Geodesy and Geodetic Infrastructure

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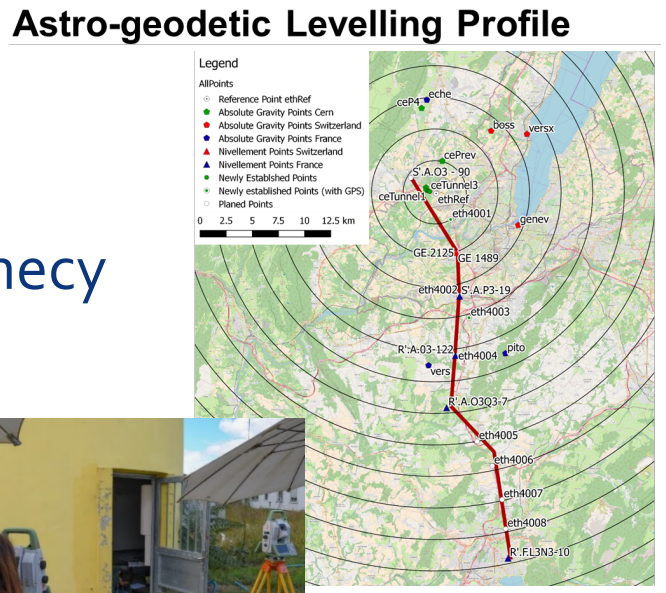
Outline

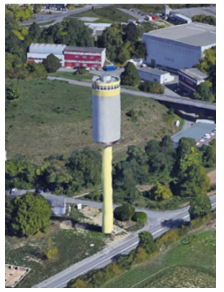
- Activities in 2017
- Alignment Tolerances
- Reference Systems
- Tunnel to Surface Transfer
- Instrument Control Baselines
- Calibration and Test Facilities
- Mathematical Models, Data Management and Data Processing
- Conclusion

Activities in 2017

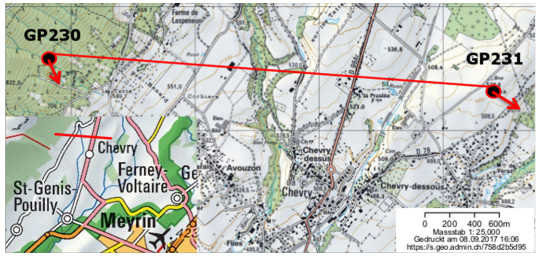
ETHZ -Mathematical and Physical Geodesy Group

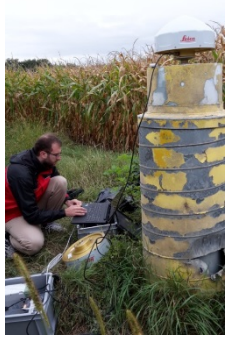
- General collaboration agreement established
- Three week Geodetic Project Course (GPC) at CERN
  - Gravimeter and Astro-Geodetic measurements towards Annecy
    - To be completed and included in geoid model studies!
  - Vertical descent tests in the CERN water tower
    - Use of the HL-LHC shafts for further tests?
  - GNSS, long distance and height difference measurements
  - Vertical angle measurement anomalies clearly explained by refraction





- Distance: ~ 3.5 km
- ΔHeight: ~ 220 m



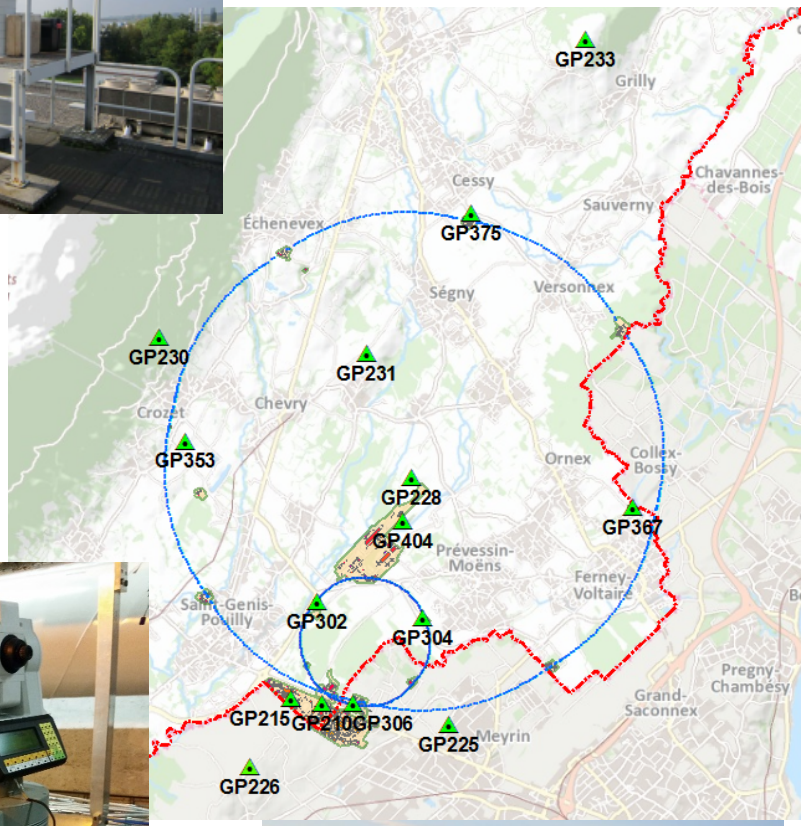


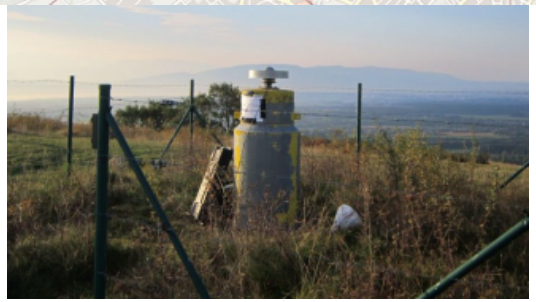
Images: ETHZ

Other Activities

- GNSS Measurement Campaign (IGN France)
  - Planimetric precision of <2 mm achieved
  - Initial analysis largely confirms the revised CCS datum position parameters
- Gyro-Theodolite returned to service
  - Will be used to clarify azimuth discrepancies between the surface and tunnel networks
- Geodesy and Tunnel Surveying Advisory Committee (GSAC)
  - Small number of external experts, 1st meeting in HEIG-VD
  - Opportunities to launch studies, R&D, and training

GNSS Antenna Images: IGN





Alignment Tolerances

- Particularly important for underground survey and alignment work (see next presentation by Dominique Missiaen)
- Also affect the choices for the reference systems and geodetic instruments
  - Absolute Tolerance
    - Spatial relationship between machines, machine sectors and transfer lines (both new and existing)
    - Surface to tunnel transfer
  - Relative Tolerance
    - Geoid model

Accelerator collider	Radius/ Circumference	Vertical (mm) @1σ	Transversal (mm) @1σ	Roll angle (mrad)
LEP(e+e-)	5km/27km	0.2-0.3	0.2-0.3	0.1
LHC (hh)	5km/27km	0.15	0.15	0.1
CLIC (e+e-)	2*25 km	17 microns radially*		
FCC-hh	16km/100km	0.2 (0.5*)	0.2 (0.5*)	1.0
FCC-ee	16km/100km	0.1*	0.1*	0.1
HE-LHC	5km/27km	0.2 (0.5*)	0.2 (0.5*)	0.1 ?

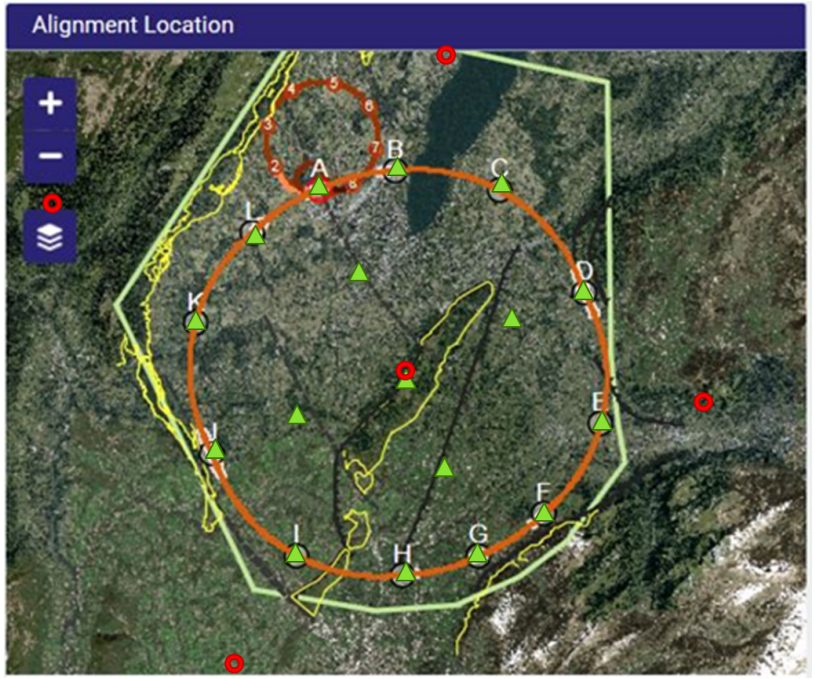
* All errors included

Reference Systems

Geodetic Surface Reference Network

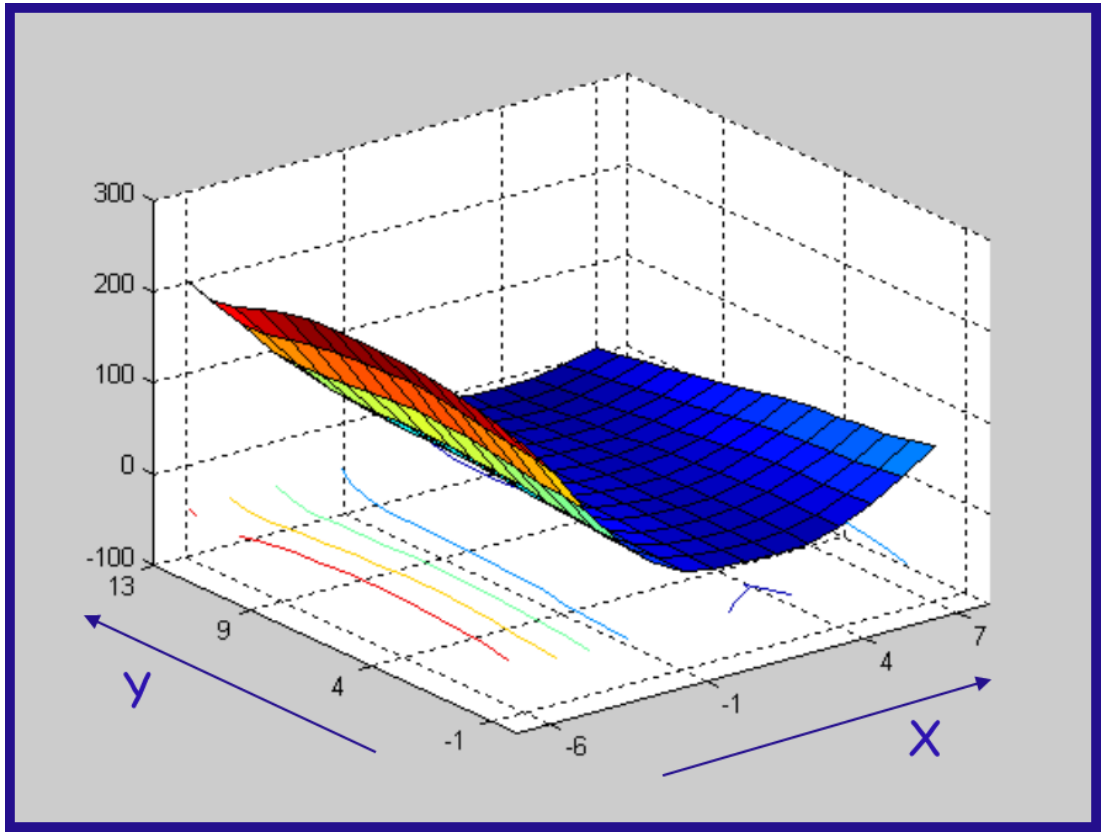
- Realisation of the CERN Coordinate System
- Probably not relevant to the HE-LHC
- Extended for the FCC machines
  - Highest possible precision required for all machines
- Combination of permanent GNSS stations and geodetic pillars
- Same for Civ. Eng. and accelerator alignment
- No network design concept, implantation on real topography comes afterwards

Permanent GNSS Station
Geodetic Reference Pillar



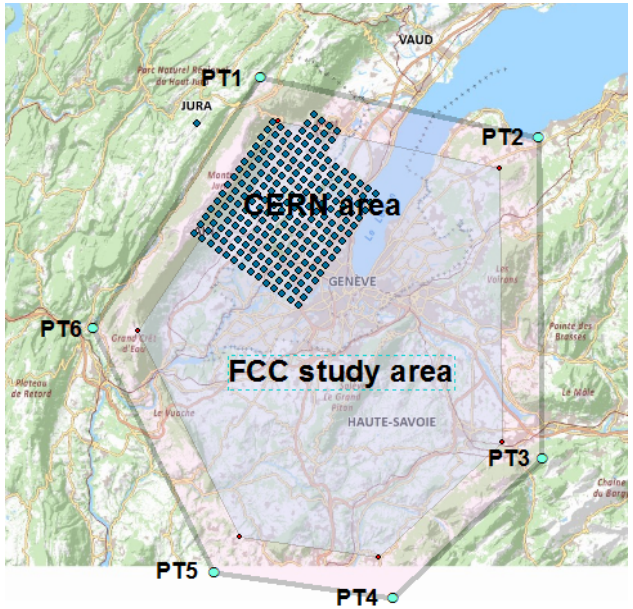
Geoid Model

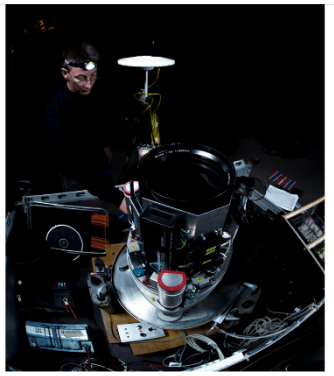
- Reference surface for heights above mean sea level
  - A measureable "upwards" quantity
- Models have evolved over the last 60 years
  - Now numerous different surfaces are used
- New CERN Geoid model required for the FCC
  - Model extended to cover the new site
  - Evolution towards a single 3D model?

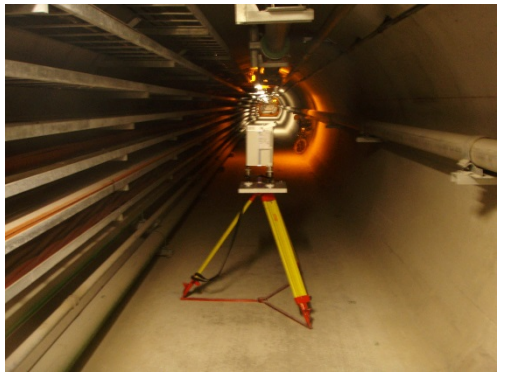


Geoid Model - FCC

- Data from Swiss and French institutes
  - Combined with additional measurements
  - Astro-geodetic, gravimetric (plus GPS & levelling?) and mass models
    - 10 additional zenith camera measurements => 5 mm precision
  - Measurement types and density a function of the alignment tolerance!
- Modified CLIC scenario will work
  - Astro-geodetic measurements
    - Only possible on clear nights, five instruments (only three exist!) => minimum of 2 years
  - Relative Gravimeter measurements (surface & tunnel)
    - 1 instrument => minimum of 2 years
- Further studies required to determine optimal measurements required for each machine

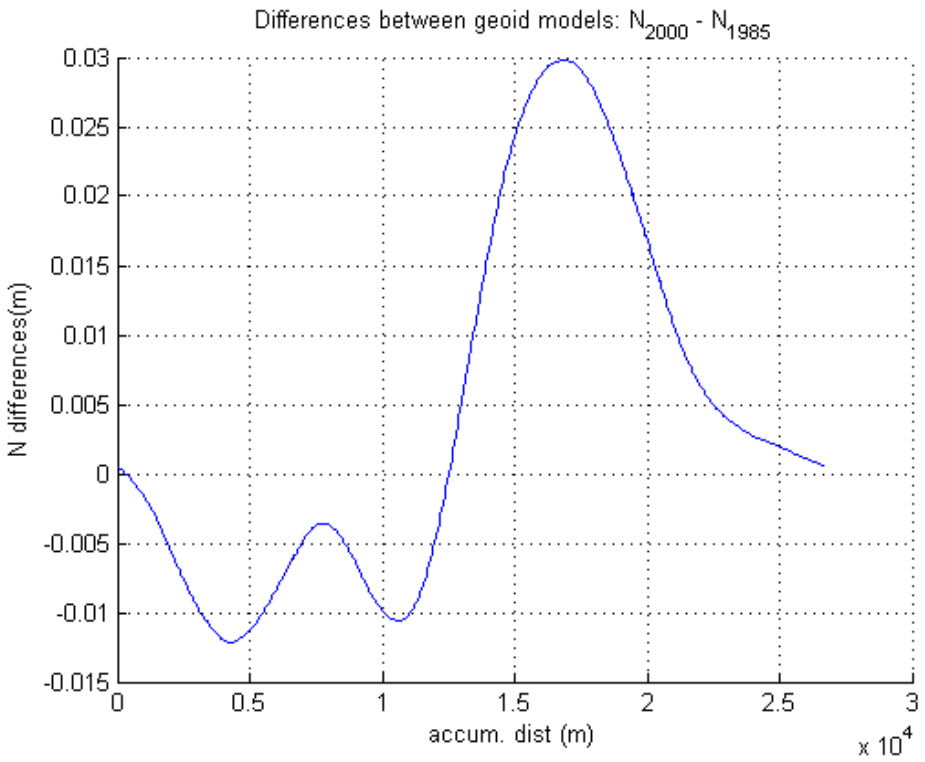






Geoid Model – HE-LHC

- CERN Geoid 1985 used for LEP add LHC
- CERN Geoid 2000 exists but not used
  - Significant differences between geoids
- Adoption of CG2000
  - Civ. Eng. intervention on floor would be required!
  - Already less space available for the jacks!
- Might be time for a new geoid model anyway!
  - Differences to CG1985?



Surface to Tunnel Transfer

- Transfer precision goal ~2 mm
- Mechanical or optical options
  - Plumb bob more precise with deep shafts > 200 m
- CLIC project tests
  - Plumb bob and Total Station
  - Estimated precision ~ 0.5 mm at 65 m depth
  - Network densification to be added
- Gotthard tunnel
  - Plumb Bob, estimated precision: ~ 8 mm at 800 m
- Improvements or new instrument developments needed!

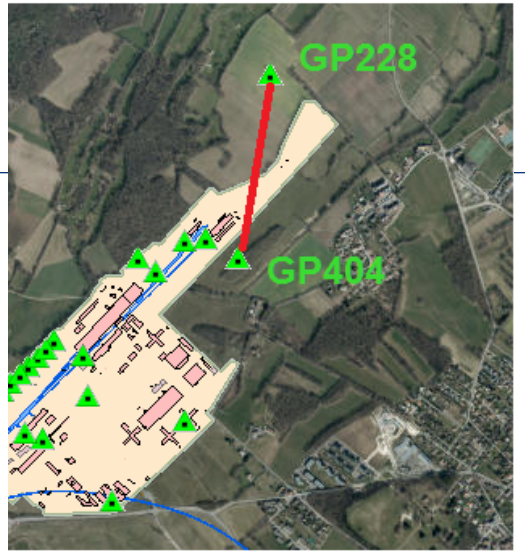
Instrument Control Baselines

Electro-optical Distance Measurement (EDM)

- Control Baseline on Prévessin site
  - Measured using the Mekometer ME5000 (30 years old)
    - Mekometer calibrated on the CERN geodetic calibration bench
  - Available to control civil engineering instruments
  - Assures homogeneous distance measurements between civil engineering and CERN survey teams
  - Placement no longer ideal due to nearby trees and shrubs
  - Measurement by GPS, or new instrument to replace ME5000!
- New baseline more centrally located for the FCC?
  - Geodetic pillars along a spatially straight line, 1.5 km long (?), open horizon

Gyro-Theodolite

- Control baseline will be (re-)established for the HiLumi Project on Meyrin or Prévessin site
- Instruments to be handled with care, instrument constant drifts, influenced by vibrations
  - Baseline(s) closer to FCC access shafts probably necessary
- Could use EDM control baseline
- Indoor baseline would guarantee availability throughout the year
- Temporary underground baselines would save time too with daily instrument controls



Location


GP228 view


GYROMAT-2000 on GP404

Calibration and Test Facilities

Calibration Facilities

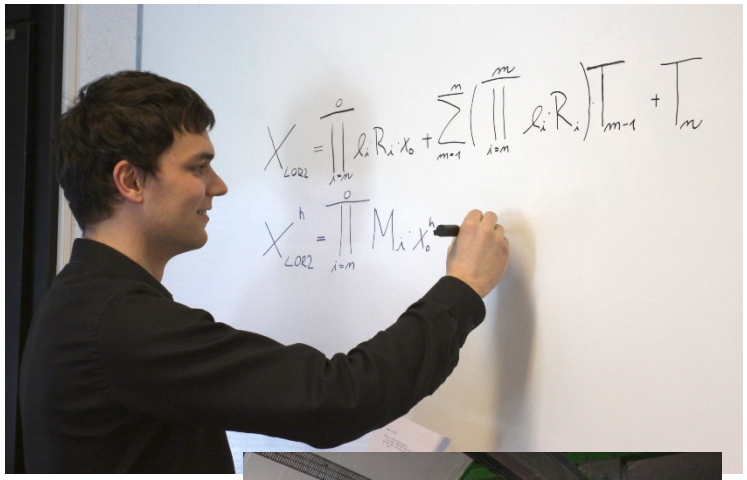
- Current calibration bench ~55 m
  - Primarily for distances
  - With mirrors can calibrate distance ~110 m
- New facility for FCC
  - Distance calibration bench
    - Distances up to 230 m => 115 m bench
  - Enlarged 3D measurement control area
  - System for Calibration of Levelling staves
  - Area for development and control of new instruments
  - Area for development, control & calibration of sensors
  - Instrument and sensor environmental test chamber/room

Test Facility

- Survey intervention and instrument testing
  - Training between long shutdowns
  - Test Instruments and Observation Models
    - Mitigate or model atmospheric/environmental effects
- Duplicate section of FCC tunnel
  - Minimum 1 cell length
  - Equivalent ventilation system
  - Appropriate heat sources
  - Arc or LSS configuration

Mathematical Models, Data Management and Processing

- Understand atmospheric and environmental effects on measurements over longer distances
  - Optical measurements, stretched wires, …
- Develop methods to mitigate the effects
  - Physical structures or mathematical modelling
- Understand structures and assemblies to be measured
- Extend data management and data processing tools
  - To handle new mathematical models, instruments and sensors
  - To manage additional parameters and relationships
  - To manage permanent Monitoring, Alignment & Maintenance Systems



Conclusions

- Concepts reasonably clear
- Permanent GPS stations and high precision GPS measurements to establish and densify the surface network
  - Need a new high precision EDM instruments to come to market to replace the ageing ME5000
- Optimisation of additional geoid model measuremens, to meet the alignment precisions of the different accelerators
- Need to increase precision for surface to tunnel transfer
  - Absolute precision requirements will drive the need for additional transfer shafts
- New calibration, control and test facilities required
- Further development of data management and data processing tools