Frequency Scanning Interferometry for CLIC component fiducialisation

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ESRF
The European Synchrotron

Contents

PACMAN Project

Particle **A**ccelerator **C**omponents **M**etrology & **A**lignment to the **N**anometre Scale

- Marie Curie Initial Training Network
- Funded by European Commission & CLIC
- Hosted by CERN
- 10 PhD students

Academic & Industrial Partners

ETH zürich, Cranfield University, Hexagon Metrology, Etalon Productive Metrology, Università degli Studi del Sannio, SIGMAPHI, Metrolab, Eltos, TU Delft, DMP, SYMME, TNO innovation for life, lapp, Cranfield University, Università di Pisa, IFIC, National Instruments

Four Work Packages

WP1: Metrology & Alignment

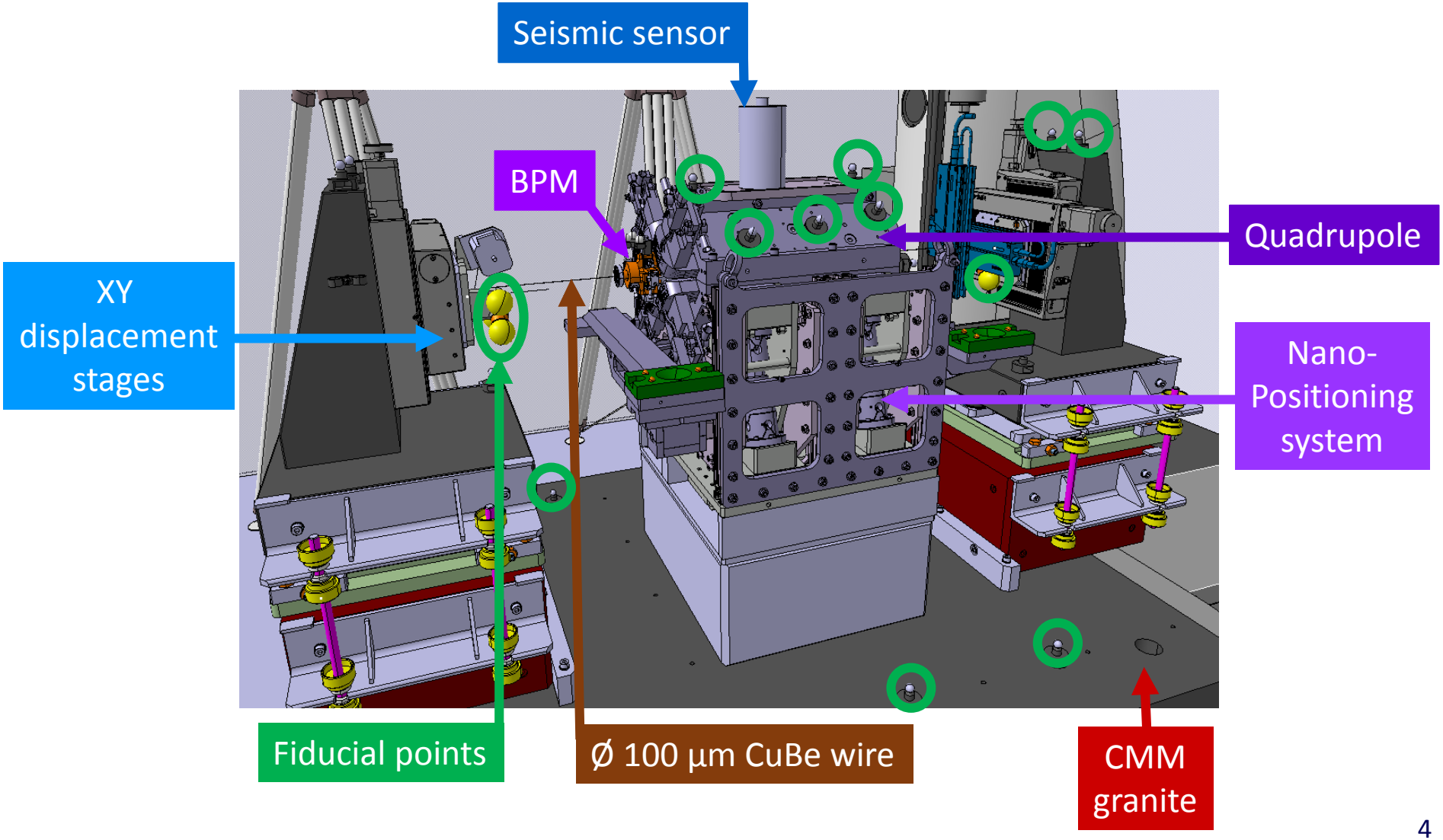
WP2: Magnetic Measurements

WP3: Precision Mechanics & Nano-positioning

WP4: Microwave Technology

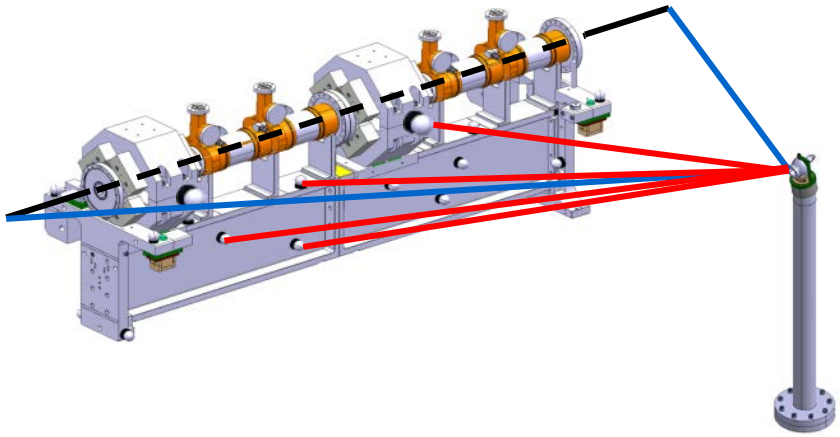
PACMAN Alignment Bench

Goal: To integrate a number of pre-alignment steps in a single test stand



Background & Objective

- **Requirement:** Fiducialisation of CLIC MBQs
- **Uncertainty Budget:** 10 µm (1 σ)
- **Option:** Leitz Infinity ($E_{L,MPE}$: 0.3 µm + 1ppm)
- **Limitations:** Measurement volume + NOT portable



Goal

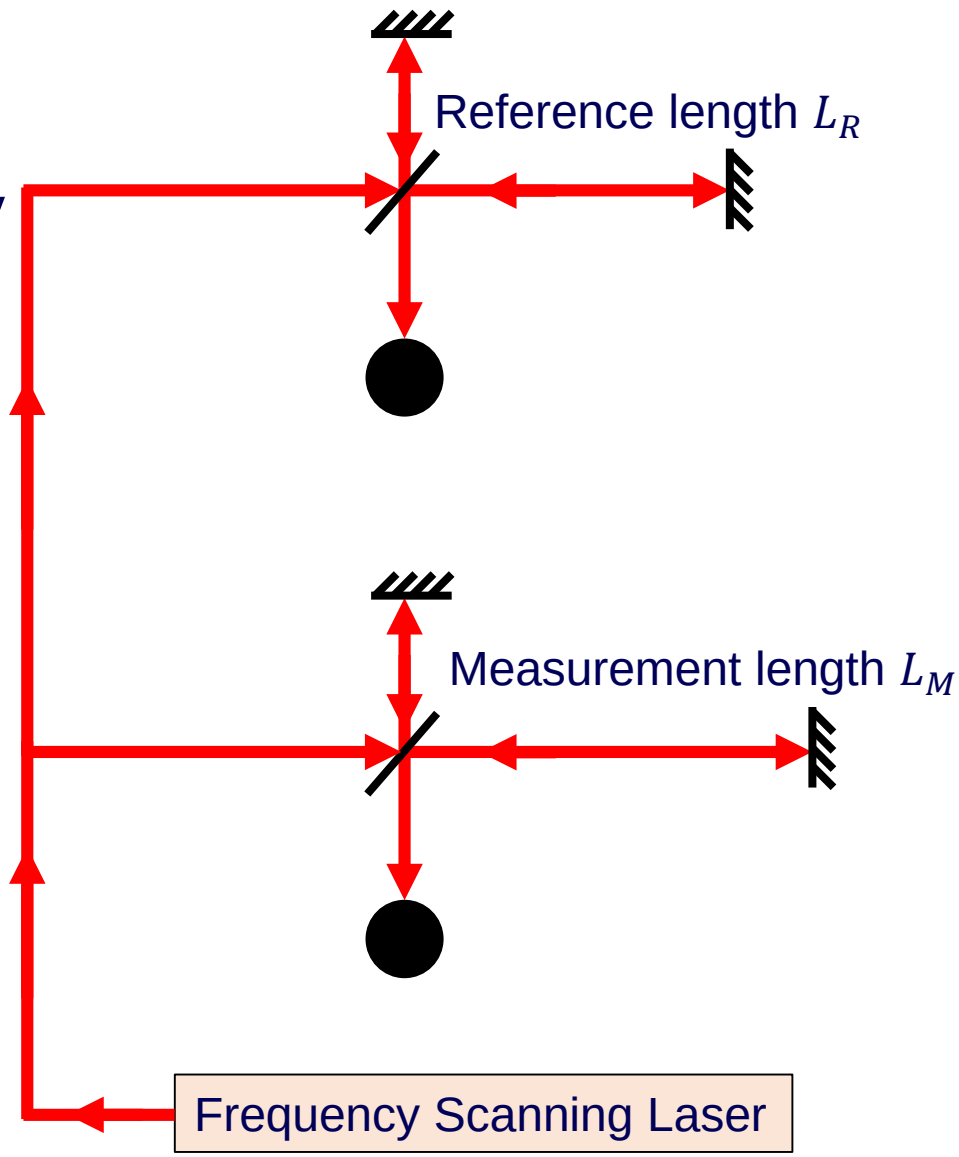
Develop & validate an FSI based coordinate measurement system that is:

- Accurate & Precise (<10 µm uncertainty)
- Portable
- Can handle larger volumes (>2 m length)

FSI: Basic Introduction

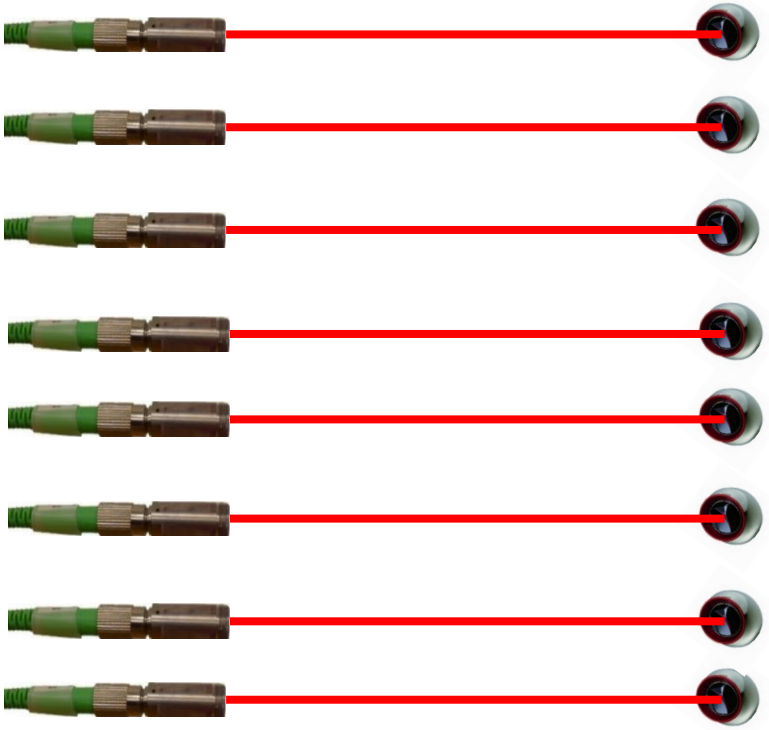
Frequency Scanning Interferometry (FSI)

- ❑Absolute distance
- ❑Fringes due to scanning laser
- ❑Unknown length inferred from known reference length
- ❑ $\frac{\Delta Phase_M}{\Delta Phase_R} = \frac{L_M}{L_R}$



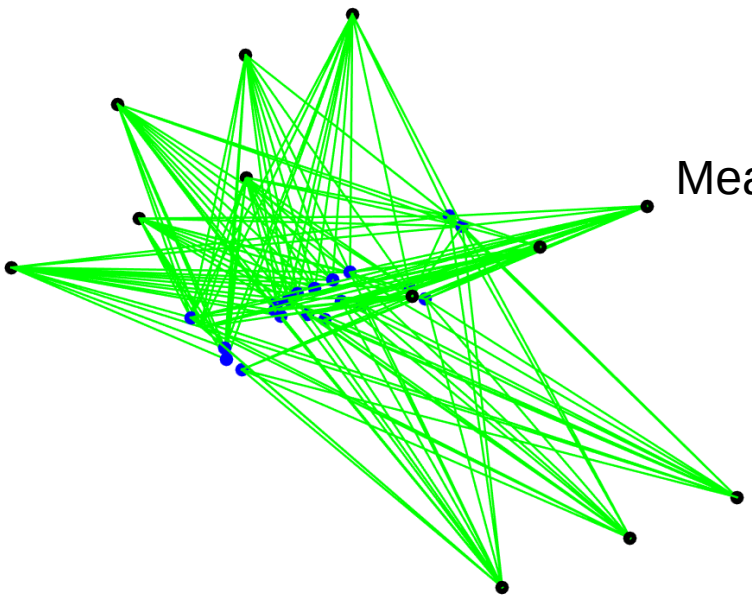
Absolute Multiline Technology

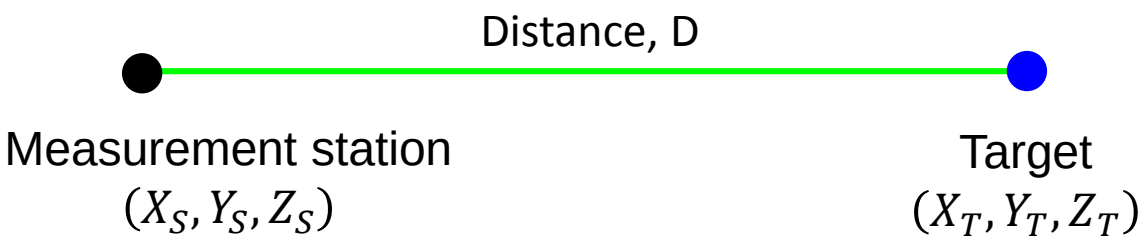
- ❑ Absolute distance measurement (FSI)
- ❑ 0.5 ppm (2 σ) Measurement Uncertainty
- ❑ 8 simultaneous measurements
- ❑ Scalable to 100 measurement lines



Multilateration

- Coordinate determination using distances only
- Requires distances in different directions from same point
- Uncertainty of coordinates depends on that of **distances** and **geometry** of network
- Compensation for systematic errors is possible
- Coordinates & their uncertainties are the output of least squares computation





Basic mathematical model

$$D + v = \sqrt{(X_S - X_T)^2 + (Y_S - Y_T)^2 + (Z_S - Z_T)^2}$$

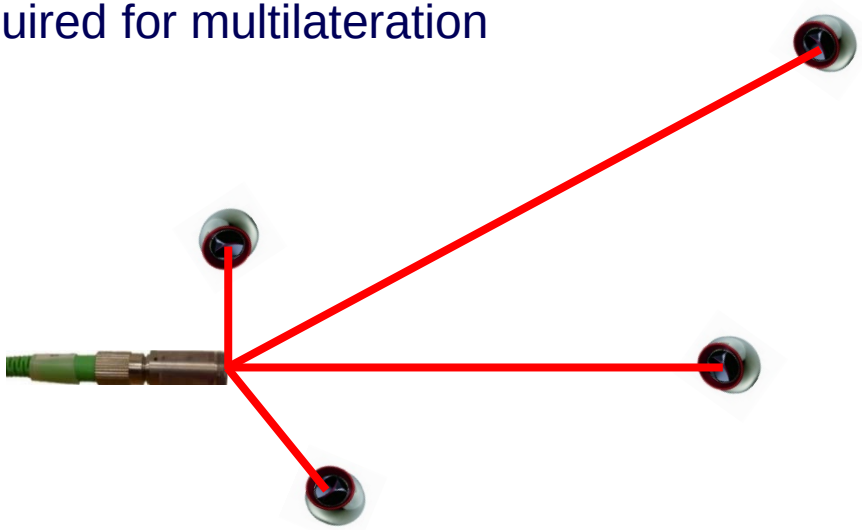
Absolute Multiline Technology

Fibre tip

Collimator

Absolute Multiline Technology

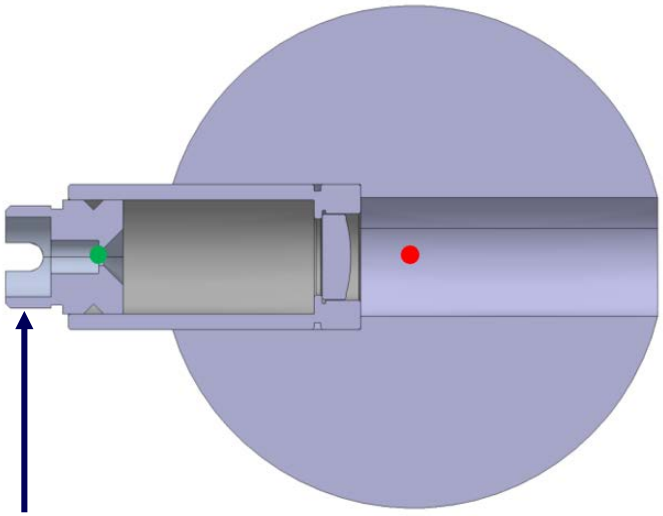
- ❑ Distance between optical fibre tip and retroreflector
- ❑ Can’t measure distances in different directions from same point.
- ❑ This is required for multilateration



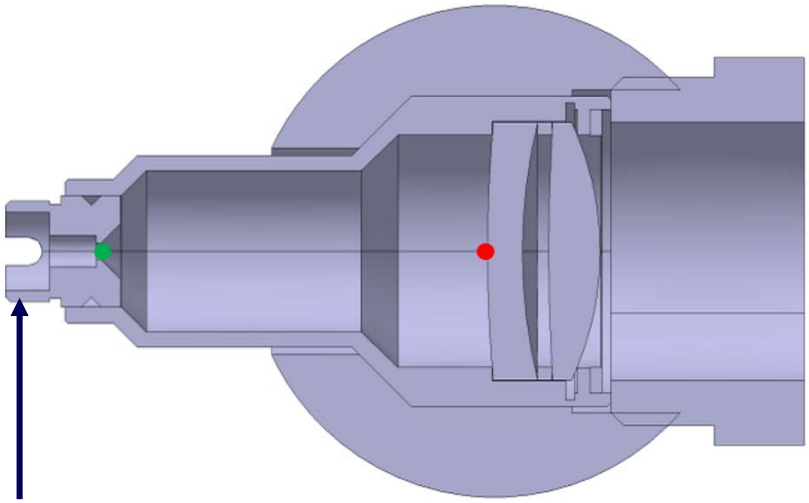
Localization of FSI Optical Fibre Tip

Reference Sphere

- Localization of fibre tip w.r.t centre of sphere
- Ceramic: Can be measured by **QDaedalus**[1] & CMM
- Alumina ceramic: Lower CTE ($8.1 \cdot 10^{-6} K^{-1}$)
- Diameter: 38.1 mm ± 0.5 µm
- Sphericity: 0.5 µm



F280FC collimator



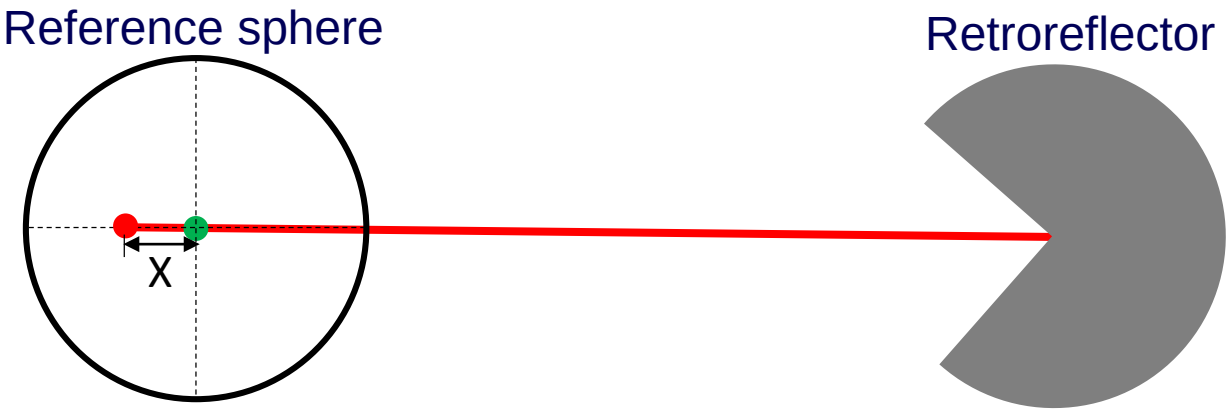
F810FC collimator

[1]**See presentation by Vasileios Vlachakis: Friday @ 9:15**

Kinematic Mount

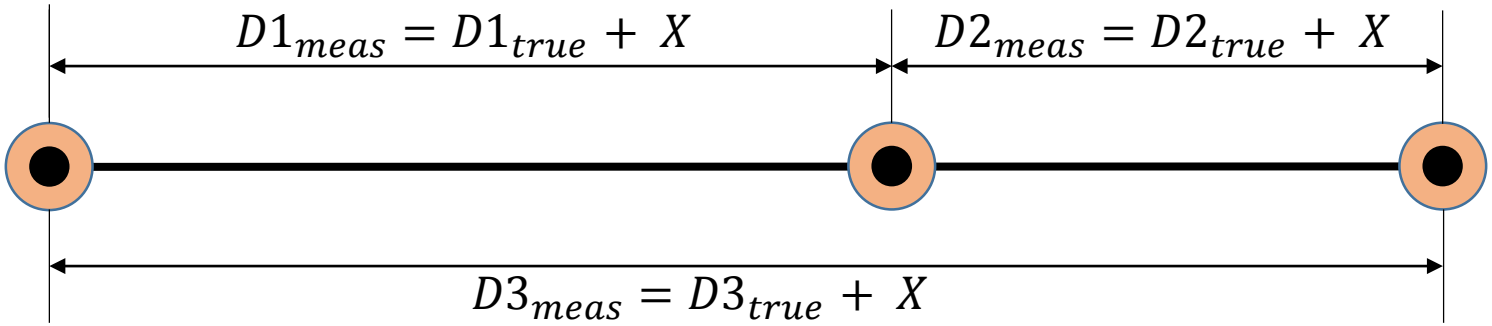
- 3 ceramic spheres for repeatable repositioning of reference sphere
- Distances in different directions from same point (centre of sphere)
- +/- 44° vertical angle & 360° horizontal angle
- For reference sphere and 1.5 inch diameter retroreflectors

Reference Sphere – Error Sources



- Offset along the beam introduces a constant systematic offset
- Can be easily calibrated by a number of techniques

Calibration of offset along the beam line



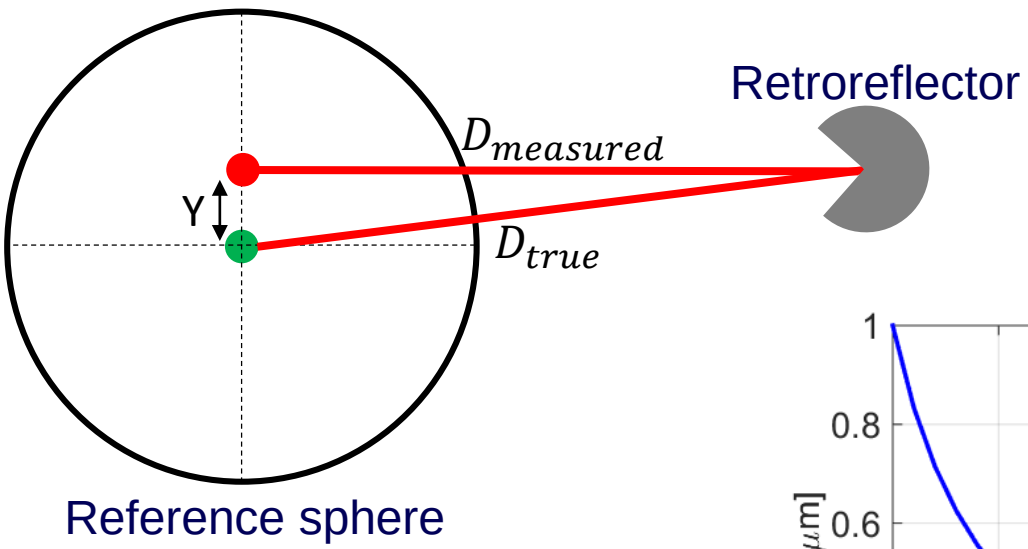
$$D3_{true} = D1_{true} + D2_{true}$$

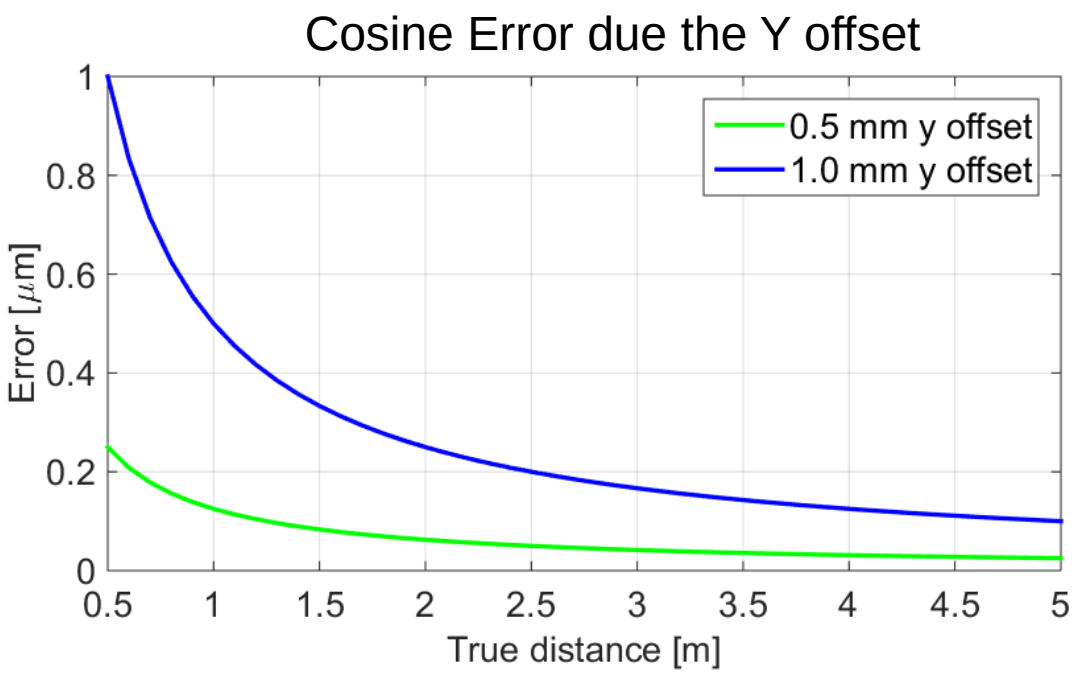
$$X = D1_{meas} + D2_{meas} - D3_{meas}$$

Reference Sphere – Error Sources

Geometrical Error Sources - Cosine error

- Due to Offset perpendicular to beam line
- Assumption: Beam perfectly aligned to centre of retroreflector

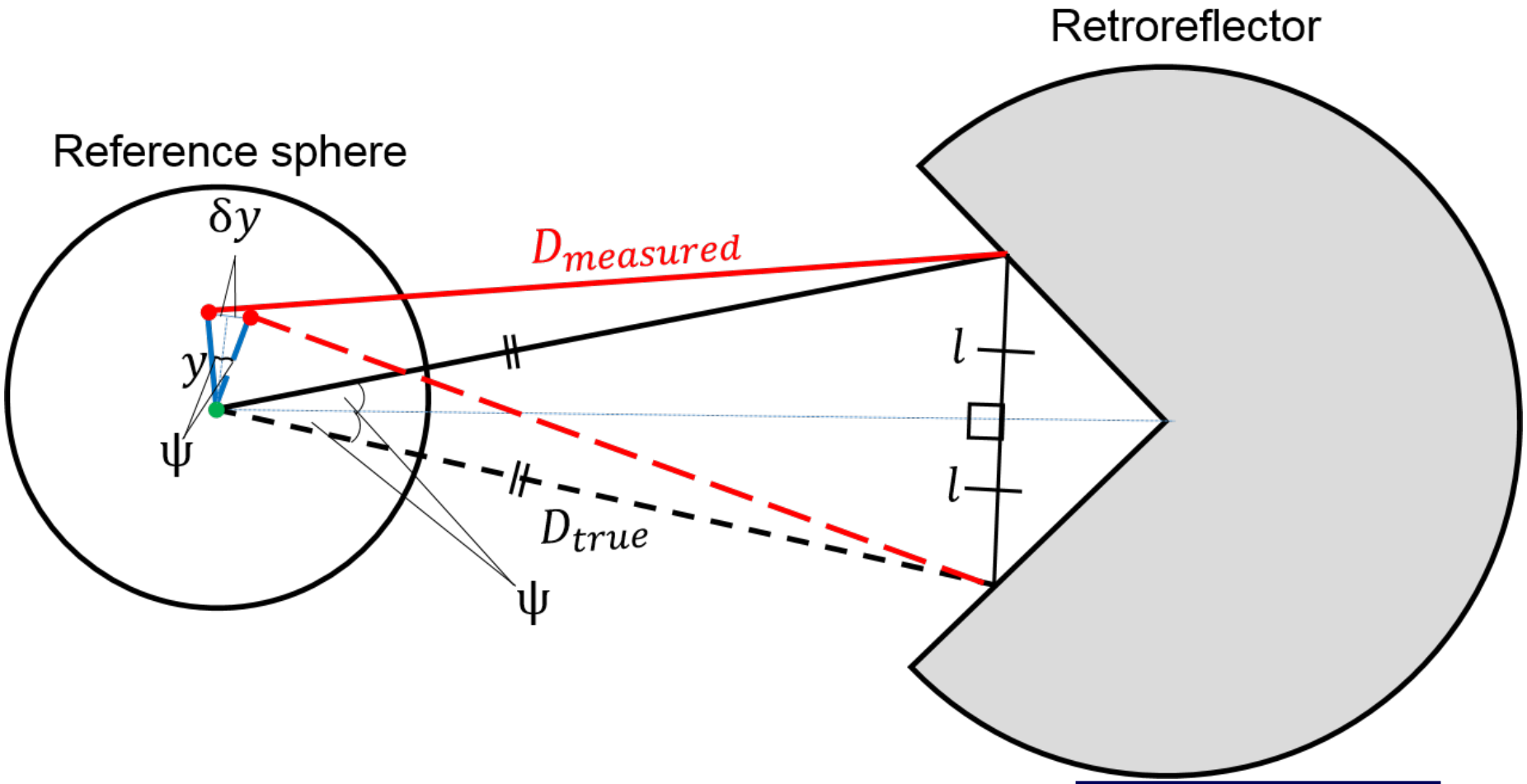




$$E_y = \sqrt{D_{measured}^2 + y^2} - D_{measured}$$

Reference Sphere – Error Sources

Geometrical Error Sources - Sine error

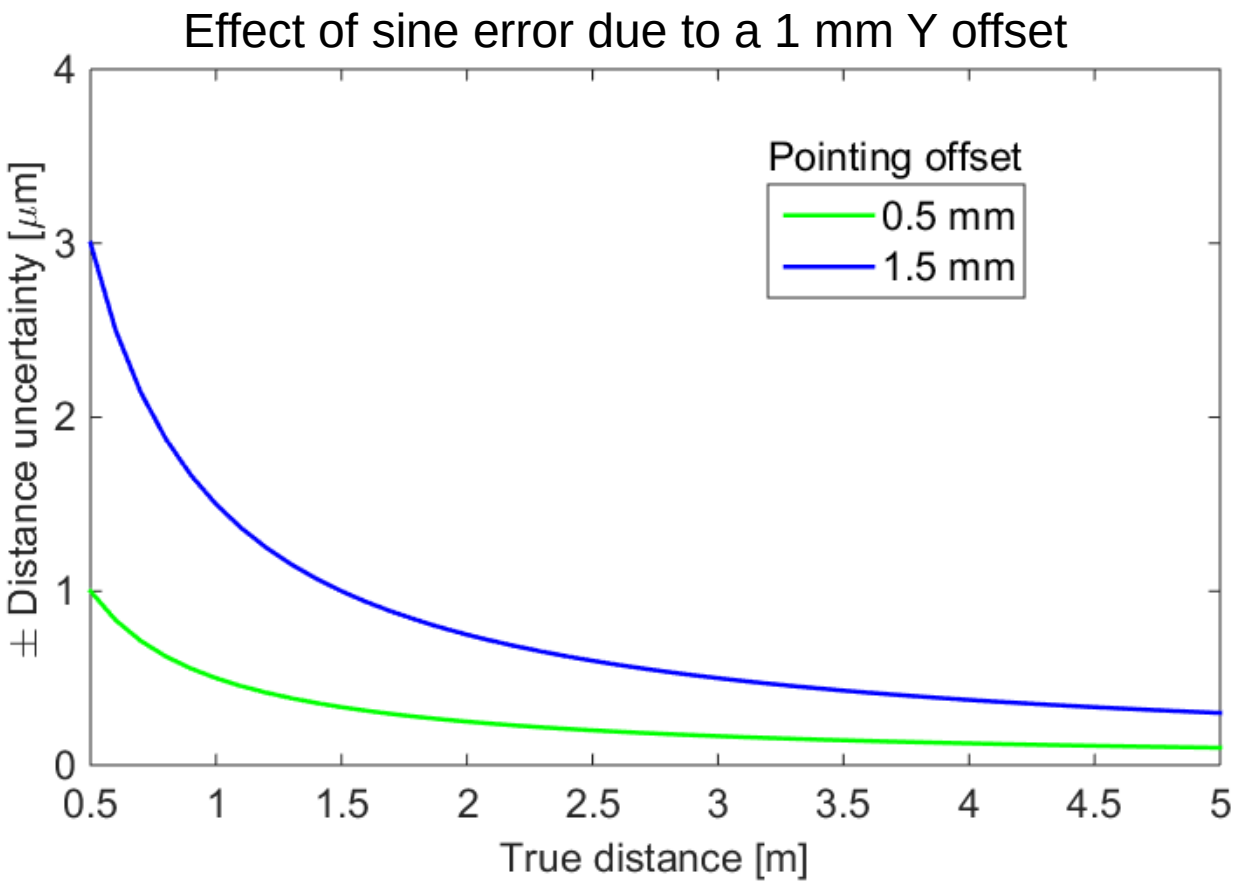


- $sin\psi = \left(\frac{l}{D_{true}}\right)$
- $\delta y \approx y sin\psi$
- $\boxed{\delta y \approx y\left(\frac{l}{D_{true}}\right)}$

Reference Sphere – Error Sources

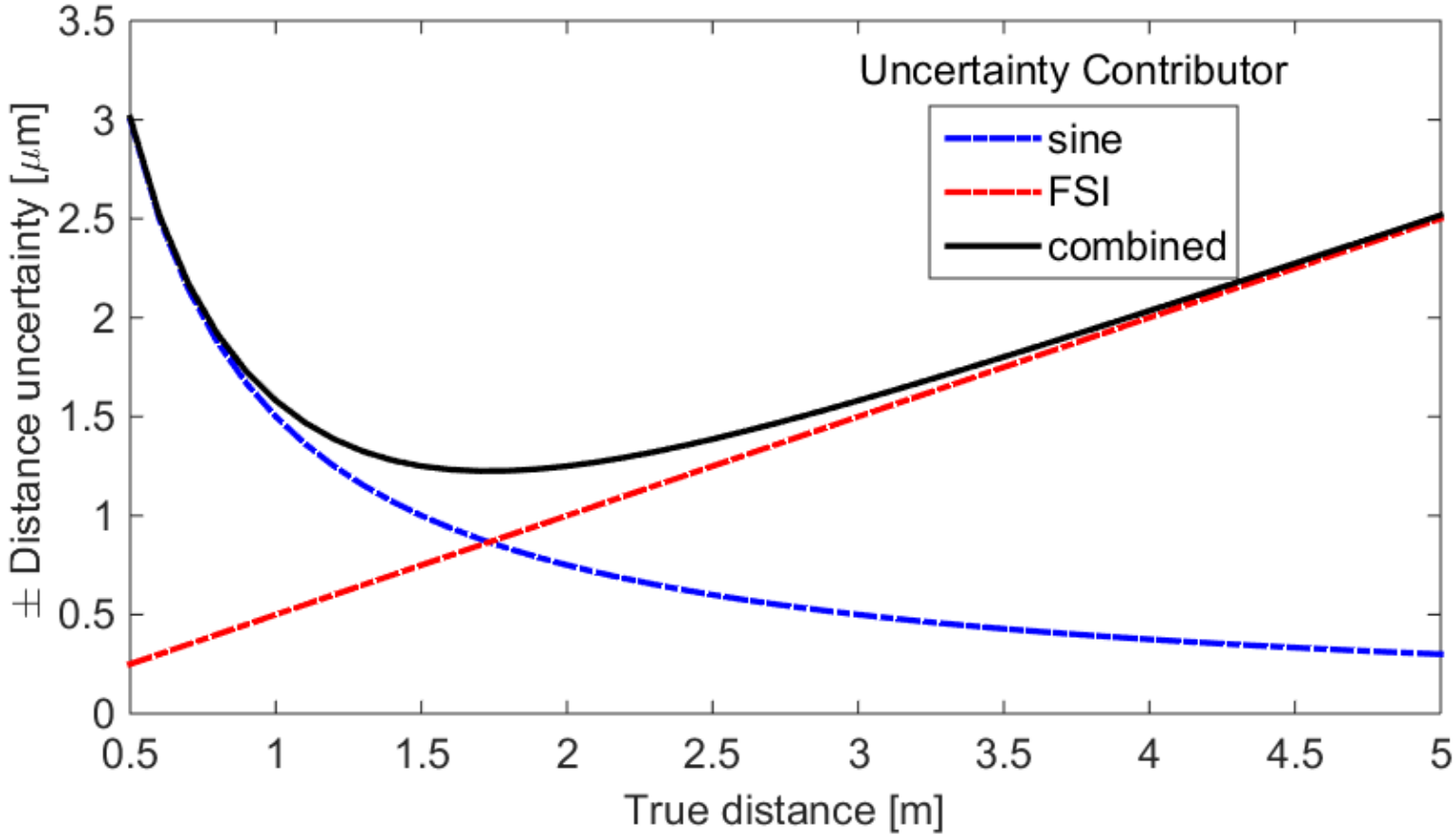
Geometrical Error Sources - Sine error

- Due to Offset perpendicular to beam line
- **And** lateral misalignment of beam on retroreflector



Combined Uncertainty

Uncertainty in presence to a 1 mm perpendicular offset and a 1.5 mm pointing offset



Reference Sphere - Repeatability

- 36 repeat measurements
- Good and Poor alignment
- Shorter and longer distance

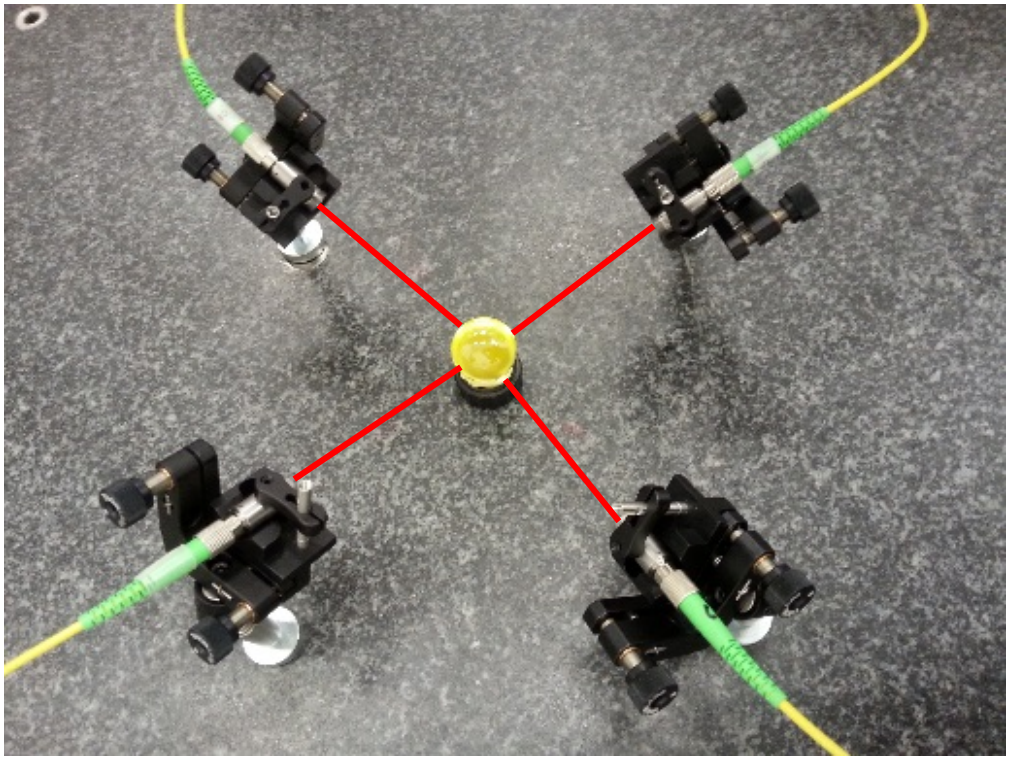
Measurement setup

Repeatability Results

Pointing Accuracy	Distance [mm]	Std [µm]	Range [µm]	Distance [mm]	Std [µm]	Range [µm]
Poor	311	2.9	9.8	994	1.9	5.9
Good	**311**	**0.8**	**2.9**	**994**	**0.5**	**2.5**

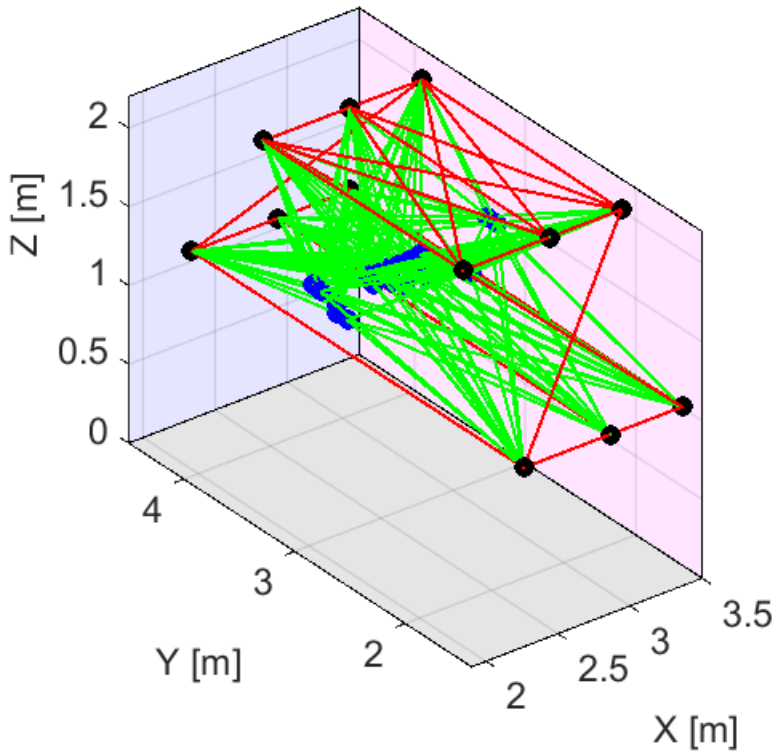
Retroreflector Study

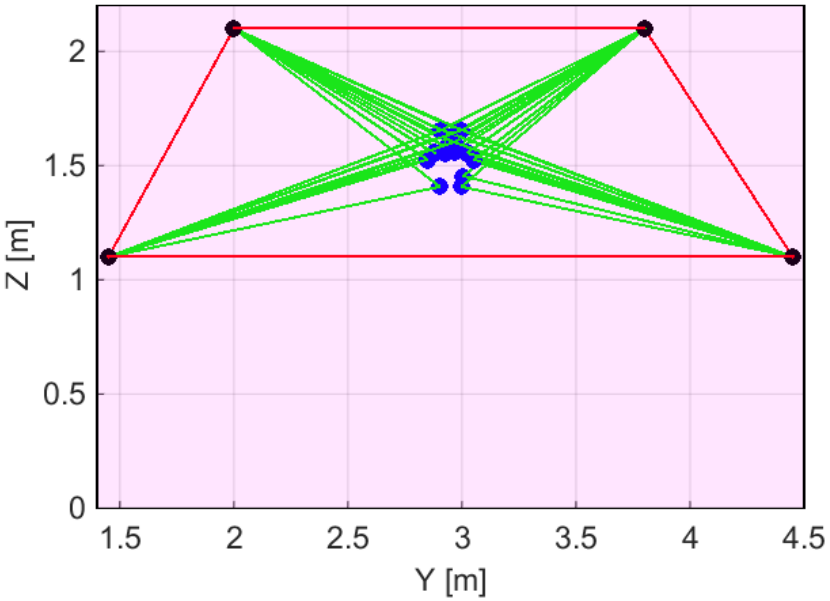
- Large acceptance angle targets yield more precise networks
- The acceptance angle of commercial corner cubes is ± 30°
- N=2 glass spheres can be used as retroreflectors
- N=2 glass spheres have an almost **unlimited acceptance angle**
- Absolute Multiline can measure at distances of **up to 4.5 m**



PACMAN Bench Network Simulation

- 170 in Observations in total
- 20 Interstation Observations
- 12 Stations, 19 fiducials
- 93 unknowns (X, Y, Z) + 1 reflector offset

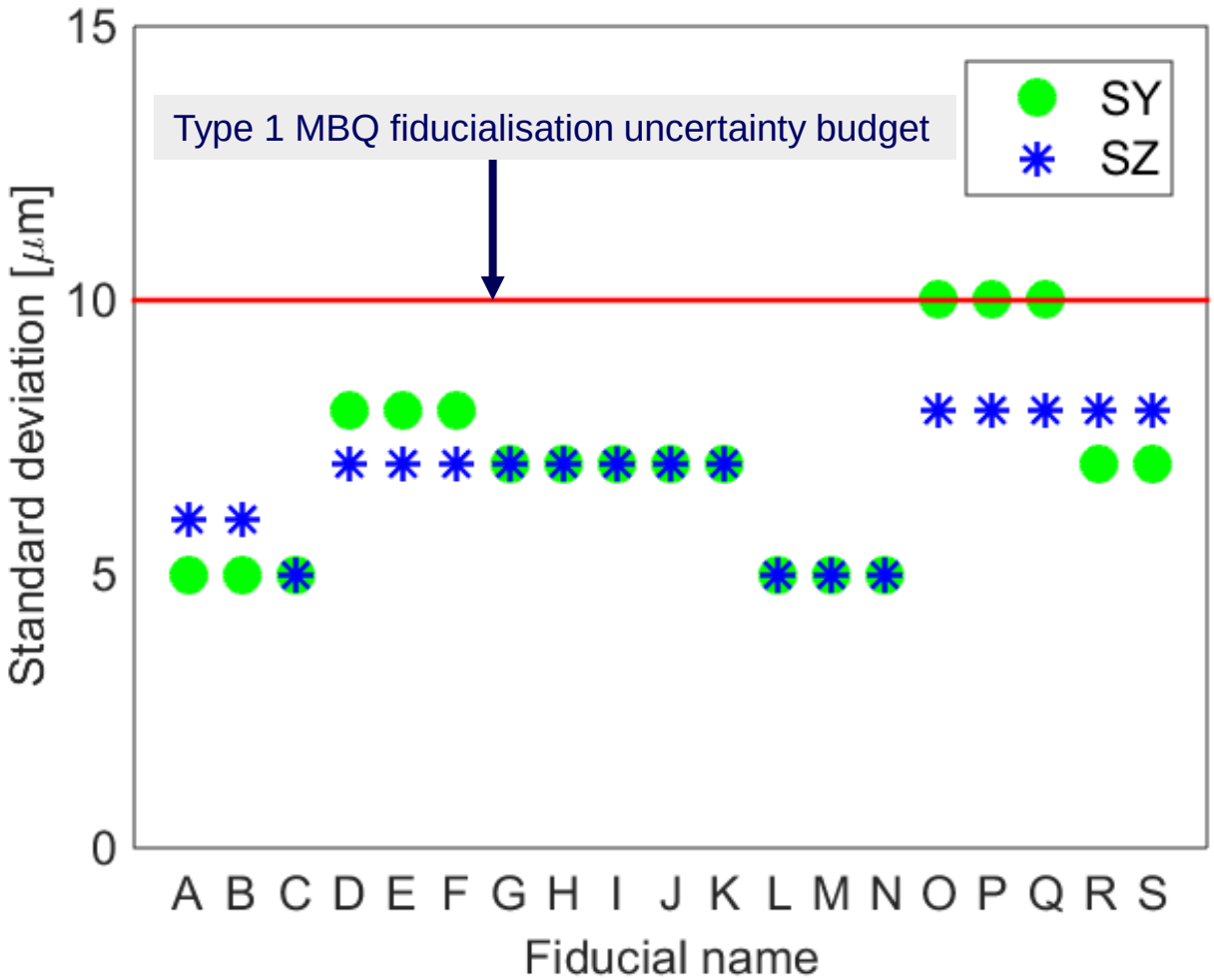




- Measurement stations
- Fiducials
- Station to fiducial observations
- Interstation observation

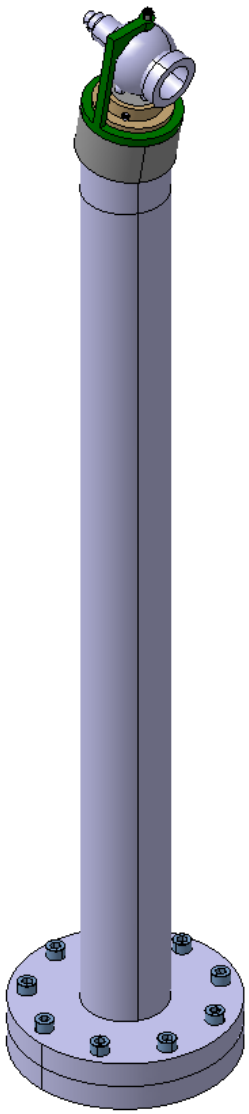
Simulation Results

Based on 10 μm a priori distance standard deviation



Next Steps

- Realise high accuracy multilateration – We have all test bench components.
- Carry out comparison tests to validate solution
- Explore motorization possibilities – will speed up data collection, reduce impact of sine error with accurate pointing



Thank You for Your Attention