displacements up to 1.6 mm horizontally and 0.5 mm vertically (driven by long-term structural deformation and thermal effects). Under same-season survey conditions, relative deviations remained < 0.5 mm.

Future Strategies

- **Network Verification:** Next time, the survey networks and ceiling opening test will be conducted at the same time. It will reduce errors during the time gap.
- **Control Point Expansion:** Increase control points at the connecting area. (covering storage ring and experimental hall)
- **Temperature Compensation:** Increase survey frequency in thermal-sensitive zones (Area B) and establish a seasonal temperature compensation model



**Thank you for your
attention!!**