# FUTURE CIRCULAR COLLIDER

# GEODESY UPDATE

11th June 2024 / FCC Week 2024

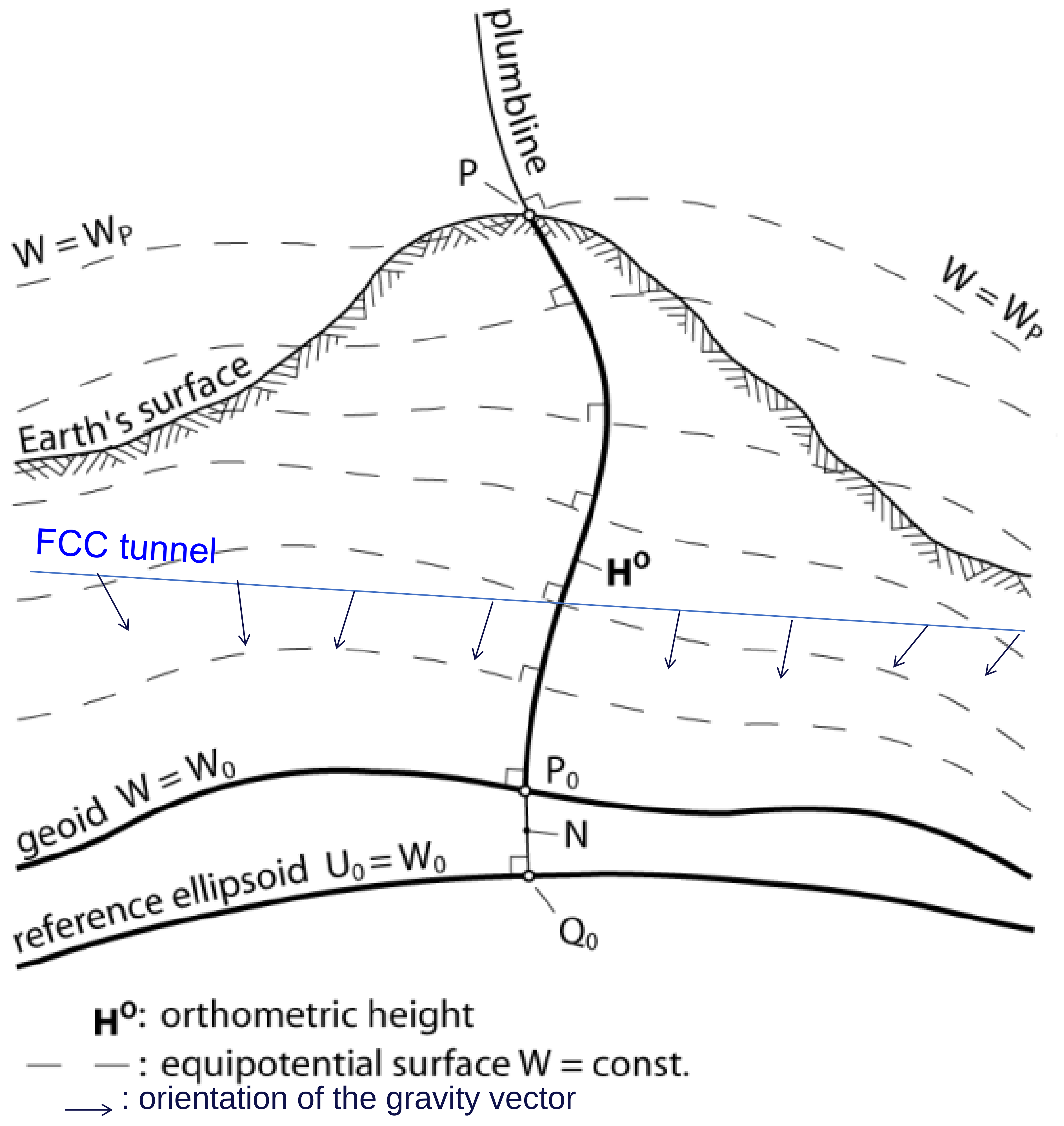
Benjamin Weyer

# Objectives of the geodetic studies

**Establish the geodetic infrastructure for the Futur Circular Collider**

- Define coordinate reference systems
- Establish the necessary geodetic reference frames
- Study the determination of a high-precision gravity field model for the FCC area

**Developpe and provide necessary documentation and transformation tools and software**




Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

**Bundesamt für Landestopografie swisstopo**
**Office fédéral de topographie swisstopo**
**Ufficio federale di topografia swisstopo**
**Uffizi federal da topografia swisstopo**

IGN
INSTITUT NATIONAL DE L'INFORMATION GÉOGRAPHIQUE ET FORESTIÈRE

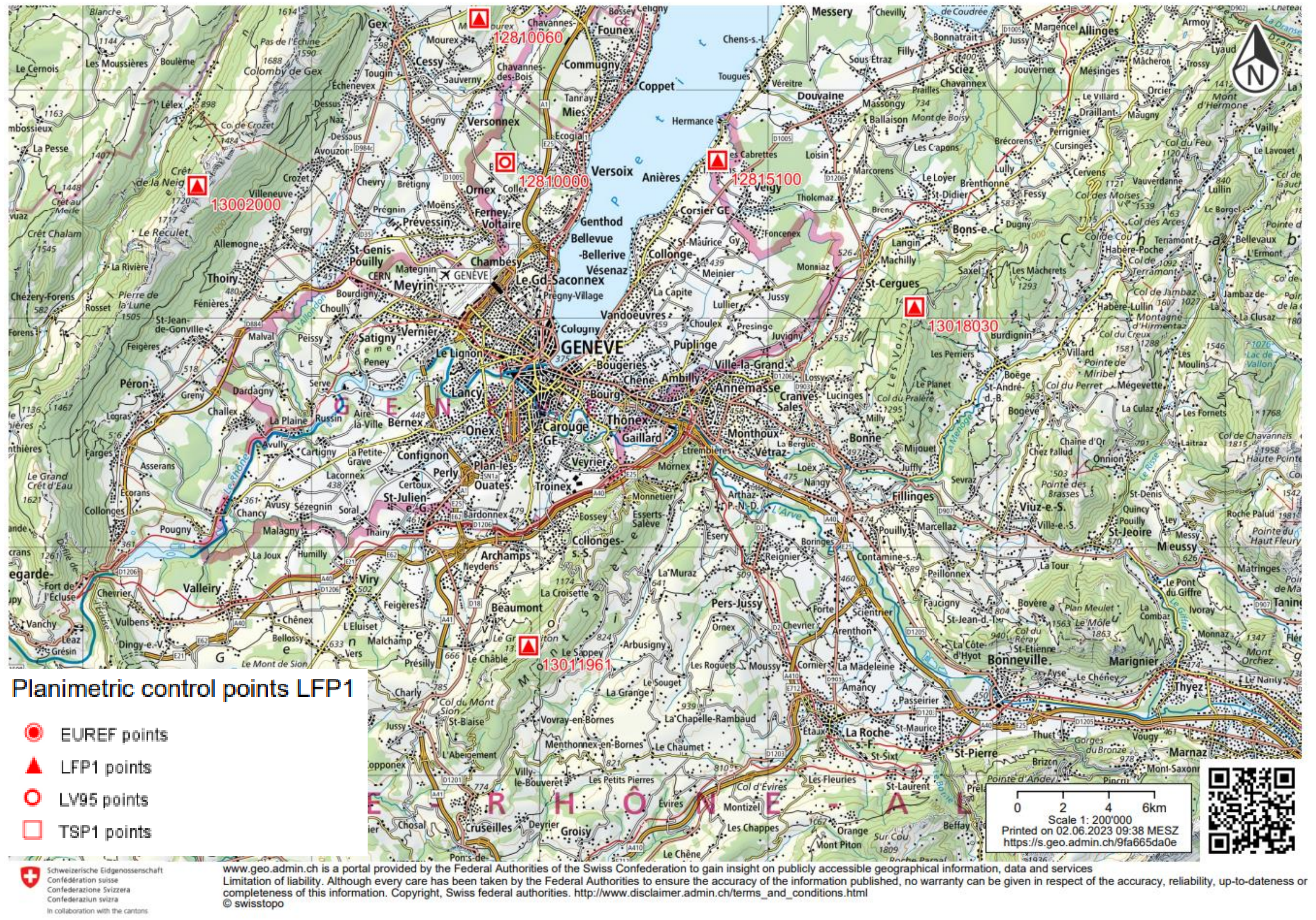
ETH zürich

HEIG VD

# Outline

1. Implementation of the Primary Surface Geodetic network
2. Geoid modelling
3. Calibration control and tests of geodetic instruments
4. Test on coordinate transfer methodology
5. Upcoming works

# Implementation of the P-SGN



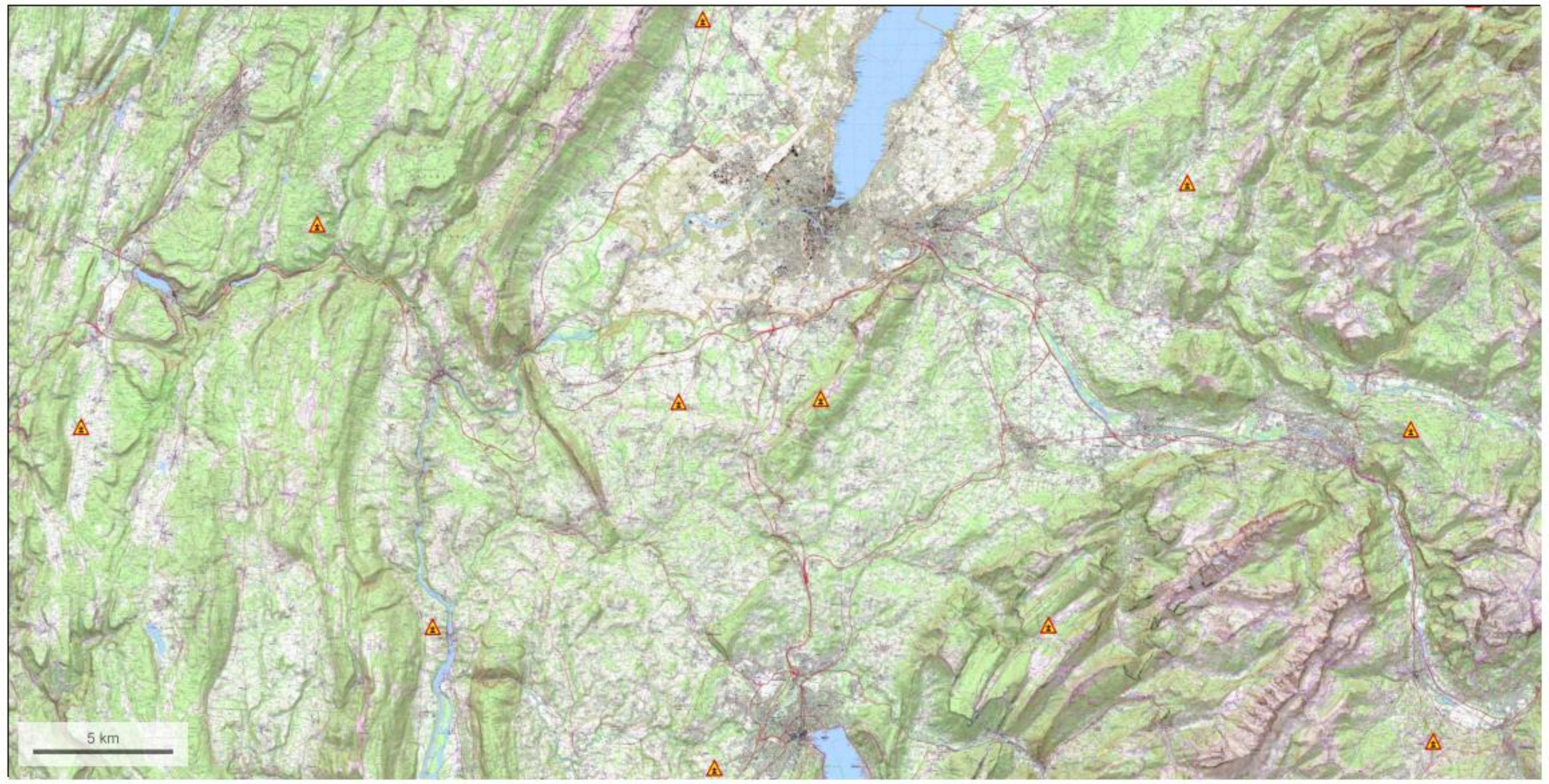

## Primary Surface Geodetic Network (P-SGN)

- P-SGN will serve different purposes
  - Materialization of the CERN Terrestrial Reference Frame (CTRF)
  - Civil-engineering and surveying works required for the construction of the FCC tunnel
  - Providing the long-wavelength basis for the later alignment work
  - Providing the reference for the geokinematic monitoring of the FCC area

- Collaboration between CERN, IGN and Swisstopo for a densification of the French and Swiss national geodetic networks around FCC area
  - P-SGN markers will be available for the entire survey community
  - New CORS will be part of the French RGP (Réseau Géodésique Permanent)

géoportail

Réseau de Base Français



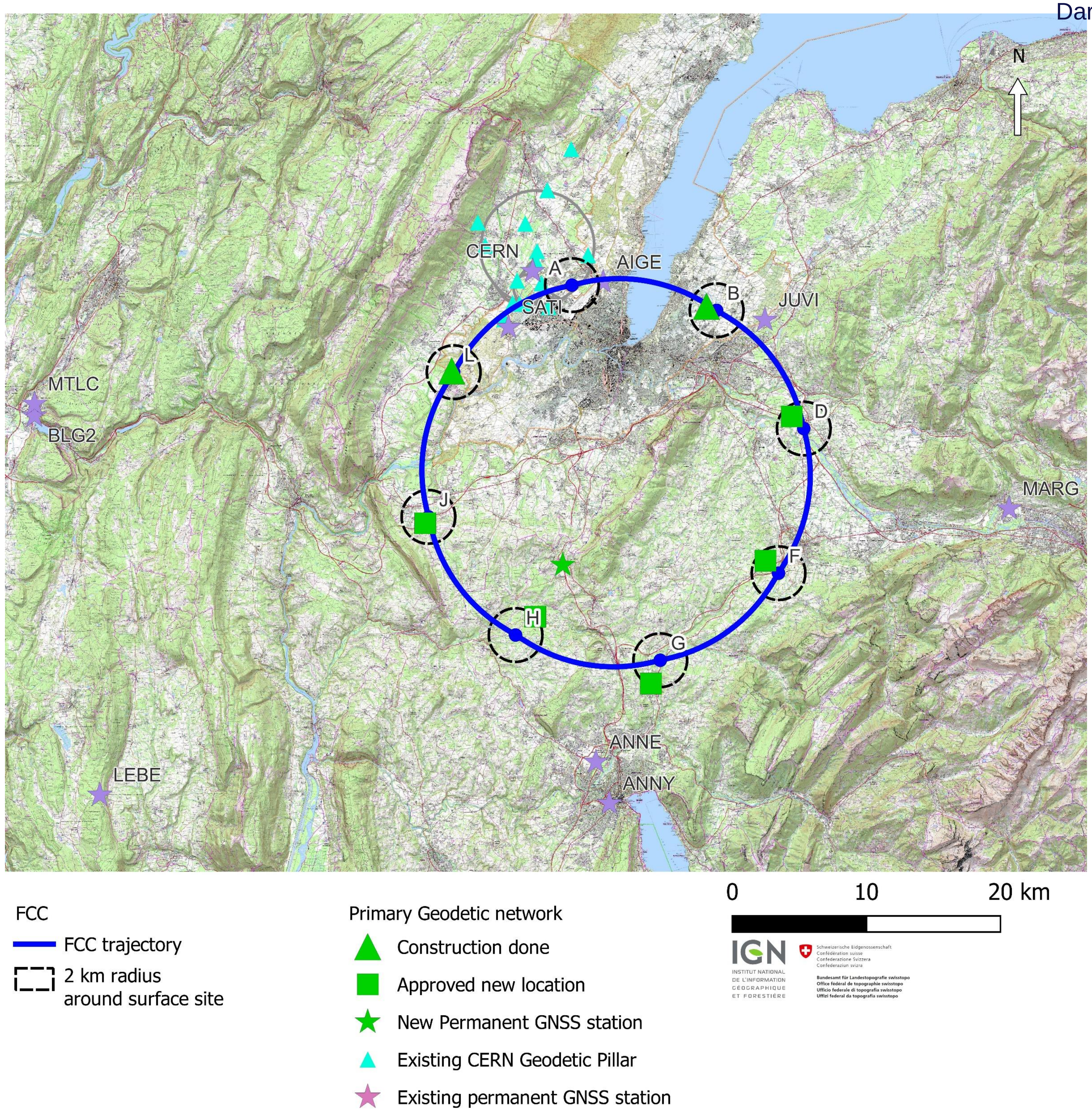
# Implementation of the P-SGN


Choulex


Dardagny

## Construction of the geodetic pillars

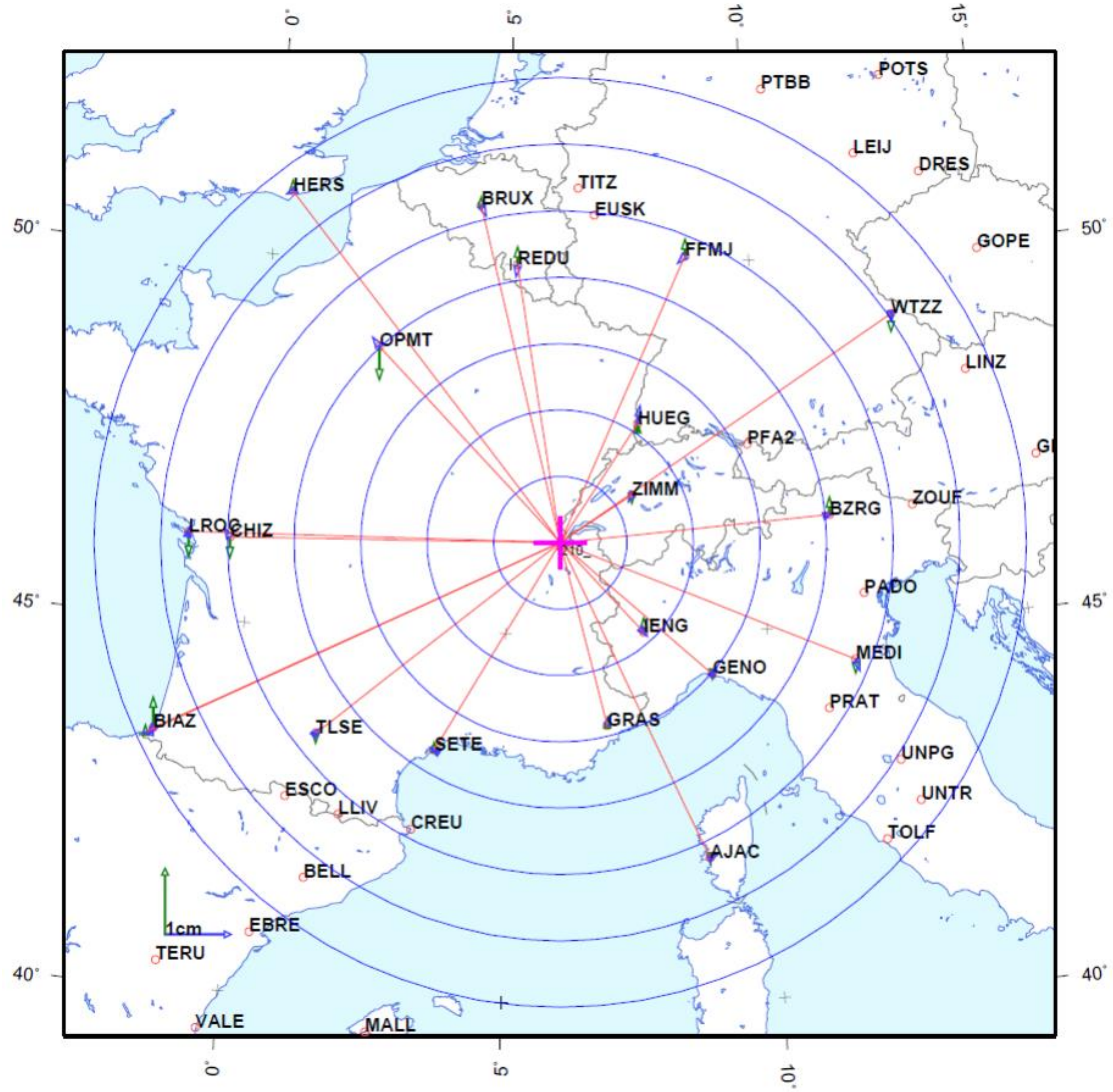
- Swisstopo built 2 new pillars in Choulex (point B) and Dardagny (point L)
- Construction pending on the French side at point D, F, G, H and J (construction expected at the beginning of the summer)
- GNSS observation of the entire network planned in fall 2024



# Implementation of the P-SGN

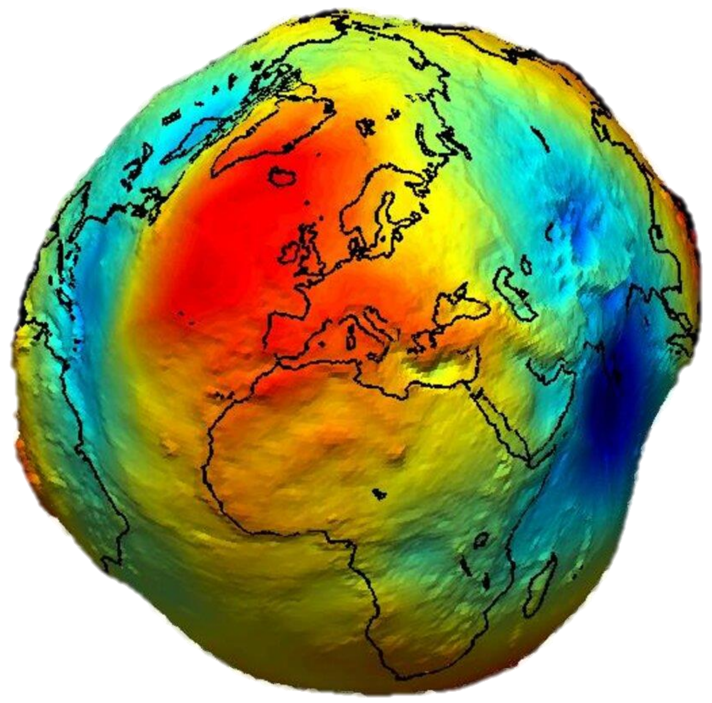
## GNSS observations and determination of the coordinates

- 2 static GNSS campaigns separated by one 1 year. 2 sessions of 48 hours per campaign
- Include existing CERN geodetic pillars in the network
- 2 independent processing (one by IGN and one by Swisstopo)
- Tying in International and European terrestrial reference frame (ITRF and ETRF)
- Expected accuracy +/- 2 mm in planimetry and +/- 5 mm in altimetry (at 1-sigma)

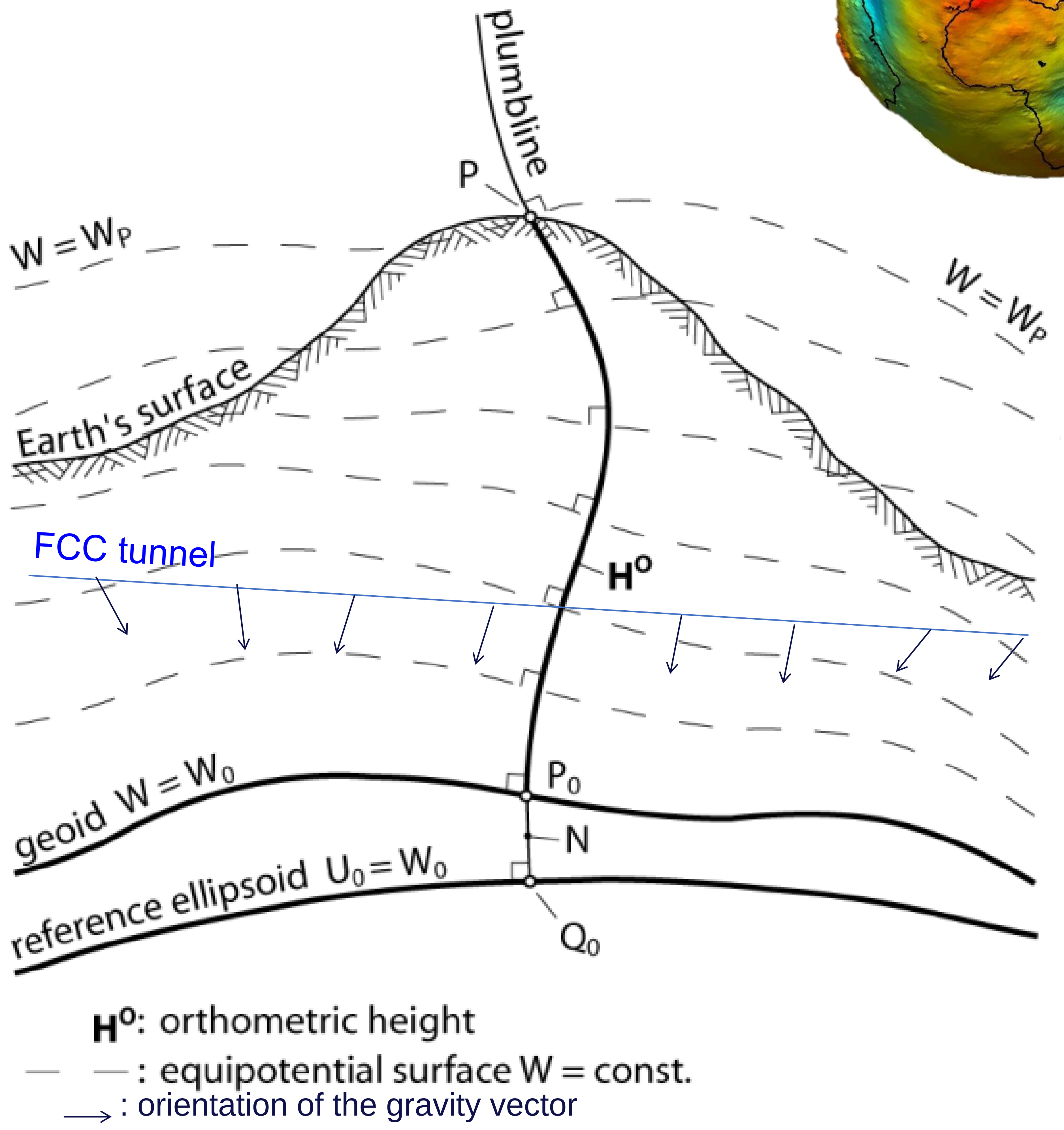



Distribution of reference stations from permanent networks known in ITRF2014 (IGS14) around the CERN

# Geoid modelling



- The geoid is a selected equipotential surface of the earth's gravity field and serves as the reference surface for height determination. It can be considered as an idealised continuation of the mean surface of the oceans beneath the continents.
- Equipotential surfaces are not parallel within the Earth
- Survey observations need to be corrected to take into account variations of the direction of the plumbline (deviation of the vertical) to align accelerator components in an Euclidean plane
- Four different levels of precision will be considered: 1 cm/km for the civil engineering and 30 µm, 50 µm and 100 µm over 225 m for the high-precision gravity field models.



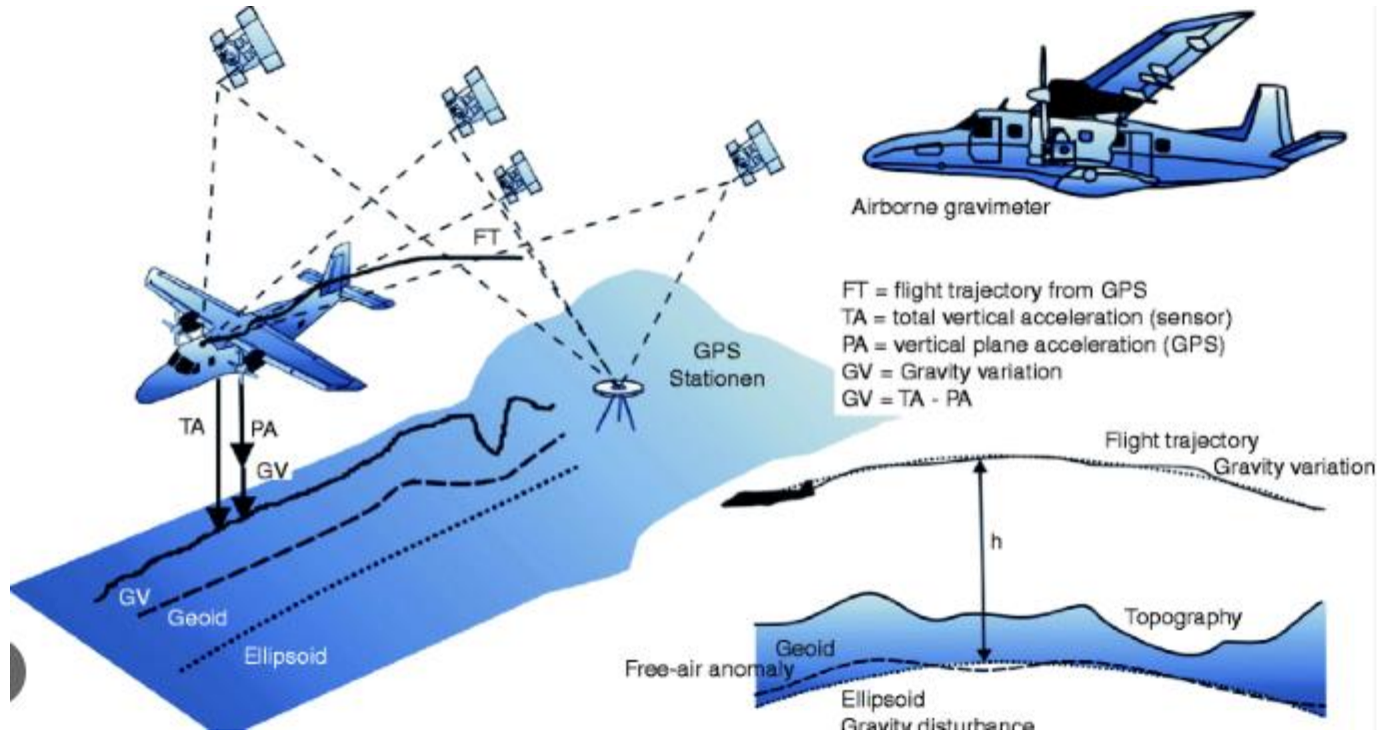
# Geoid modelling



## Database of methodologies, instruments and auxiliary data for gravity field determination

- Planning and construction phase:
  - Use the 2 QDaedalus systems already owned by CERN updated QDaedalus systems (currently under development at HEIG-VD)
  - Rent from/collaborate with Swisstopo to use CODIAC and (spring based) relative gravimeter
- Alignment phase of the components in the tunnel ( depending on analysis in report IGP-AA-1.5)
  - Gravity measurements in the tunnel could become crucial to reach 30 $\mu m$ - 100 $\mu m$/225 m
  - Transportable free-fall quantum gravimeter, Instruments based on cold atom optical lattice
- **Precise processing and analysis of the data is essential to exploit the full potential**

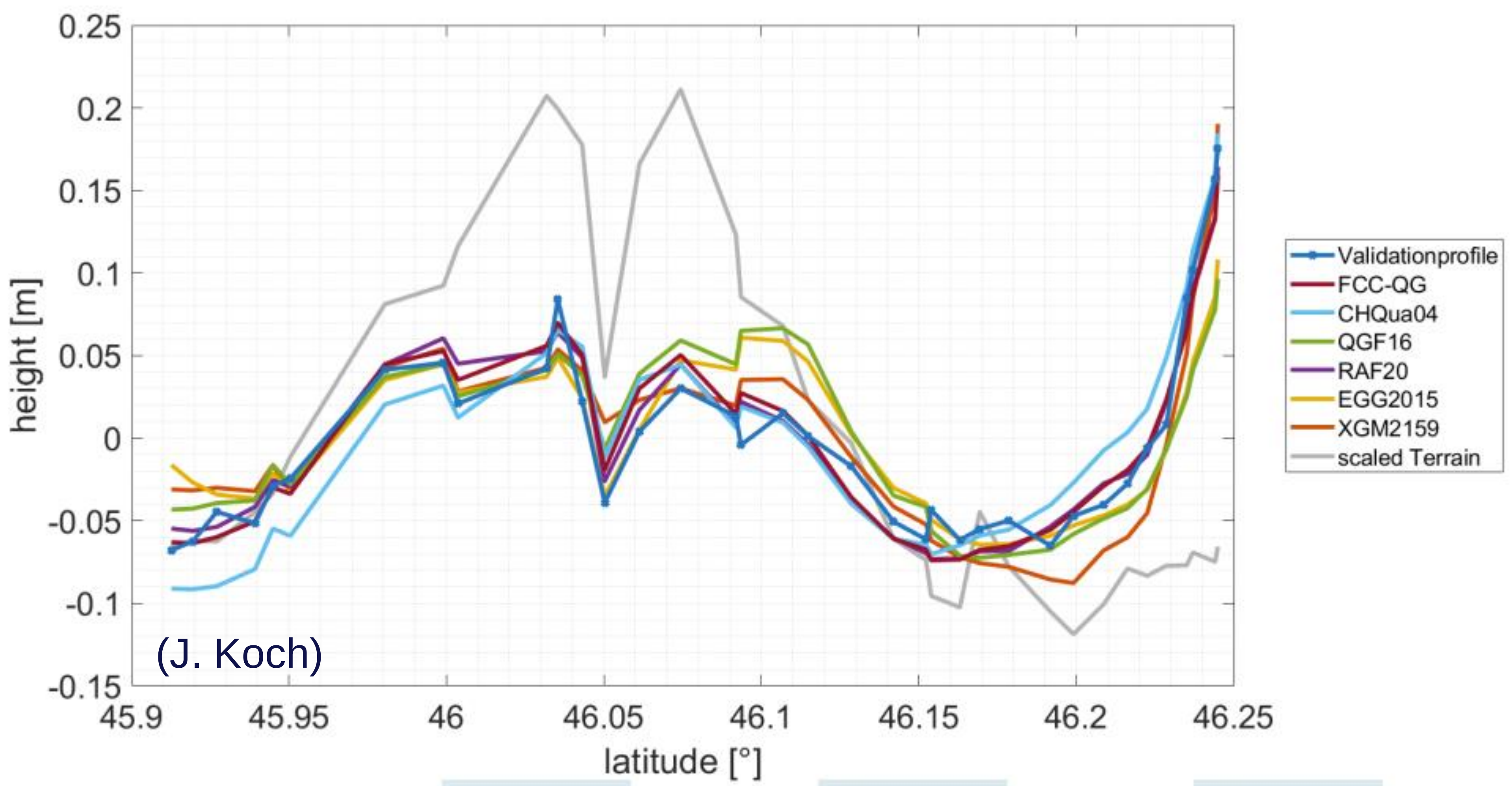
- Monitoring of time-variable gravity changes during FCC's lifetime
  - Hydrostatic leveling system (HLS) in LHC seems to observe changes
  - Actual cause of the time-variable changes in the HLS measurments must be examined
  - To continuously monitor the changes at least 3 or 4 instruments distributed along the tunnel will be necessary



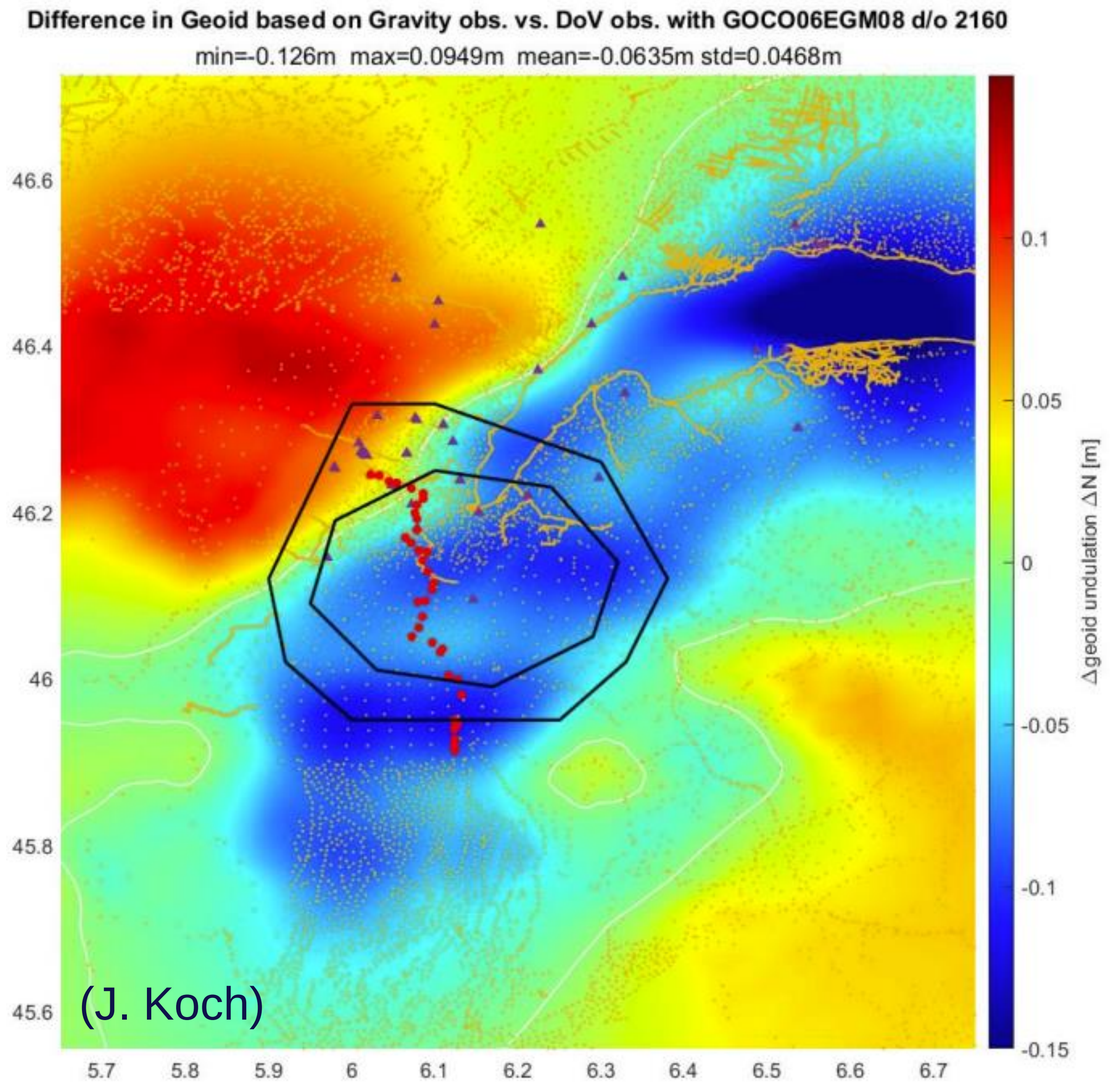
# Geoid modelling

## Progress on computation of local geoid model

- Gravimetric geoid calculated in GROOPS (TU Graz) fits well to validation data
- Geoid calculated in GROOPS using only astrogeodetic observations is inconclusive
- Combination of gravity and DoV (Deflection of Vertical) observations (correct weighting in the regularization needed) under investigation




| | FCC-QG | CHQua04 | QGF16 | RAF20 | EGG2015 | XGM2159 |
|---|---|---|---|---|---|---|
| Offset [cm] | 37.2 | 14.4 | 50.2 | 49.7 | 4.7 | 37.3 |
| Standard deviation [cm] | 1.5 | 2.3 | 3.4 | 1.5 | 3.1 | 2.3 |



# Concept for calibration, checking and testing of geodetic equipment

- Several geodetic equipment will be used: GNSS receivers/antennas, total stations, digital leveling systems, laser trackers, laser scanners, …
- Limit errors in the measurments
- Calibration at different levels
- Cost of in-house calibration facility vs outsourced services
- Requires dedicated infrastructure (building, reference baselines, …)

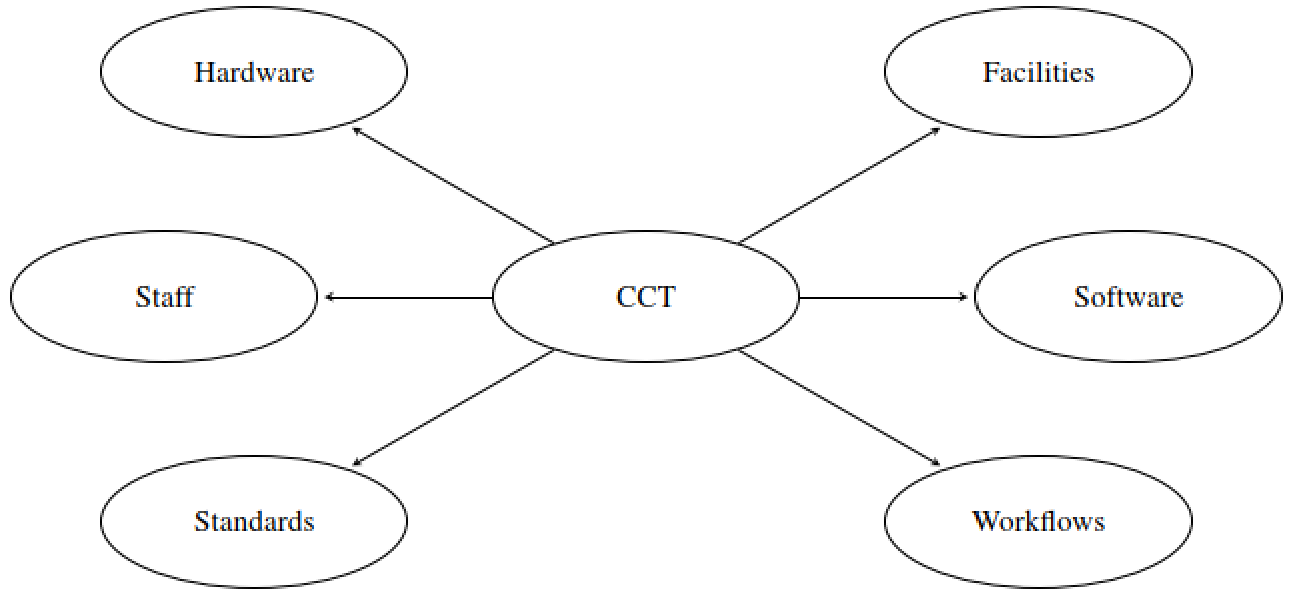
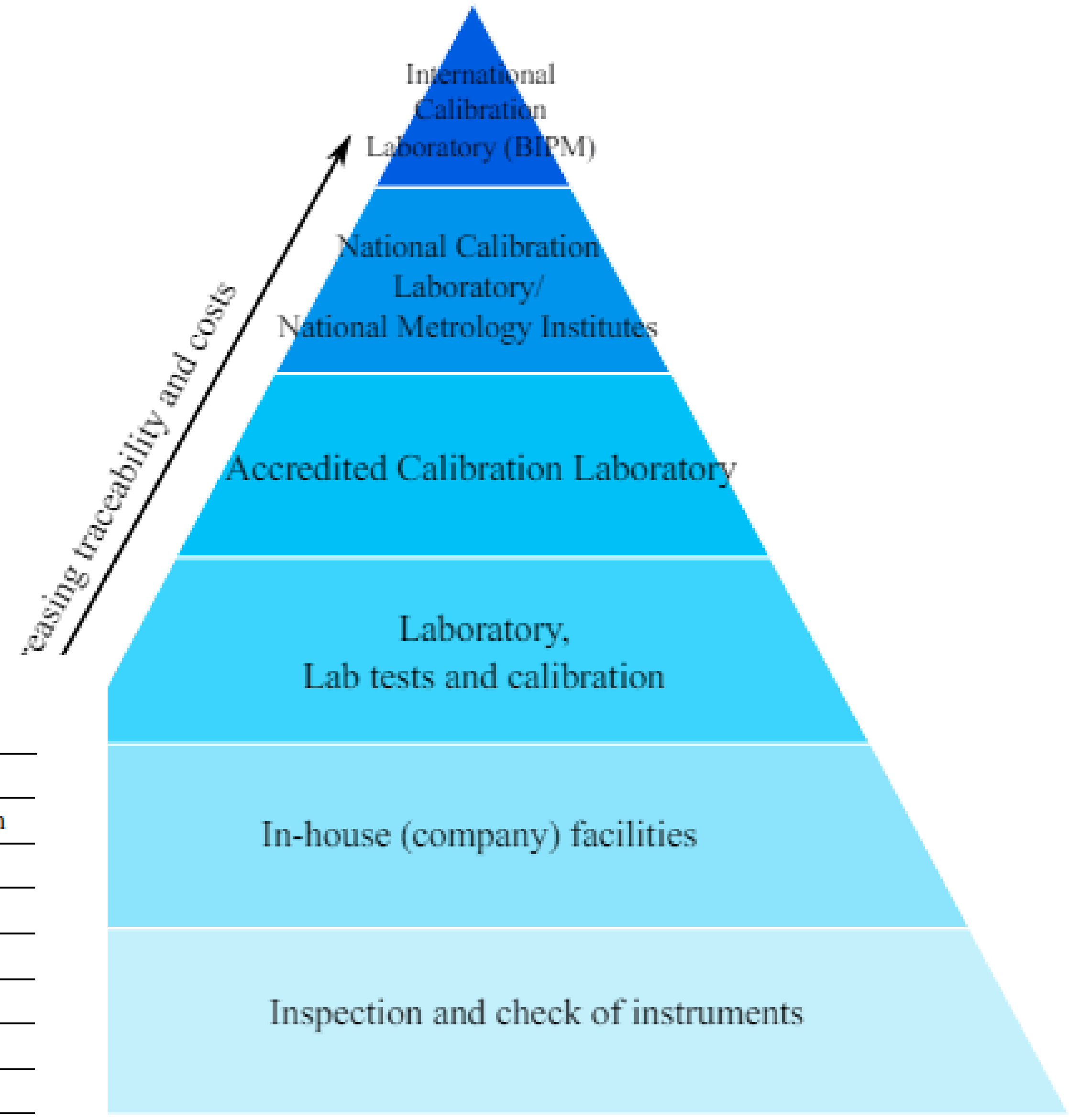


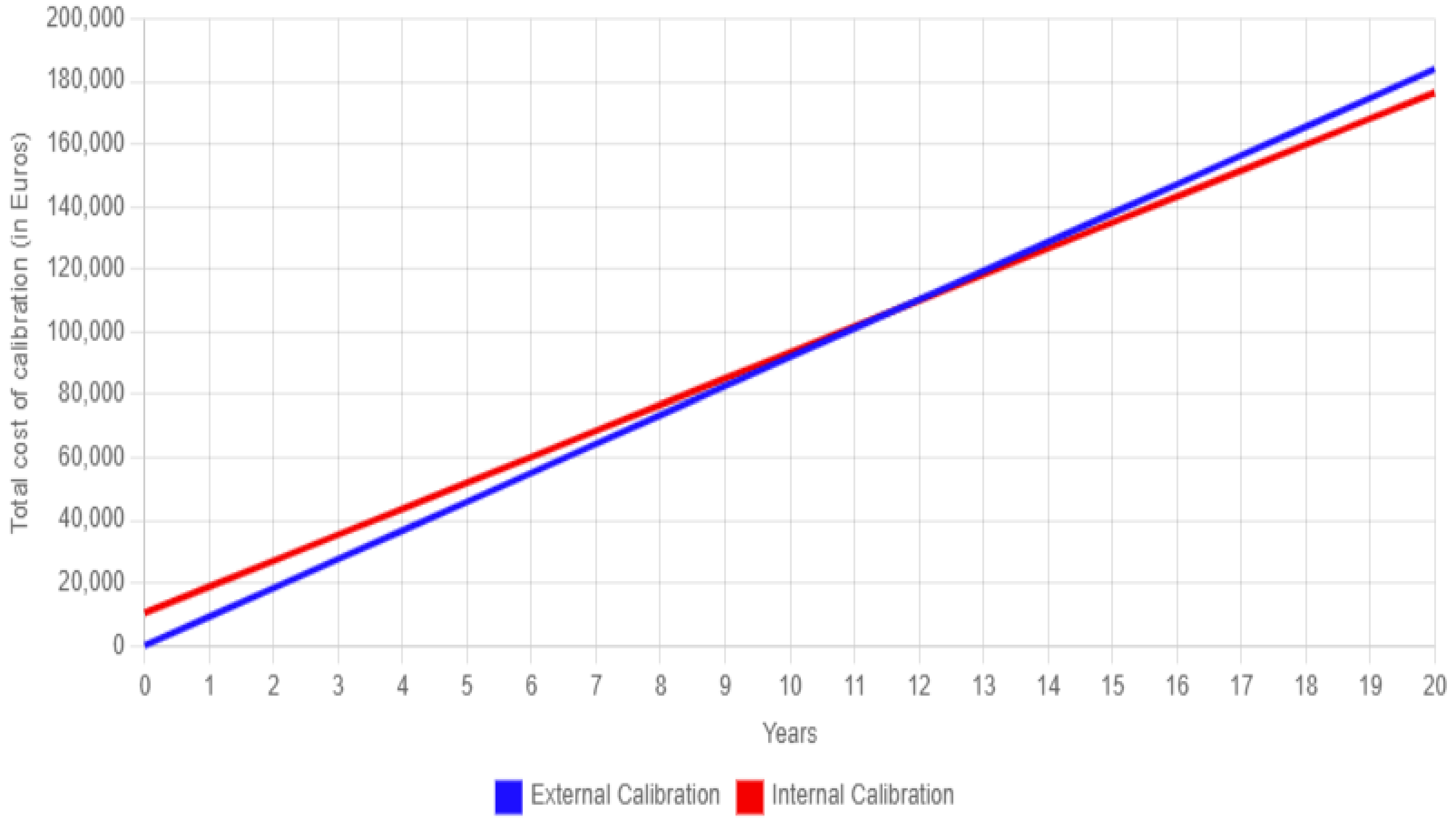

Table 2: Facility and equipment required for calibration or testing of observation types and equipment

| Name | Observation type | | | | | | Facility/Equipment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HA | VA | LS | D, short | D, long | Antenna | Camera | TS | LT | LR | LI | TLS | Prism |
| calibration baseline, outdoors | | | ■ | | ■ | | | ■ | | | | | ■ |
| calibration baseline, indoors | | | ■ | ■ | | | | ■ | | | | | ■ |
| calibration bench, level rods | | | ■ | | | | | | | ■ | | | |
| camera calibration field, indoor | ■ | ■ | ■ | ■ | | | ■ | | | | | ■ | |
| climate chamber or room | ■ | ■ | ■ | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | |
| collimator | ■ | ■ | | | | | | ■ | | | ■ | | |
| comparator, horizontal | | | ■ | ■ | | | | ■ | | | | | |
| comparator, vertical | | | ■ | | | | | | | ■ | ■ | | |
| laser interferometer | ■ | ■ | ■ | ■ | | | | ■ | | ■ | ■ | | |
| meteo sensors | | | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | [obscured] | [obscured] |
| reference wall, outdoors | ■ | ■ | | ■ | | | | | | | | | |
| robotic arm | | | | | | ■ | | | | | | | |
| rotary calibration table | ■ | ■ | | | | | | | | | | | |
| scale bars | | | ■ | | | | | | | | | | |

Legend: ■ required; HA: Horizontal Angles; LS: linear scale; VA: Vertical Angles; D… D, long: long range dist; Antenna: GNSS Antenna; TS: total station; LR: level rod; L…

(Varga M. & Wieser A.)

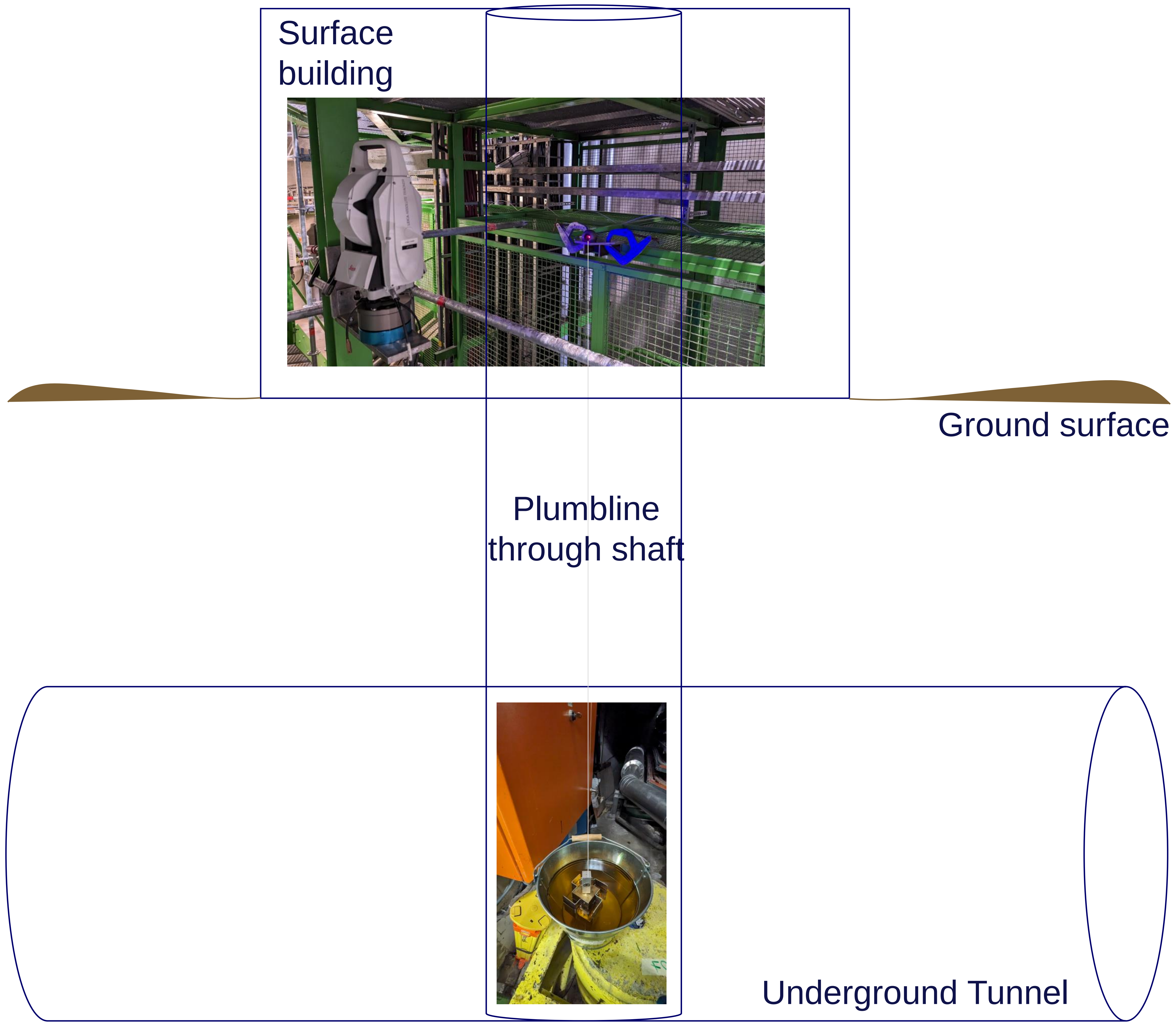


# Test on coordinate transfer methodology

## Computation of transformation parameters between CCS and CTRF

- We will need to calculate transformation parameters between CCS and CTRF
- Weak knowledge of the global accuracy of the coordinates calculated in CCS: Are the coordinates calculated underground consistent with coordinates of the surface reference points?
- Coordinate transfer through 4 LHC shafts were done in January 2024 (mechanical plumbing)
- Precision of the calculated coordinates: 1 mm

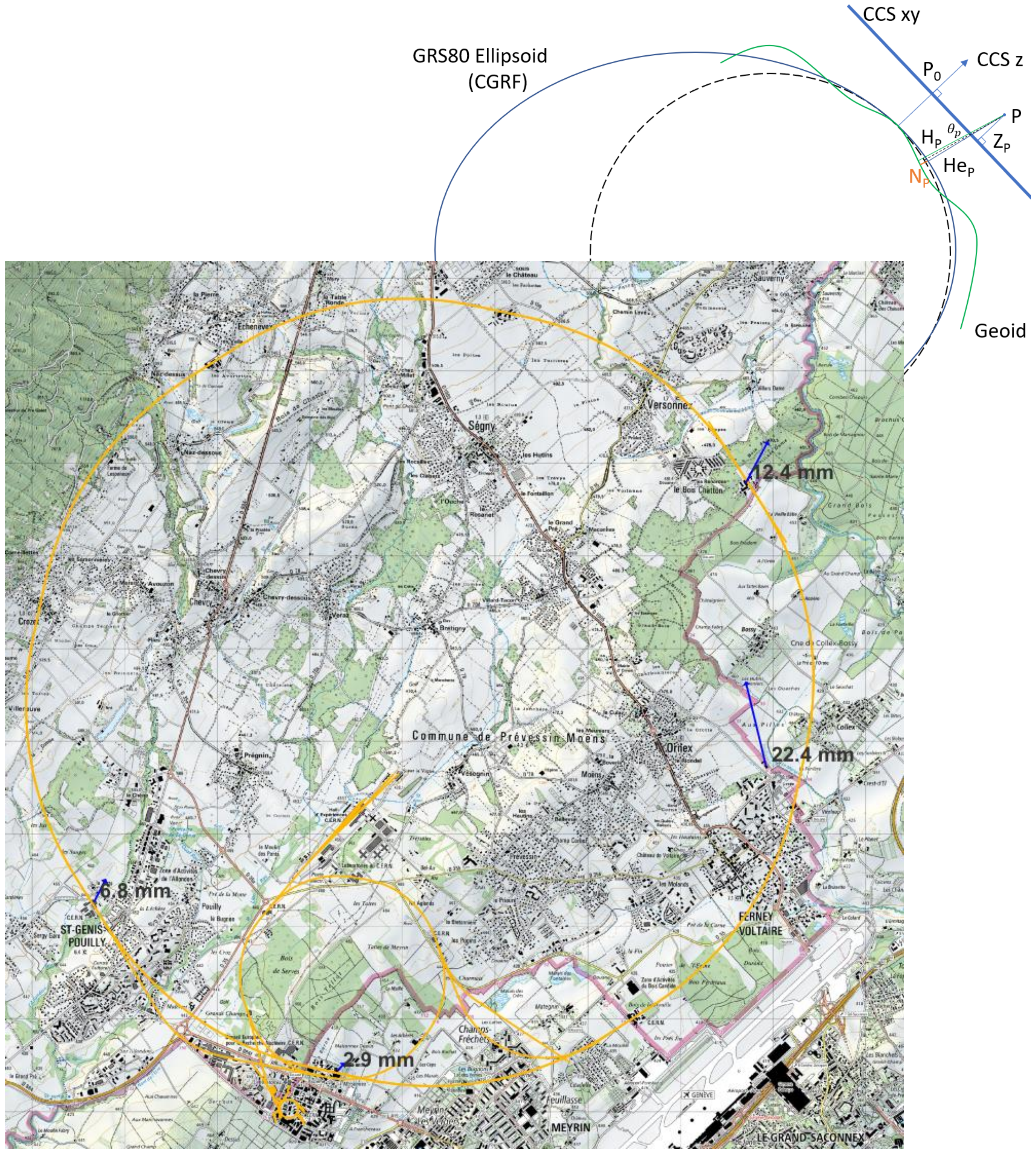


# Test on coordinate transfer methodology

## Computation of transformation parameters between CCS and CTRF

Comparison between coordinates of the wire calculated underground and at the surface

| | Delta East LV95 [mm] | Delta North LV95 [mm] |
|---|---|---|
| Point 1 (depth = 83 m) | 2.0 | 2.1 |
| Point 2 (depth = 46 m) | 3.1 | 6.0 |
| Point 6 (depth = 96 m) | 5.8 | 10.9 |
| Point 7 (depth = 96 m) | -5.3 | 21.8 |



# Upcoming works

- Geomonitoring proposal: study existing ground mouvements over FCC area
- Additionnal coordinate transfer observations to improve quality of coordinate transformation model
- Pending reports