



Microtriangulation for Automated Contactless High-Precision Metrology

Sébastien Guillaume

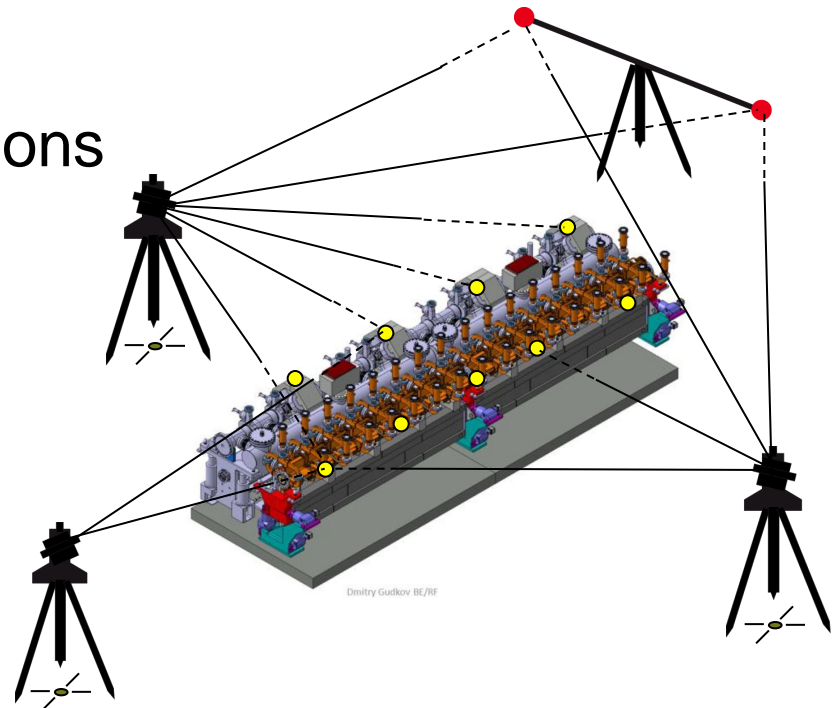
Institute of Geodesy and Photogrammetry
Geodesy and Geodynamics Laboratory
ETH Zürich

The Measurement System

QDaedalus

Qdaedalus for Microtriangulation

- Traditional geodetic network
- High Precise : $< 10 \mu\text{m}/\text{m}$
- Touchless
- Fully Automated
- Static and Kinematic Applications
- Low-cost
- Open & Flexible Software



QDaedalus: System Components

- Main Components

- Total Station
- CCD Sensor
- Focusing Mechanics
- Software (Qt c++)



- Additional Components

- Front Lens (for long range obs. > 13 m)
- Interface box (CCD Triggering synchronization of multiple system)
- External GPS Receiver (for Absolute CCD Timing)

QDaedalus: System Components

■ Main Components

- Total Station
- **CCD Sensor**
- Focusing Mechanics
- Software (Qt c++)



- 1024 x 768 pixel (4.65 x 4.65 μm)
- Fire Wire connection (30 fps)
- External Trigger
- Black and White

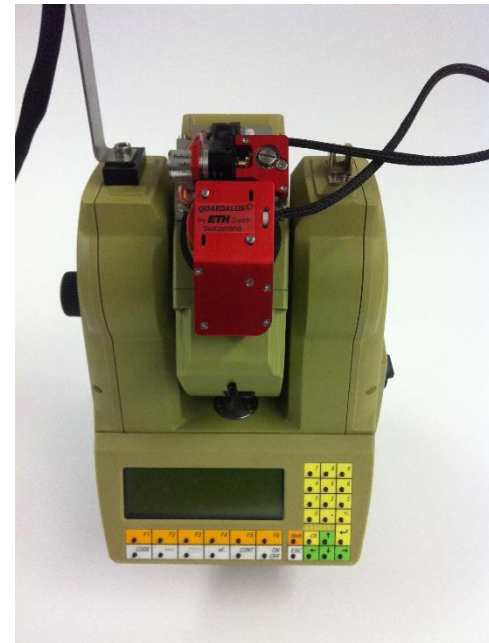
1 pixel = 4 arcsec

■ Additional Components

- Front Lens (for long range obs. > 13 m)
- Interface box (CCD Triggering synchronization of multiple system)
- External GPS Receiver (for Absolute CCD Timing)

QDaedalus: System Components

- Main Components
 - Total Station
 - **CCD Sensor**
 - Focusing Mechanics
 - Software (Qt c++)
- Additional Components
 - Front Lens (for long range obs. > 13 m)
 - Interface box (CCD Triggering synchronization of multiple system)
 - External GPS Receiver (for Absolute CCD Timing)



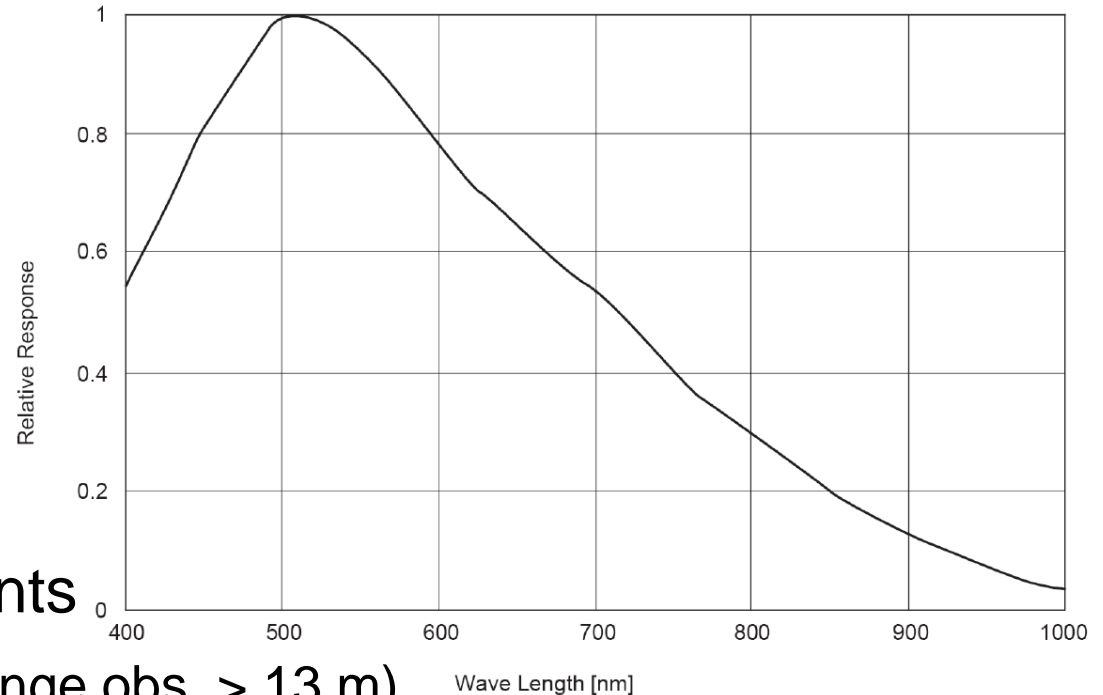
QDaedalus: System Components

- Main Components

- Total Station
- **CCD Sensor**
- Focusing Mechanics
- Software (Qt c++)

- Additional Components

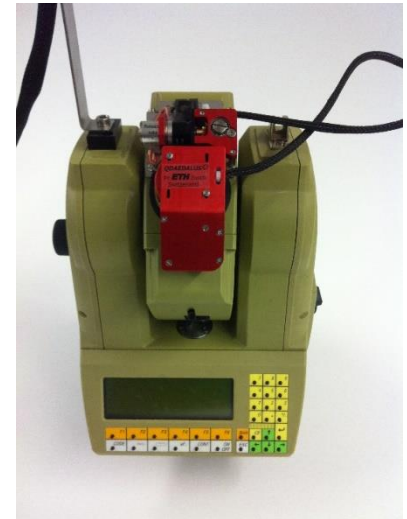
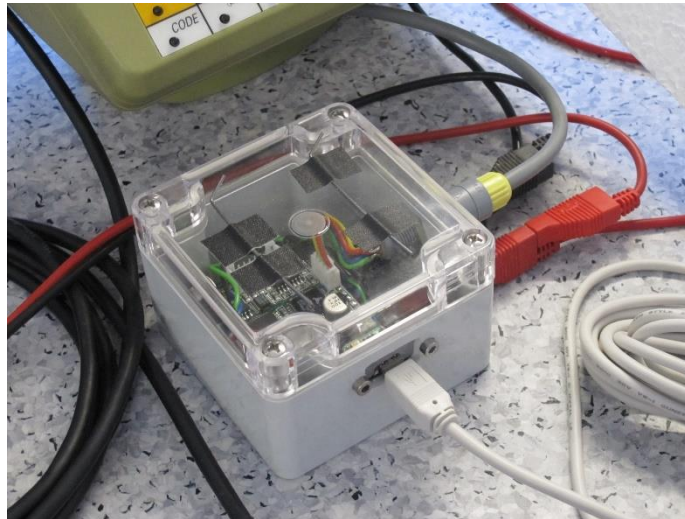
- Front Lens (for long range obs. > 13 m)
- Interface box (CCD Triggering synchronization of multiple system)
- External GPS Receiver (for Absolute CCD Timing)



QDaedalus: System Components

- Main Components

- Total Station
- CCD Sensor
- **Focusing Mechanics**
- Software (Qt c++)



- Additional Components

- Front Lens (for long range obs. > 13 m)
- Interface box (CCD Triggering synchronization of multiple system)
- External GPS Receiver (for Absolute CCD Timing)

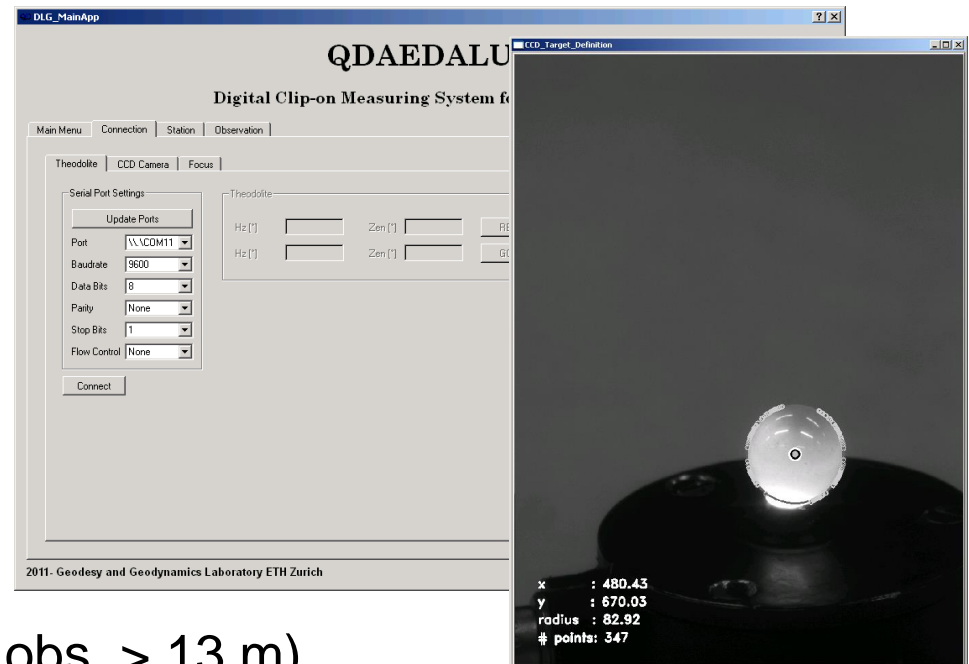
QDaedalus: System Components

- Main Components

- Total Station
- CCD Sensor
- Focusing Mechanics
- **Software (Qt c++)**

- Additional Components

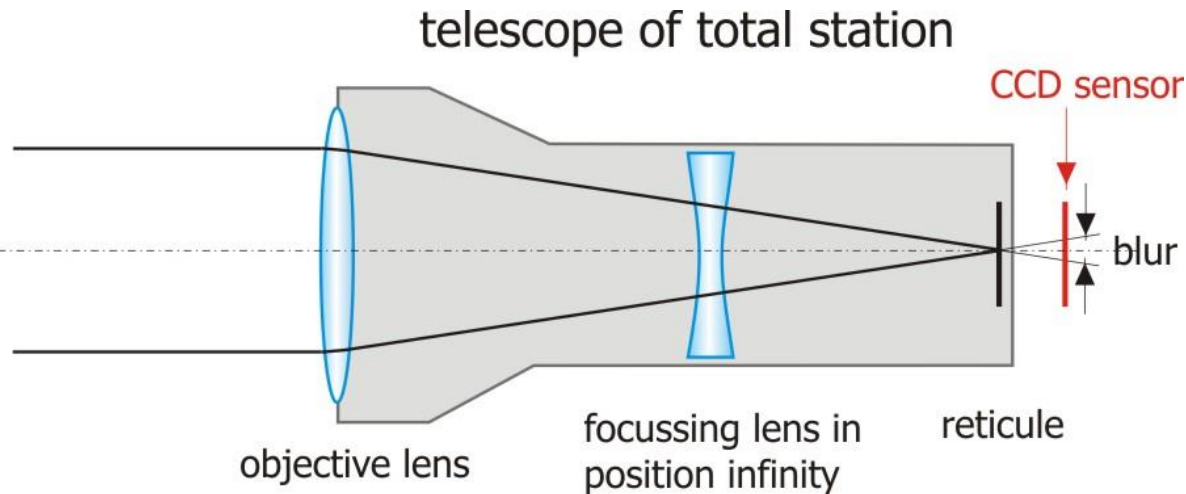
- Front Lens (for long range obs. > 13 m)
- Interface box (CCD Triggering synchronization of multiple system)
- External GPS Receiver (for Absolute CCD Timing)



QDaedalus: System Components

- Main Components

- Total Station
- CCD Sensor
- Focusing Mechanics
- Software (Qt c++)



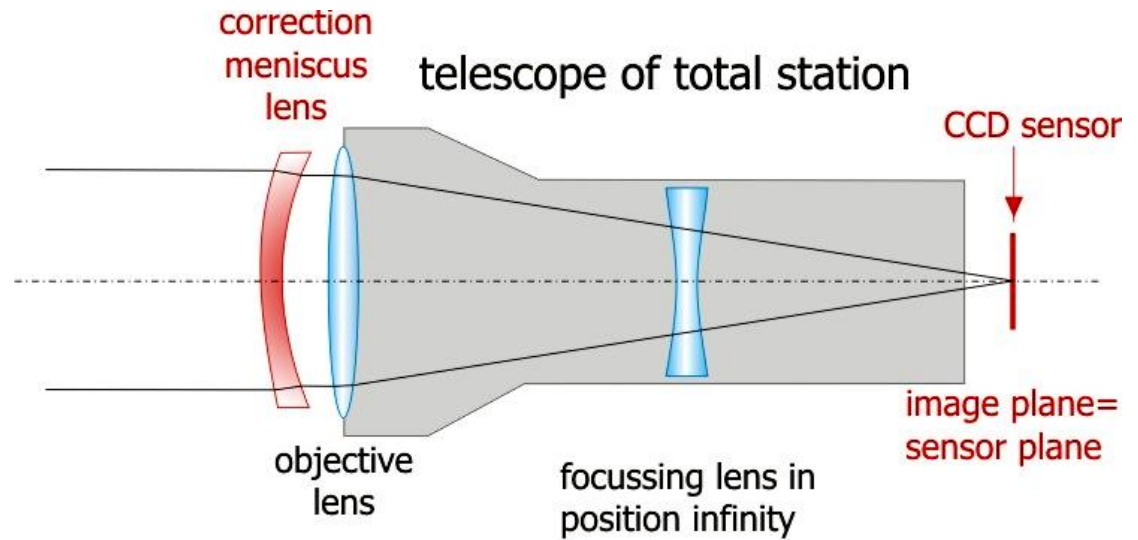
- Additional Components

- **Front Lens (for long range obs. > 13 m)**
- Interface box (CCD Triggering synchronization of multiple system)
- External GPS Receiver (for Absolute CCD Timing)

QDaedalus: System Components

■ Main Components

- Total Station
- CCD Sensor
- Focusing Mechanics
- Software (Qt c++)

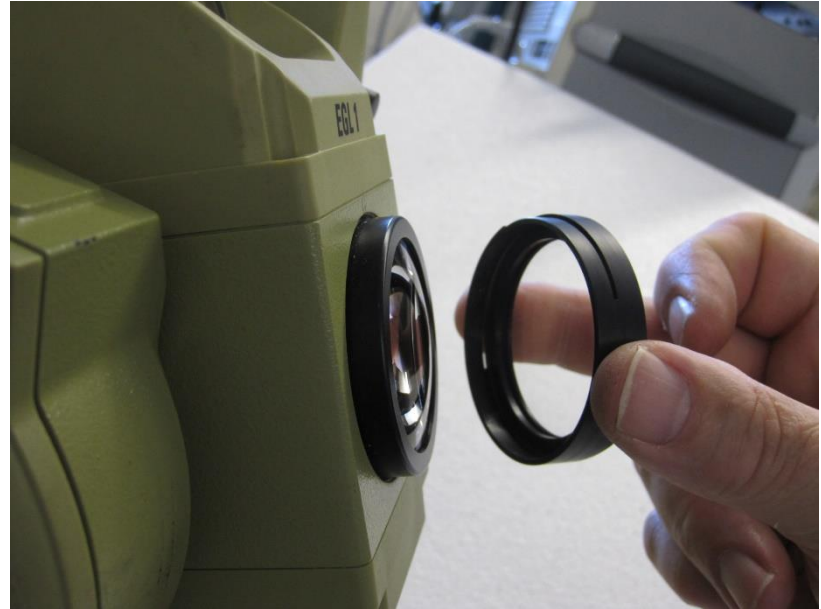


■ Additional Components

- **Front Lens (for long range obs. > 13 m)**
- Interface box (CCD Triggering synchronization of multiple system)
- External GPS Receiver (for Absolute CCD Timing)

QDaedalus: System Components

- Main Components
 - Total Station
 - CCD Sensor
 - Focusing Mechanics
 - Software (Qt c++)
- Additional Components
 - **Front Lens (for long range obs. > 13 m)**
 - Interface box (CCD Triggering synchronization of multiple system)
 - External GPS Receiver (for Absolute CCD Timing)



QDaedalus: System Components

- Main Components

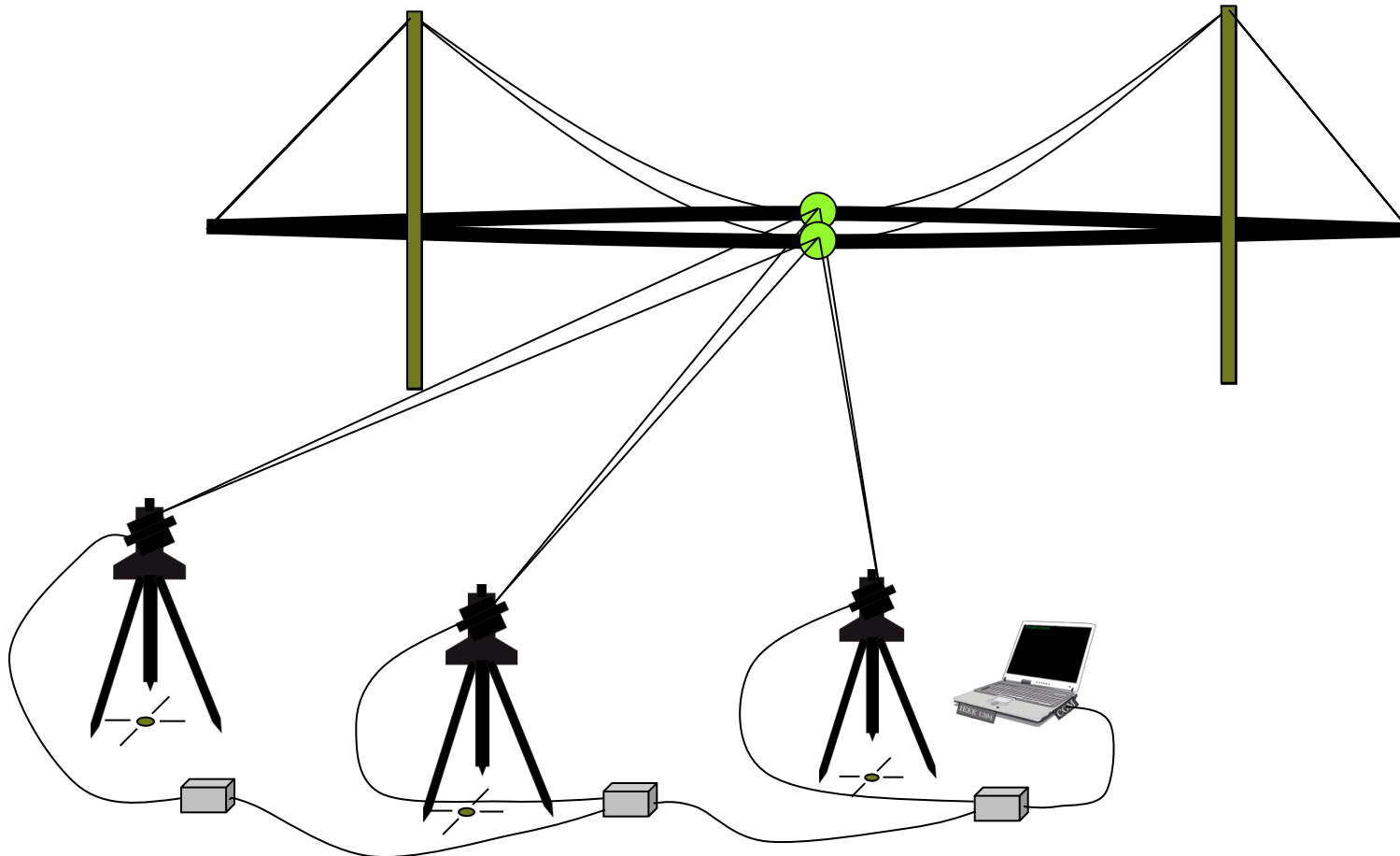
- Total Station
- CCD Sensor
- Focusing Mechanics
- Software (Qt c++)



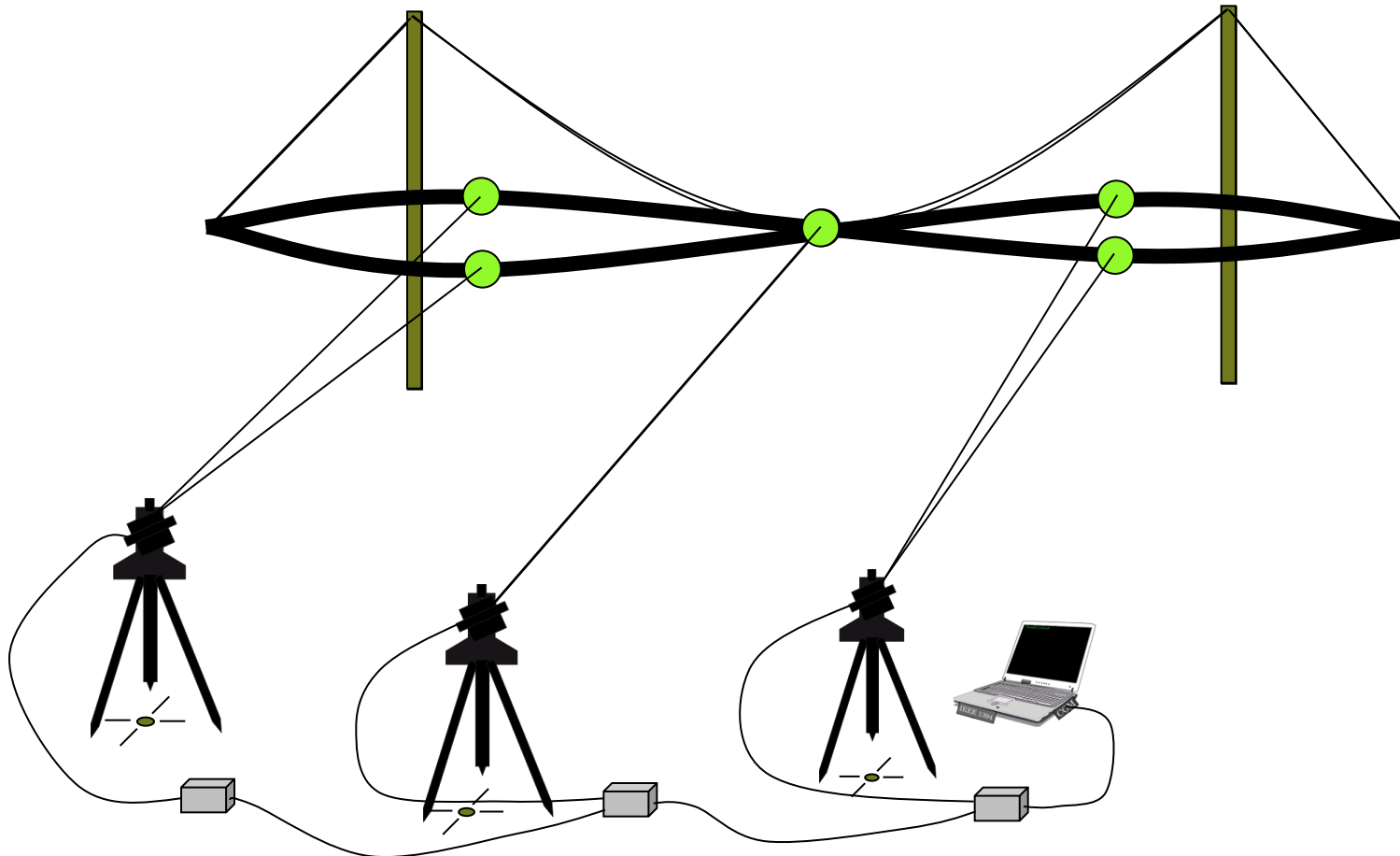
- Additional Components

- Front Lens (for long range obs. > 13 m)
- **Interface box (CCD Triggering synchronization of multiple system)**
- External GPS Receiver (for Absolute CCD Timing)

QDaedalus: System Components



QDaedalus: System Components



QDaedalus: System Components

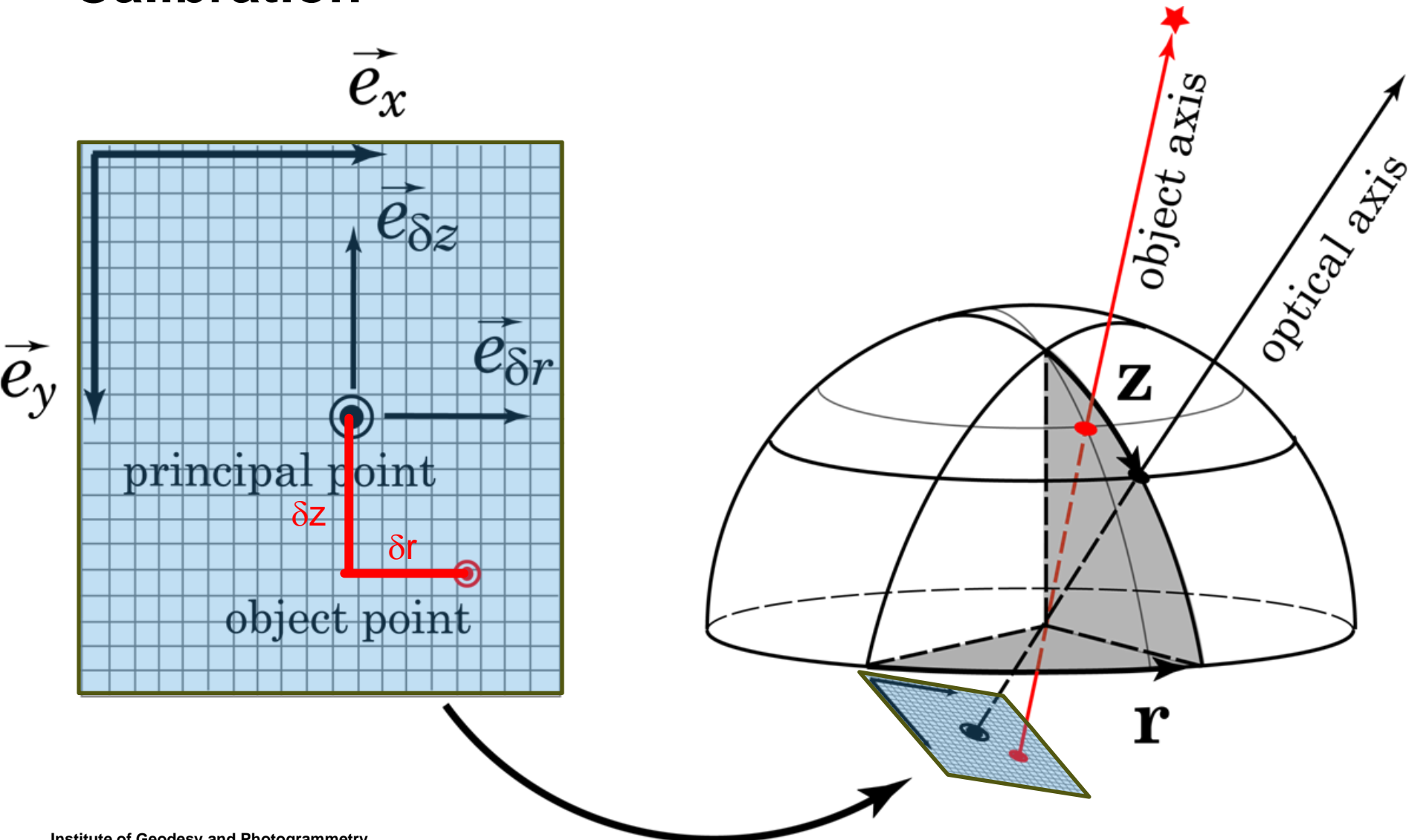
- Main Components
 - Total Station
 - CCD Sensor
 - Focusing Mechanics
 - Software (Qt c++)
- Additional Components
 - Front Lens (for long range obs. > 13 m)
 - Interface box (CCD Triggering synchronization of multiple system)
 - **External GPS Receiver (for Absolute CCD Timing)**



CCD-Space  **Theodolite-Space**

Calibration

Calibration



Calibration

Affine Transformation (6 parameters)

$$\begin{array}{l}
 r_{object} \\
 z_{object}
 \end{array}
 =
 \begin{array}{l}
 r_p \\
 z_p
 \end{array}
 +
 \underbrace{\frac{1}{\sin z_p} [a_{11} \cdot (x_{object} - x_p) + a_{12} \cdot (y_{object} - y_p)]}_{\delta r}$$

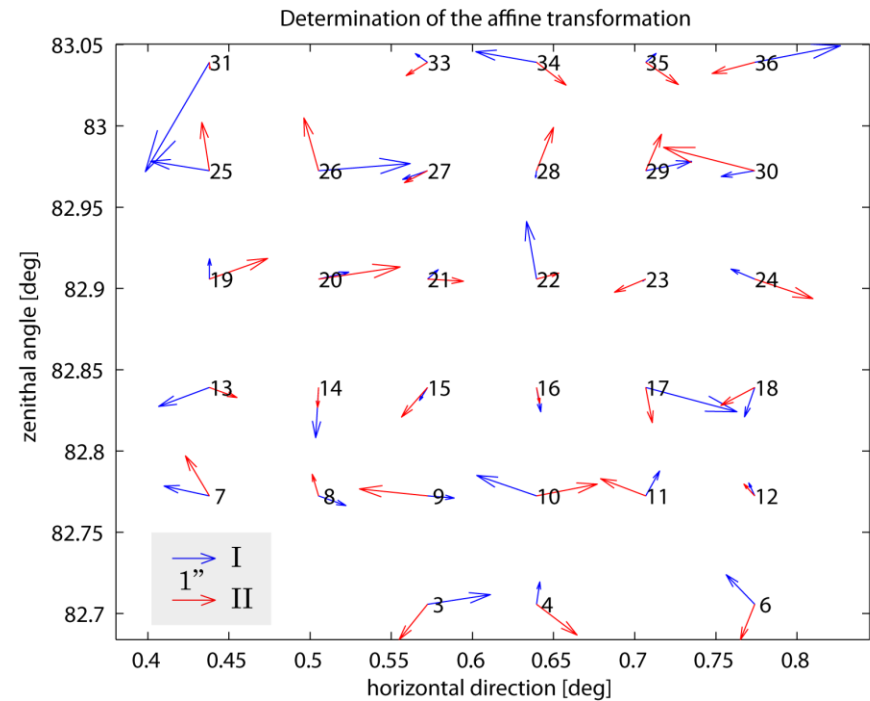
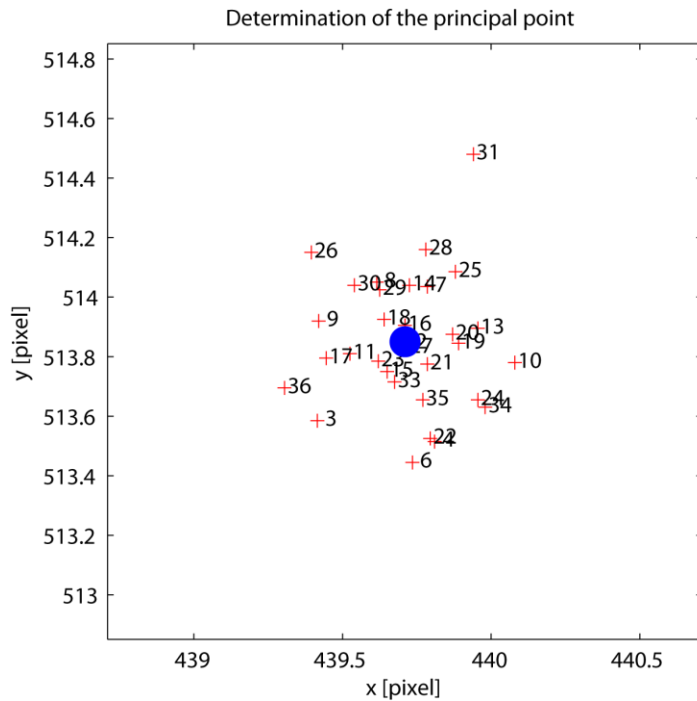
$$\begin{array}{l}
 r_{object} \\
 z_{object}
 \end{array}
 =
 \begin{array}{l}
 r_p \\
 z_p
 \end{array}
 +
 \underbrace{-a_{21} \cdot (x_{object} - x_p) - a_{22} \cdot (y_{object} - y_p)}_{\delta z}$$

object
angles

telescope
readings

calculated Hz and V
corrections

Calibration

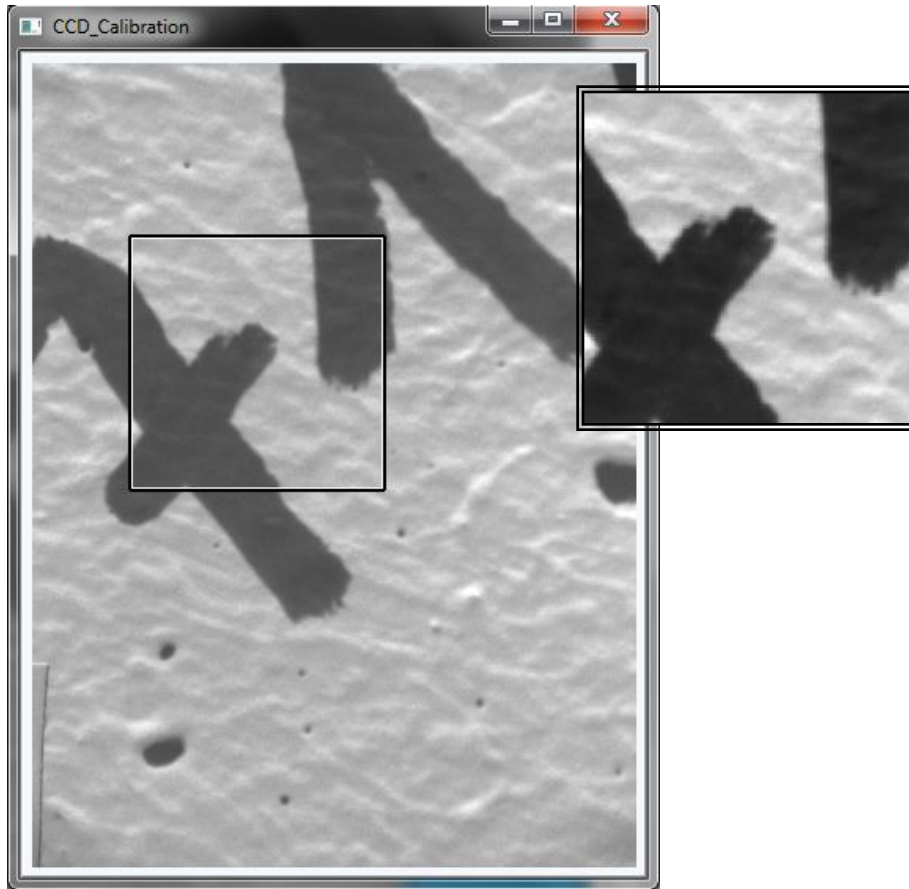


Identification & Extraction of Objects

Optical Target Recognition

- Least-squares template matching.
- Centroid operator.
- Robust circle matching.
- Robust ellipse matching.

OTR: Least-Squares Template Matching



PARAMETERS

- template

ADVANTAGES

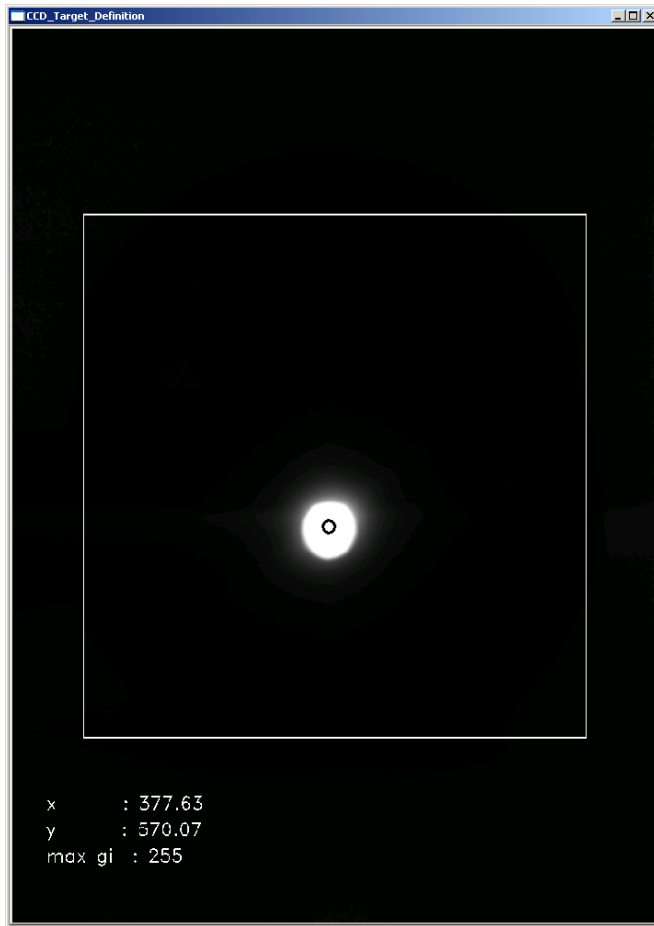
- arbitrary objects with texture
- very accurate

DESADVANTAGES

- systematic bias in the target definition
- time computation for real-time tracking
- not invariant with respect to view

precision < 0.1 pixel = 0.4 arcsec = $2.5 \mu\text{m/m}$

OTR: Centroid Operator



PARAMETERS

- automatic threshold for the background (inverse image also)
- minimal area of target
- center of mass or 2D gaussian

ADVANTAGES

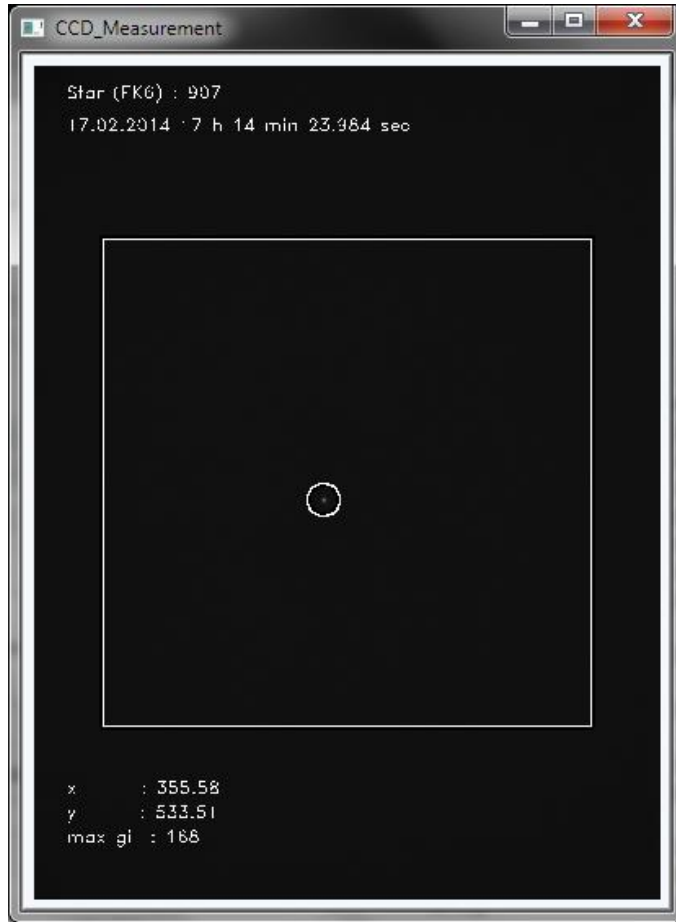
- robust and reliable segmentation
- short computation time (real-time)
- very accurate
- simple targets (lamps, diodes, ...)
- precise focusing not needed

DESADVANTAGES

- usually mandatory active targets
- mechanical reference not optimal
- not invariant with respect to view

precision < 0.1 pixel = 0.4 arcsec = 2.5 $\mu\text{m}/\text{m}$

OTR: Centroid Operator



PARAMETERS

- automatic threshold for the background (inverse image also)
- minimal area of target
- center of mass or 2D gaussian

ADVANTAGES

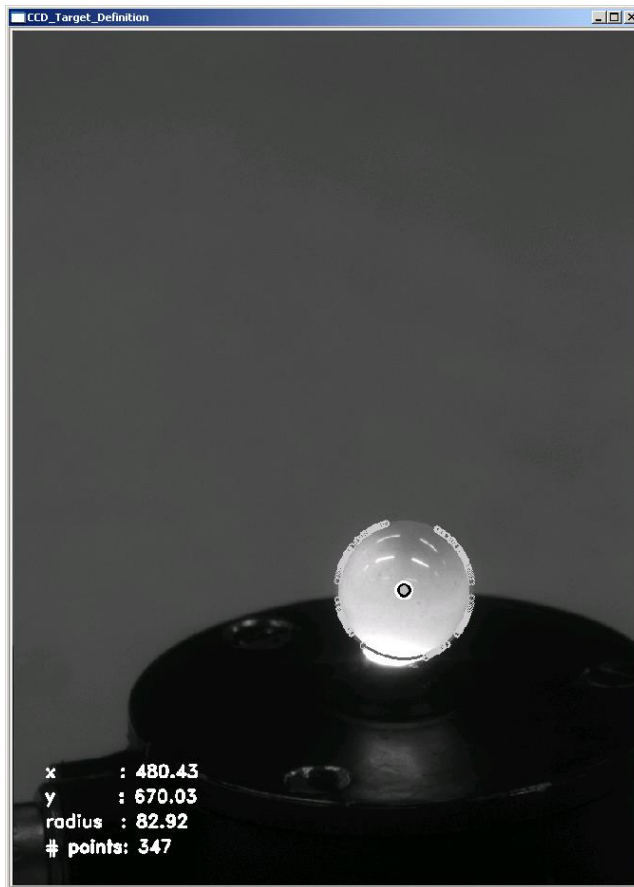
- robust and reliable segmentation
- short computation time (real-time)
- very accurate
- simple targets (lamps, diodes, ...)
- precise focusing not needed

DESADVANTAGES

- usually mandatory active targets
- mechanical reference not optimal
- not invariant with respect to view

precision < 0.1 pixel = 0.4 arcsec = 2.5 $\mu\text{m}/\text{m}$

OTR: Robust Circle Matching Operator



PARAMETERS

- canny edge detector sensitivity
- minimal point for adjustment
- minimal and maximal radius

ADVANTAGES

- optimal for spherical objects
=> optimal mechanical reference
- very accurate
- simple passiv target
- well adapted for automated microtriangulation

DESADVANTAGES

- mandatory focusing
- range limited (>> sphere, >> dist.)

precision < 0.1 pixel = 0.4 arcsec = 2.5 $\mu\text{m}/\text{m}$

OTR: Robust Ellipse Matching Operator



PARAMETERS

- automatic threshold for the background (inverse image also)
- minimal area of target
- minimal number of points

ADVANTAGES

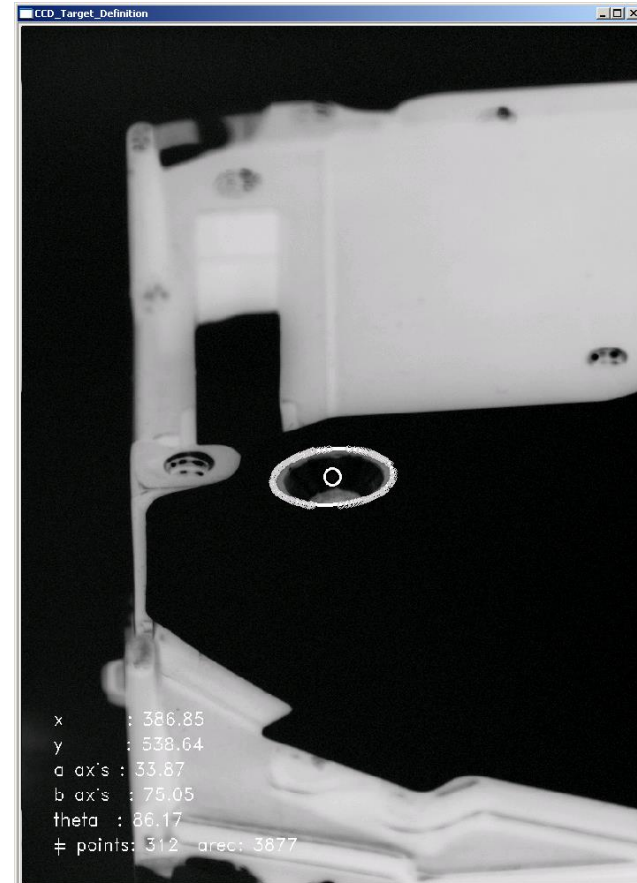
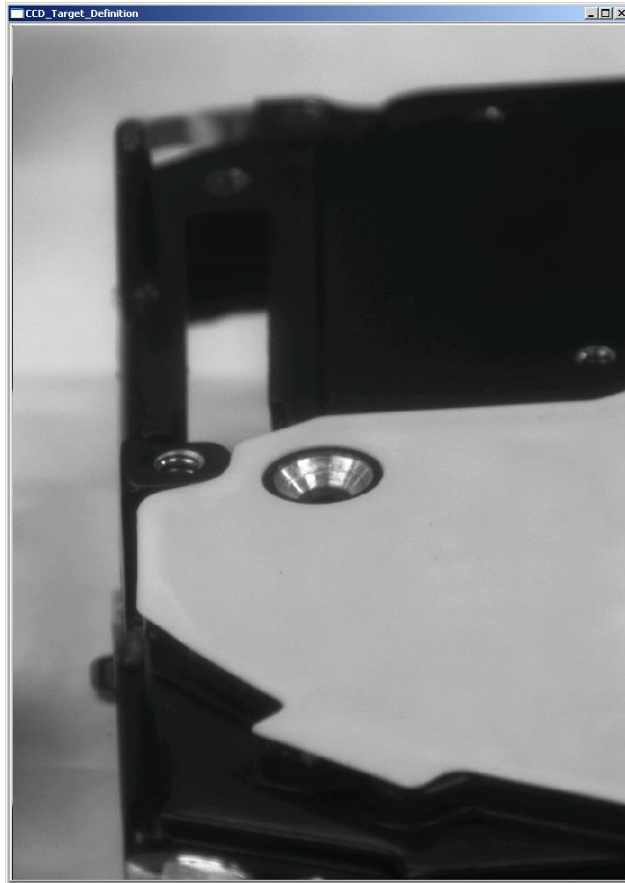
- optimal for circular objects
=> optimal mechanical reference
- simple passiv targets (hole, black circle on white background)

DESADVANTAGES

- mandatory precise focusing
- range limitation (>> circle, >> dist.)

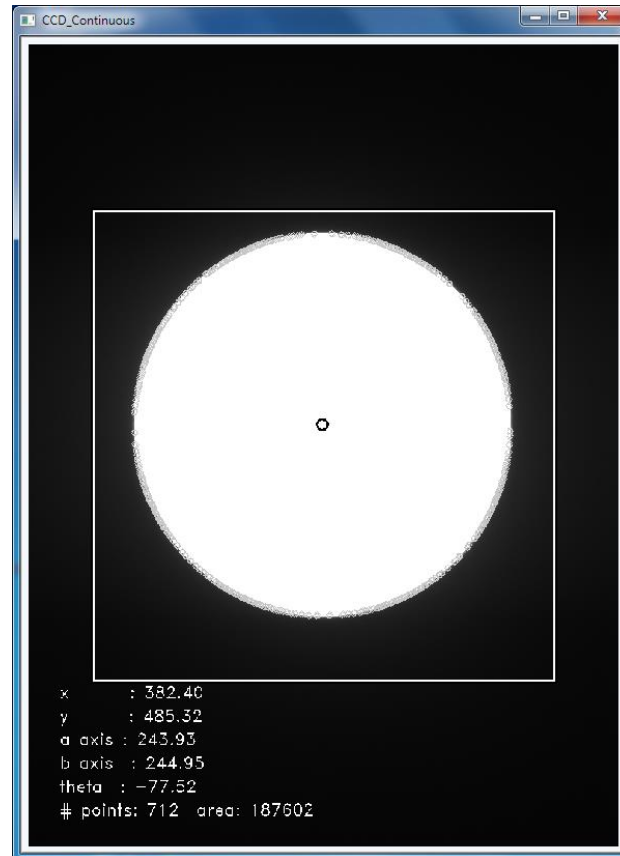
precision < 0.1 pixel = 0.4 arcsec = 2.5 $\mu\text{m}/\text{m}$

OTR: Robust Ellipse Matching Operator



precision < 0.1 pixel = 0.4 arcsec = 2.5 $\mu\text{m}/\text{m}$

OTR: Robust Ellipse Matching Operator



precision < 0.1 pixel = 0.4 arcsec = 2.5 $\mu\text{m}/\text{m}$

Measuring with QDaedalus

Measuring with QDaedalus (Start)

DLG_MainApp

QDAEDALUS

Digital Clip-on Measuring System for Total Stations

Main Menu | Connection | Station | Observation | Adjustment

PROJECT

Project name :

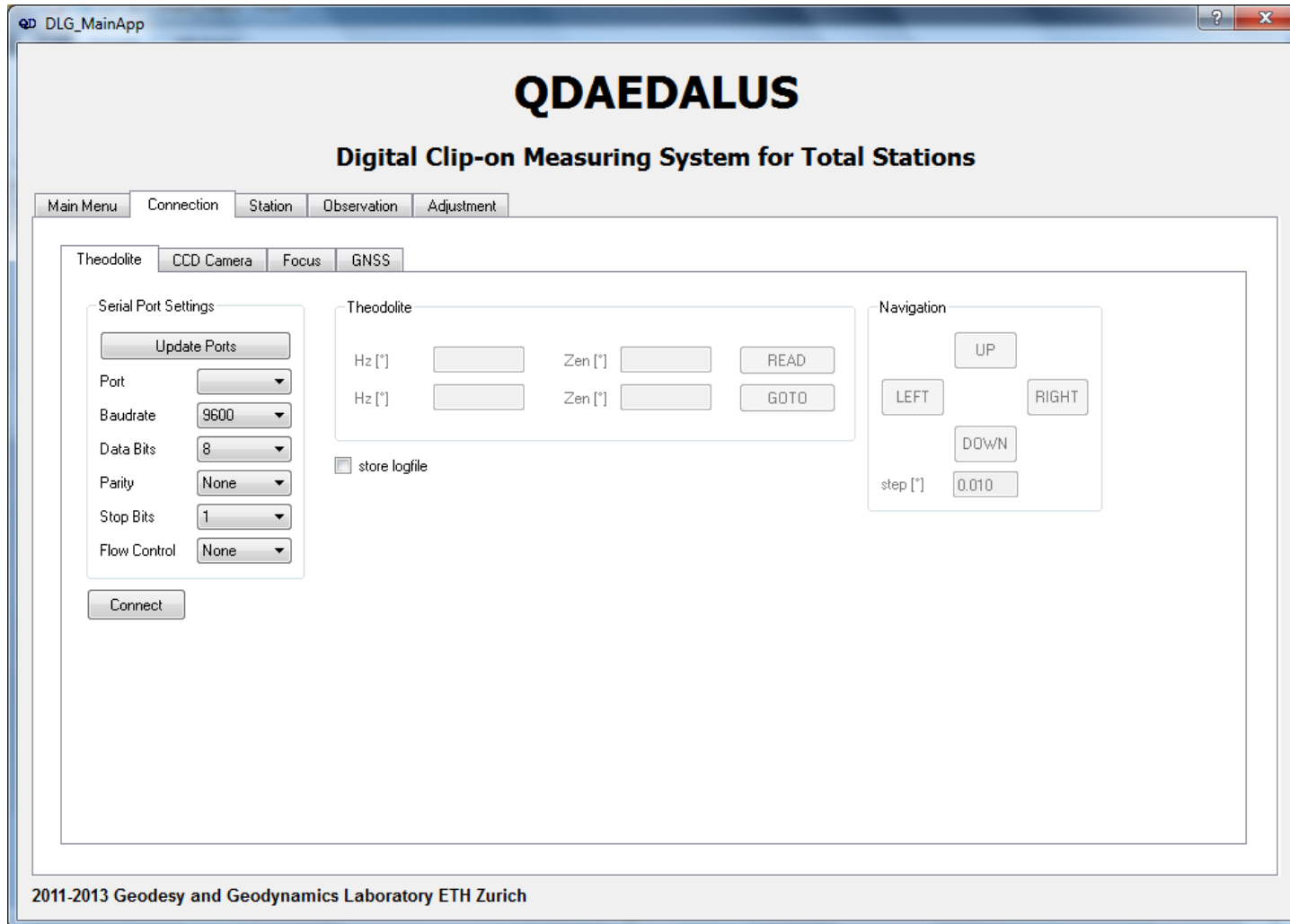
Description :

Date of creation :

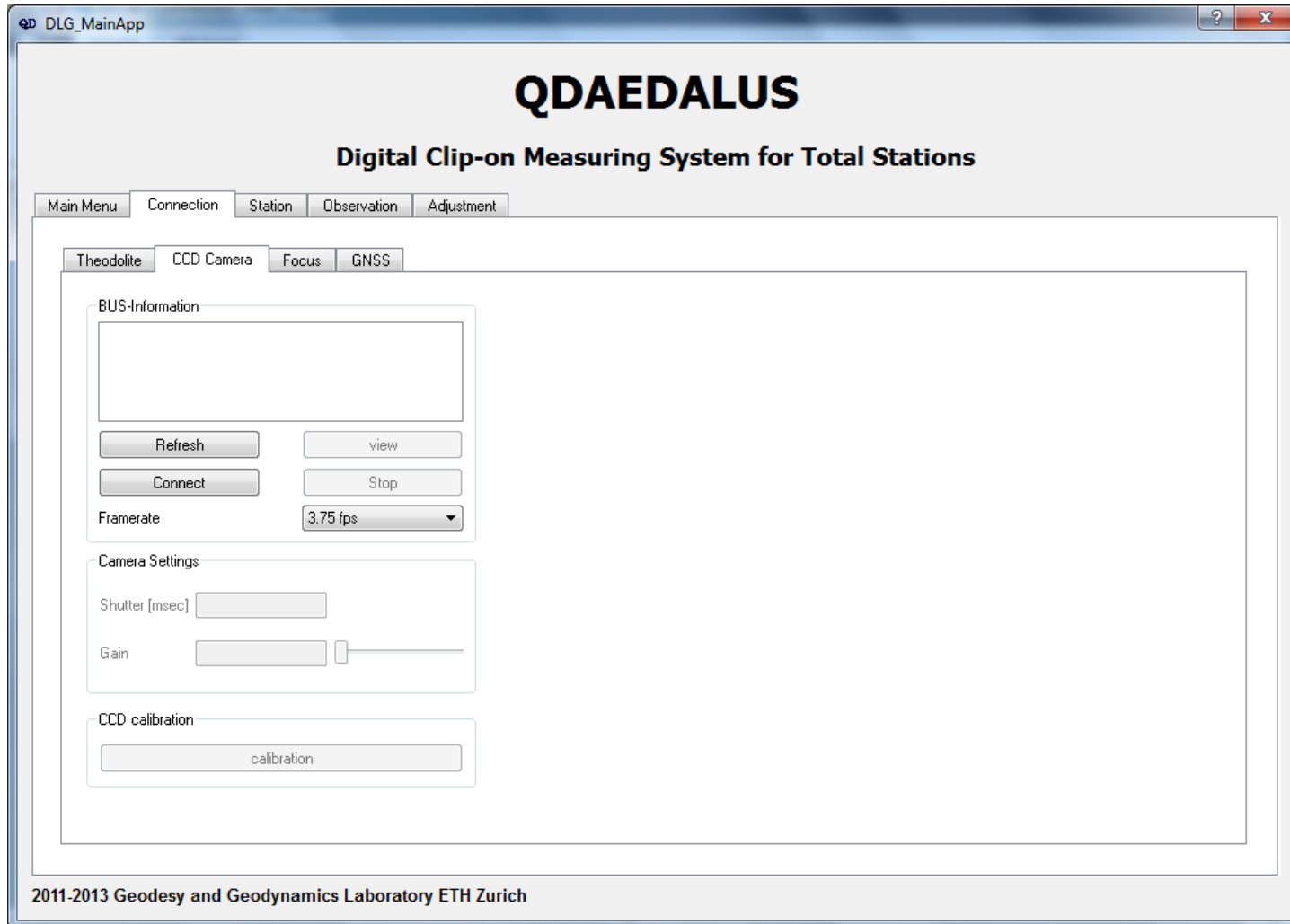
Creator :

2011-2013 Geodesy and Geodynamics Laboratory ETH Zurich

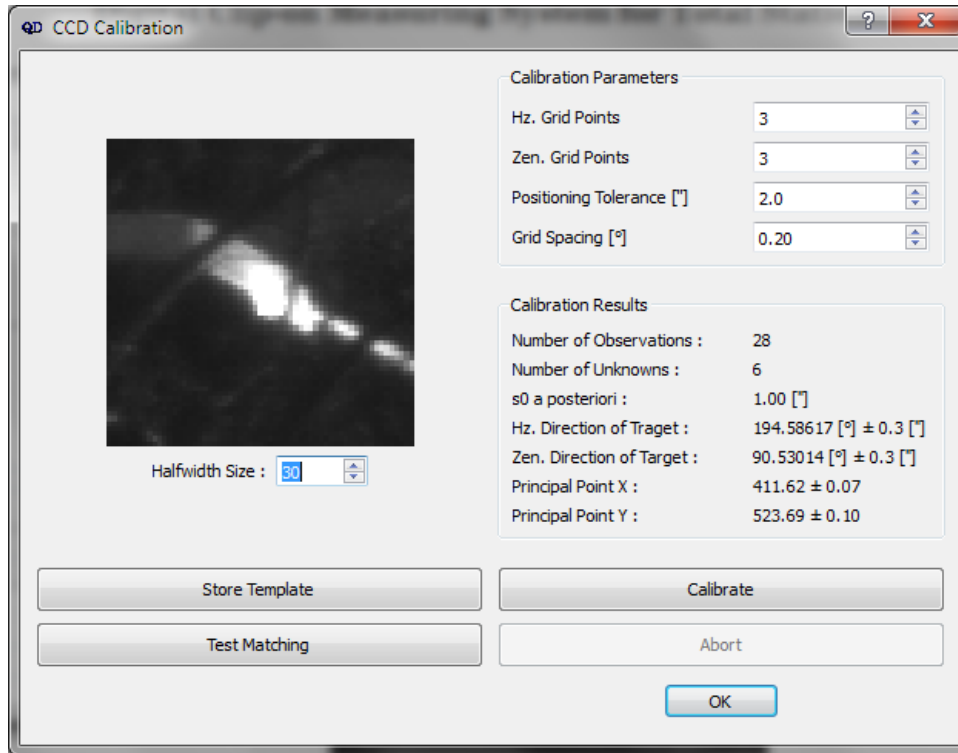
Measuring with QDaedalus (Connection)



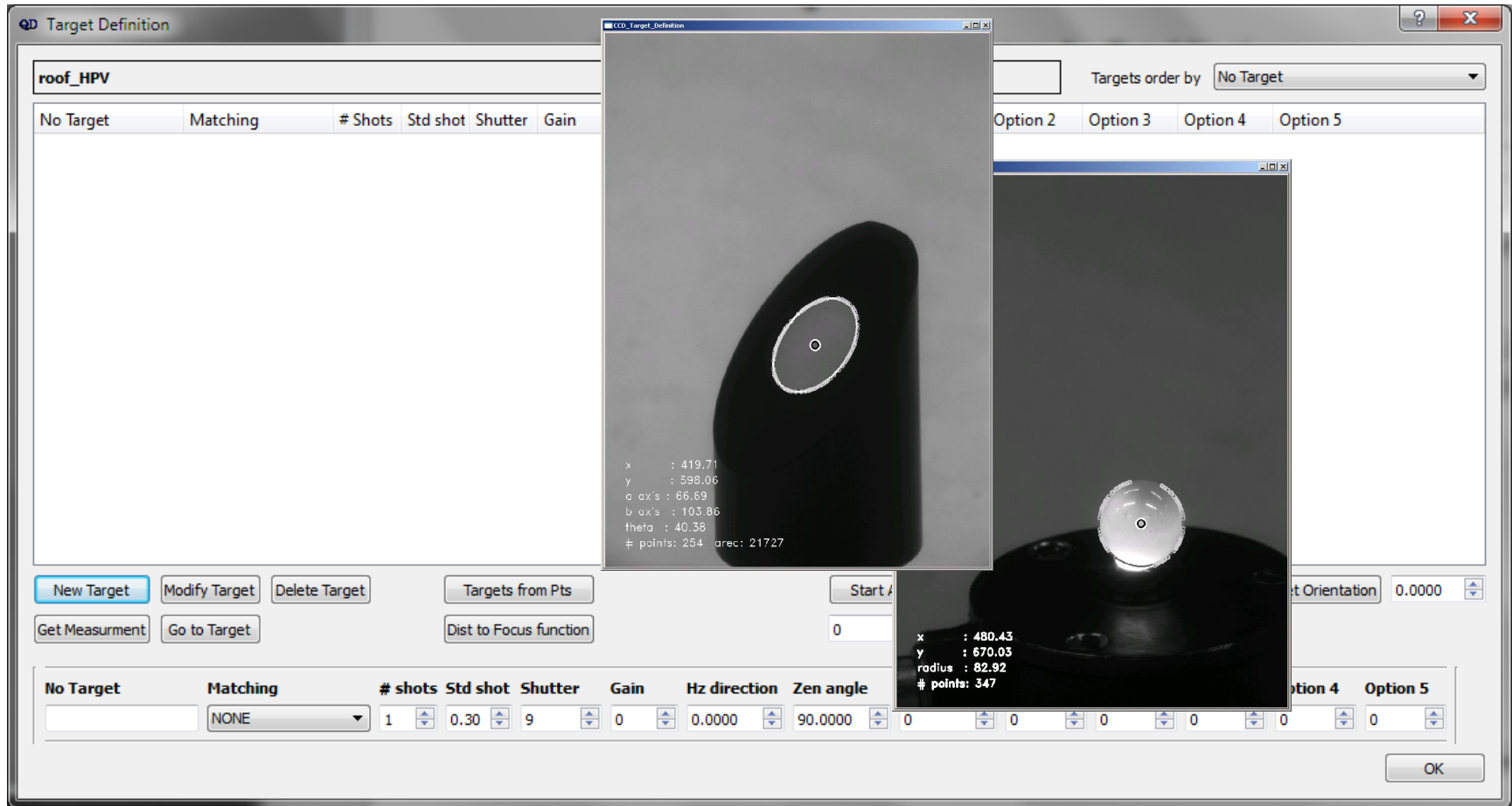
Measuring with QDaedalus (Connection)



Measuring with QDaedalus (Calibration)



Measuring with QDaedalus (Target Def.)



Measuring with QDaedalus (Meas. Process)

Dialog

111_5

Targets to observe

#	No Target	Position	Result
1	24	I	
2	24	I	
3	24	I	
4	14	I	
5	14	I	
6	14	I	
7	25	I	
8	25	I	
9	25	I	
10	15	I	
11	15	I	
12	15	I	
13	24	II	
14	24	II	
15	24	II	
16	14	II	
17	14	II	
18	14	II	
19	25	II	
20	25	II	

Position: II

Observations: 3

Repetitions: 0

Order by: Focus Pos

sd Hz [°]: 0.50 sd Zen [°]: 0.50

< ADD

DELETE

Start Measurement Process

Stop Measurement Process

Targets

No Target	Matching	# Shots	Shutter	Gain	Hz dir	Zh angle	Focus
24	ELLIPSE_MATCHI...	5	500	200	19.7612	87.5118	113993
14	ELLIPSE_MATCHI...	5	500	200	19.9713	91.6910	114001
25	ELLIPSE_MATCHI...	5	500	200	23.9838	87.2796	114208
15	ELLIPSE_MATCHI...	5	500	200	24.1747	91.4938	114210
13	ELLIPSE_MATCHI...	5	500	200	15.8279	91.9162	114228
31	ELLIPSE_MATCHI...	5	500	200	350.6058	75.6466	114277
23	ELLIPSE_MATCHI...	5	500	200	15.5635	87.7316	114278
16	ELLIPSE_MATCHI...	5	500	200	28.3463	91.2398	114859
26	ELLIPSE_MATCHI...	5	500	200	28.1346	87.0652	114960
22	ELLIPSE_MATCHI...	2	500	200	11.4380	87.9745	115190
12	ELLIPSE_MATCHI...	2	500	200	11.6663	92.1642	115256
32	ELLIPSE_MATCHI...	2	500	200	21.2987	75.6820	115980
27	ELLIPSE_MATCHI...	2	500	200	32.2053	86.9143	116147
17	ELLIPSE_MATCHI...	2	500	200	32.4084	91.0386	116198
11	ELLIPSE_MATCHI...	2	500	200	7.6042	92.3259	116555
21	ELLIPSE_MATCHI...	2	500	300	7.3822	88.2392	116588
28	ELLIPSE_MATCHI...	2	500	200	36.1752	86.7986	117871
18	ELLIPSE_MATCHI...	2	500	200	36.3664	90.8233	117892
19	ELLIPSE_MATCHI...	2	500	250	40.1773	90.6173	119832
29	ELLIPSE_MATCHI...	2	500	250	39.9999	86.6885	119968

OK

Practical Experiment of QDaealus at CERN

Automatic Microtriangulation of Linear Collider Components

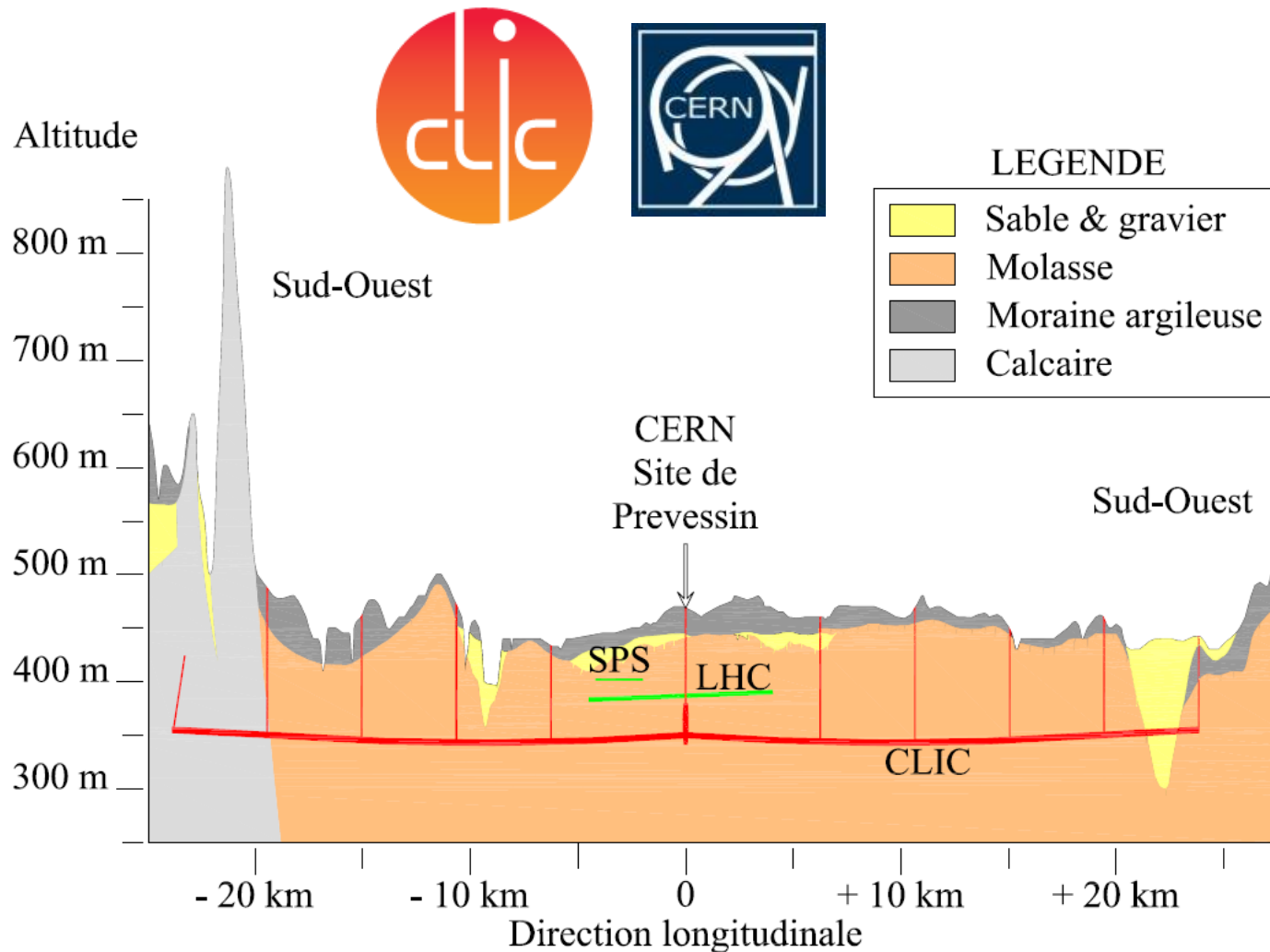


ETH

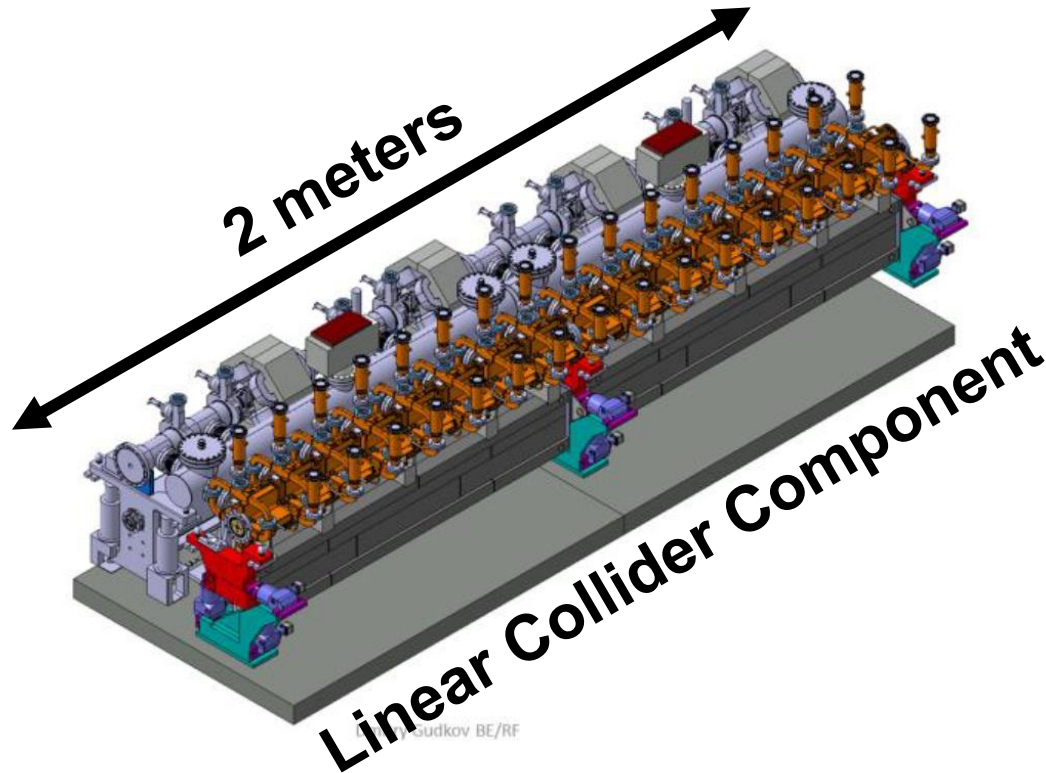
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich



Automatic Microtriangulation



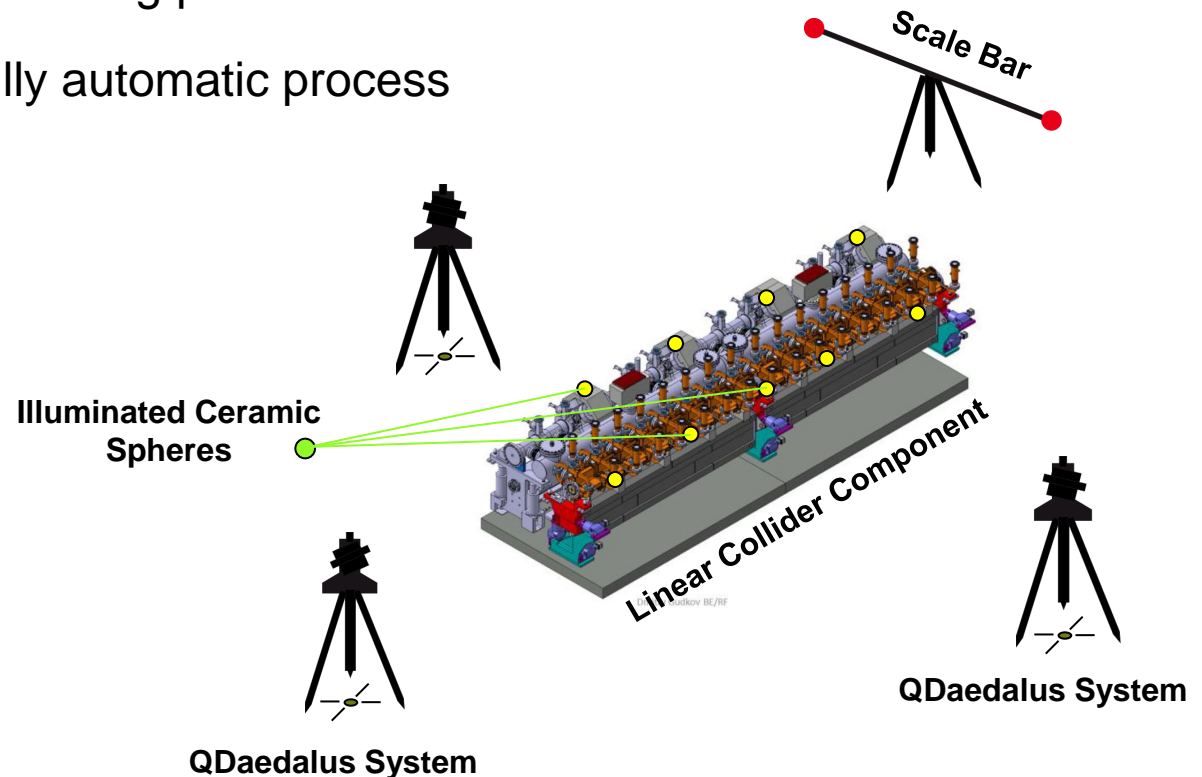
Automatic Microtriangulation



➔ more than 20 000 modules in total
to be measured !

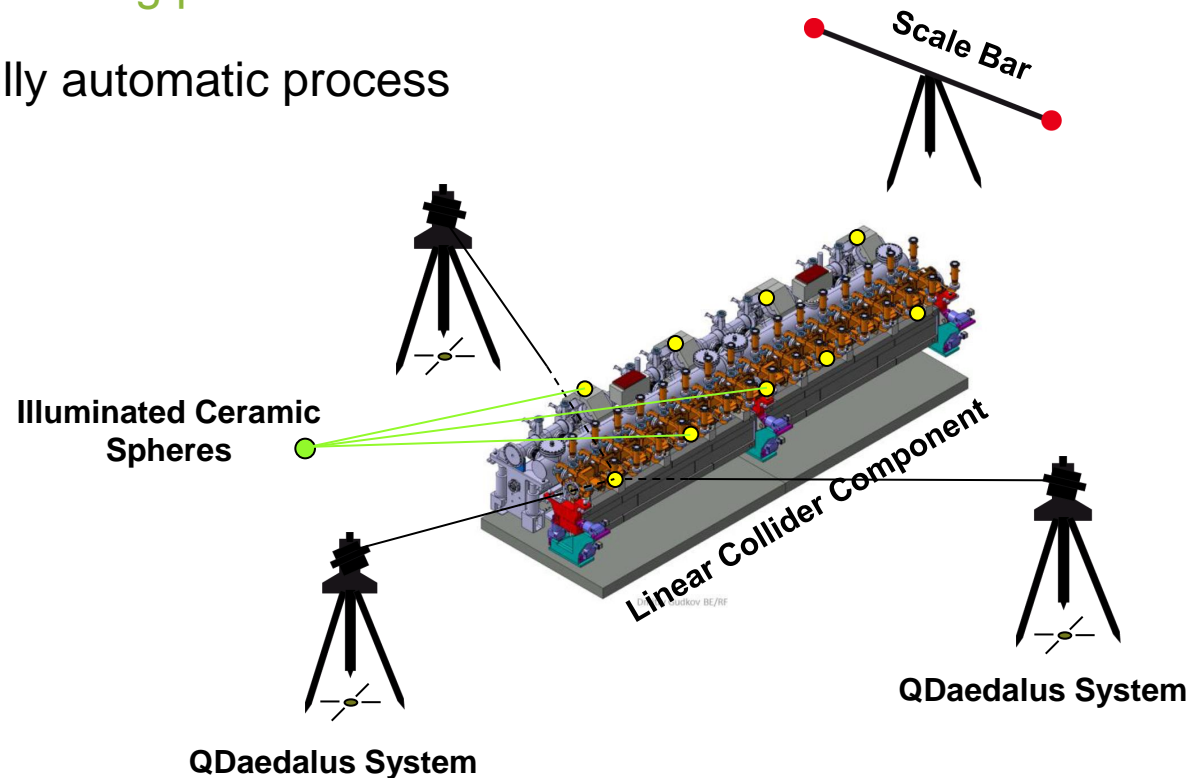
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



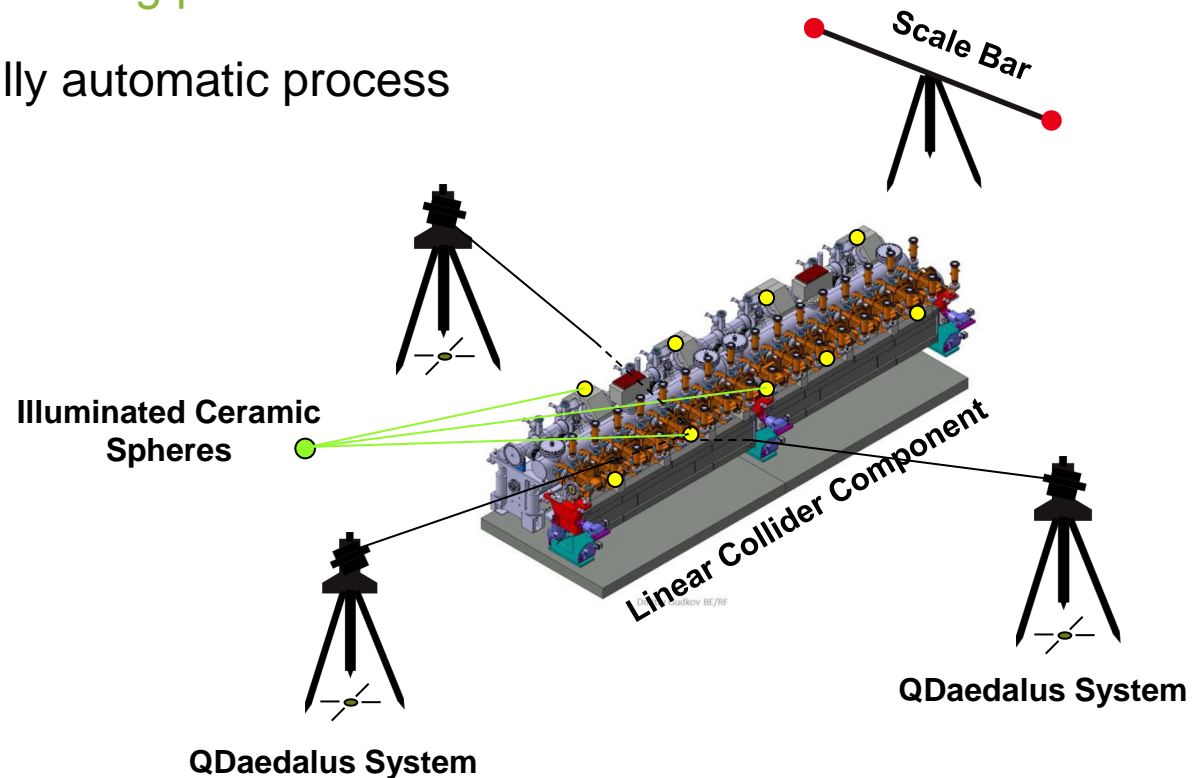
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



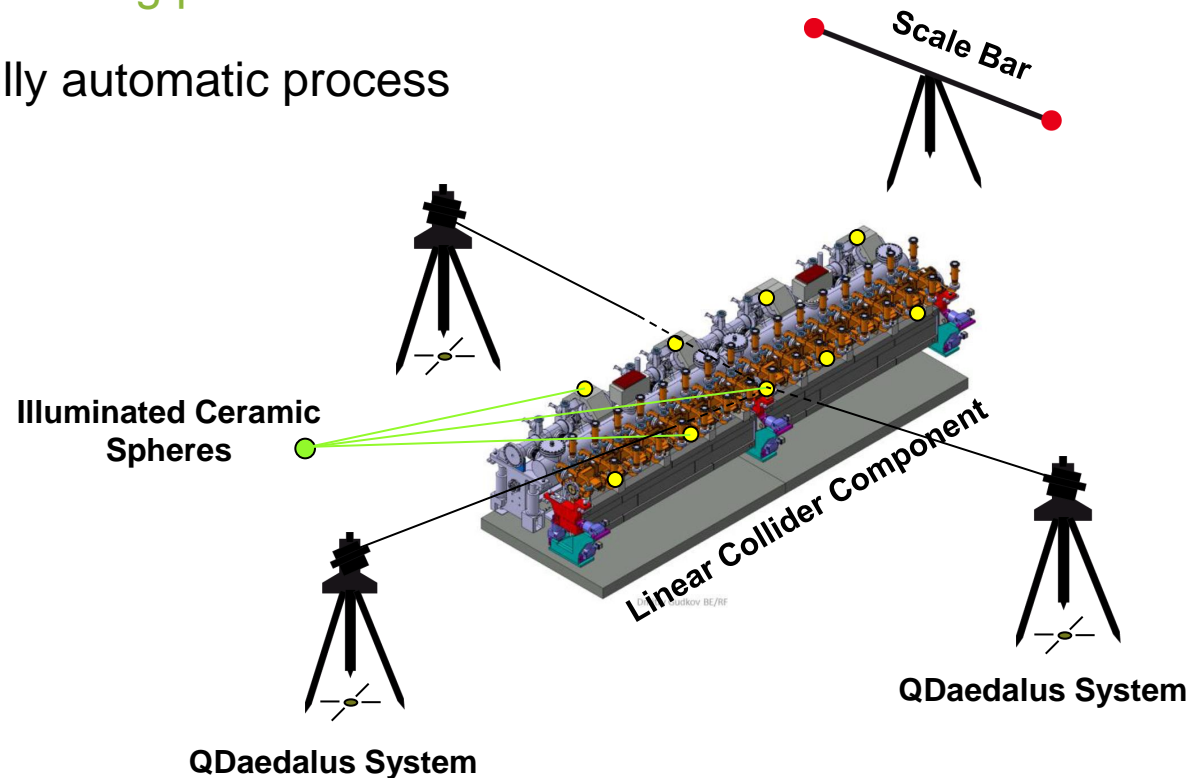
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



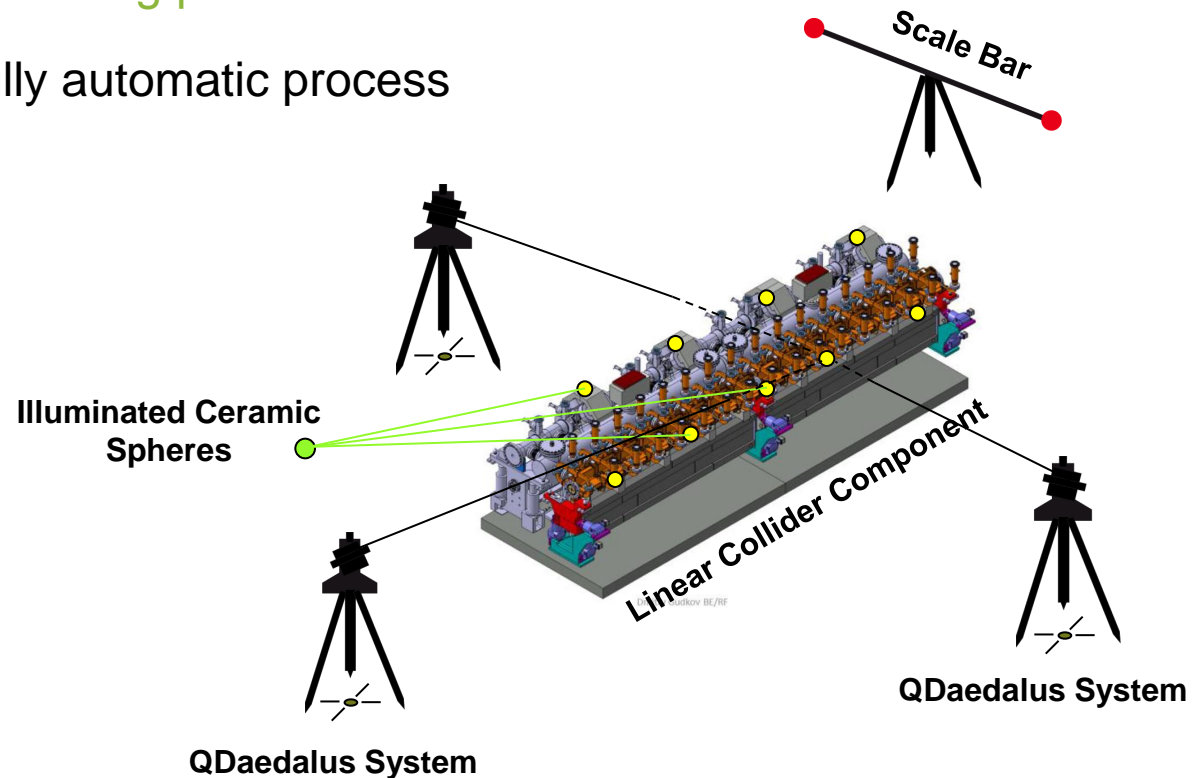
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



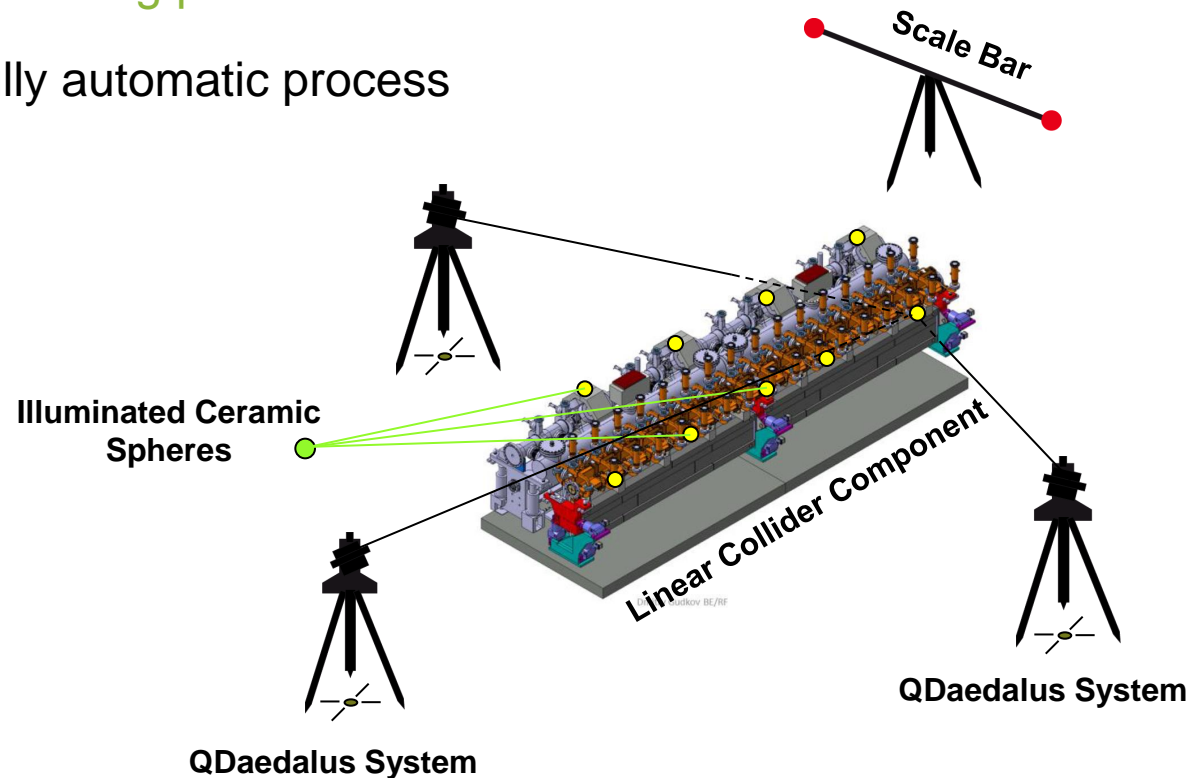
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



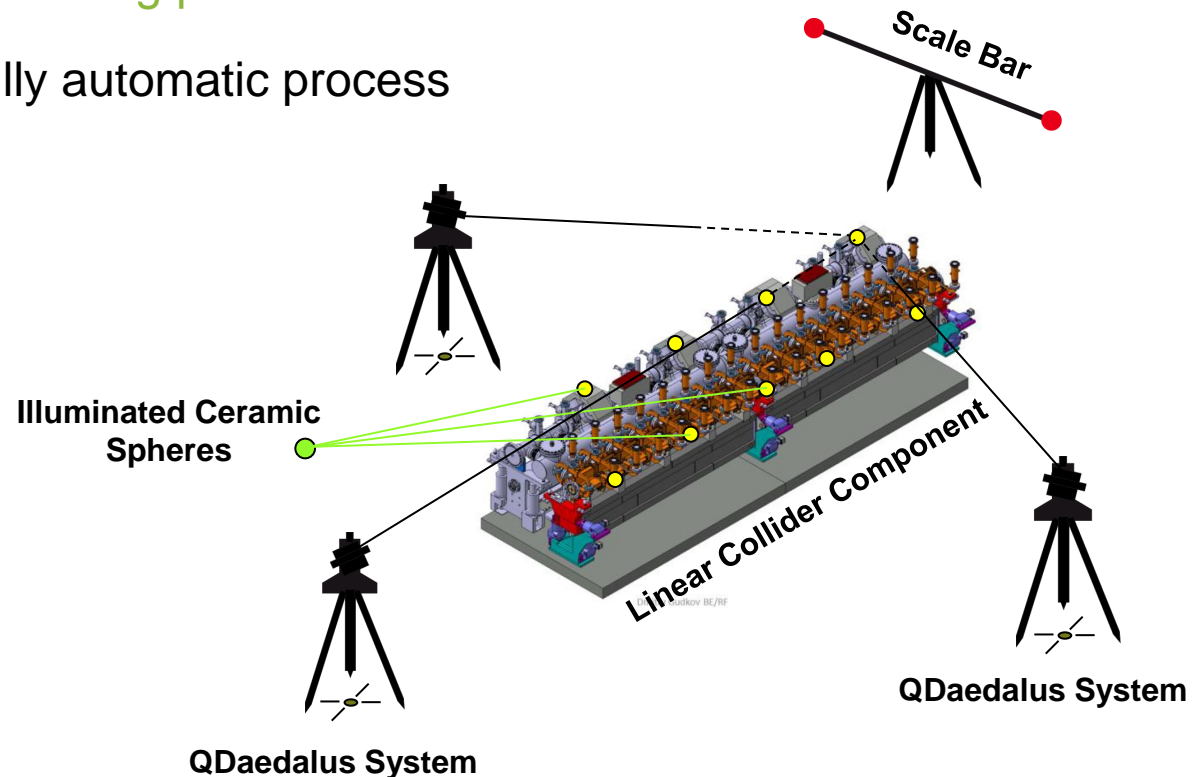
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



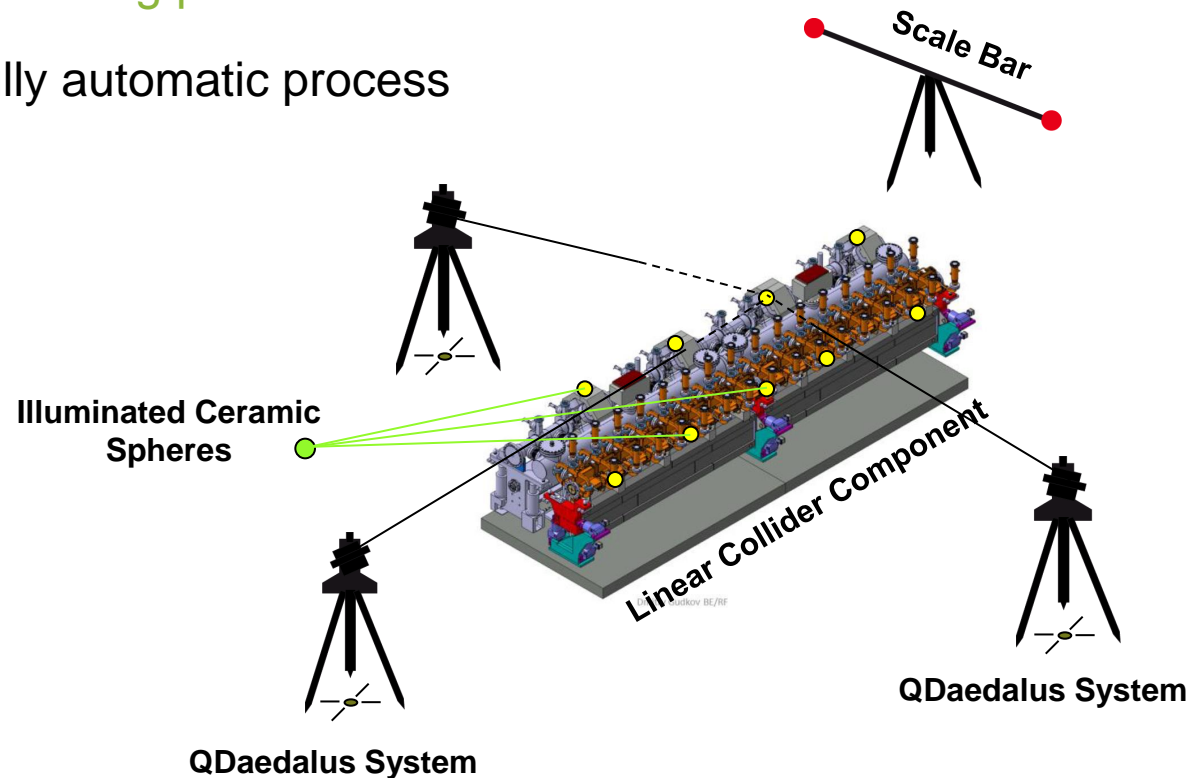
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



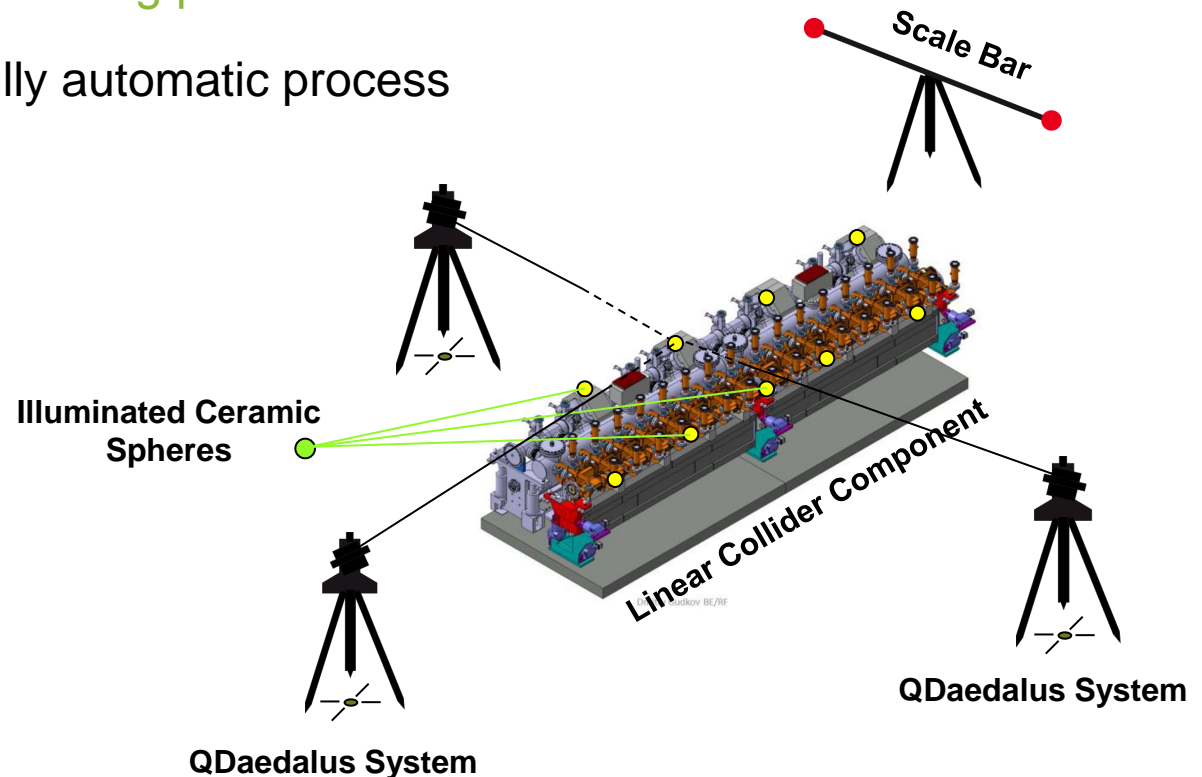
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



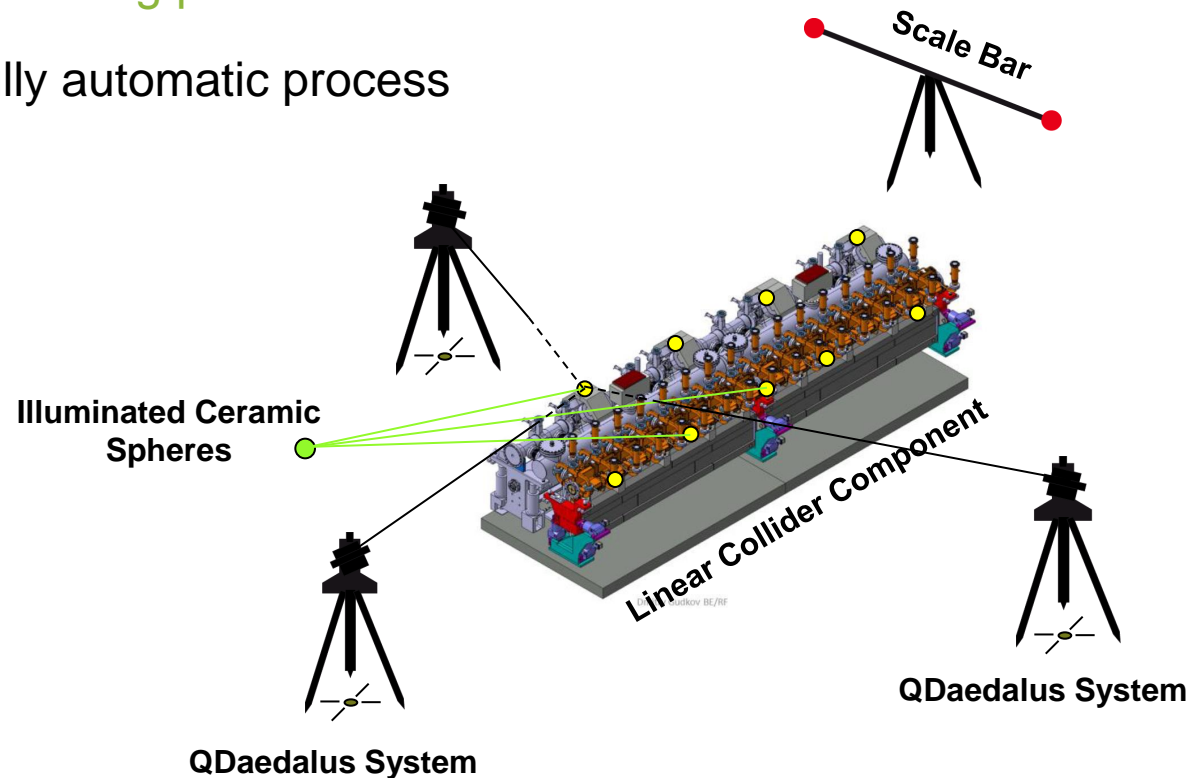
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



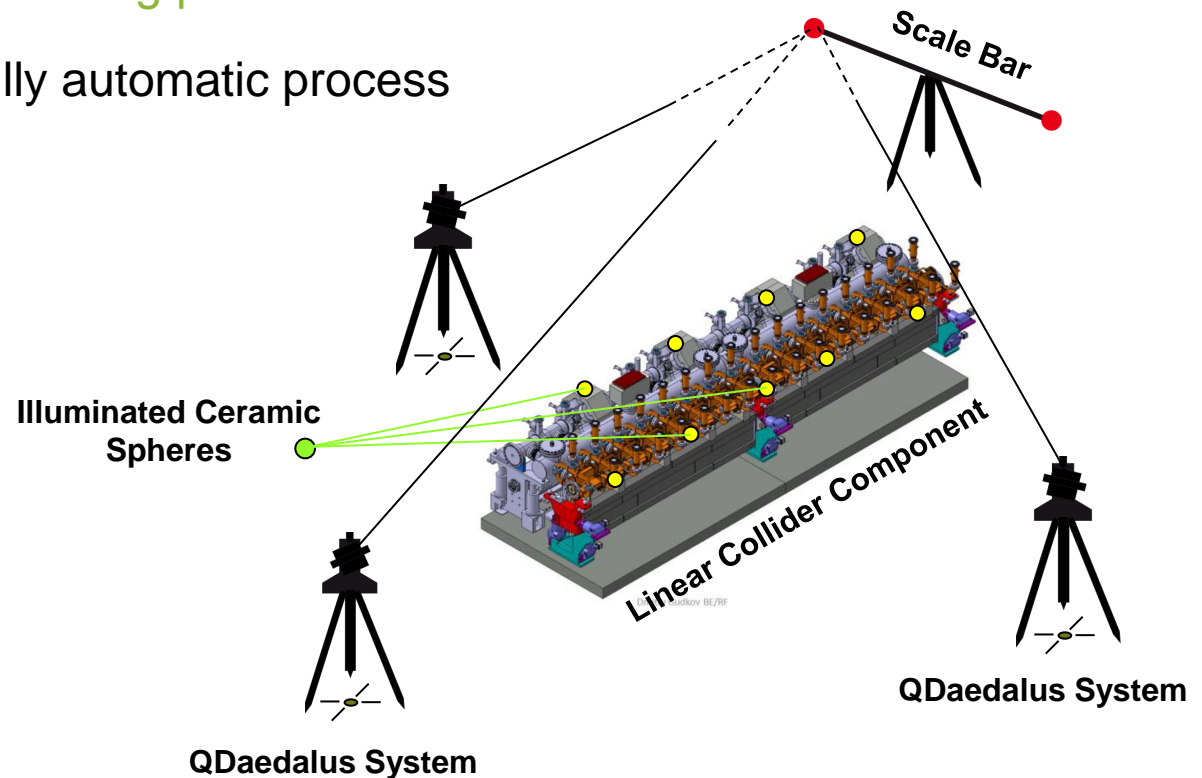
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



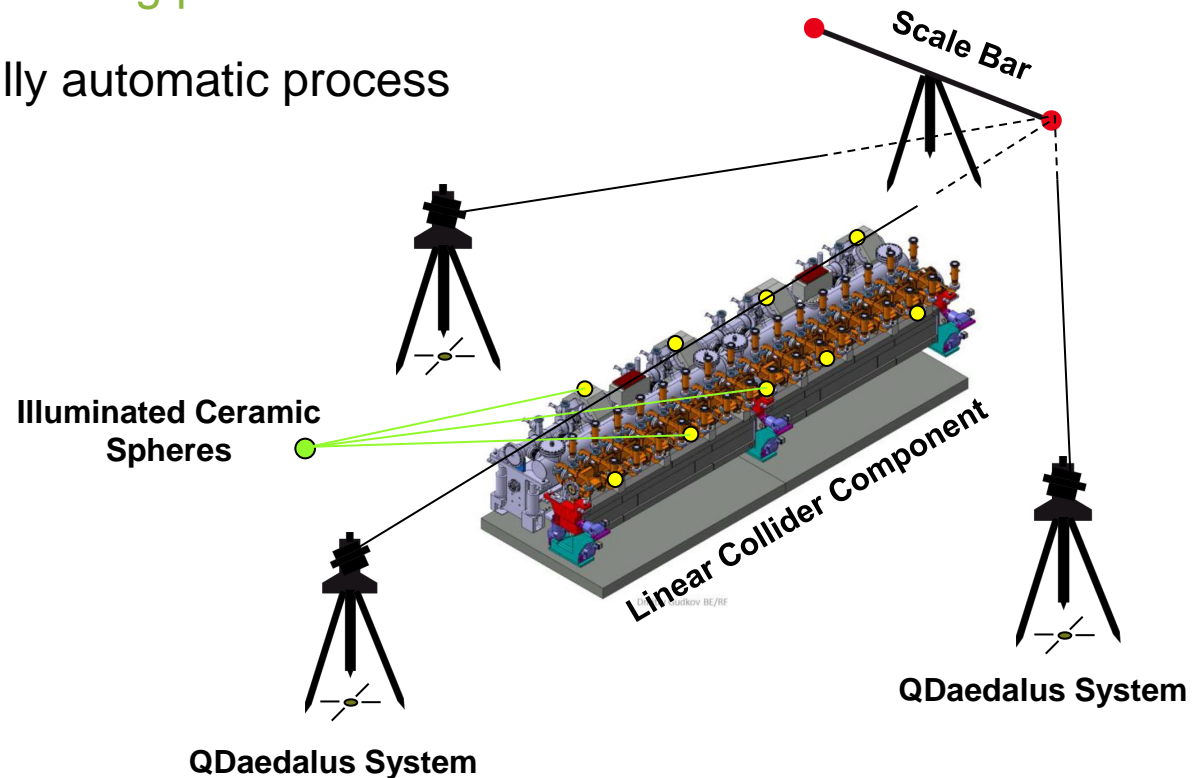
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process



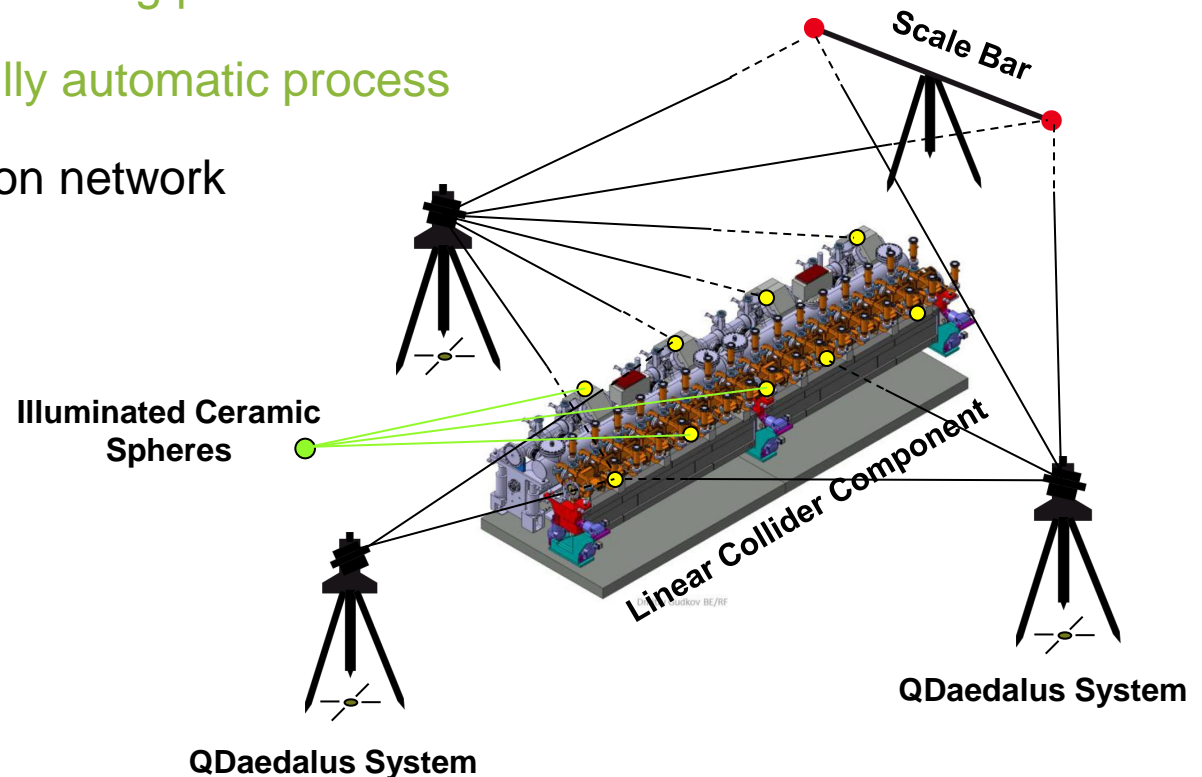
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process

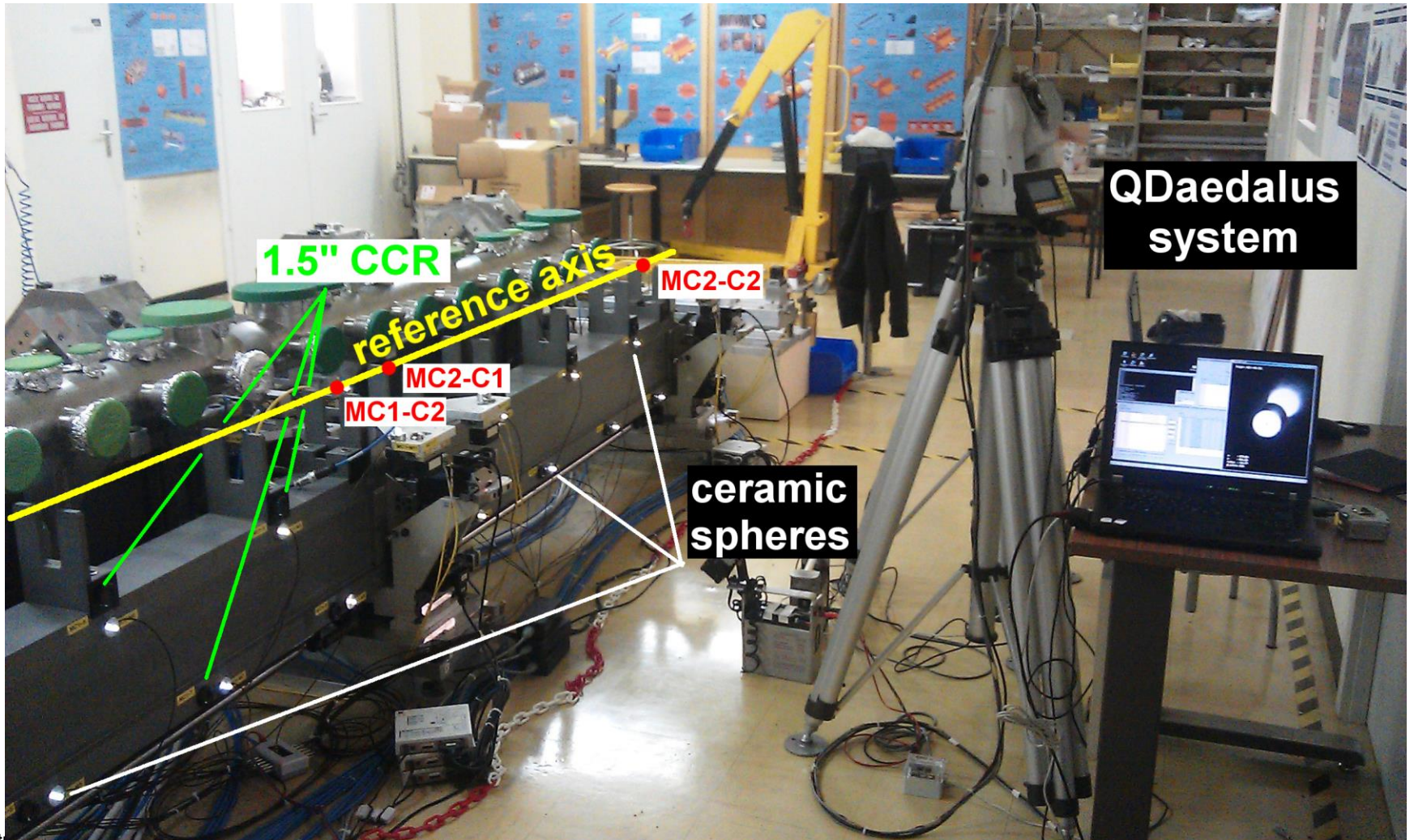


Automatic Microtriangulation

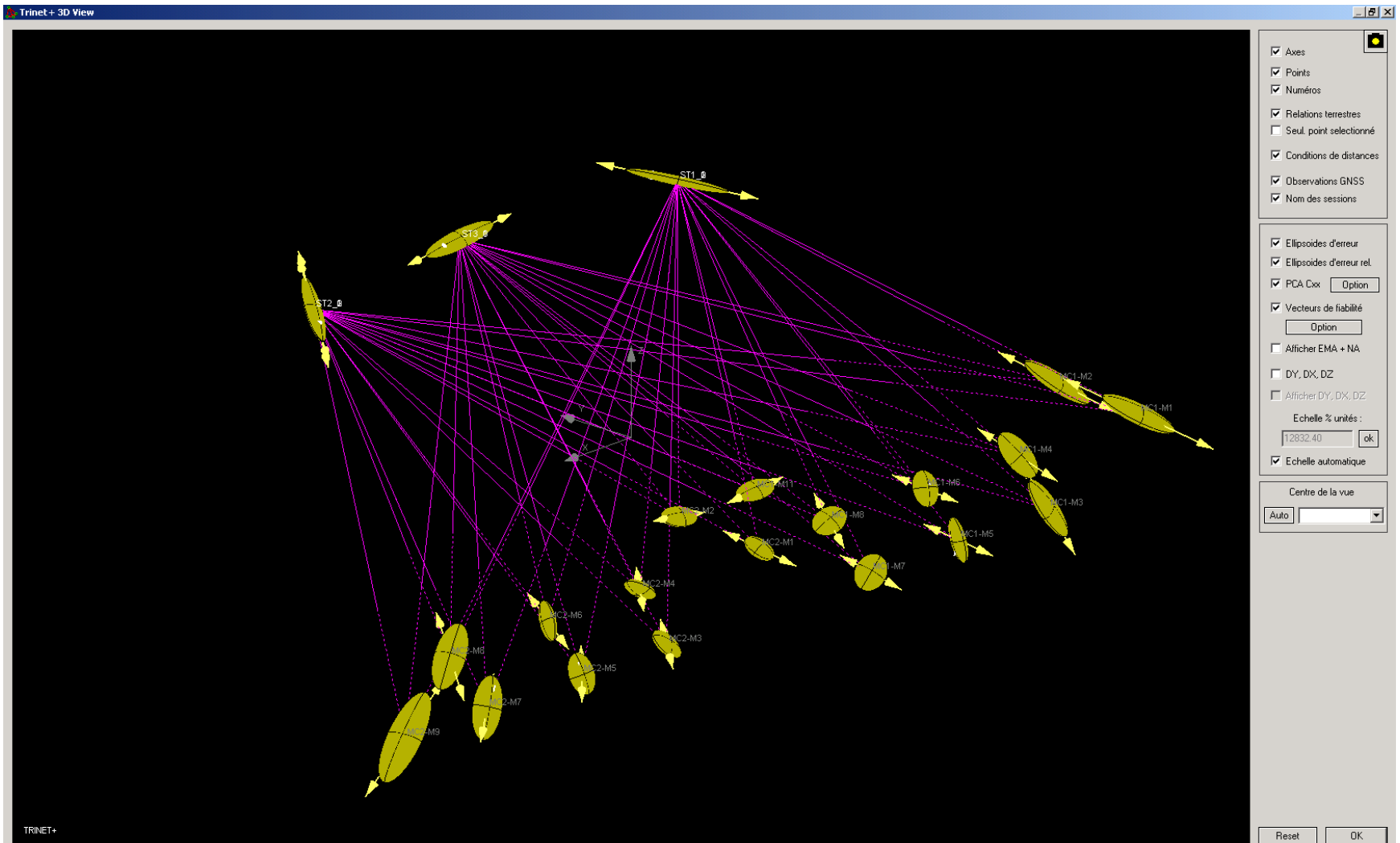
1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters... definition
3. Start measurements, fully automatic process
4. Adjust micro-triangulation network



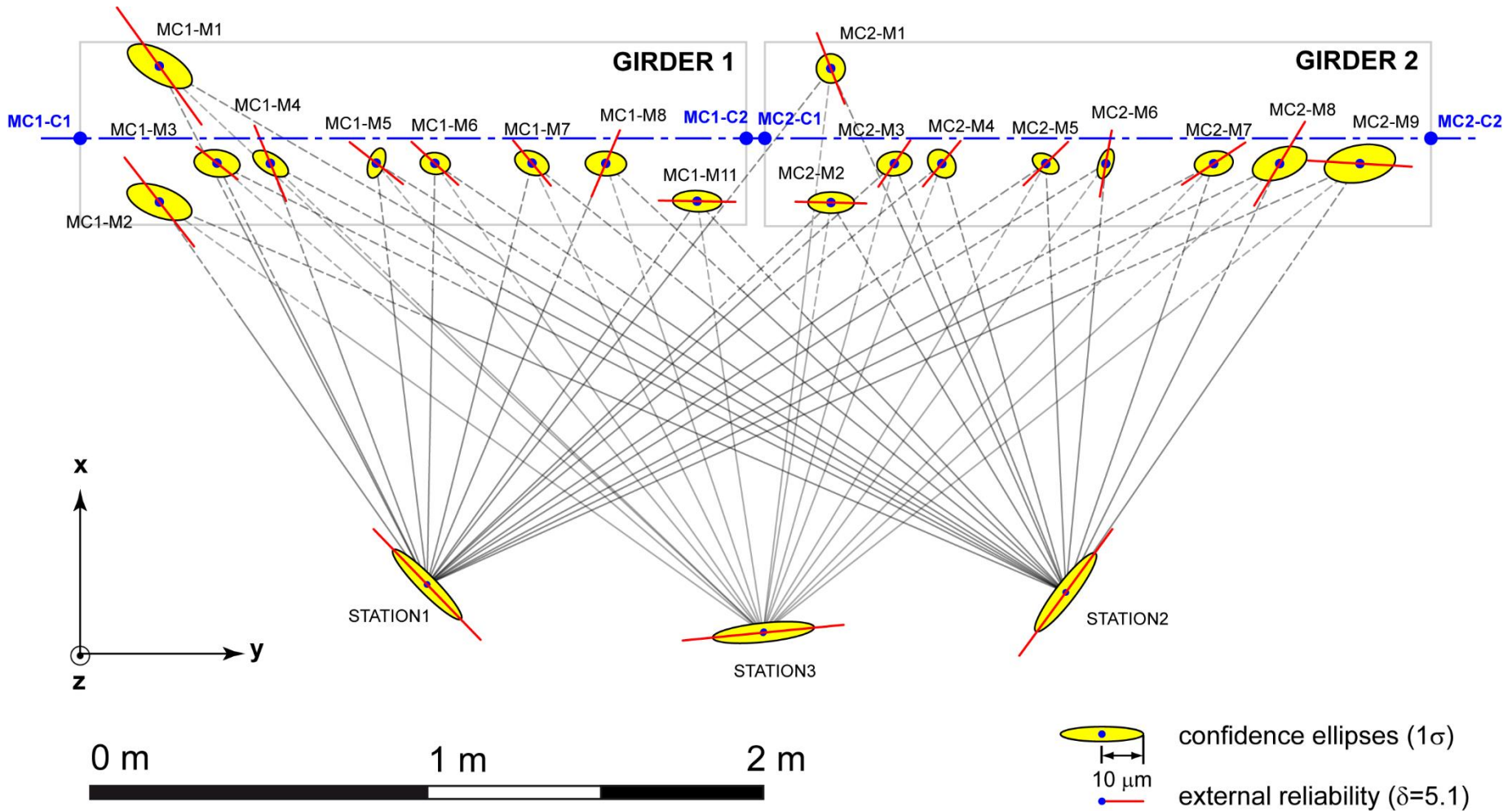
Automatic Microtriangulation



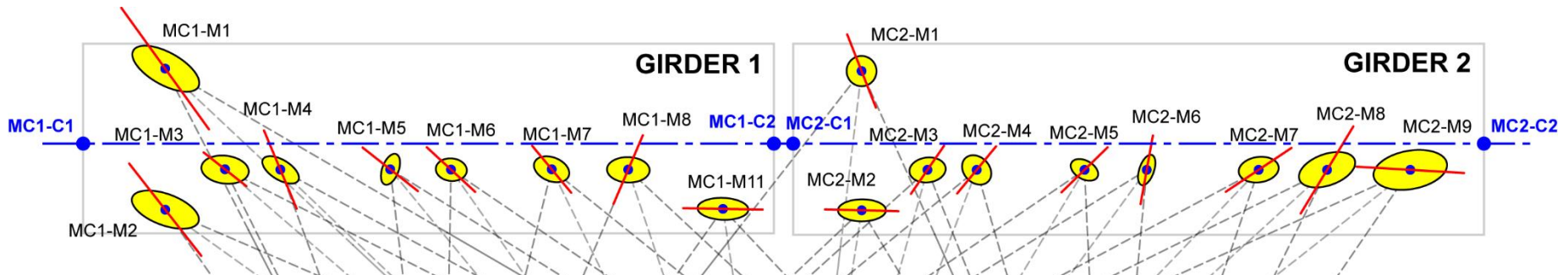
Automatic Microtriangulation



Automatic Microtriangulation

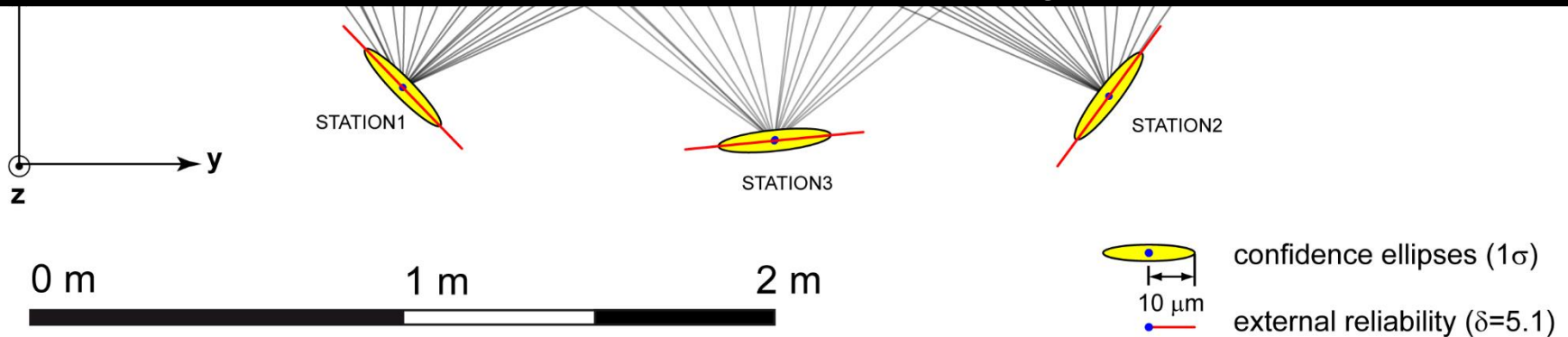


Automatic Microtriangulation



empirical $\sigma_{hz} = \sigma_{zen} = 0.5 \text{ arcsec} = 1.5 \text{ cc}$

TDA 5005 spec = $\sigma_{hz} = \sigma_{zen} = 1.5 \text{ cc}$



Automatic Microtriangulation

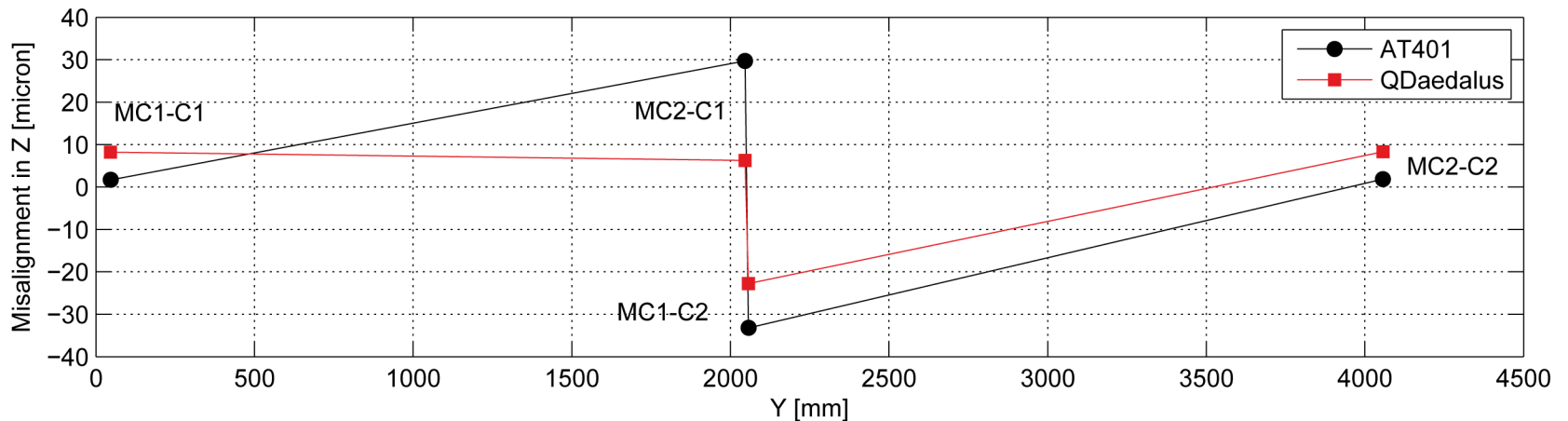
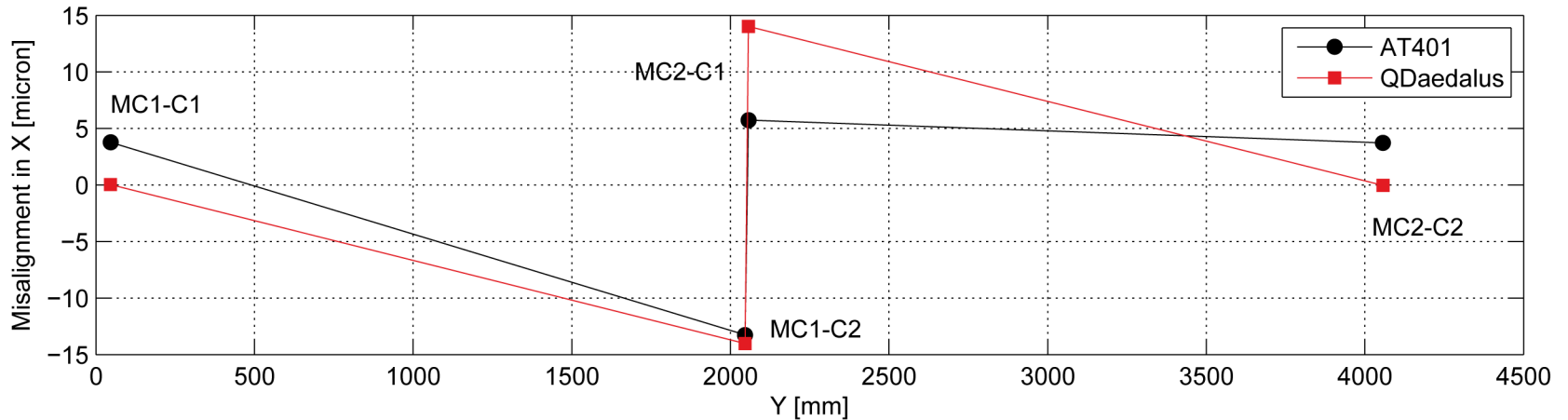
Empirical standard deviation and differences with respect to the Coordinates Measurement Machine (CMM $\sigma = 1\mu\text{m}$) of the points measured with the system QDaedalus.

Empirical Standard Deviation

Differences with Coordinate Measurement Machine

	sX [microns]	sY [microns]	sZ [microns]	dX [microns]	dY [microns]	dZ [microns]	d3D [microns]
MC1-M3	5	6	9	-3	-2	1	4
MC1-M4	5	4	7	8	-6	7	12
MC1-M5	4	3	6	1	-5	-10	11
MC1-M6	4	4	5	-11	9	-5	15
MC1-M7	4	5	4	2	7	4	8
MC1-M8	4	6	3	3	-3	3	5
MC2-M3	3	5	4	1	8	2	9
MC2-M4	3	4	4	5	16	0	17
MC2-M5	4	3	6	0	8	-7	11
MC2-M6	4	3	5	-5	-2	4	7
MC2-M7	5	5	8	-8	-8	-4	12
MC2-M9	6	11	10	7	-23	6	24

Automatic Microtriangulation



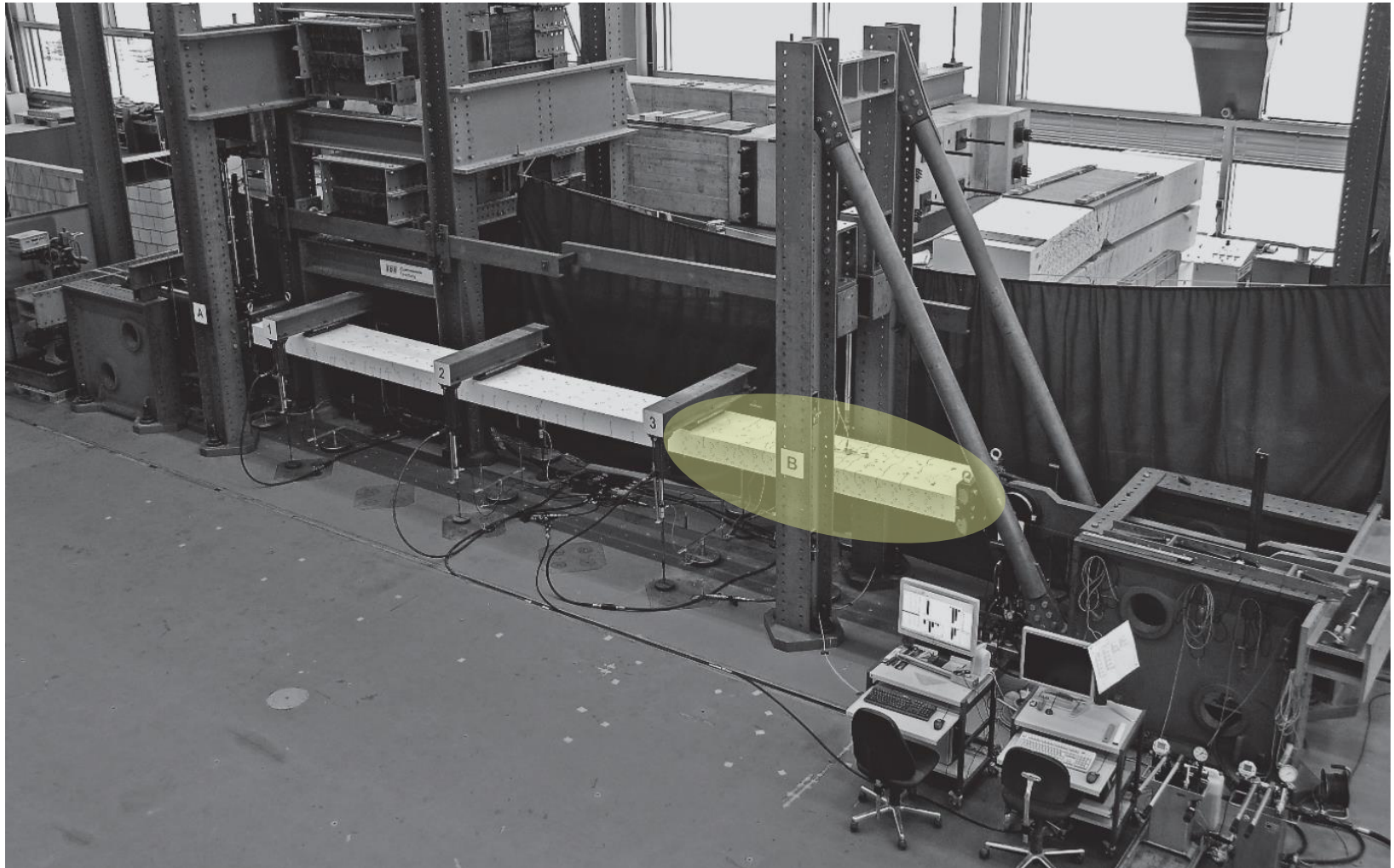
Automatic Microtriangulation for Stress Analysis in Reinforced Concrete Beams



ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Stress in Reinforced Concrete Beam

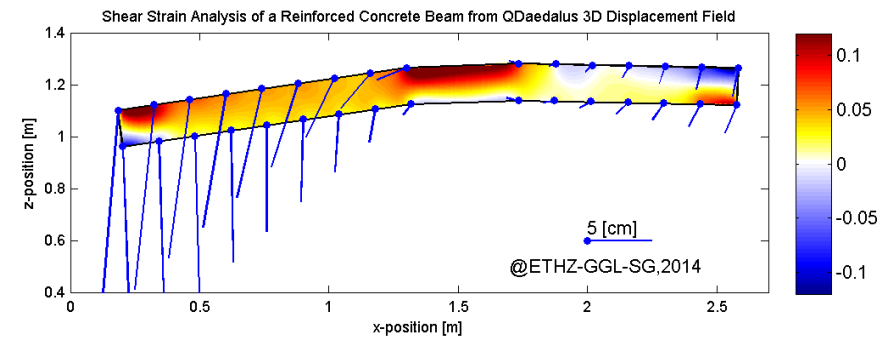
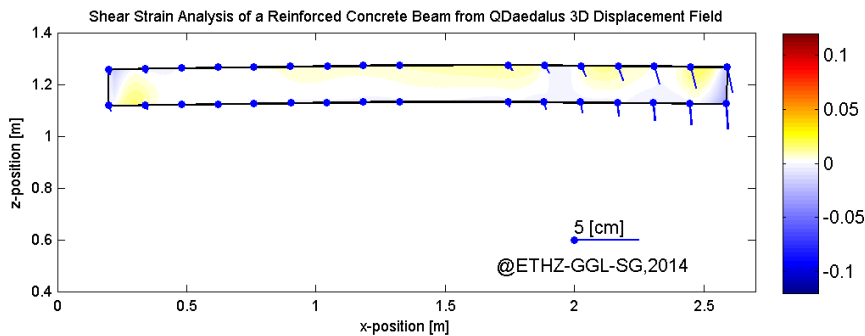
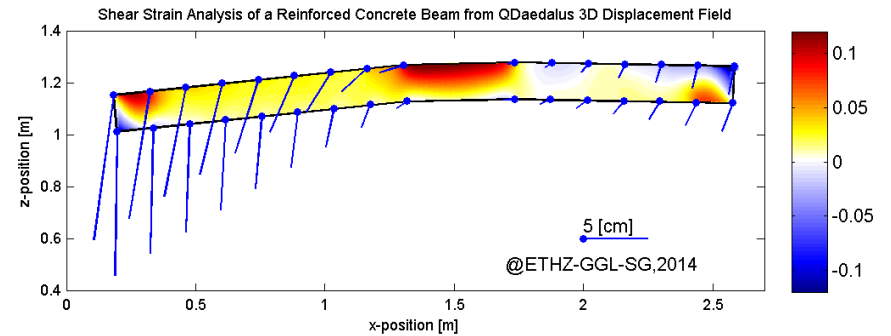
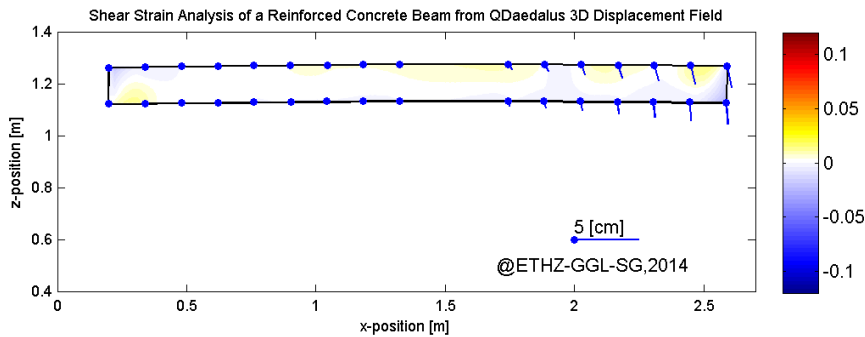
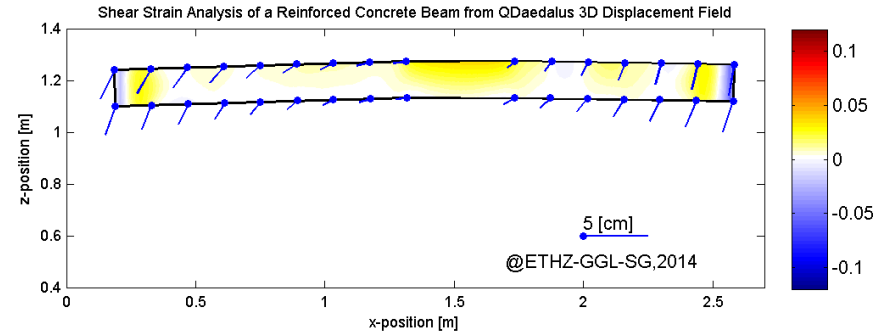
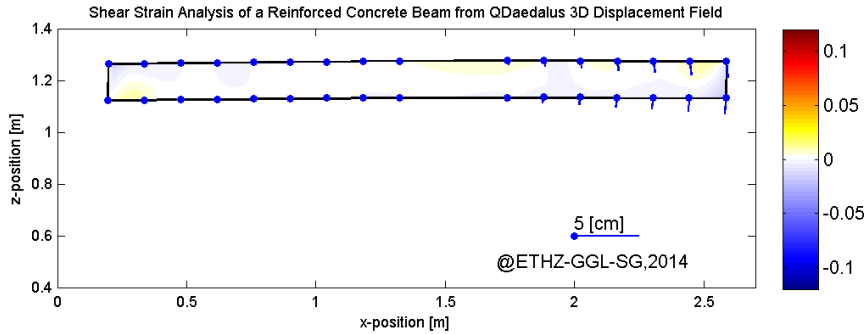


Stress in Reinforced Concrete Beam

1 complete acquisition in ~15 minutes



Stress in Reinforced Concrete Beam



Kinematic Measurements with QDaedalus



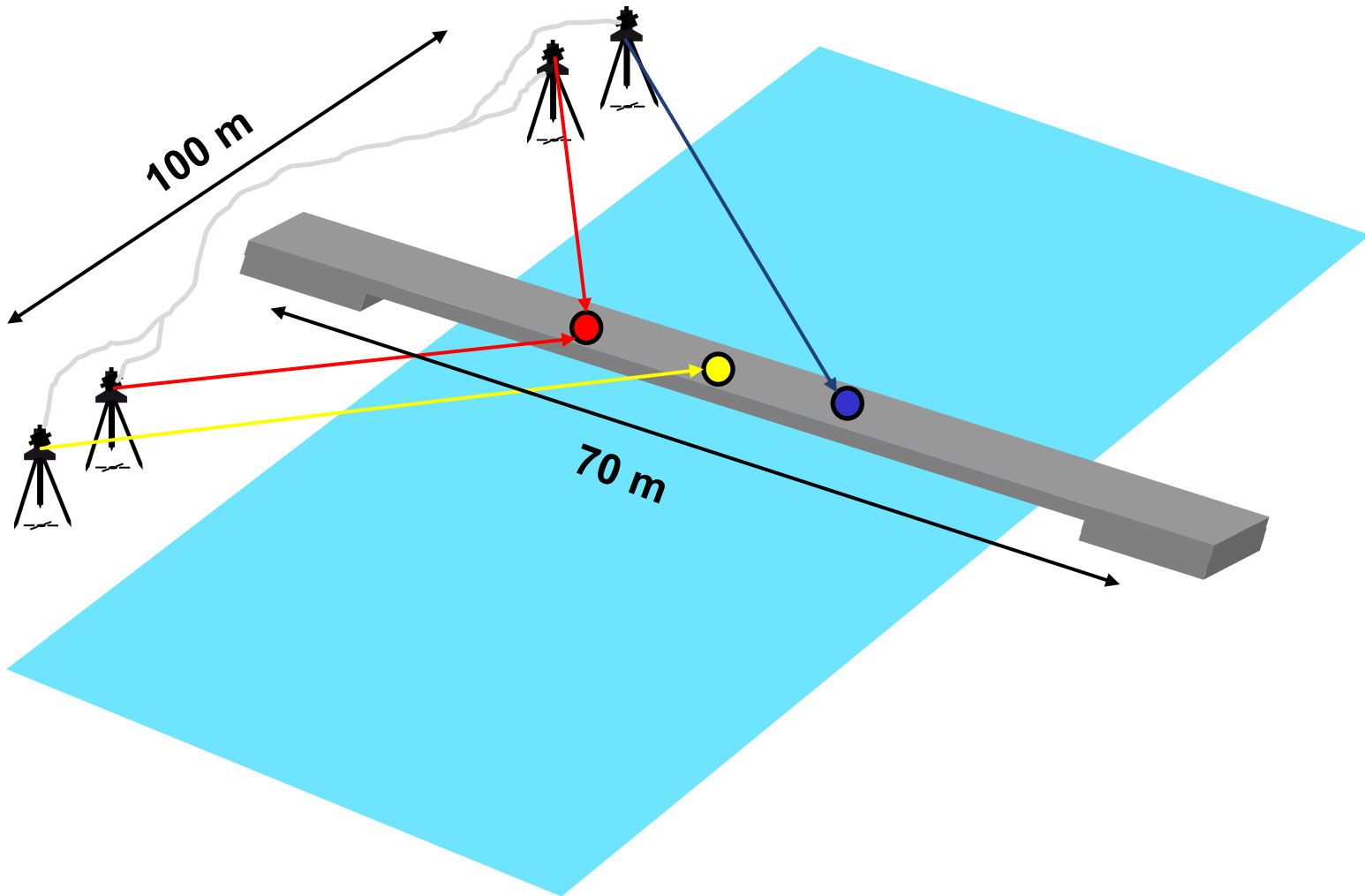
ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

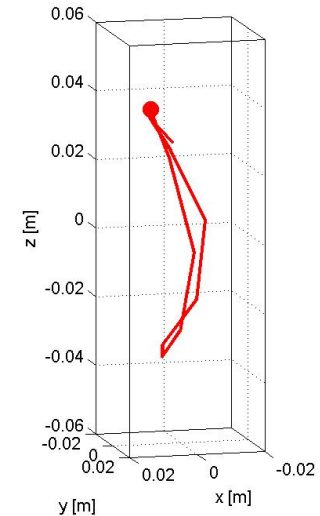
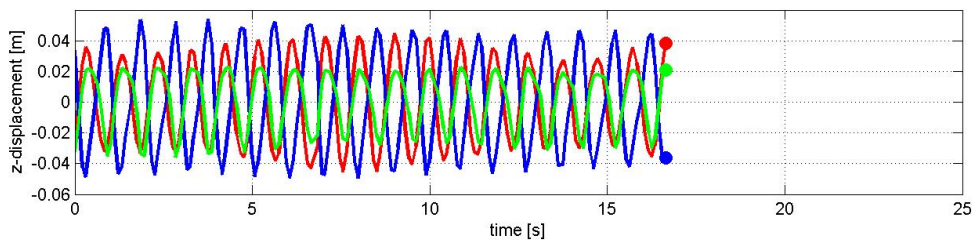
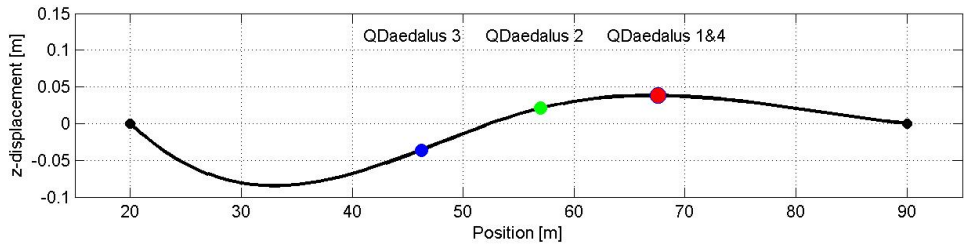
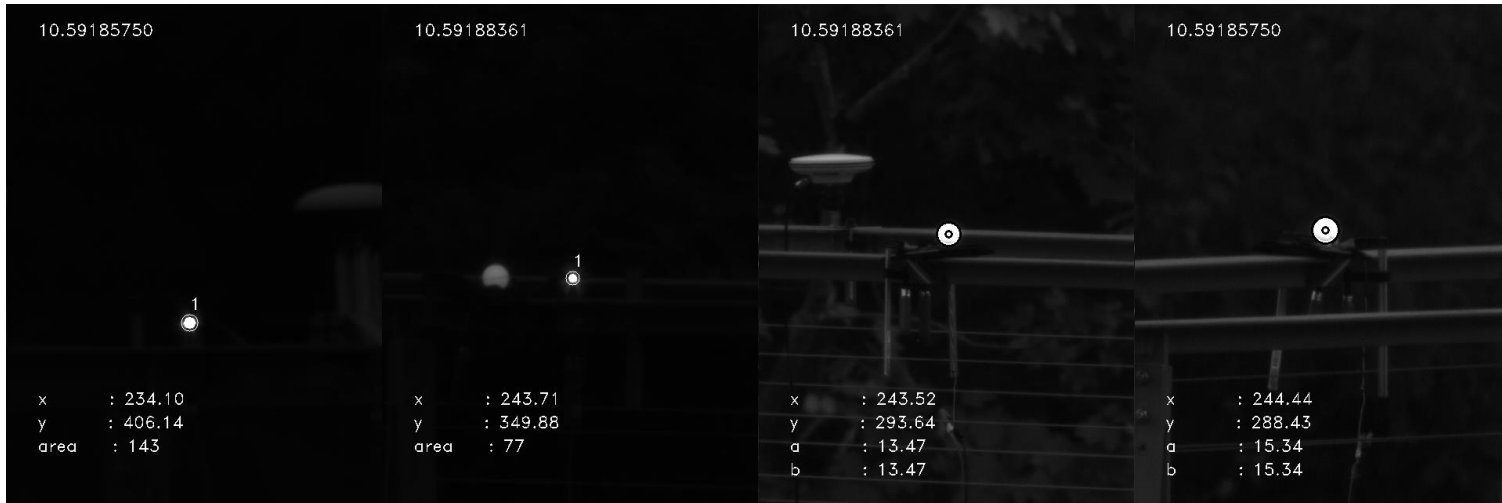
Kinematic Measurements



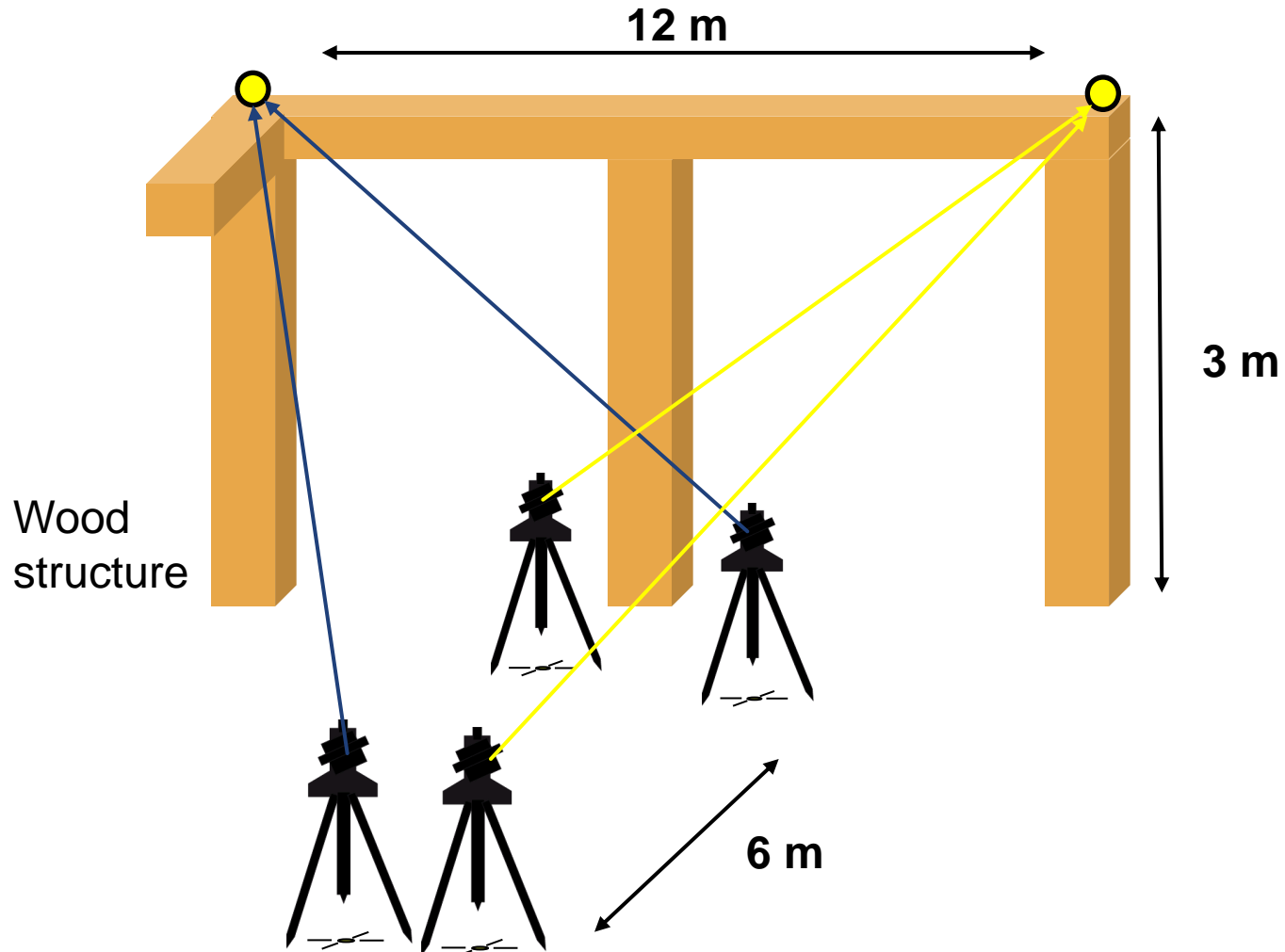
Kinematic Measurements



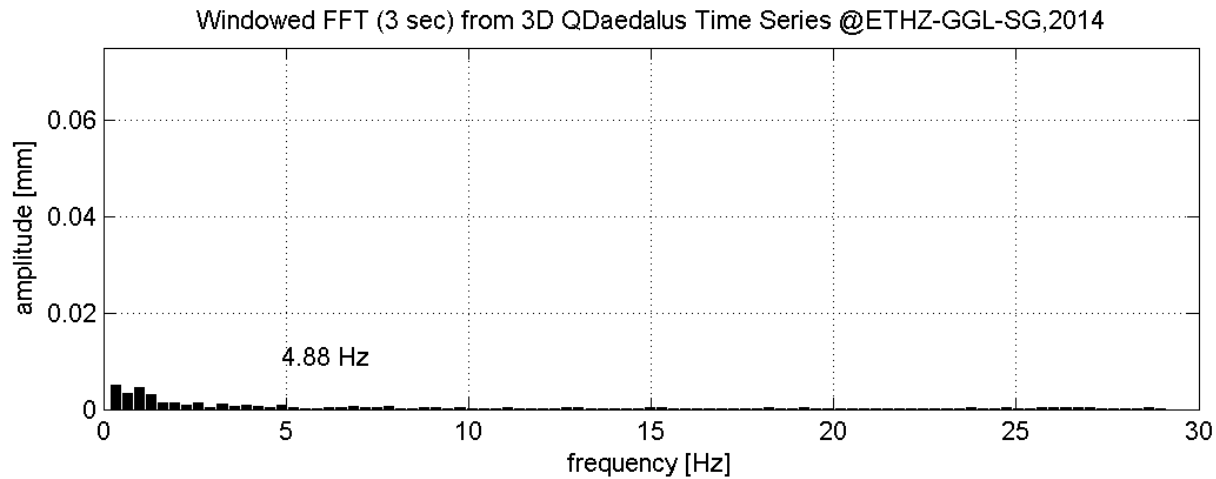
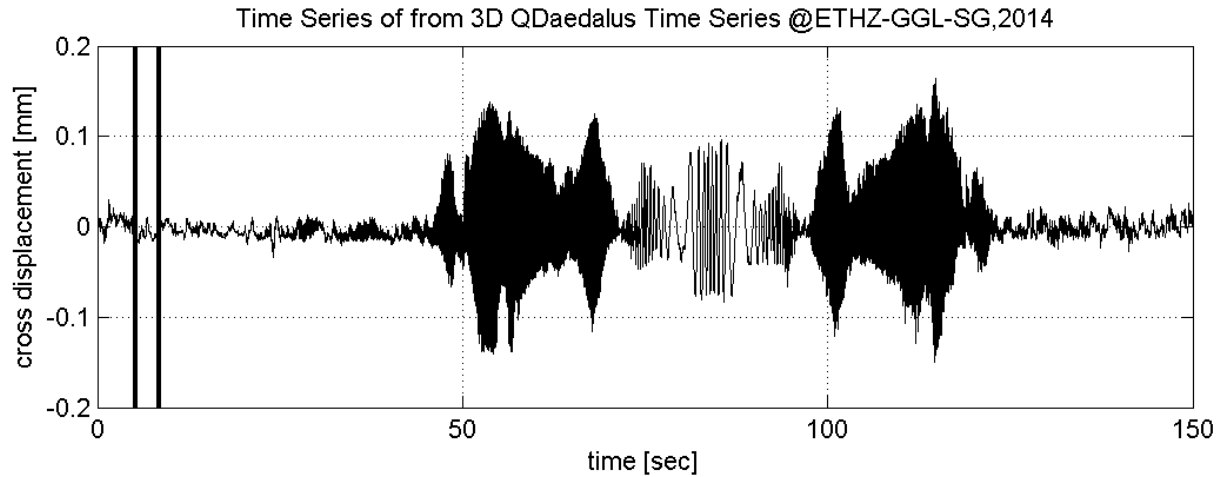
Kinematic Measurements



Kinematic Measurements

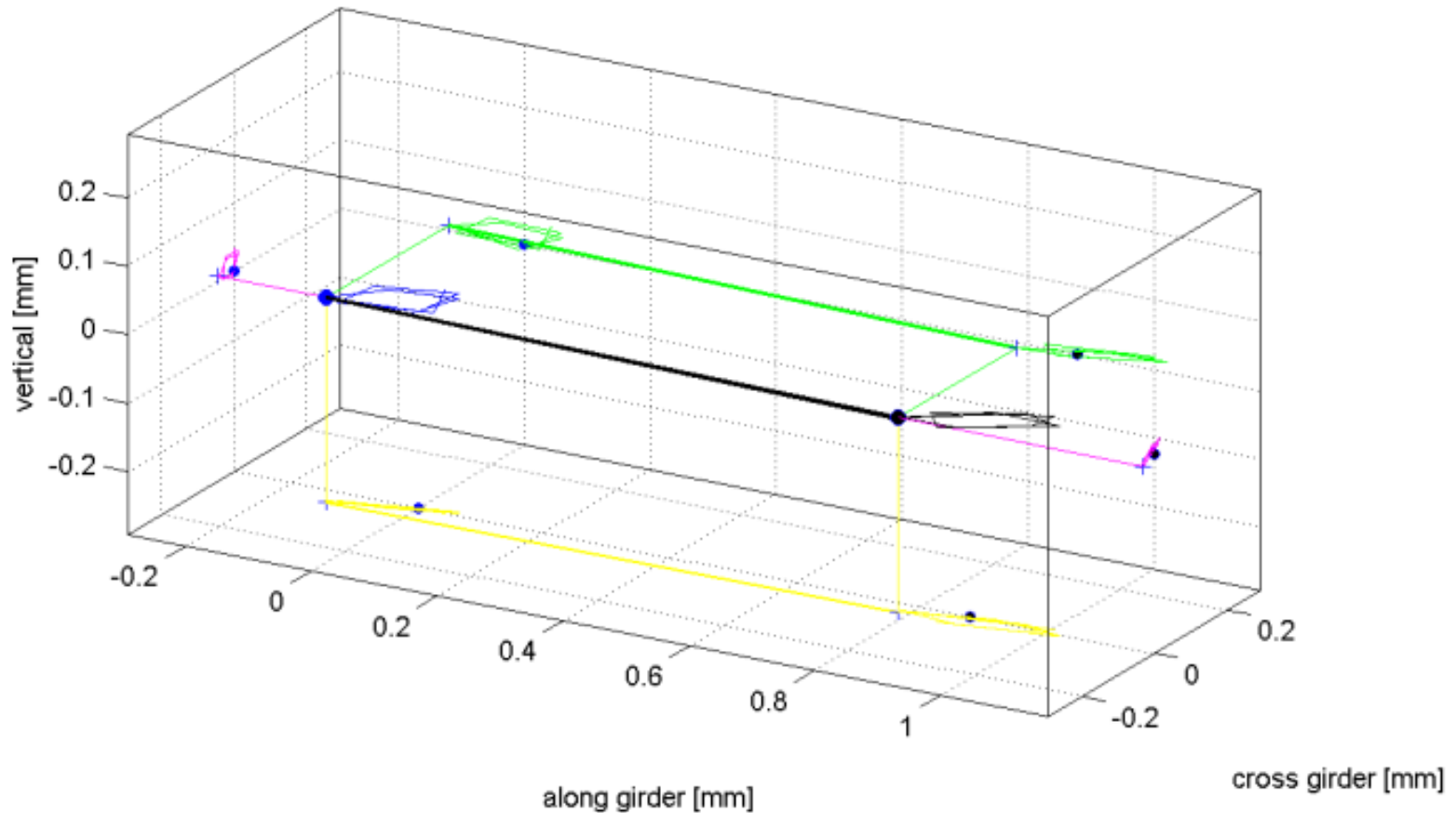


Kinematic Measurements



Kinematic Measurements

20140129_D1_shaker_07 & 20140129_D2_shaker_07 t = 49.89 sec @GGL-ETHZ SG,2014 QDaedalus



Thanks for attention

guillaume@geod.baug.ethz.ch

www.ggl.ethz.ch