Traversing Spiral Decline

(error propagation and surveying strategies)

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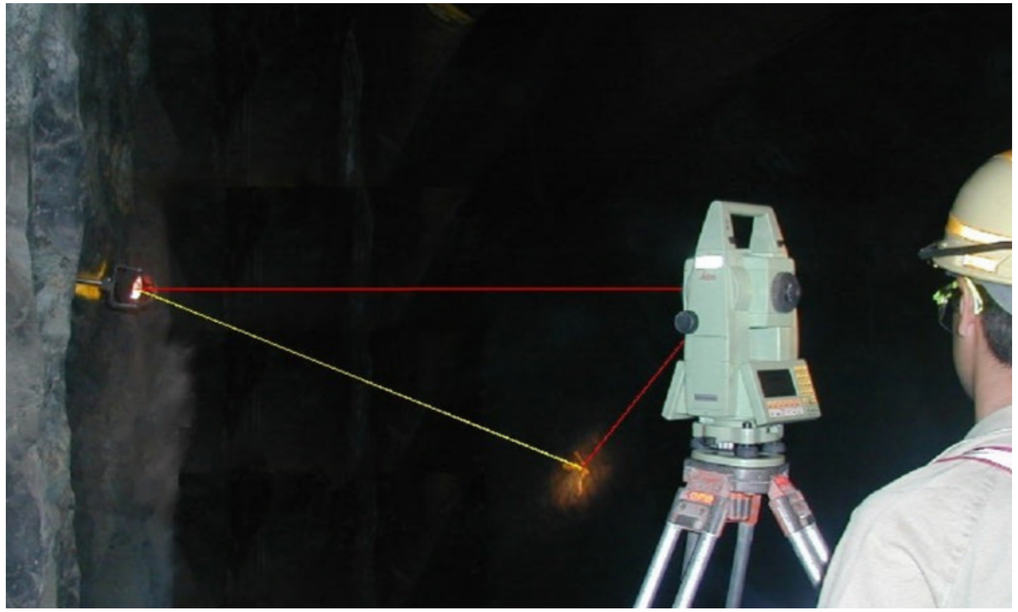
Test Survey Objectives

- To test propagation of errors (direction and position) along a spiral decline
- To test different survey strategies and their impact on error propagation
- To develop the best surveying strategy to minimise error propagation

Wall Stations (Reference Points) Surveying Technique

- Initially proposed by B. McCormack in 2001[1]
- Objectives:
  - To improve safety and speed of reference points installation process
  - To simplify stabilisation and access to reference points
  - To simplify instrument setup (TP anywhere)
- WS technique is seen as replacement of classical traversing
- Use of resection (free stationing) as a method to establish position of a total station at TP
- It become possible, when coaxial total stations achieved high accuracy for distance and angular measurements

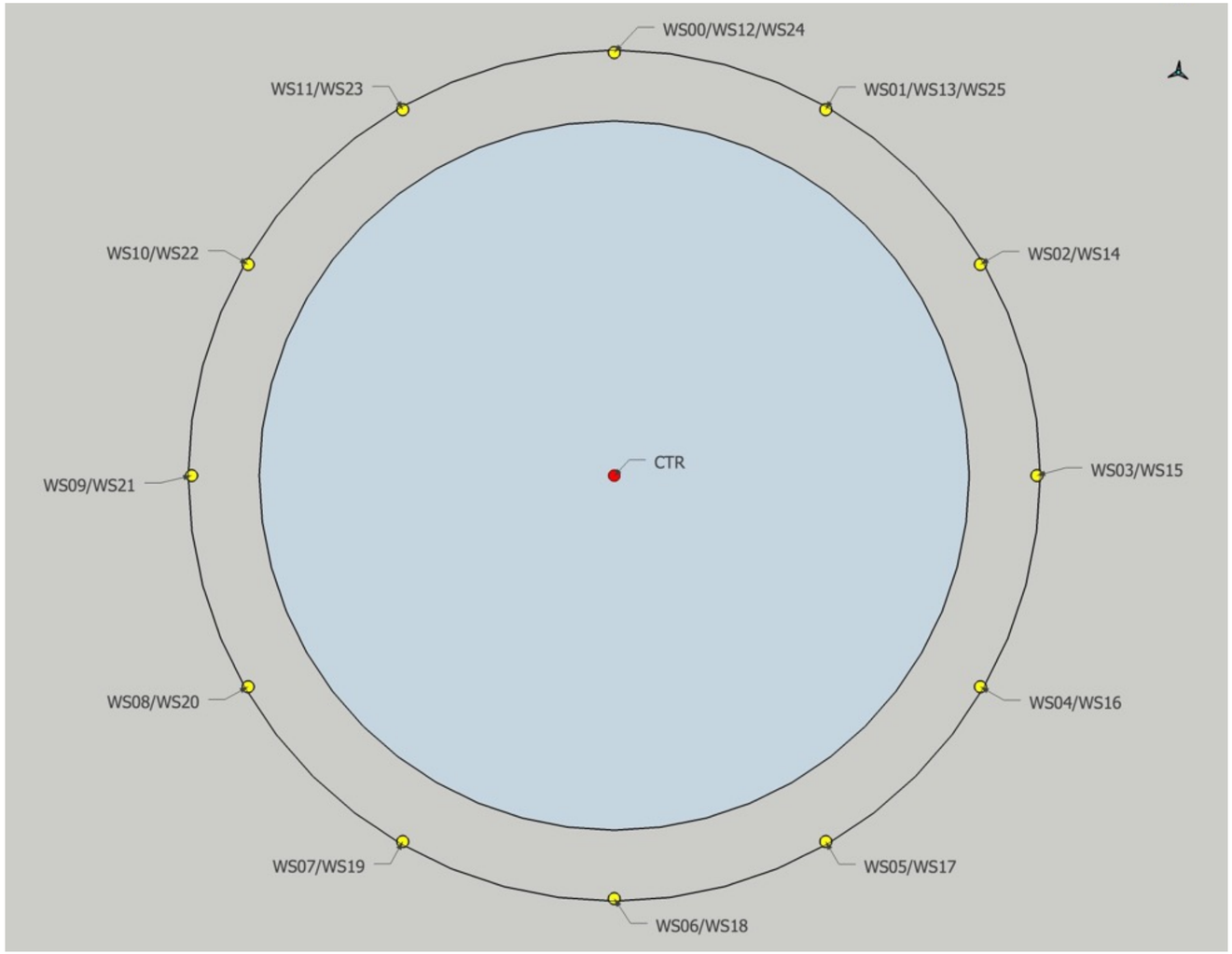


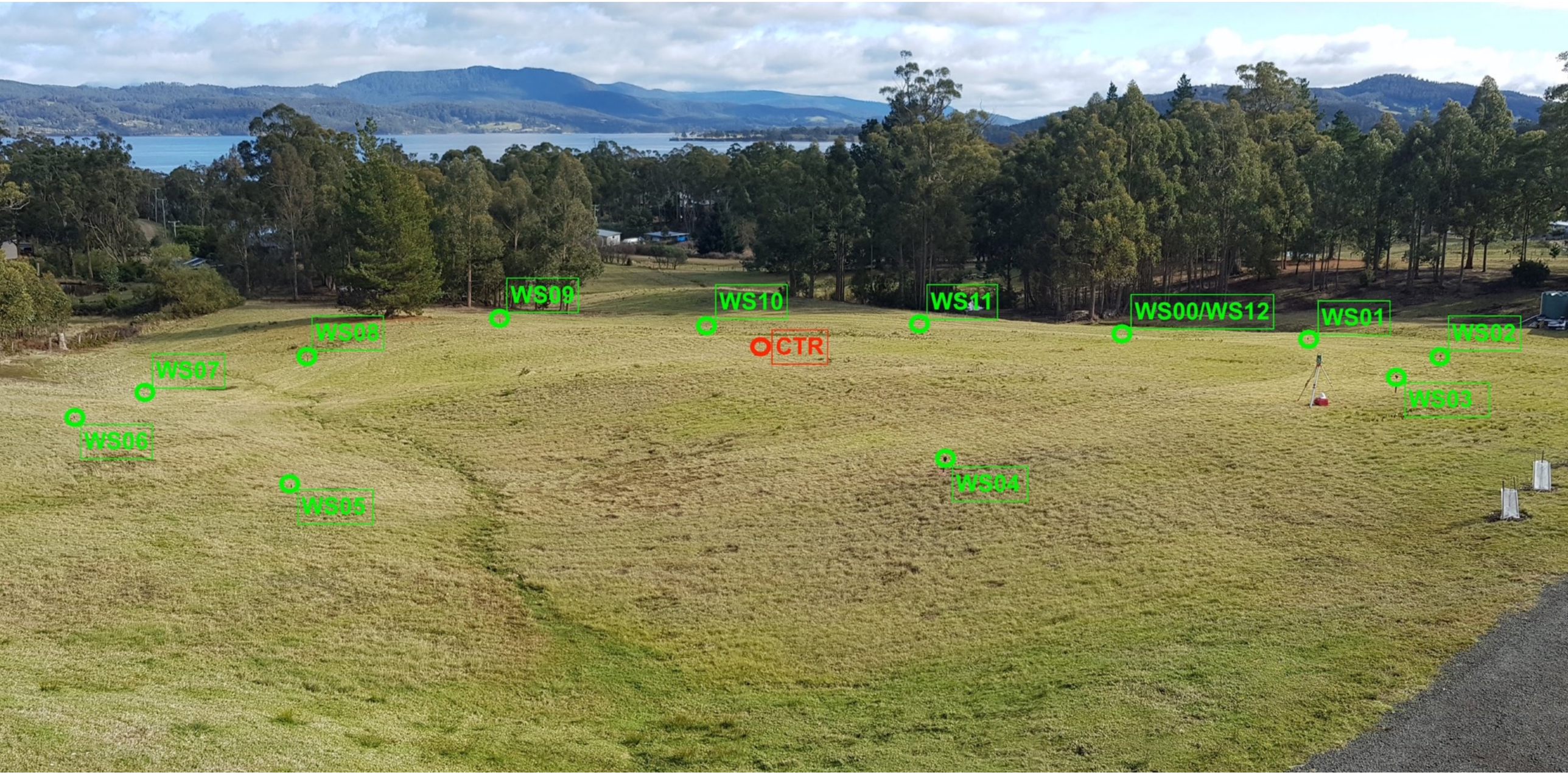
Source: McCormac, B, 2001[1]

Reference: [1] C, Wall Stations (Reference Points) - The Use of Resection to Replace Conventional Underground Traversing. http://benchmarksoftware.com.au/downloads/Wall%20Stations.pdf. accessed August 2019

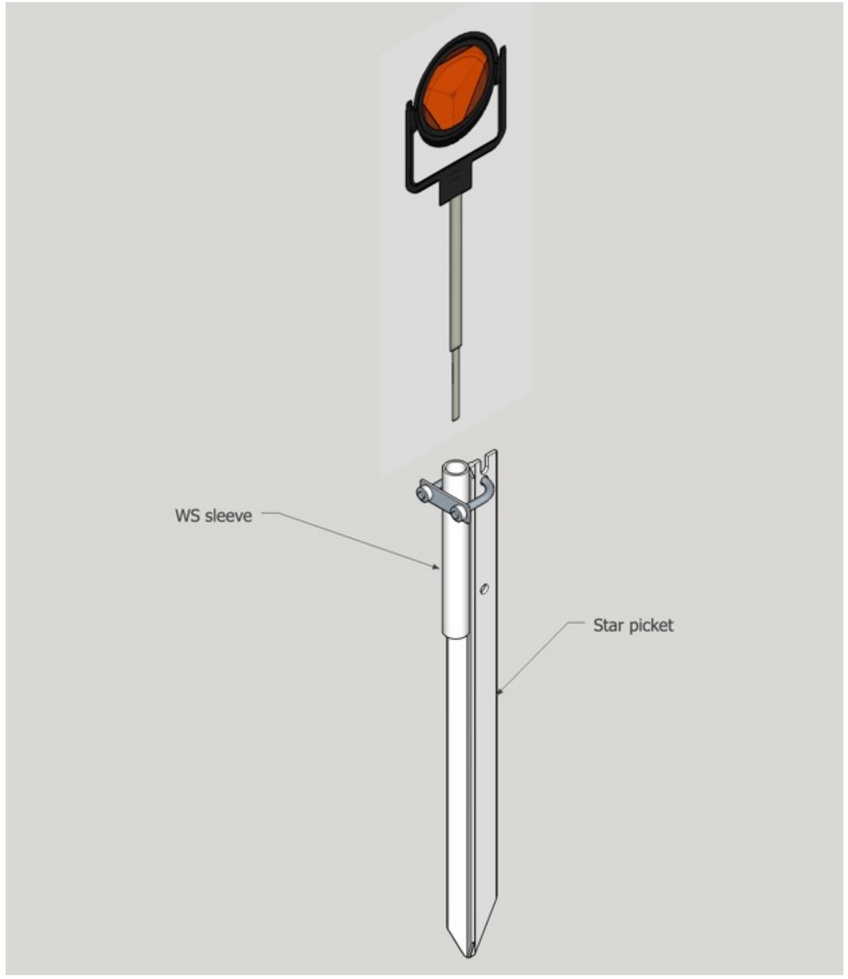
Test Surveys Setup

- Emulation of a spiral (circular) decline
- Radius 30m
- Width 6m
- 12 Wall Stations - WS00 .. WS11 (positioned as hours on a clock)
- Distance between WS ~18m
- Local coordinate system
- Exact location of control points (WS00 .. WS11) surveyed from the centre - CRT (FL & FR, 2 series)




WS09
WS10
WS11
WS00/WS12
WS01
WS02
WS08
CTR
WS07
WS03
WS06
WS04
WS05

Reference Stations (WS)



Instrumentation

- Total Station
  - Model: Leica TCRA 1105plus
  - Accuracies:
    - Angle (Hz & V): 5”
    - Distance: 2mm + 2ppm
    - ATR: +-3”
- Leica Standard Prism (GPR1) with holder (GPH1) x4
- WS stems x4
- Tripod x3
- Target assembly (GRT144) x2

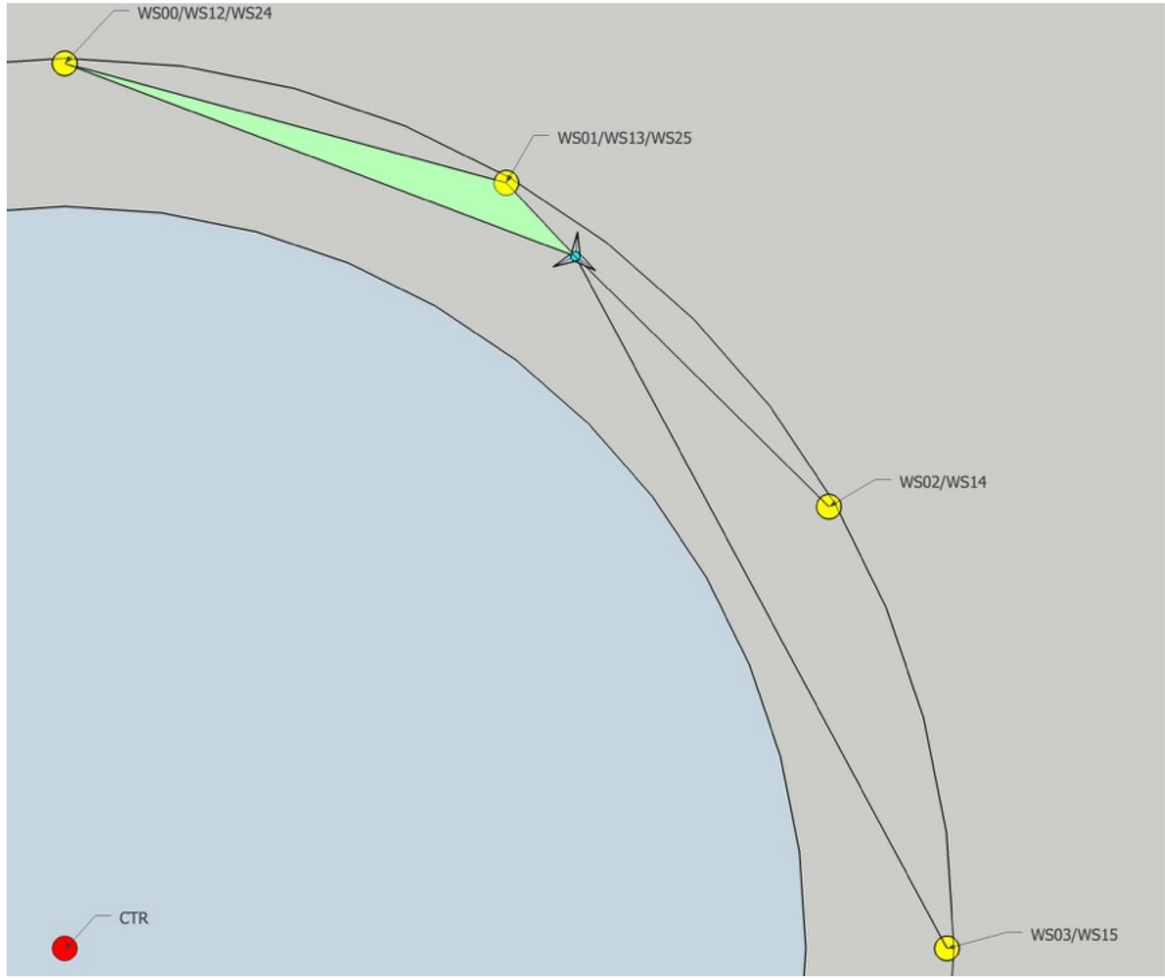
Resection / Free Stationing

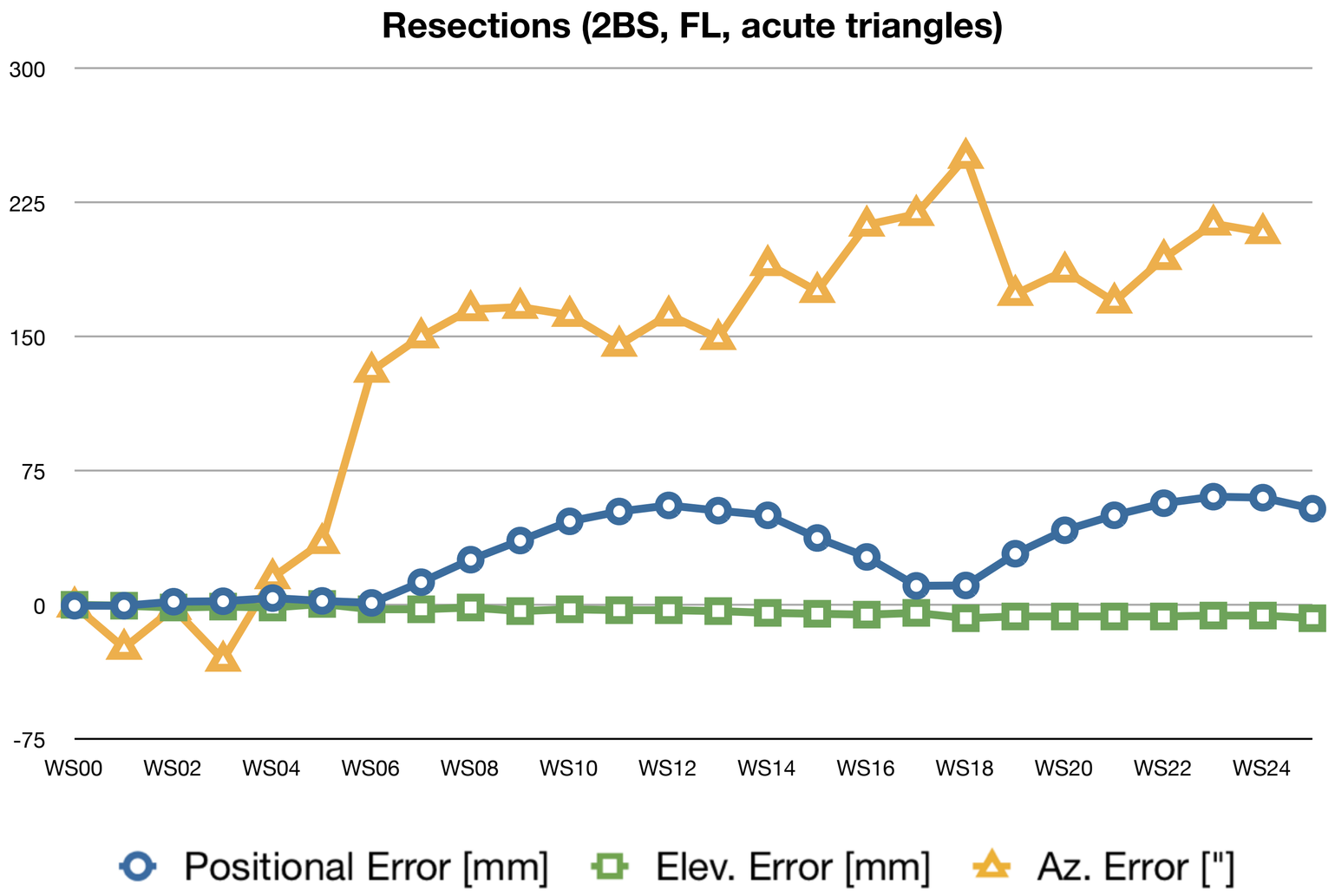
Survey Scenarios Tested

- **Case#1:** Simple resections (2BS, FL, one series of angles, acute triangle, TP close to one of the WS forming resection base)
- **Case#2:** Simple resections (2BS, FL, one series of angles, ~90^{o} triangle, TP close to one of the WS forming resection base)
- **Case#3:** Simple resections (2BS, FL, one series of angles, acute triangle, TP at mid position between WS)
- **Case#4:** Free stationing (3BS+TP, FL, one series of angles, acute triangles, TP close to one of the WS forming resection base)
- **Case#5:** Simple resections (2BS, FL+FR, one series of angles, acute triangle, TP close to one of the WS forming resection base)
- **Case#6:** Free Stationing (3BS) at the start and then Forced Centred Traverse (FL only, one series of angles, WS as sideshots)
- **Case#7:** Free Stationing (4BS) at the start and then Forced Centred Traverse (FL + FR, two series of angles, WS as sideshots)

Case#1 - Simple Resections (2BS, FL, acute triangles)

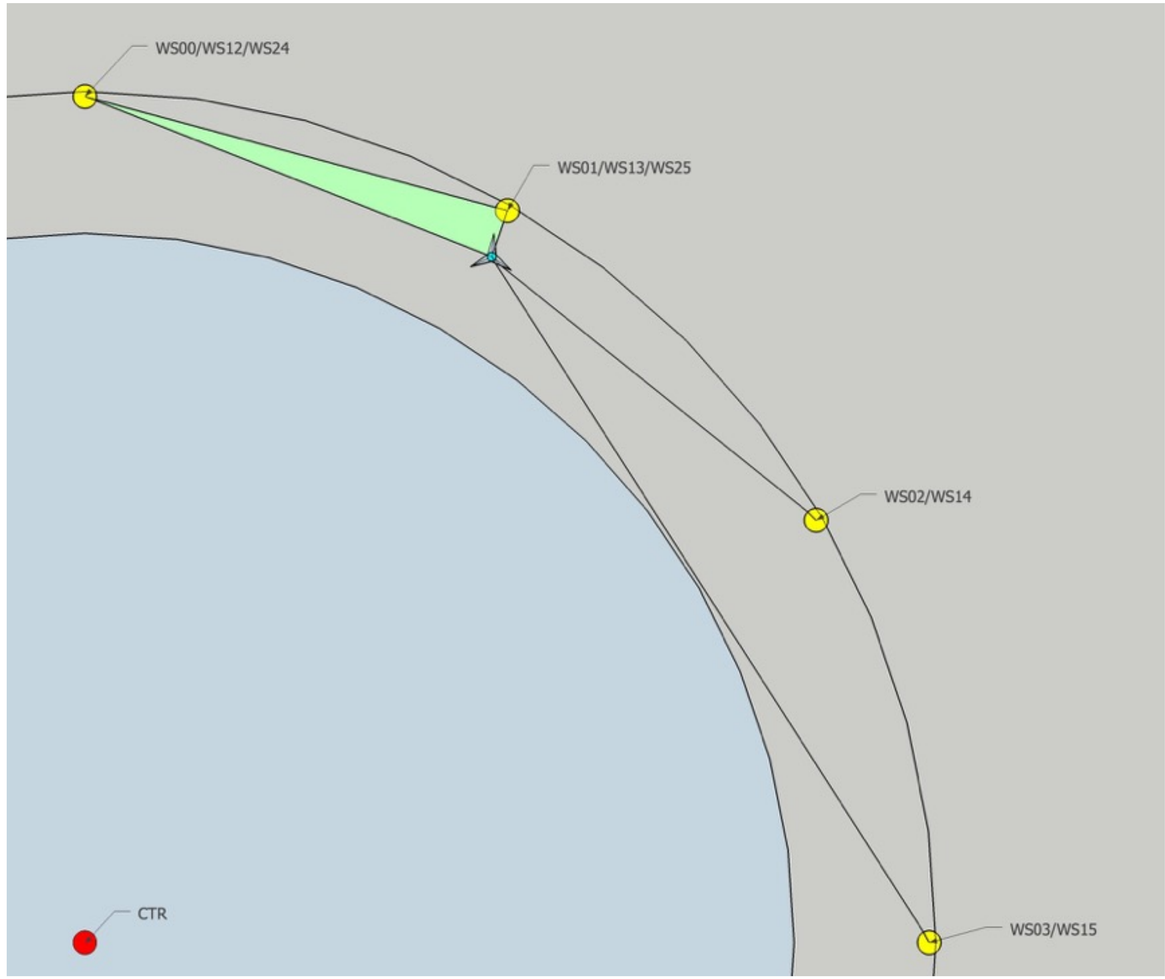
- Survey starts from the base WS00-WS01 (stations with known positions - coords)
- Instrument (TP) located close (~4m) to one of the wall stations (WS01)
- Acute shape of the resection triangle
- Measurements:
  - one series on angles, only one face (FL),
  - 2 directions & 2 distances to backsight stations (WS00 & WS01)
  - 2 directions & 2 distances to foresight stations (WS02 & WS03)
- Transfer of instrument to new position (after WS03)
- Continuation of surveys until 2 full rounds are achieved

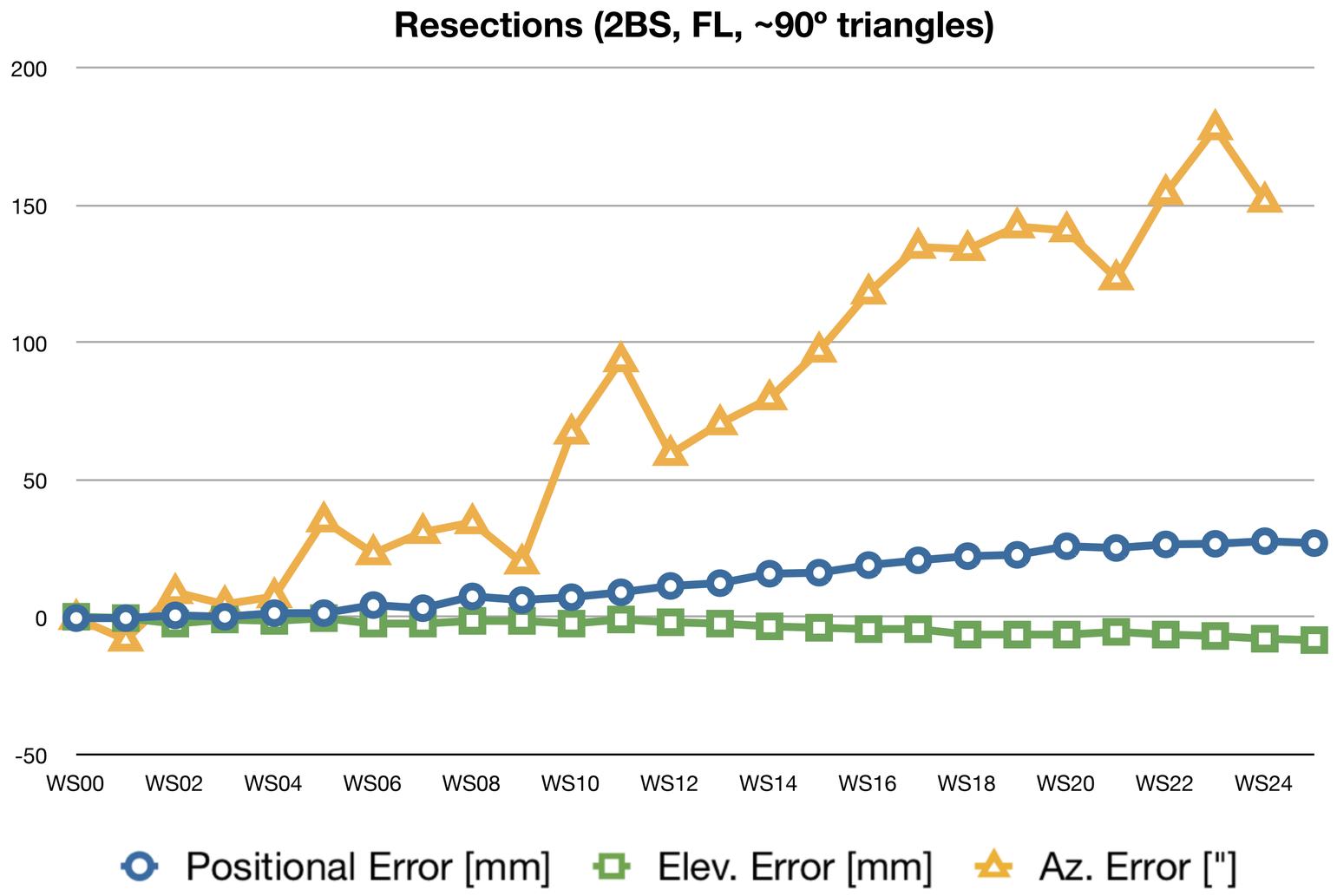



Resections (2BS, FL, acute triangles)
300
225
150
75
0
-75
WS00
WS02
WS04
WS06
WS08
WS10
WS12
WS14
WS16
WS18
WS20
WS22
WS24
Positional Error [mm]
Elev. Error [mm]
Az. Error ["]

Case#2 - Simple Resections (2BS, FL, ~90° triangles)

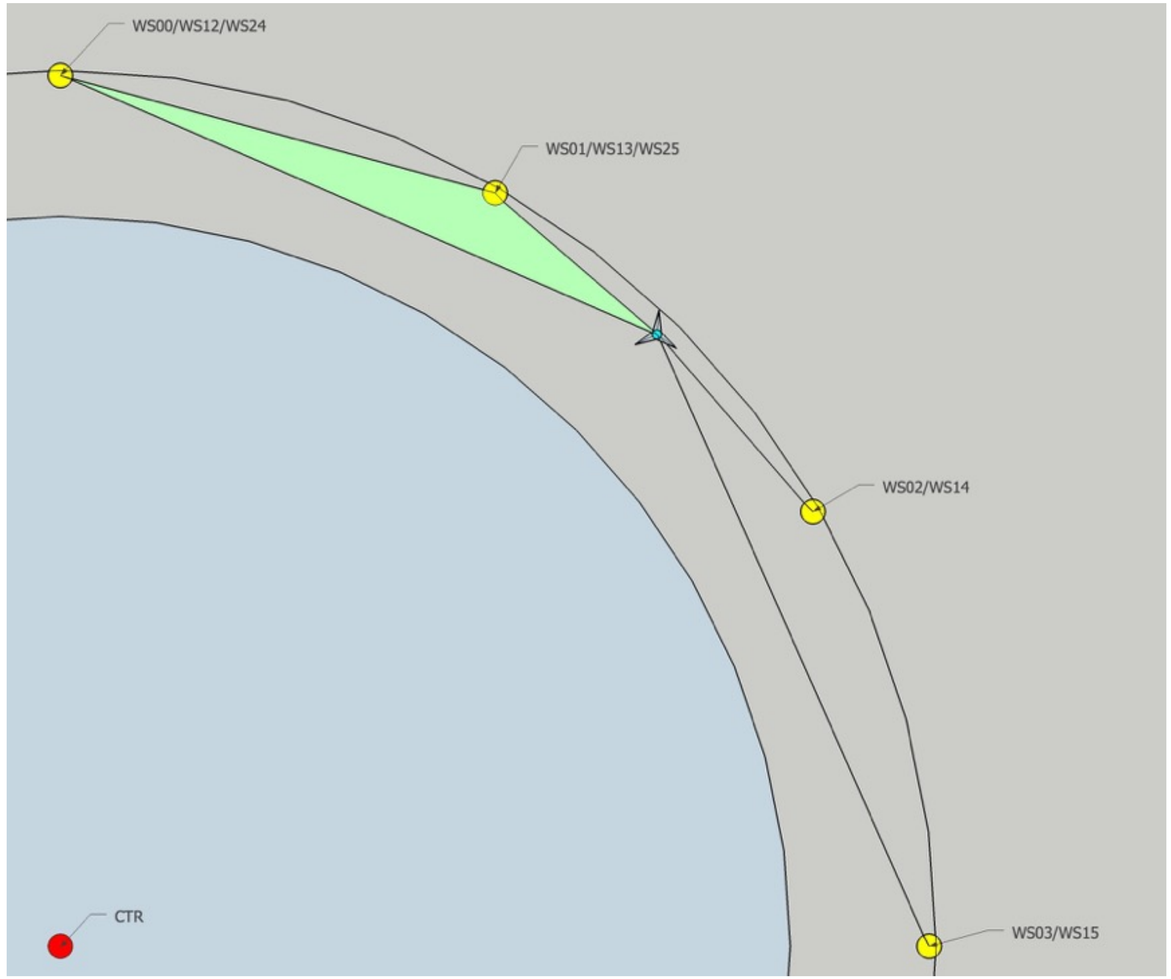
- Survey starts from the base WS00-WS01 (stations with known positions - coords)
- Instrument (TP) located close (~2.5m) to one of the wall stations (WS01)
- Right angle resection triangle
- Measurements:
  - one series on angles, only one face (FL),
  - 2 directions & 2 distances to backsight stations (WS00 & WS01)
  - 2 directions & 2 distances to foresight stations (WS02 & WS03)
- Transfer of instrument to new position (after WS03)
- Continuation of surveys until 2 full rounds are achieved

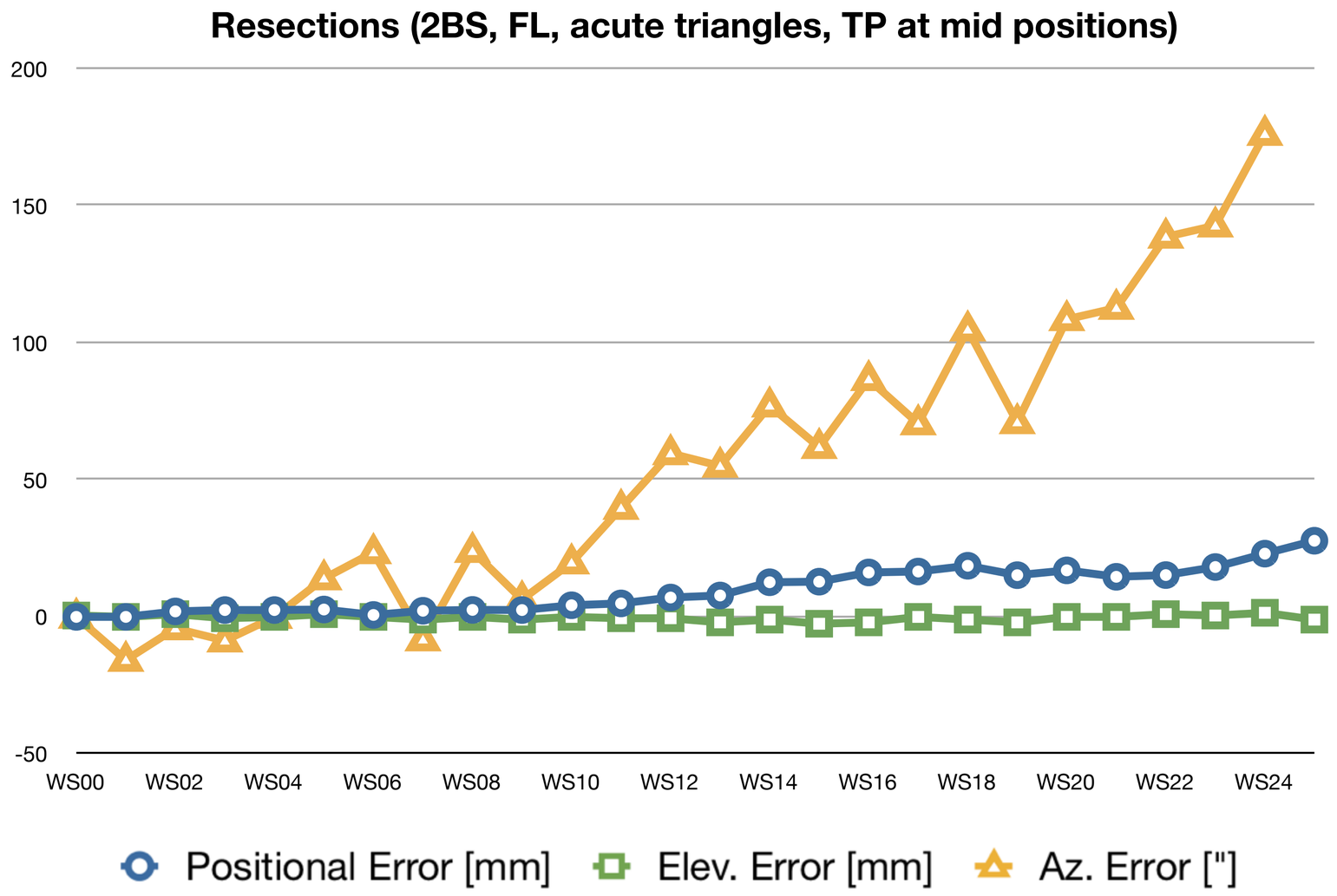



Resections (2BS, FL, ~90º triangles)
200
150
100
50
0
-50
WS00
WS02
WS04
WS06
WS08
WS10
WS12
WS14
WS16
WS18
WS20
WS22
WS24
Positional Error [mm]
Elev. Error [mm]
Az. Error ["]

Case#3 - Simple Resections (2BS, FL, acute triangles, TP at mid position)

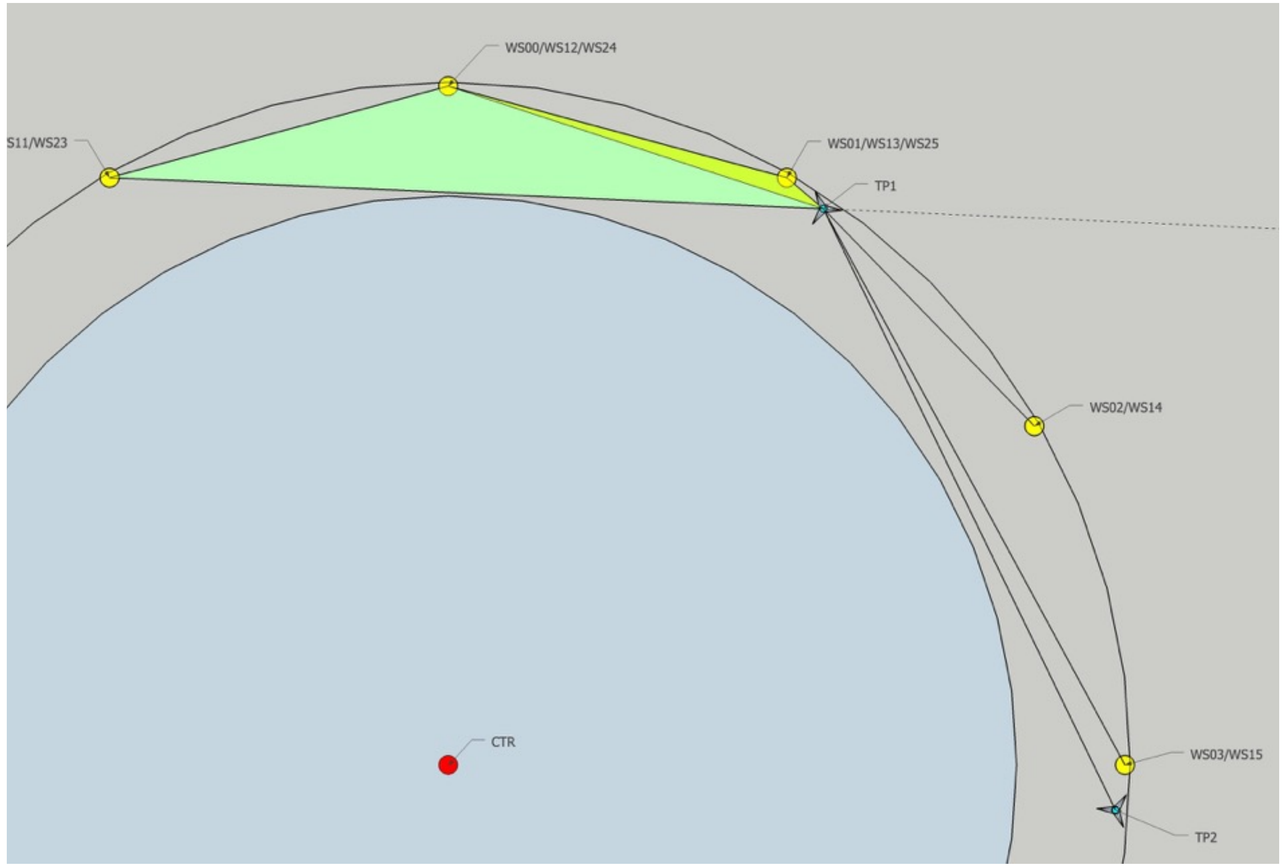
- Survey starts from the base WS00-WS01 (stations with known positions - coords)
- Instrument (TP) located at mid position between wall stations (WS01 & WS02)
- Acute shape of the resection triangle
- Measurements:
  - one series on angles, only one face (FL),
  - 2 directions & 2 distances to backsight stations (WS00 & WS01)
  - 2 directions & 2 distances to foresight stations (WS02 & WS03)
- Transfer of instrument to new position (between WS03 & WS04)
- Continuation of surveys until 2 full rounds are achieved




Resections (2BS, FL, acute triangles, TP at mid positions)
200
150
100
50
0
-50
WS00
WS02
WS04
WS06
WS08
WS10
WS12
WS14
WS16
WS18
WS20
WS22
WS24
Positional Error [mm]
Elev. Error [mm]
Az. Error ["]

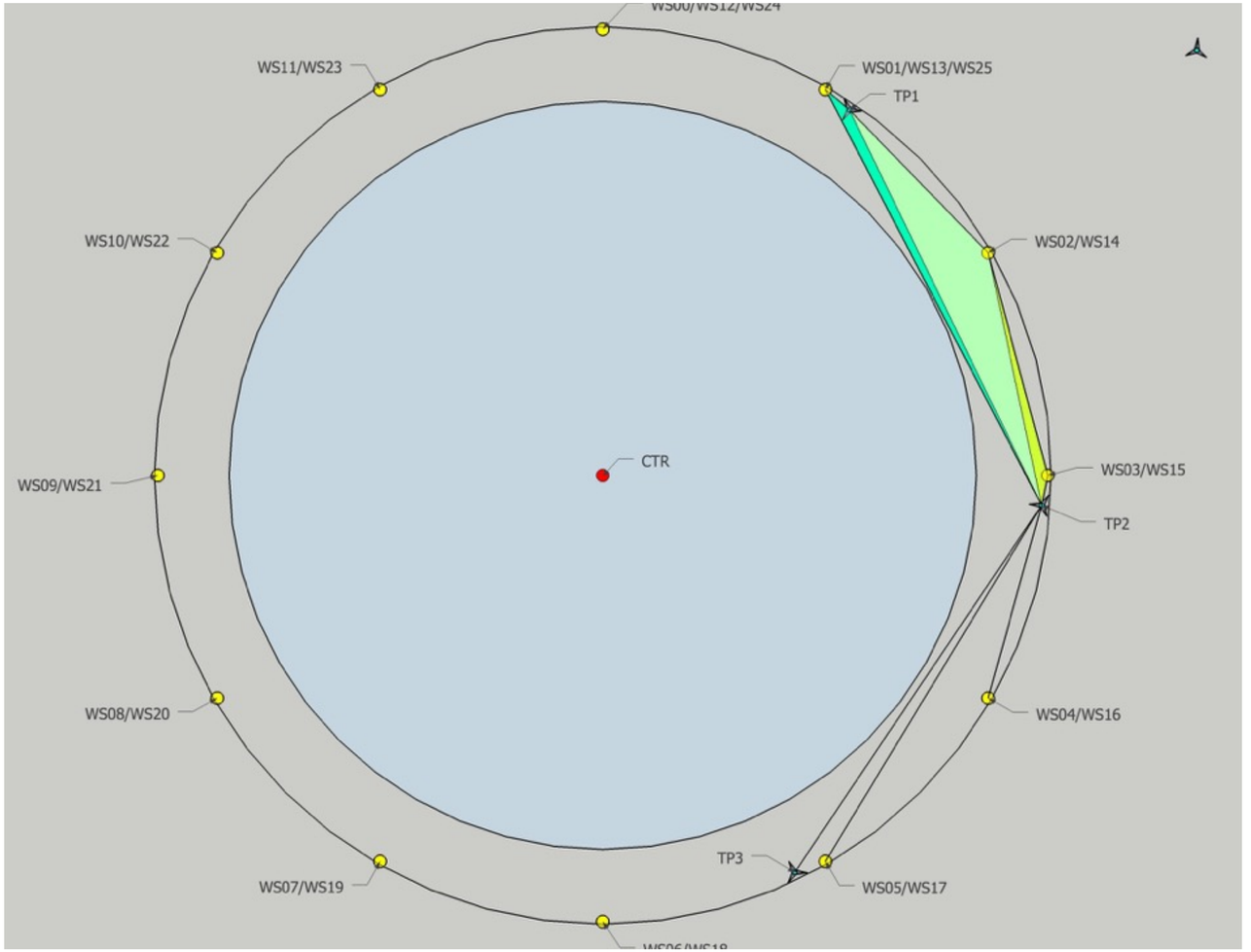
Case#4 - Free Stationing (3BS+TP, FL, acute triangles)

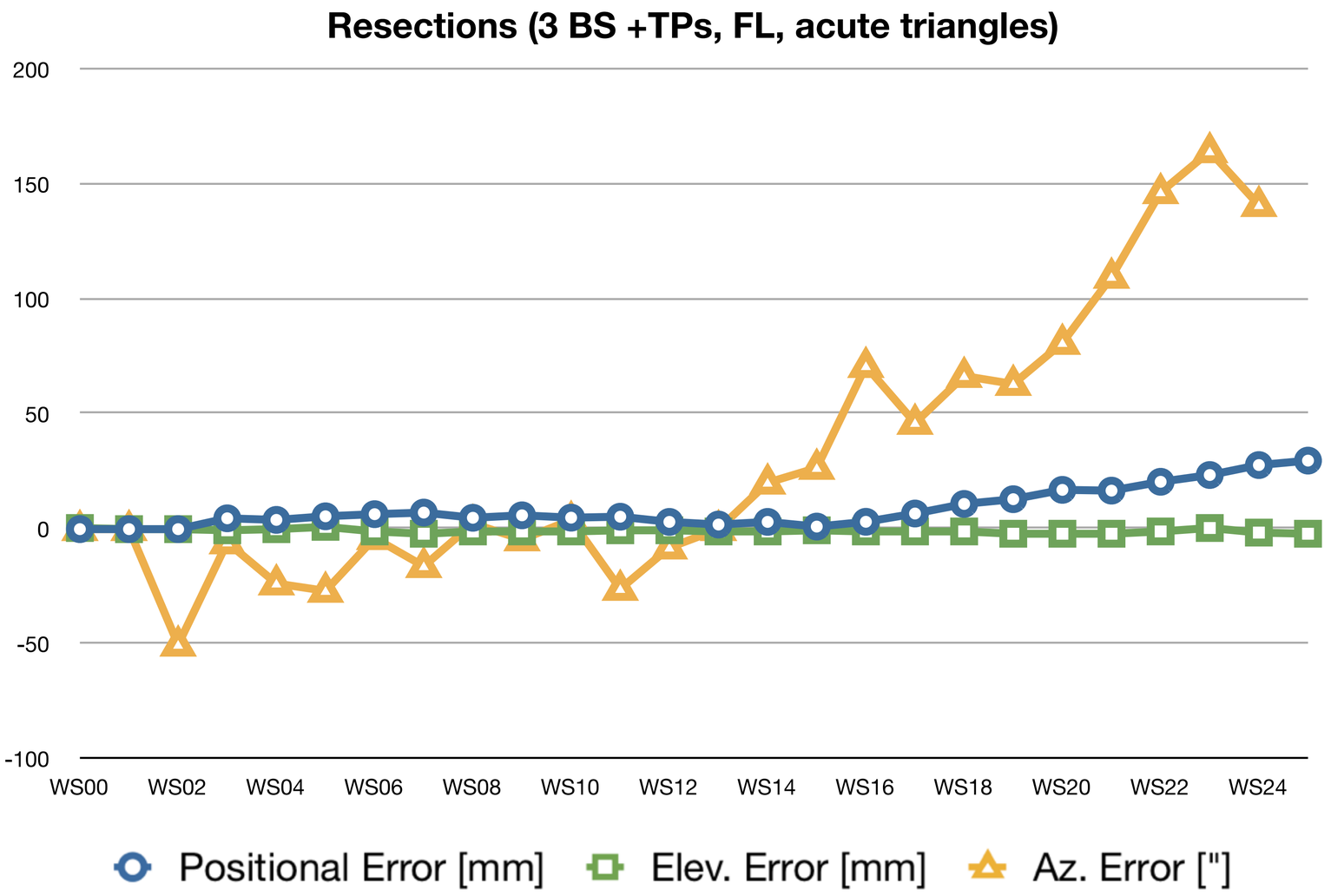
- Survey starts from the base WS11-WS00-WS01 (3 stations with known positions - coords)
- Instrument (TP) located close to the last station (WS01)
- Acute shape of the resection triangle
- Measurements:
  - Setup at the station TP1 (one series on angles, only one face (FL)),
  - 3 directions & 3 distances to backsight stations (WS11, WS00 & WS01)
  - 3 directions & 3 distances to foresight stations (WS02 & WS03 and TP2)
- Transfer of instrument to the new position (TP2)



Case#4 (cont.) - Free Stationing (3BS+TP, FL, acute triangles)

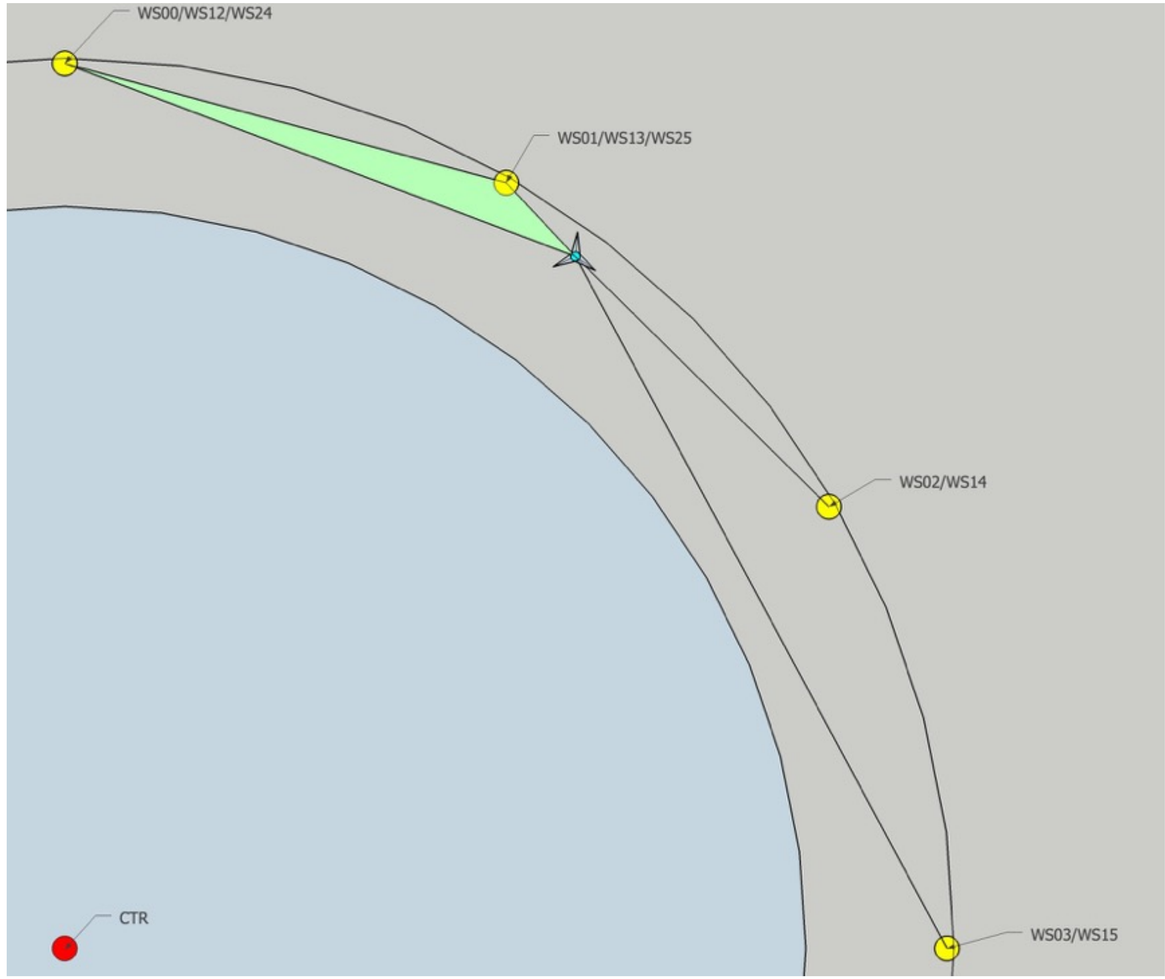
- Transfer of instrument to the new position (TP2)
- Measurements:
  - Setup at the station TP2 (one series on angles, only one face (FL)),
  - 4 directions & 4 distances to backsight stations (WS01, TP1, WS02 & WS03)
  - 3 directions & 3 distances to foresight stations (WS04 & WS05 and TP3)
- Transfer of instrument to the new position (TP3)
- Continuation of surveys until 2 full rounds are achieved

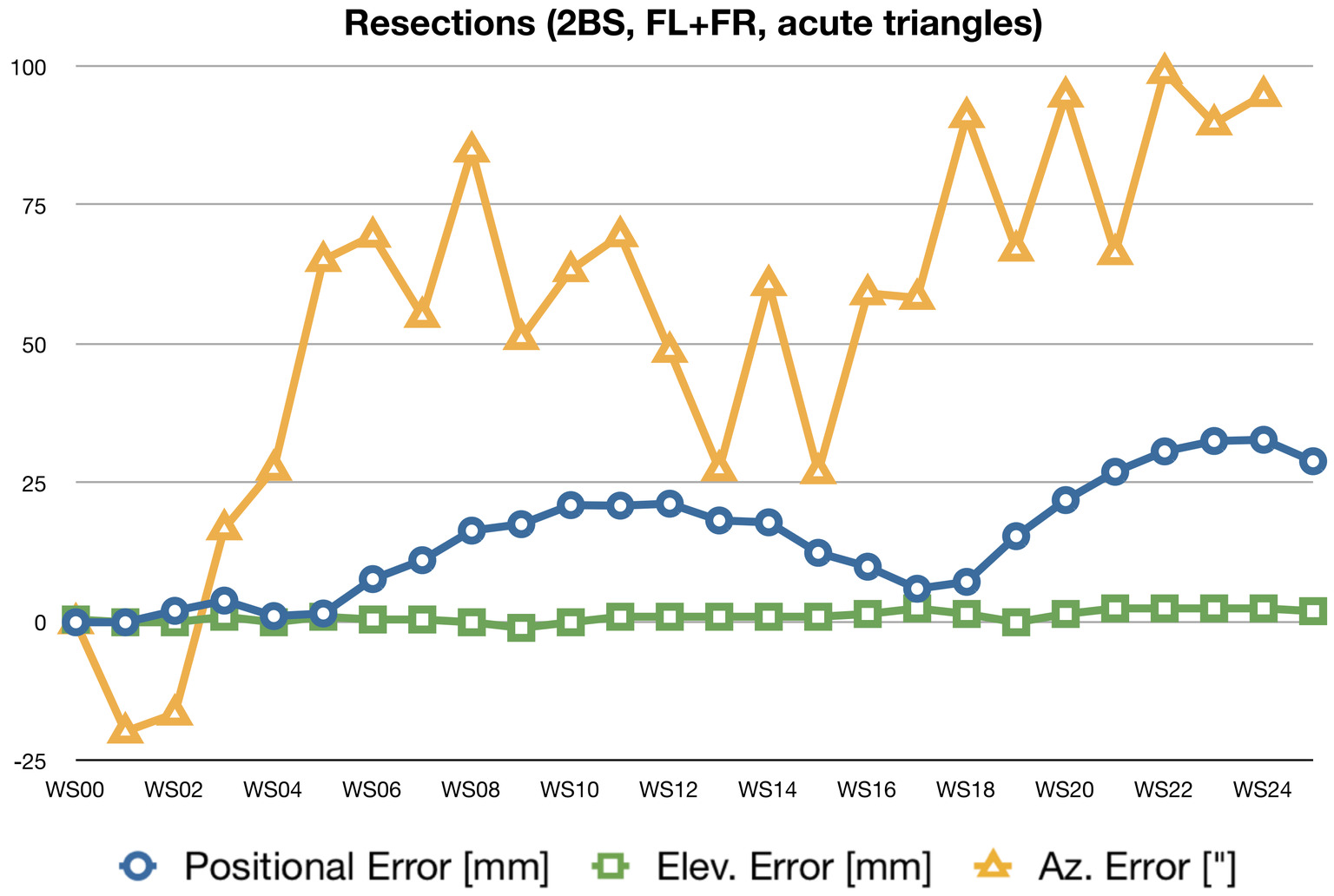



Resections (3 BS +TPs, FL, acute triangles)
200
150
100
50
0
-50
-100
WS00
WS02
WS04
WS06
WS08
WS10
WS12
WS14
WS16
WS18
WS20
WS22
WS24
Positional Error [mm]
Elev. Error [mm]
Az. Error ["]

Case#5 - Simple Resections (2BS, FL+FR, acute triangles)

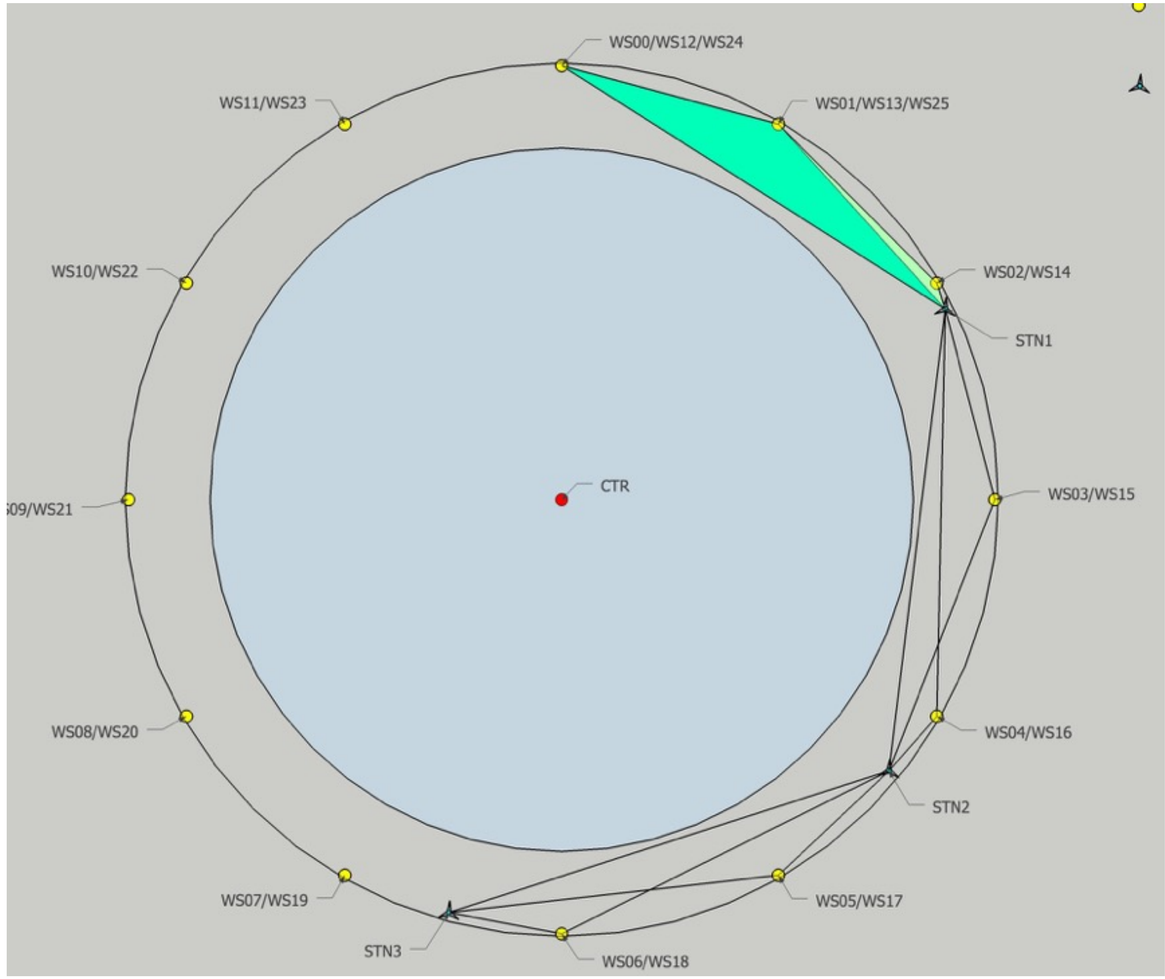
- Survey starts from the base WS00-WS01 (stations with known positions - coords)
- Instrument (TP) located close (~4m) to one of the wall stations (WS01)
- Acute shape of the resection triangle
- Measurements:
  - **angles are measured using Face Left (FL) and Face Right (FR)**
  - 2 directions & 2 distances to backsight stations (WS00 & WS01)
  - 2 directions & 2 distances to foresight stations (WS02 & WS03)
- Transfer of instrument to new position (after WS03)
- Continuation of surveys until 2 full rounds are achieved

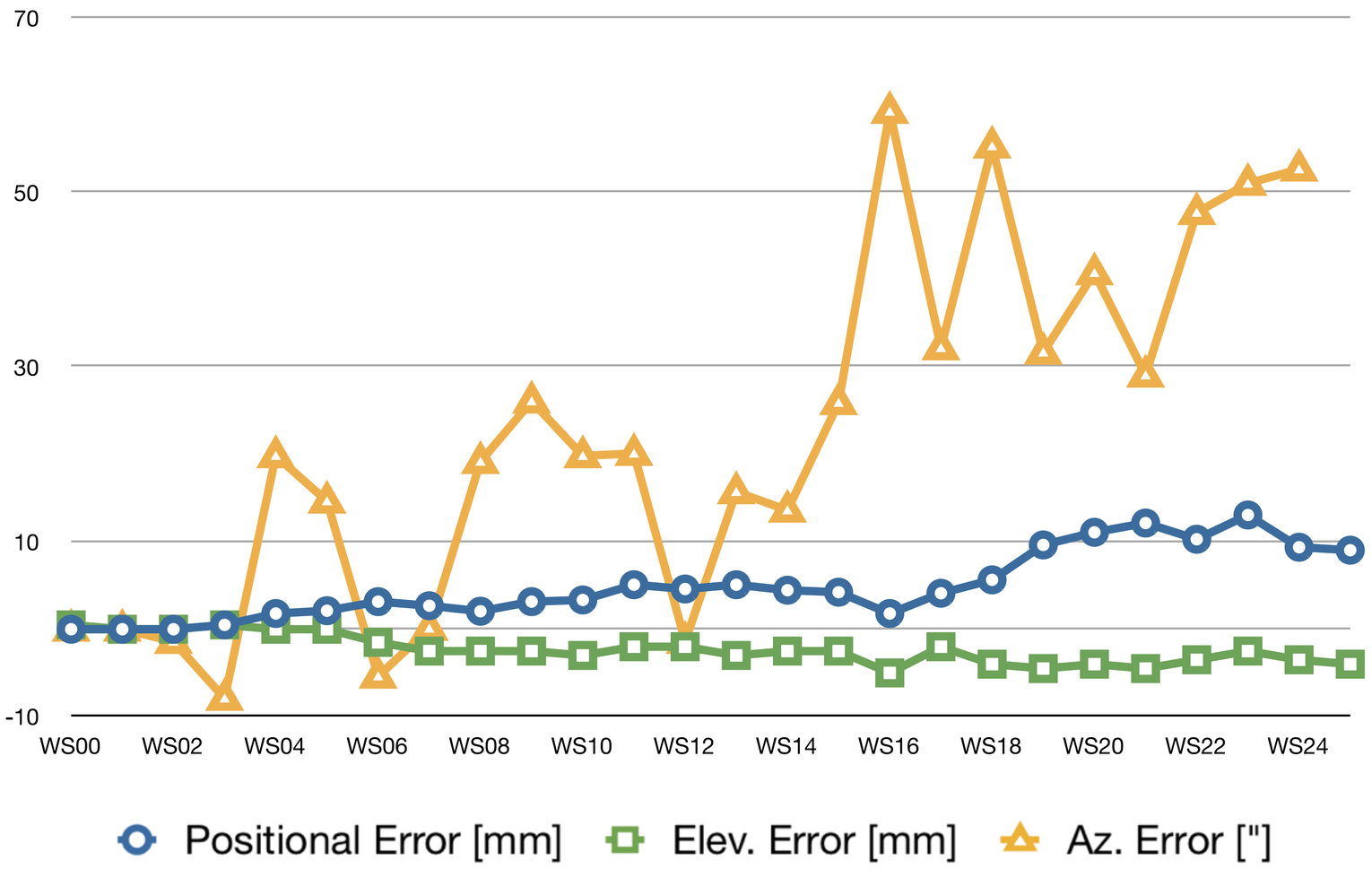



Resections (2BS, FL+FR, acute triangles)
100
75
50
25
0
-25
WS00
WS02
WS04
WS06
WS08
WS10
WS12
WS14
WS16
WS18
WS20
WS22
WS24
Positional Error [mm]
Elev. Error [mm]
Az. Error ["]

Case#6 - Forced Centred Traverse (FL only, WS as sideshots)

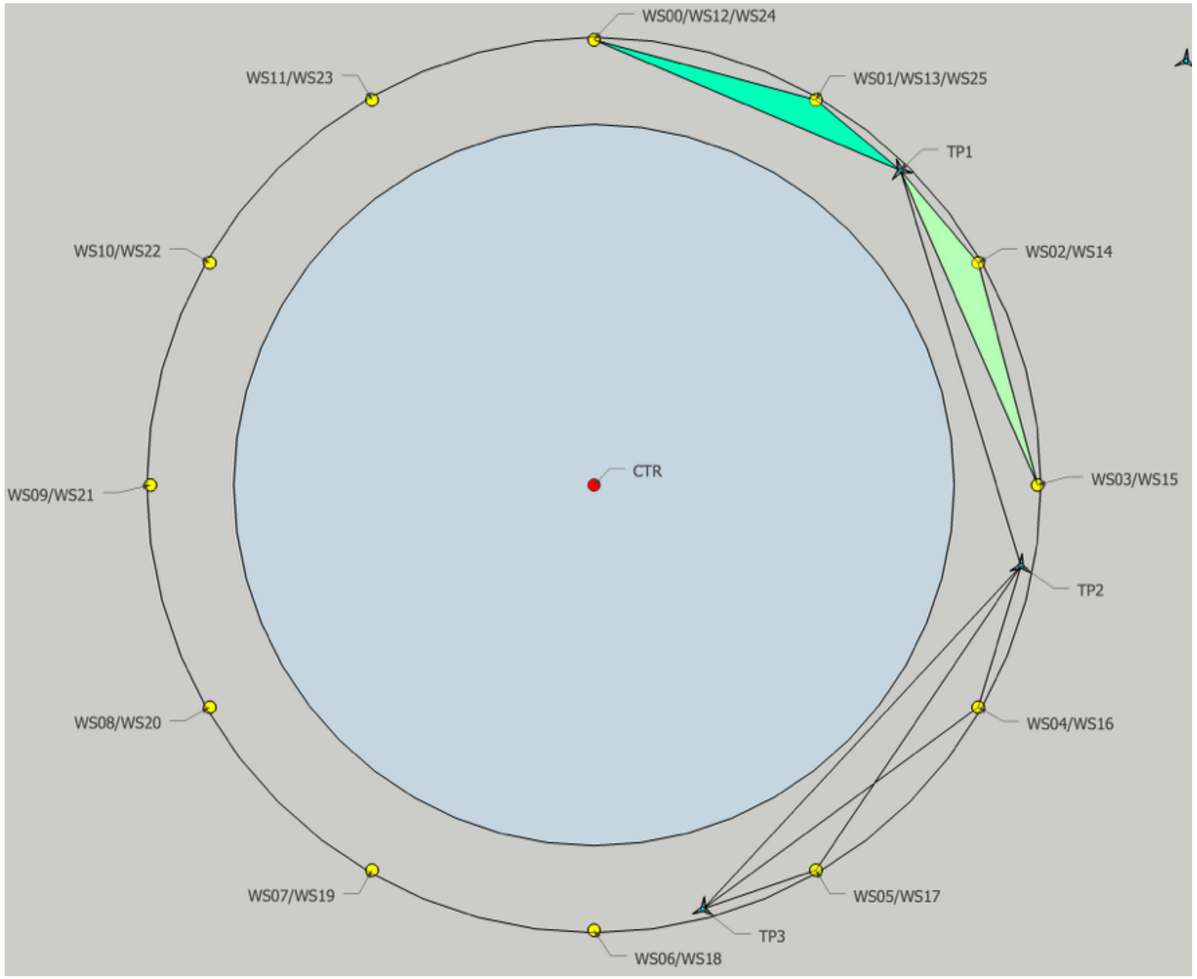
- Survey starts from the base WS00-WS01-WS02 (3 stations with known positions - coords)
- Instrument (STN1) located close to the last station (WS02)
- Acute shape of the resection triangle
- Measurements:
  - 3 directions & 3 distances to backsight stations (WS00, WS01 & WS02) - position and orientation of the first traverse station (STN1) by Free Stationing (one series on angles, only one face (FL)),
  - Start of a traverse (STN1)
  - Foresight on the next station (STN2)
  - Sideshots on WS03 & WS04
- Transfer of instrument to the new position (STN2) - forced centring
  - Backsight on STN1 and Foresight on STN3
  - 4 sideshots on WS03, WS04, WS05 & WS06
- Continuation of surveys until 2 full rounds are achieved

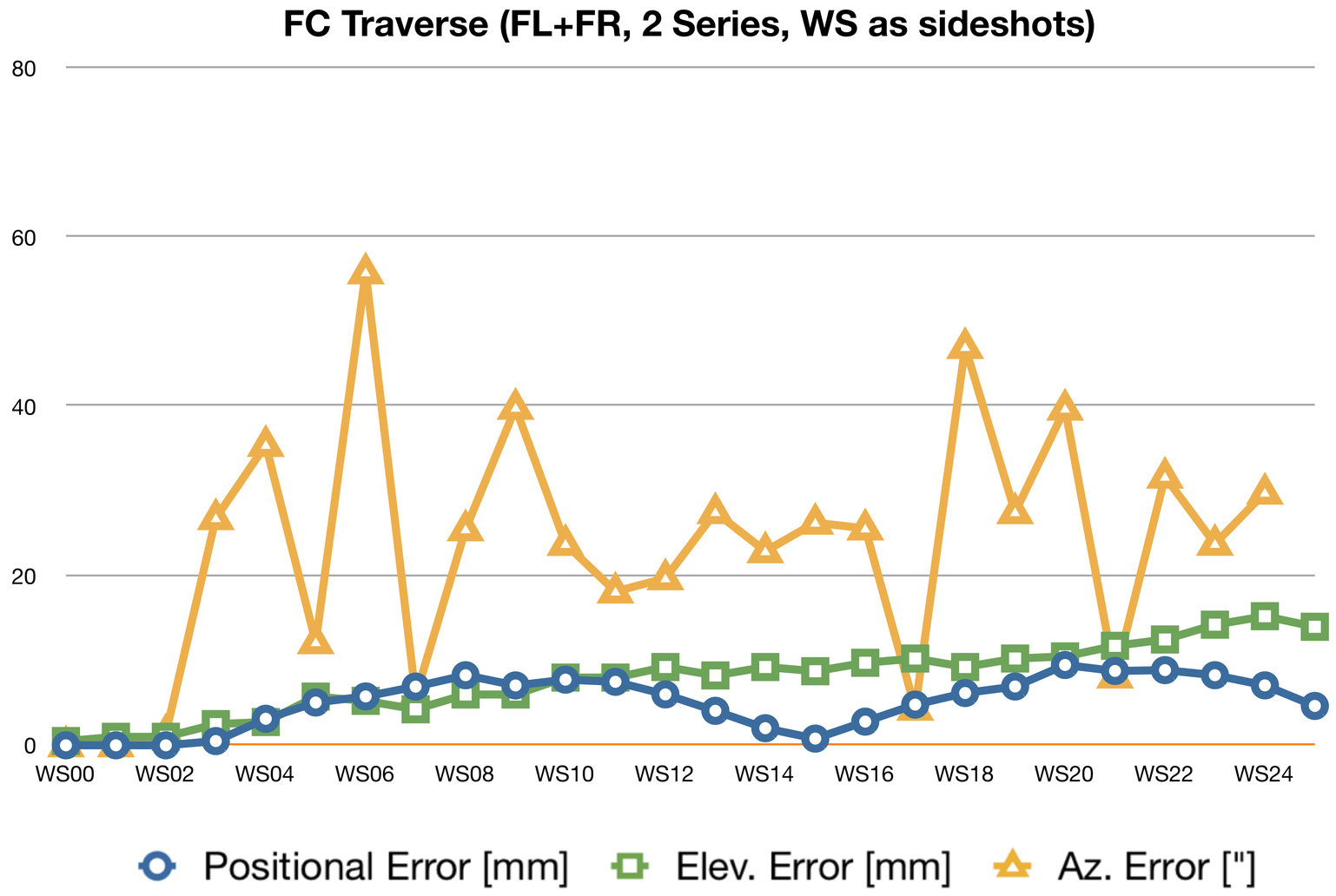



FC Traverse (FL, WS as sideshots)
70
50
30
10
-10
WS00
WS02
WS04
WS06
WS08
WS10
WS12
WS14
WS16
WS18
WS20
WS22
WS24
Positional Error [mm]
Elev. Error [mm]
Az. Error ["]

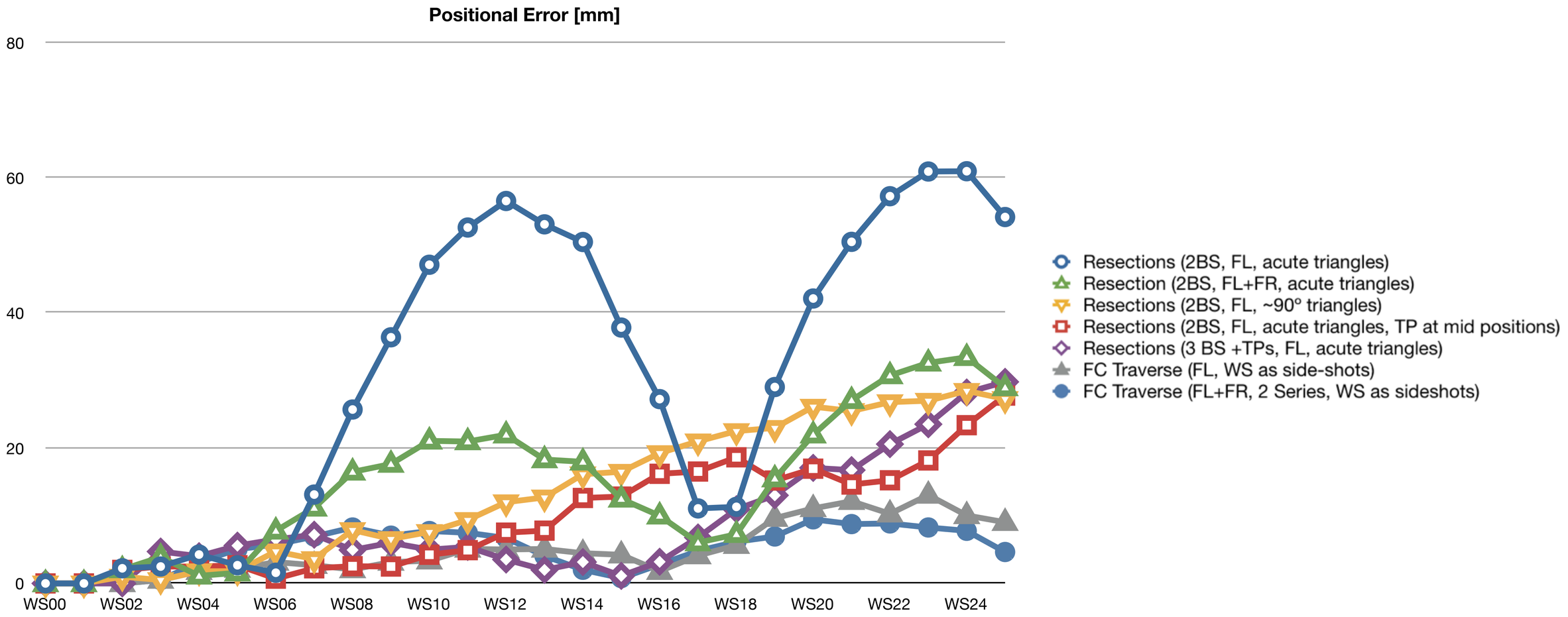
Case#7 - Forced Centred Traverse (FL+FR, 2 series, WS as sideshots)

- Survey starts from the base WS00-WS01-WS02-WS03 (4 stations with known positions - coords)
- Instrument (TP1) located between stations WS01 & WS02
- Acute shape of the resection triangle
- Measurements:
  - 4 directions & 4 distances to backsight stations (WS00, WS01, WS02 & WS03) - position and orientation of the first traverse station (STN1) by Free Stationing (two series on angles, FL & FR)
  - Start of a traverse at TP1
  - Foresight on the next station (TP2) (two series on angles, FL & FR)
  - Transfer of instrument to TP2 (forced centring) and backsight on TP1
  - Sideshots on WS04 & WS05 (one series, FL & FR)
  - Transfer of instrument to TP3 (forced centring), backsight on TP2 and foresight on TP4
  - 4 sideshots on WS04, WS05, WS06 & WS07
- Continuation of surveys until 2 full rounds are achieved

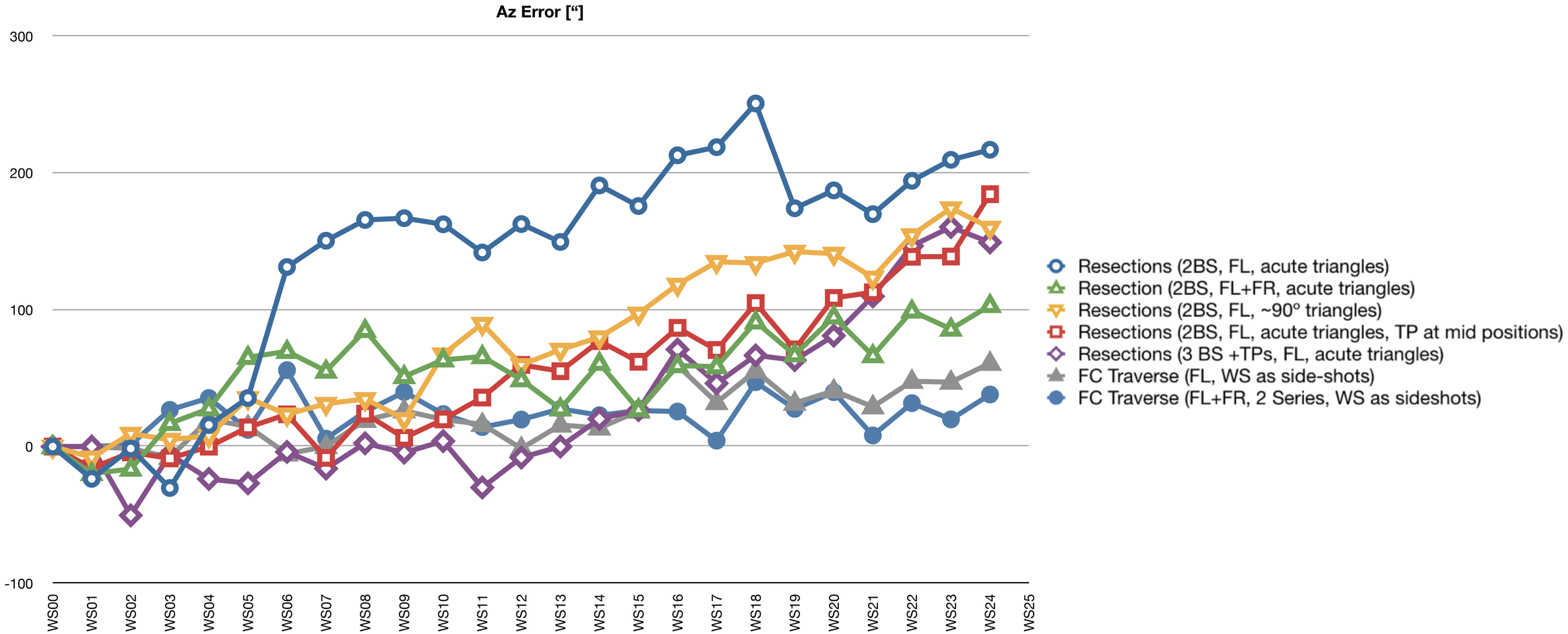


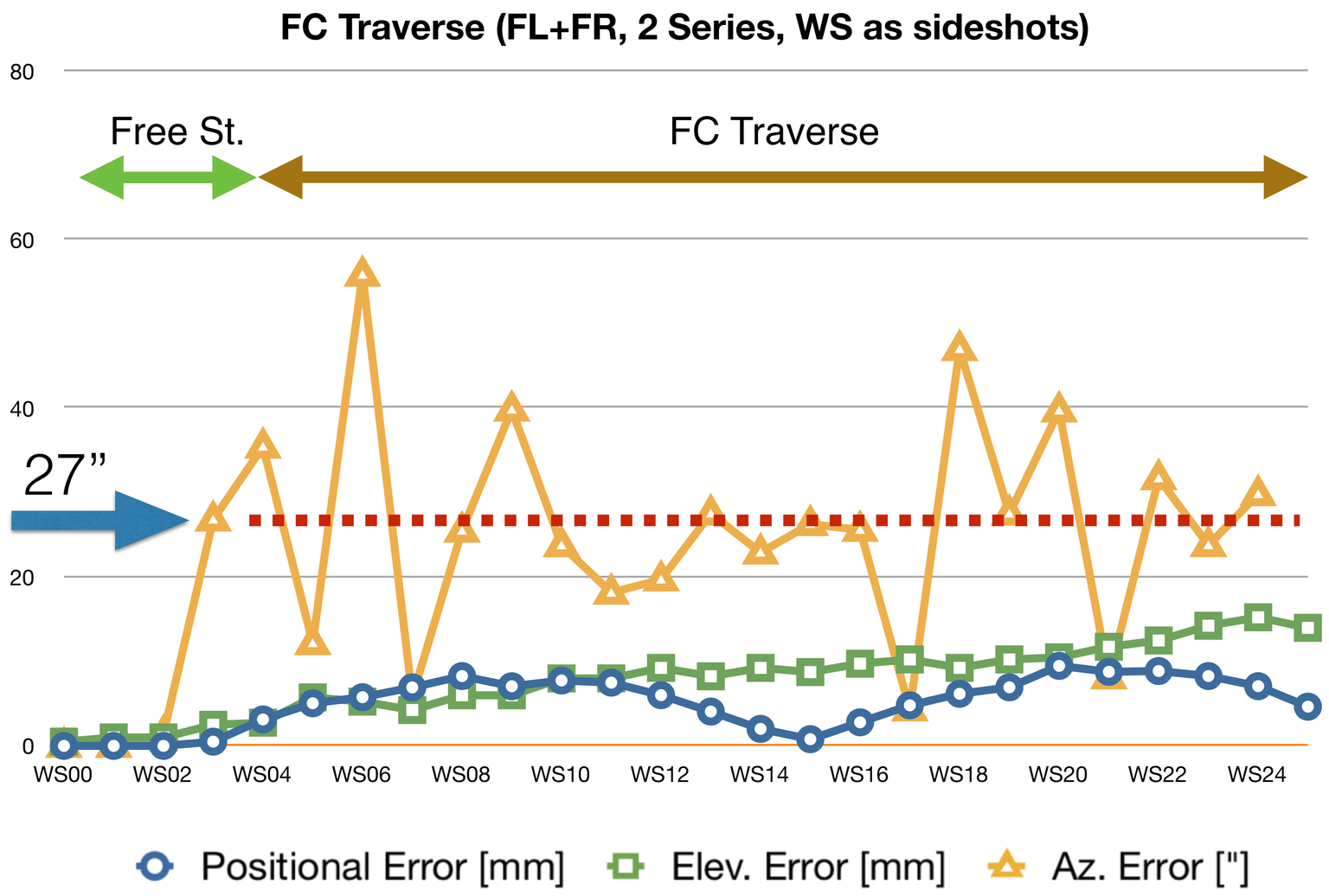

FC Traverse (FL+FR, 2 Series, WS as sideshots)
80
60
40
20
0
WS00
WS02
WS04
WS06
WS08
WS10
WS12
WS14
WS16
WS18
WS20
WS22
WS24
Positional Error [mm]
Elev. Error [mm]
Az. Error ["]

Comparison of Positional Errors

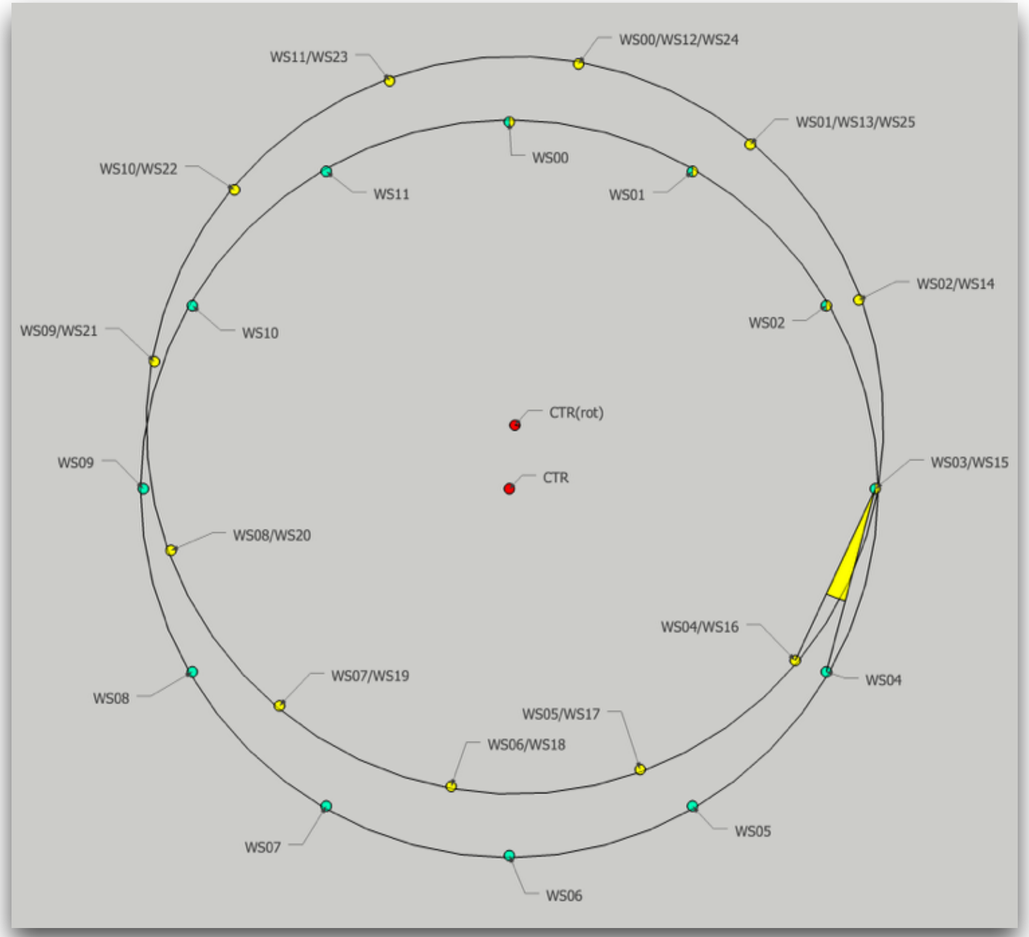


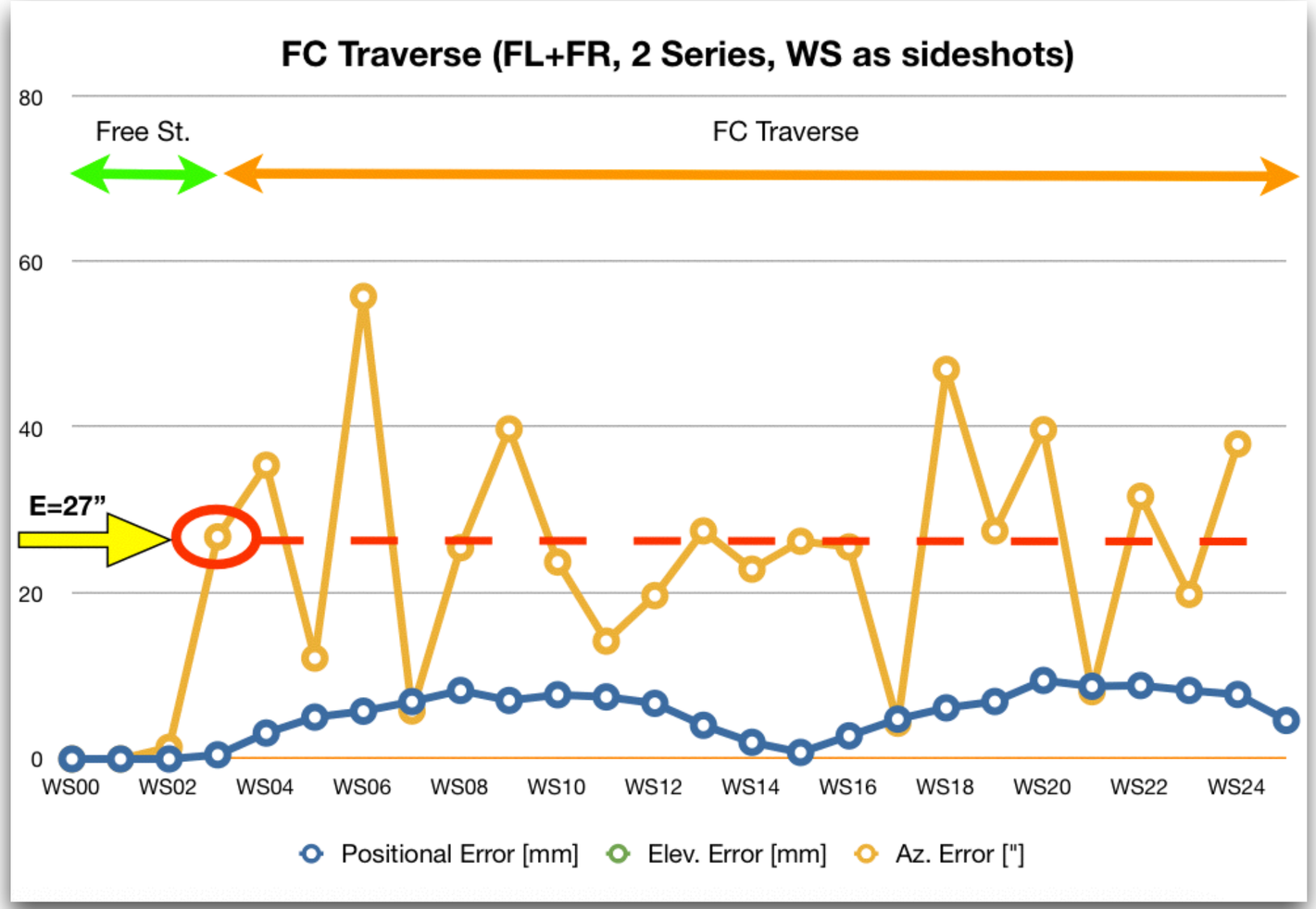
Comparison of Az Errors



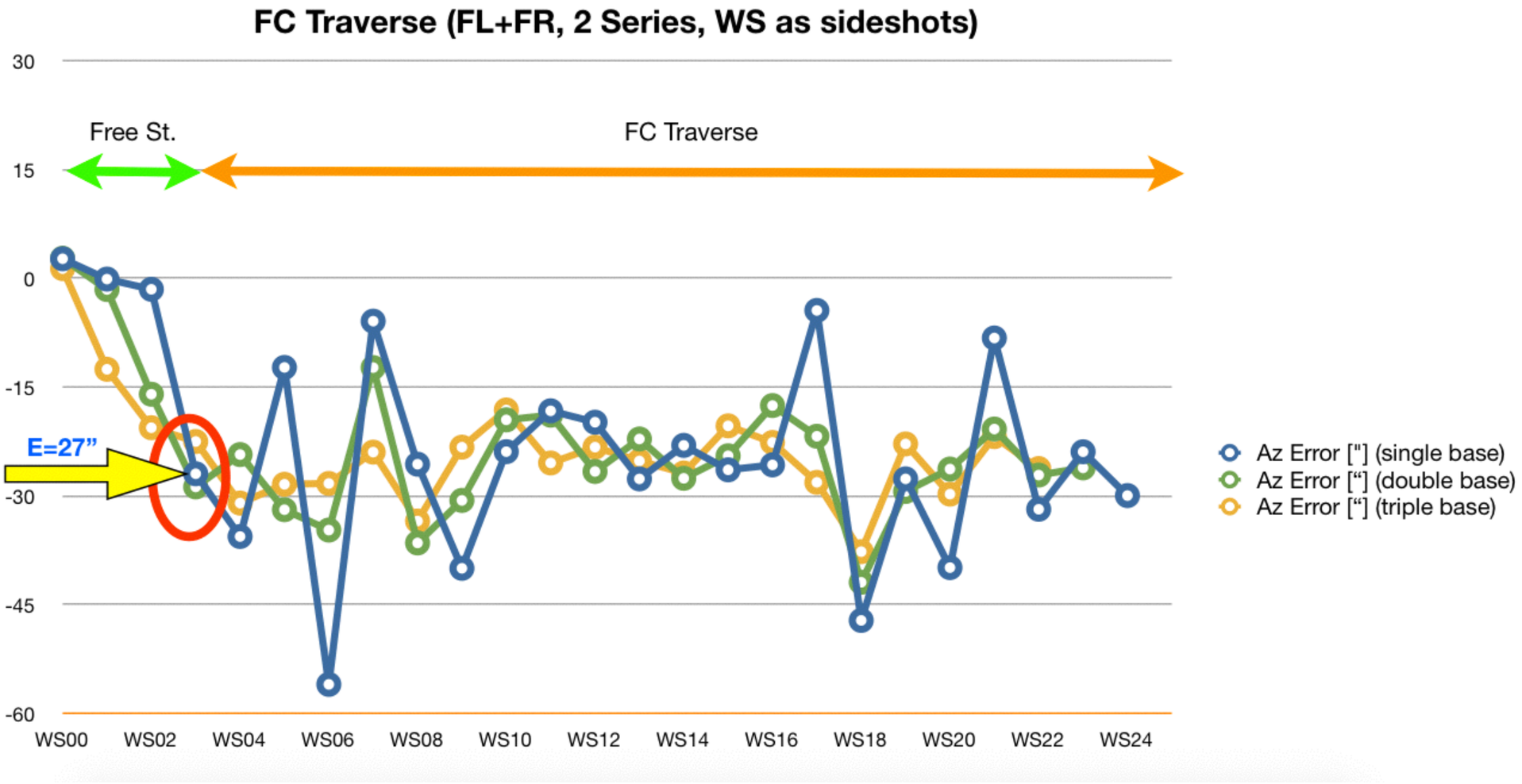

FC Traverse (FL+FR, 2 Series, WS as sideshots)
80
60
40
20
0
Free St.
FC Traverse
27”
WS00
WS02
WS04
WS06
WS08
WS10
WS12
WS14
WS16
WS18
WS20
WS22
WS24
Positional Error [mm]
Elev. Error [mm]
Az. Error ["]

Impact of Initial Az Error

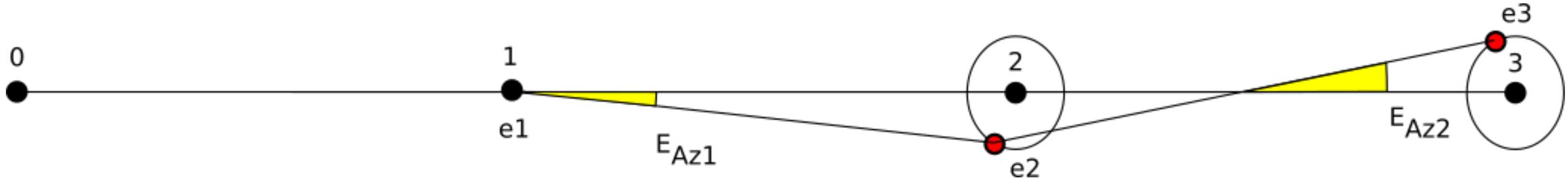




Impact of Initial Az Error



Impact of Position Error on Direction Error



$$E_{Az} = \frac{\rho''}{b}\sqrt{\frac{e_1^2 + e_2^2}{2}}$$

Base (b) [m]	e1=0 e2=1	e1=0 e2=2
18	8.1	16.2
35	4.2	8.3

e2=1 e3=1	e2=2 e3=2
11.5	22.9
5.9	11.8

Conclusions

- Positional & Directional errors along a spiral decline are affected by two components:
  - The initial survey linking the following survey structure (along a decline) to the starting control points (Wall Stations)
  - Surveying technique applied for the transfer of position and direction along a decline
- The best results could be achieved using the following strategy:
  - Free Stationing to 3 or more WS as the initial survey (linking survey). FL & FR with angles measured minimum in two series. Coordinates and orientation of TP should be calculated by use of the Least Squares Adjustment (LSA).
  - Special care should be applied to the initial survey, as the initial Az Error will be transferred (and magnified) to the all following control points.
  - Use Forced Centring Traverse over temporary stations (TPs) to transfer position and direction along a decline to the next set of WS. WS are surveyed as side-shots from the traverse TPs.
  - Surveys should be done using FL & FR with angles measured minimum in two series.