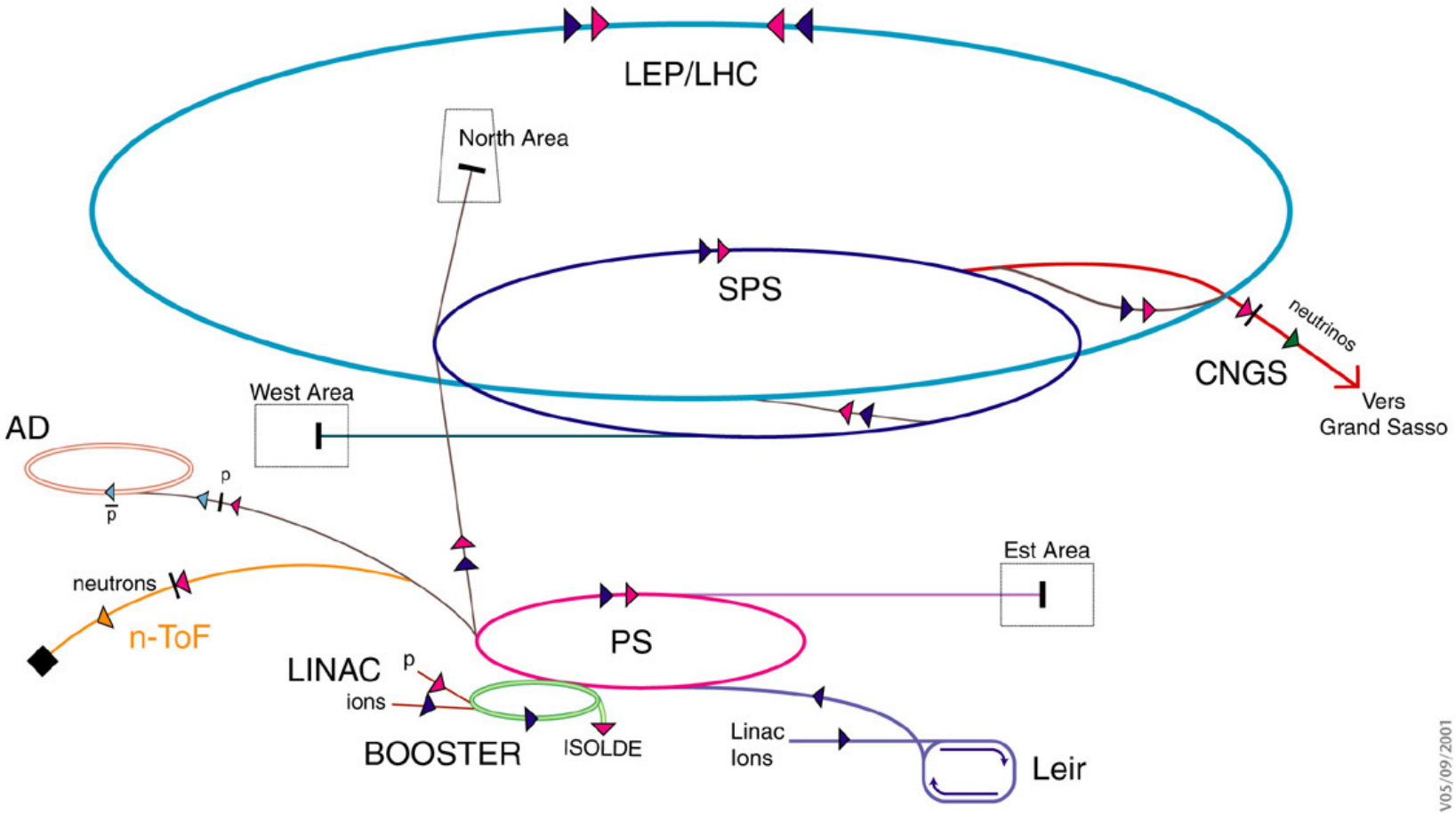
Status report on the Survey and Alignment of the Accelerators at CERN

- PS and SPS
- LEIR
- CTF3 / CLIC
- CNGS
- LHC
- Conclusion

On behalf of M. Jones, H. Mainaud Durand, D. Missiaen, J.P. Quesnel and their colleagues of the "Large Scale Metrology Group" at CERN

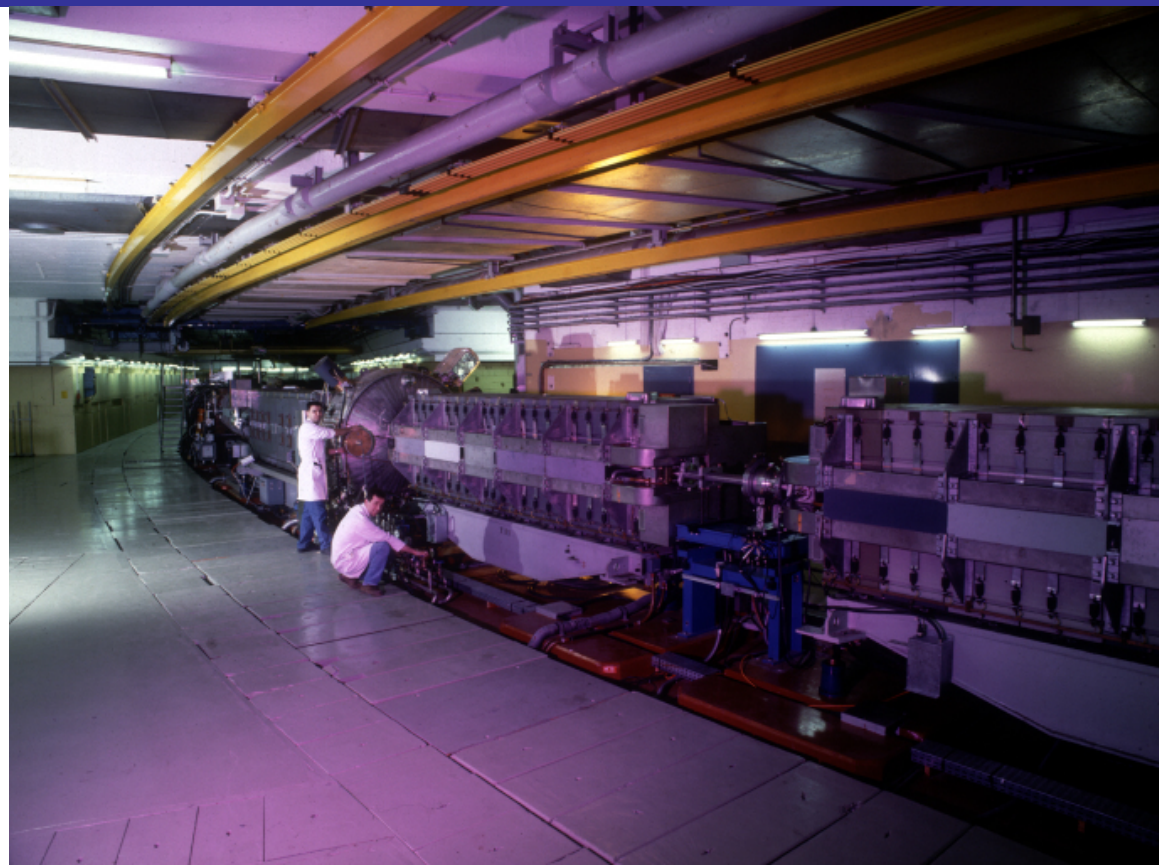
Accelerator chain

Accelerator chain of CERN (operating or approved projects)

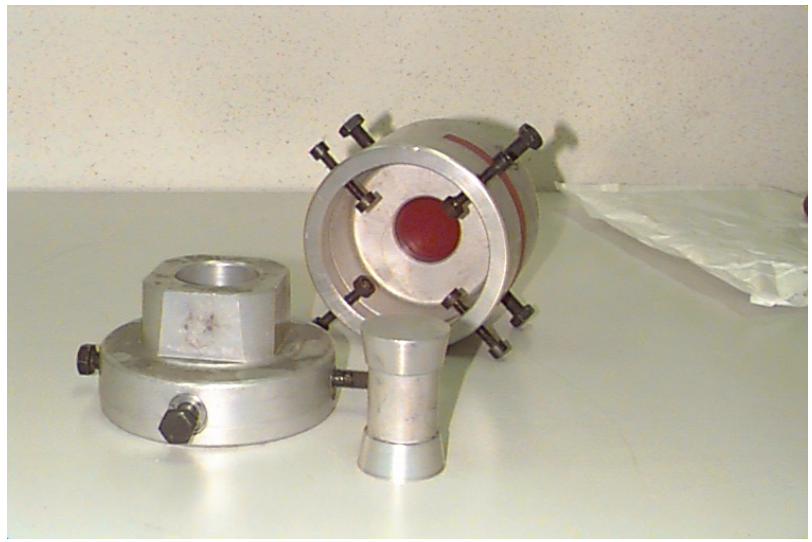


PS and SPS

- PS
  - Repair of 30 magnets
  - Complete smoothing of all 100 magnets



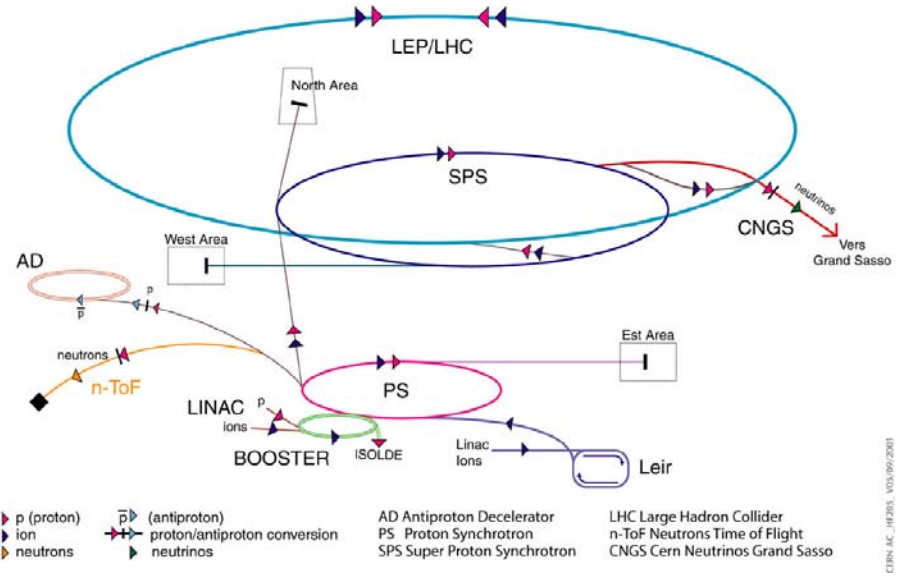
SPS

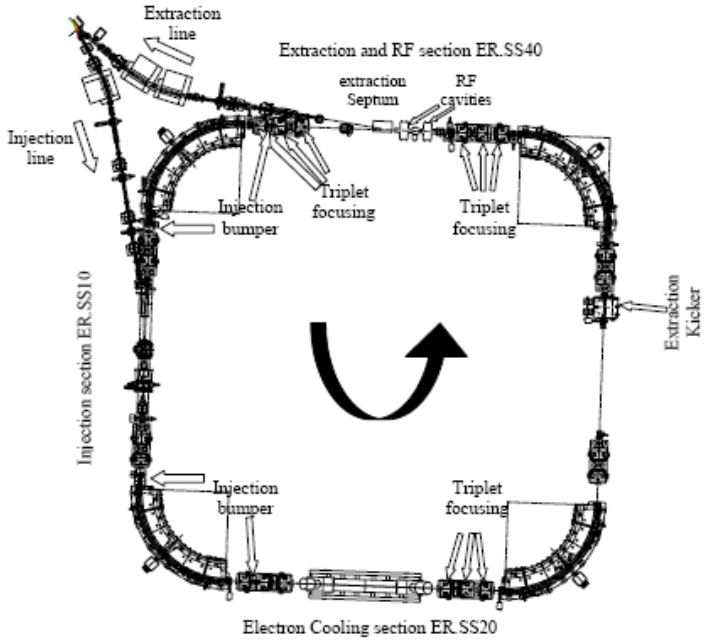


- Repair of the polyurethane jacks
- Smoothing of all the 216 quadrupoles and the SSS
- 100m long stretched wires and offset measurements up to 1.3m.

LEIR

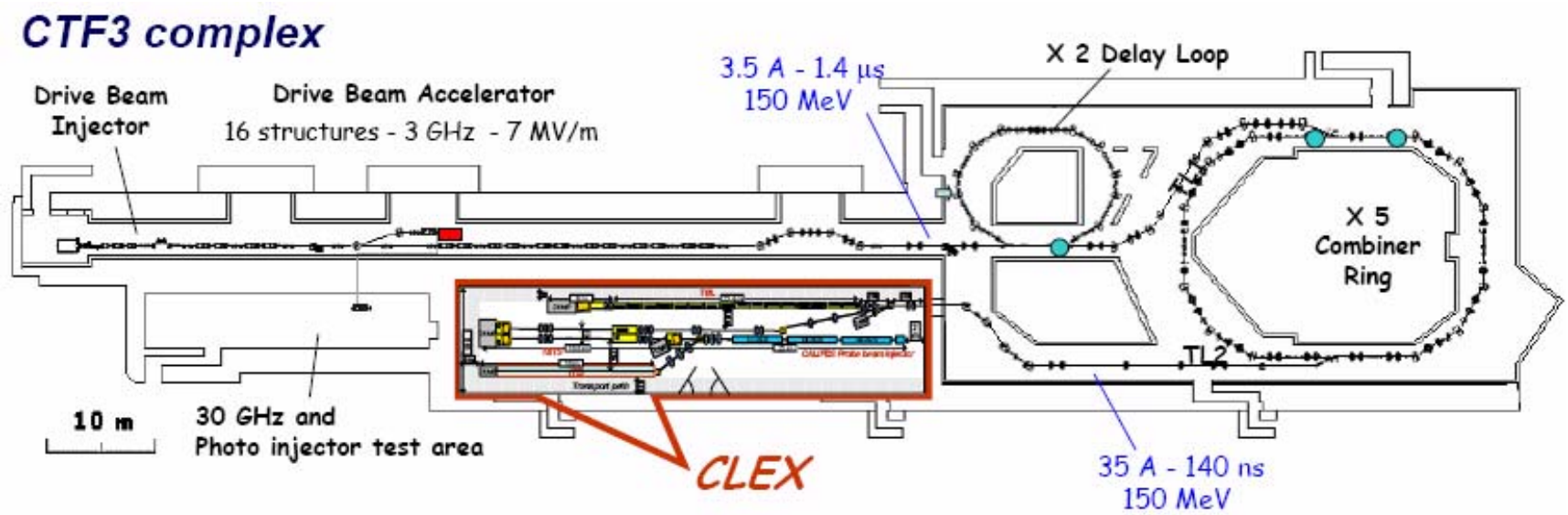
Accelerator chain of CERN (operating or approved projects)

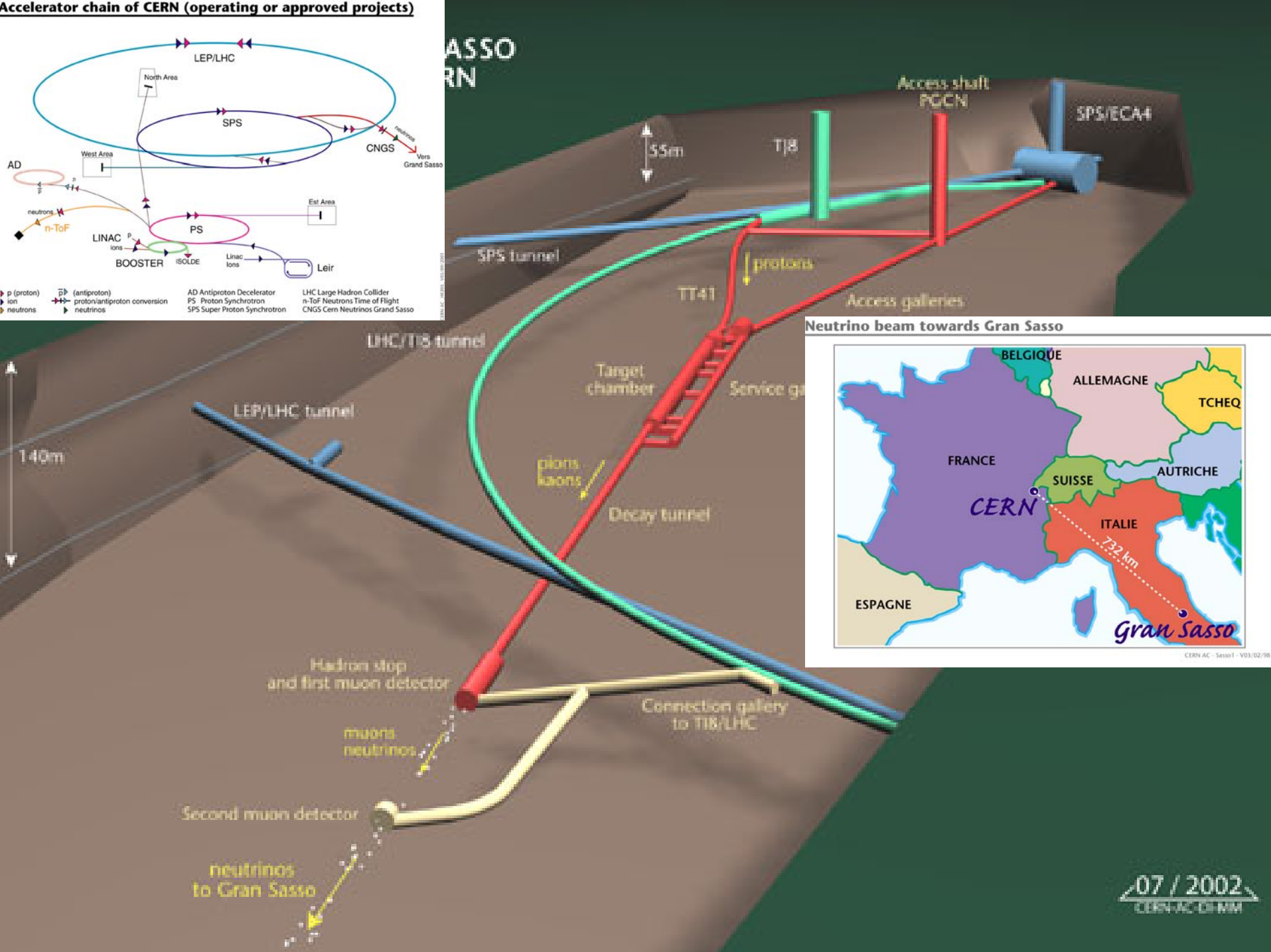




- For injection of ions
- Transformation of LEAR machine (used for pbars)
- Metrology based on a square of 4 pillars
- Straight sections reconfigured
- New injection and ejection lines

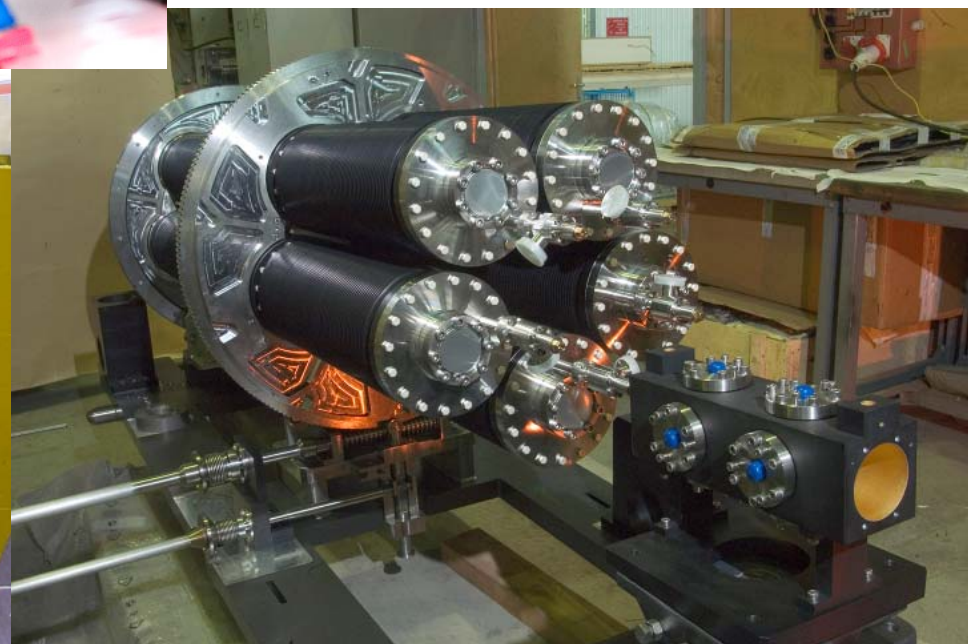
CLIC Test Facility




Accelerator chain of CERN (operating or approved projects)
LEP/LHC
North Area
SPS
CNGS
neutrinos
Vers Grand Sasso
West Area
AD
p
p̄
neutrons
n-ToF
LINAC
ions
BOOSTER
ISOLDE
PS
Est Area
Linac
Ions
Leir
p (proton)
ion
neutrons
(antiproton)
proton/antiproton conversion
neutrinos
AD Antiproton Decelerator
PS Proton Synchrotron
SPS Super Proton Synchrotron
LHC Large Hadron Collider
n-ToF Neutrons Time of Flight
CNGS Cern Neutrinos Grand Sasso
ASSO
RN
Access shaft
PGCN
SPS/ECA4
55m
TI8
SPS tunnel
protons
TT41
Access galeries
LHC/TI8 tunnel
Target
chamber
Service g
LEP/LHC tunnel
140m
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos
to Gran Sasso
07 / 2002
CERN-AC-CH-NM
Neutrino beam towards Gran Sasso
BELGIQUE
ALLEMAGNE
TCHEQ
FRANCE
SUISSE
AUTRICHE
CERN
ITALIE
732 km
ESPAGNE
Gran Sasso
CERN AC - Sasso1 - V03/02/98

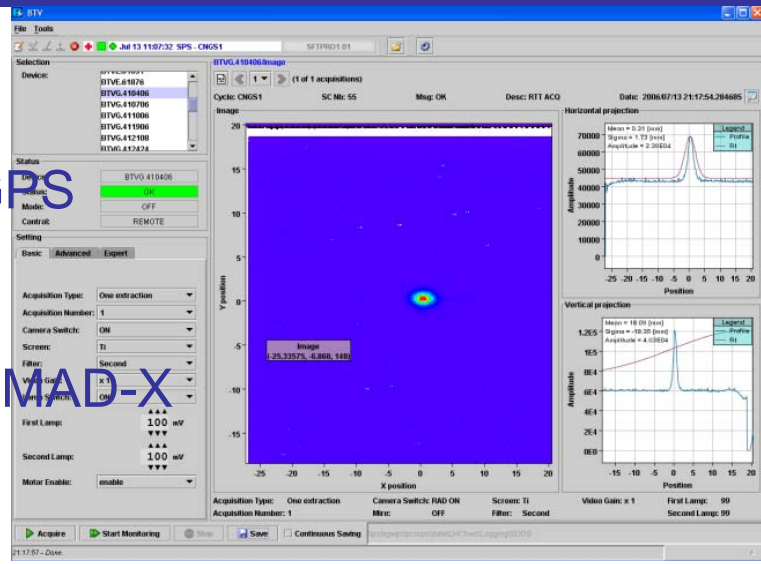
CNGS

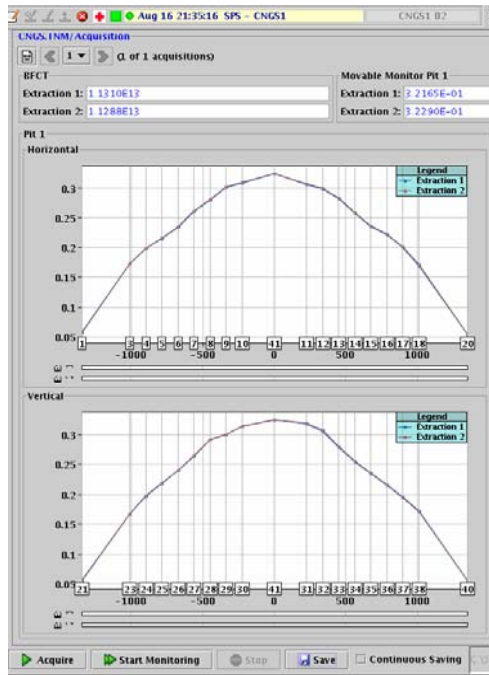
The protons beam line extracted from the SPS, and the target station



CNGS

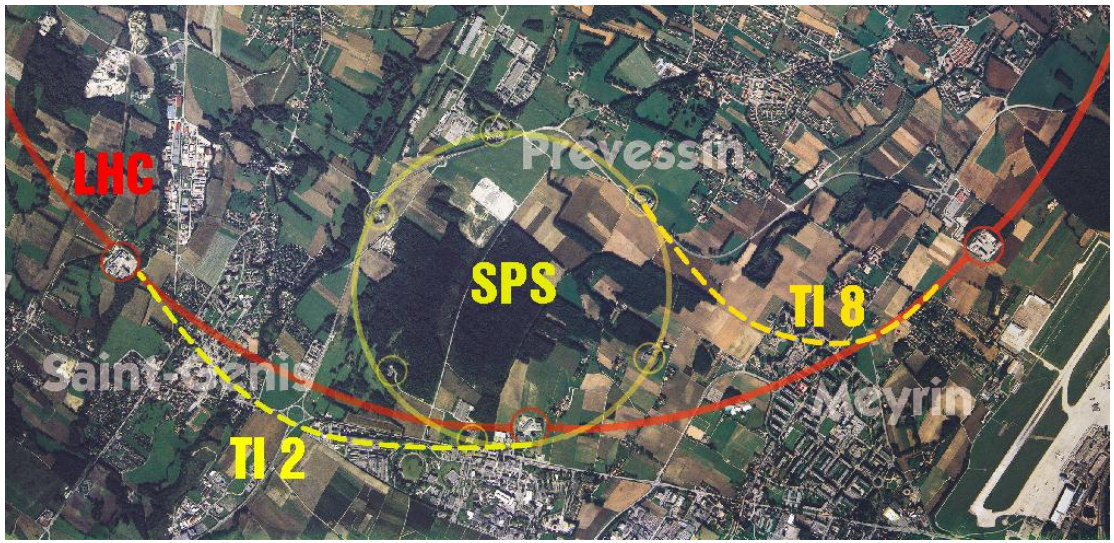
- Geodetic aspects
  - Determine Grand Sasso in CCS with GPS (Italy, Switzerland, France, CERN).
  - Modelling of the geoid
  - Calculation of the beam trajectory with MAD-X
- Alignment
  - Underground ref. network
    - Gyro + mekometer + wire offsets + leveling
  - Total station + direct leveling
  - Smoothing with stretched wire
- Metrology on the target and the horn with the laser tracker.





LHC

LHC / Injection line TI8



TI8

- Length : 2 km
- 400 magnets and beam positioning monitors
- Slope ~3.5%
- Tunnel diameter: 3m

Geodetic network :

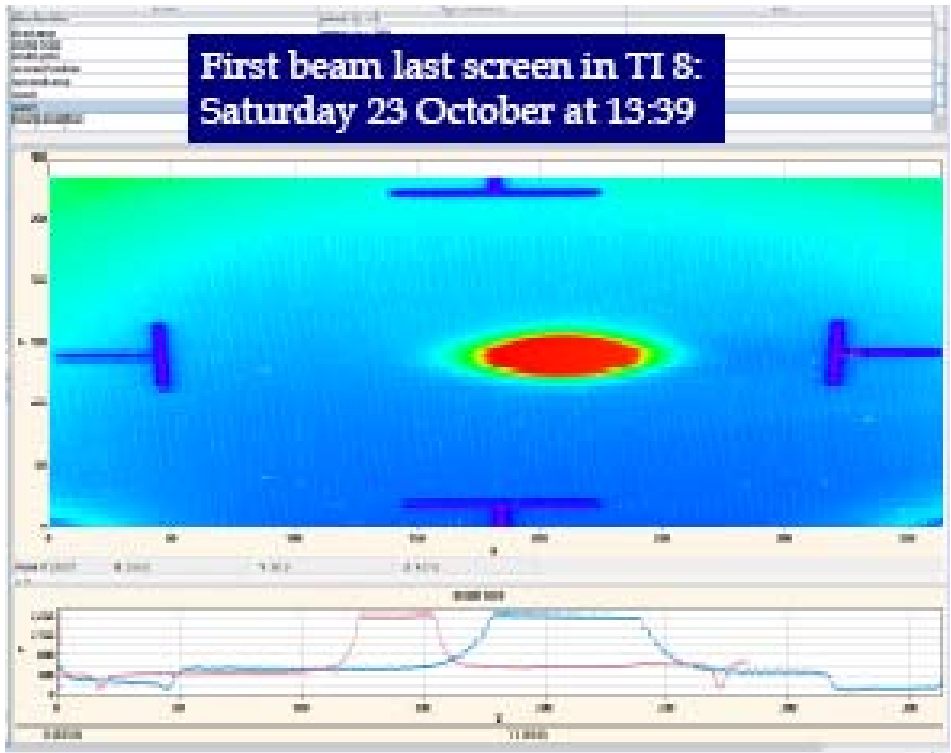
- Angles
- Gyroscopic measurements every 120m
- Mekometer for distances
- Direct leveling

Alignment :

- Total station from the network for XY
- Direct leveling for Z
- Smoothing with stretched wire

LHC / Injection line test

First shot, no correctors



Vacuum chamber

LHC / Cryogenic line

- Poor flexibility of the bellows (articulations not independent)
- Inaccurate construction of the service modules (several cm !)
- Tilted plane of the machine not considered
- Generates parasitic stresses on the SSS → risks of misalignments
- ~200 jumper connections

LHC / Cryogenic line

- Typical example of work where Survey has been neglected
  - No theoretical geometrical definition of the line
  - Bad geometrical quality of the critical elements
  - No attention paid to positioning (staff, references, positionners)

Define the theoretical position of the line in XYZ

Measure the real shape of the service modules, and install alignment targets

Calculate the theoretical position of the elements

Develop positionners

For 1 sector (made by CERN),
Alignment based on classical total station methods

For the contractor part: draw the positions on the floor and check the critical elements

- The line is installed is 100% installed and the last sector is under test.

LHC / Fiducialisation of magnets

- Fiducialisation
  - Control of the shape of the cryomagnets
  - Determination of the fiducials
    - W.r.t. mechanical axis for dipoles
    - W.r.t. mechanical and magnetic axis for SSS
- Cartography of the ends
  - Position of the pipes / fiducials
  - Position of the BPMs / fiducials
- ~70% achieved (87%for fiducialisation of the dipoles).
- Random tests of stability of the cold masses after transport in the tunnel
- Additional works for assembly and controls
  - Special magnets (low beta quads…)
  - Special elements (RF cavities, DFBs, Wigglers…)
- All the information stored in EDMS and MTF

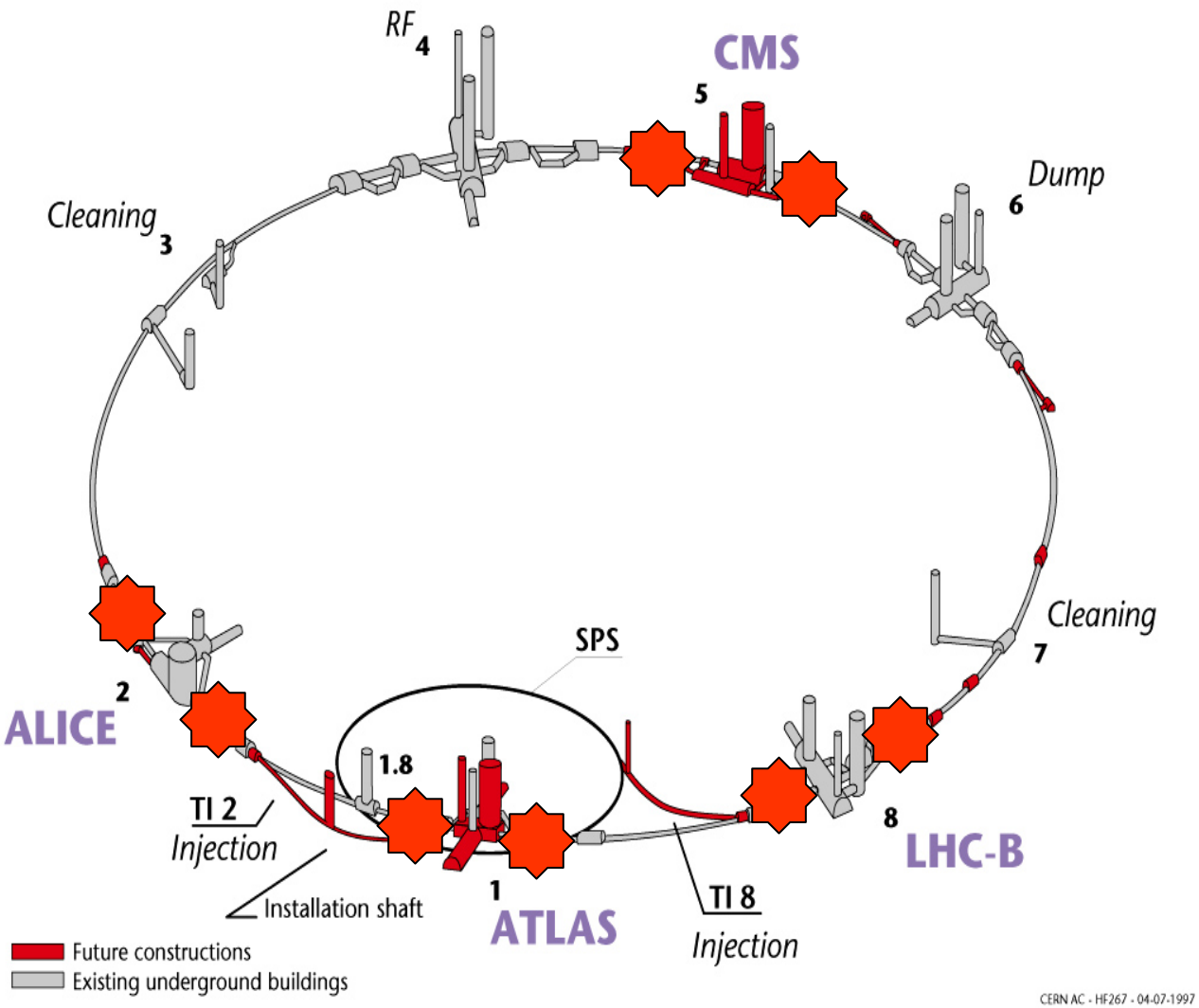
LHC / Alignment of the ring

- 60% of the magnets installed, 54% aligned
- Periodic controls of the network (leveling + radial meas. with stretched wire)
- Alignment : with total station and leveling, and then radial smoothing with long wires
- Final smoothing (H +V) when cooled.
- Most positive aspects:
  - The installation process: marking, align the jacks.
  - Jacks/targets
  - Methodology / flexibility / accuracy

LHC / Alignment of the ring

LHC / insertion magnets

Layout of the LEP tunnel including future LHC infrastructures.

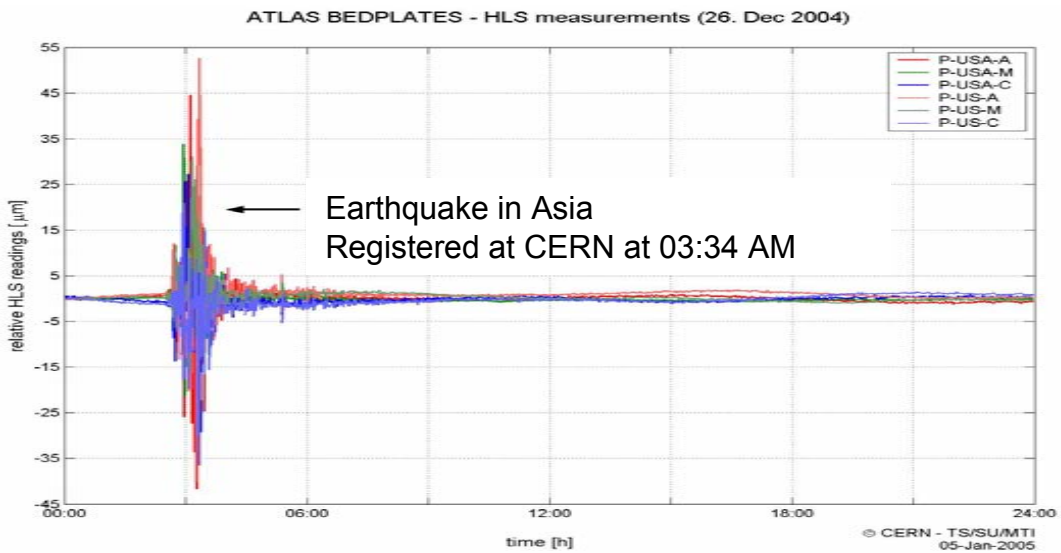


LHC / insertion magnets

- Permanent monitoring with HLS and WPS
- Length of the networks: 120m
- The jacks are motorized
- Permanent link with the experiments

LHC / insertion magnets

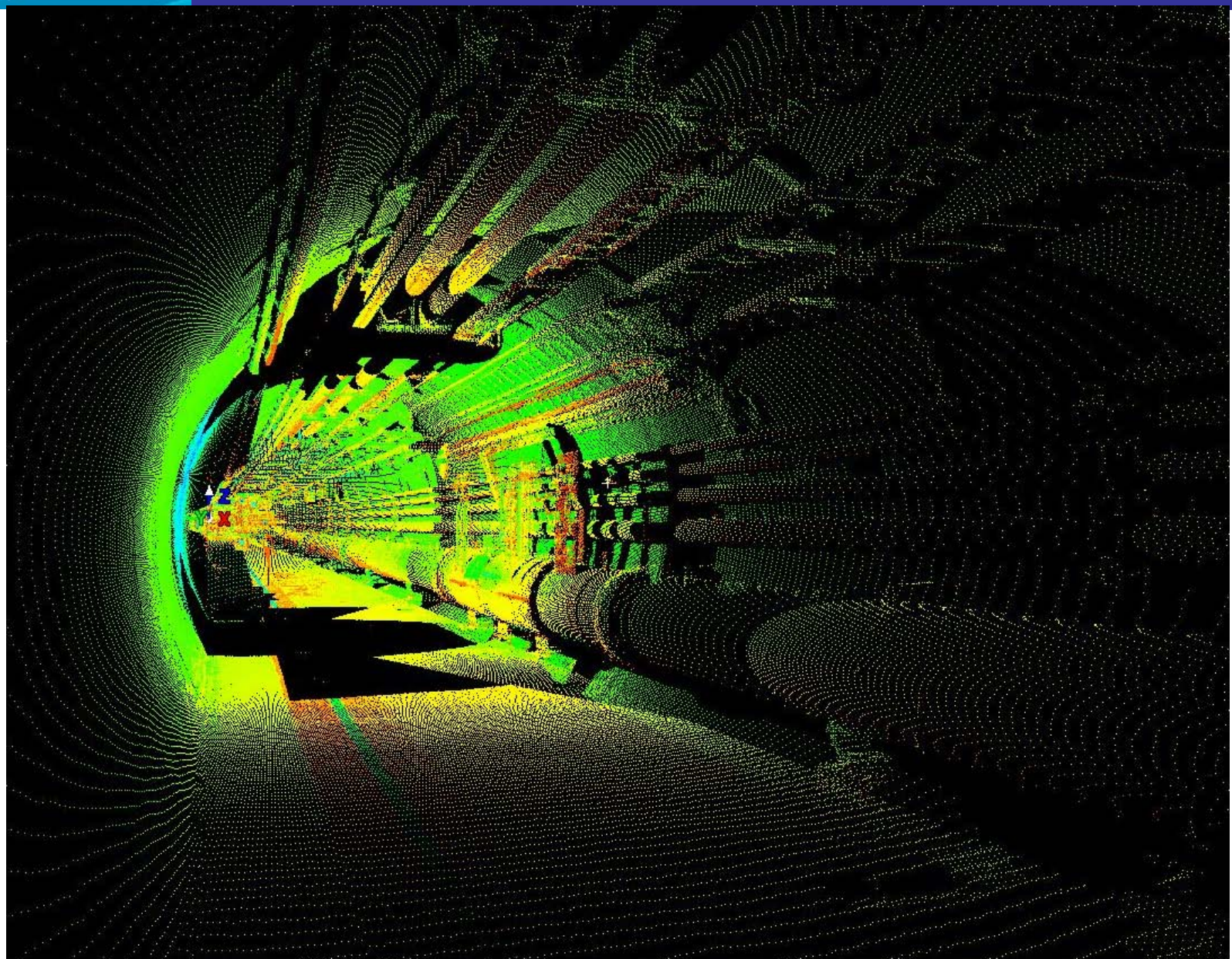
- The group is responsible for the design, the hardware (instrumentation + motors), the installation, the software, the electronics, the measurements, the data acquisition and storage
- Collaboration with RRCAT (India) for the actuators, and Control group for the data acquisition from the control room



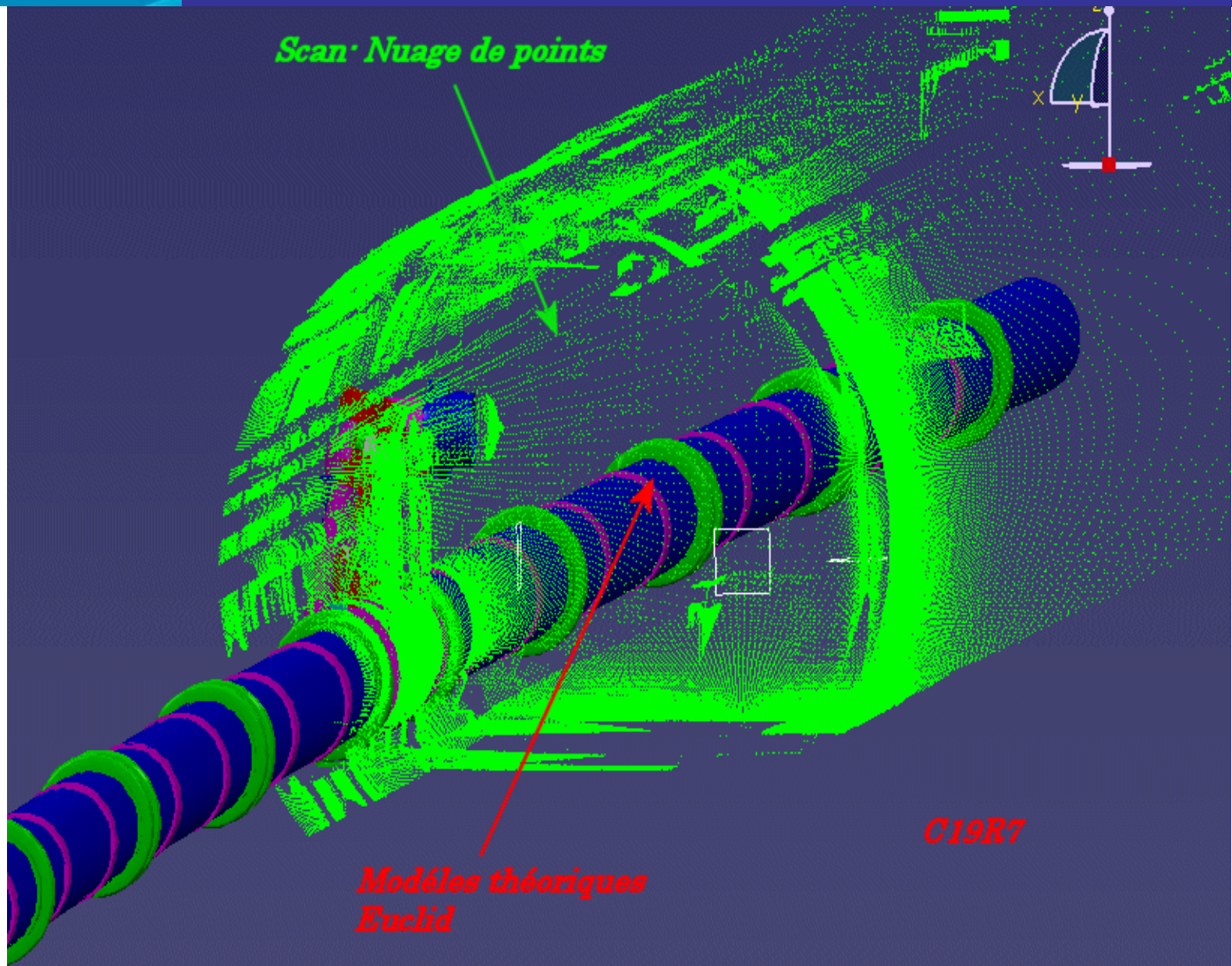
LHC / As-built measurements

- Scan with the Leica HDS3000
- Main goal: avoid any topological conflict at each step of the installation.
- Clouds of points are imported into CATIA, where surface meshes are fitted.
- Then the theoretical mock-up can be merged with the scans thanks to a unique geo-referenced system.
- 8 km of tunnel have been scanned with a point every ~20mm in XYZ.

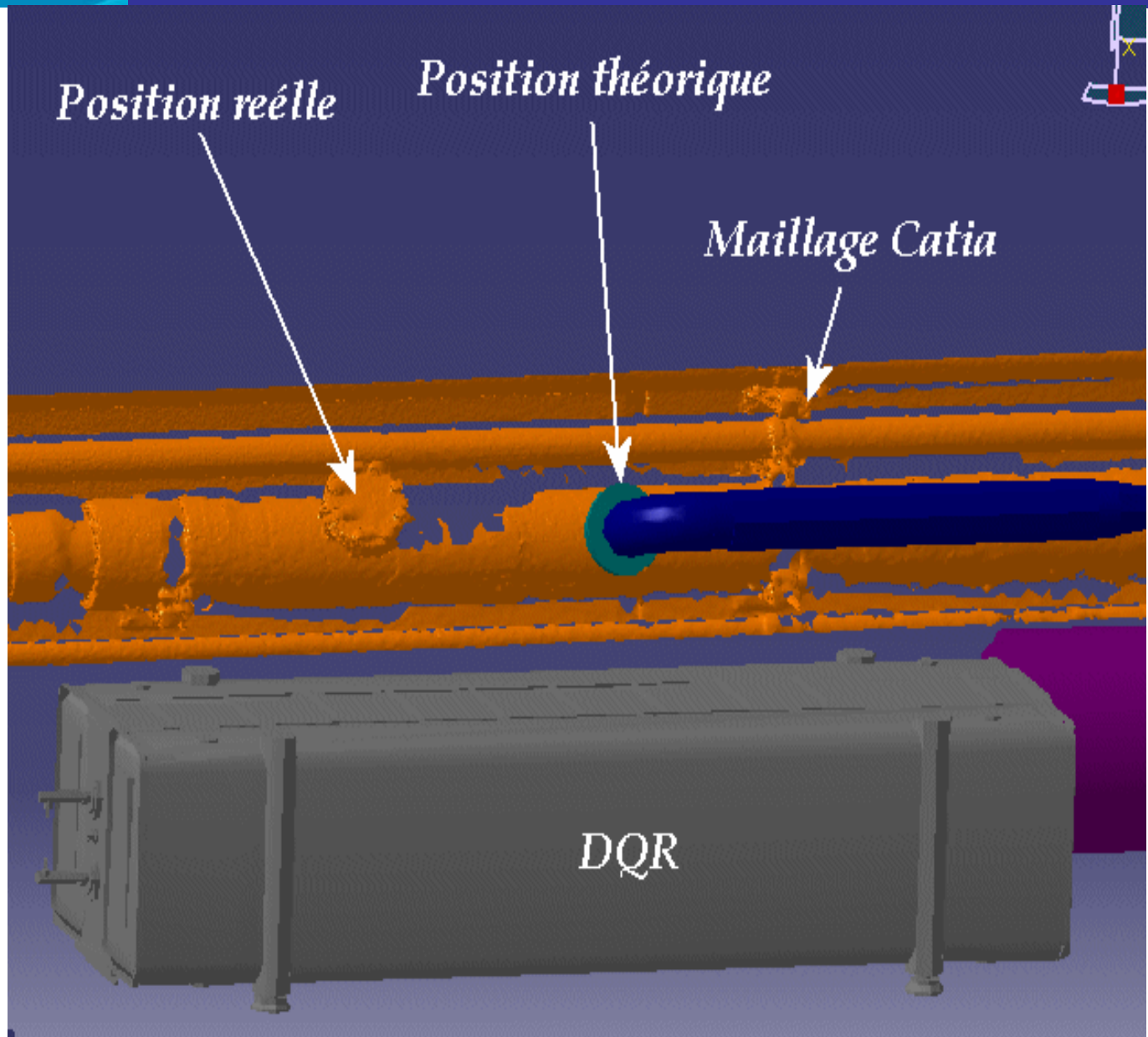
LHC / As built measurements



LHC / As built measurements



LHC / As built measurements



Our experience

- Technical aspects
  - Need for metrological controls of the elements
    - Responsibility of the quality controls to be taken by professionals
    - Redundancy is absolutely necessary
    - Introduce the measurements as early as possible during the manufacturing process
    - To be able to control at CERN by CERN even if controls have been made by the manufacturer
  - Define vocabulary “Tolerance / Accuracy…etc”
  - Make CAD and Geodetic considerations compatible by using a unique coordinate system

Our experience

- Installation process
  - A key role for surveyors (from the very beginning to the very end). Full process of the installation to be studied.
  - We contributed to the design of the elements very early on, and we concentrated on targets, supports, access, free space. This influenced the alignment methodology (and the cost) a lot.
  - Maximum flexibility for maximum efficiency
    - Define correctly the work and conditions, but lots of changes will occur
    - Choice of the methods of alignment to generate a minimum of constraints
- Database
  - The integrity is absolutely necessary. Hard to reach.
  - Write a software spy to detect unannounced changes.

Our experience

- Management
  - External contracts
    - 1 contract for the fiducialisation of the magnets, 1 for the alignment works in the tunnels.
    - Result oriented contracts for the repetitive work
    - Special works carried out by CERN staff
    - CERN provides tools, instruments, software, and has defined all the procedures in detail.
  - International collaborations
    - US labs for special magnets, RRCAT from India for adjustment supports of magnets.
  - Management tools
    - Definition of a WBS
    - Efficient tool for managing the budget costs, thanks to the flexibility left to the users

Conclusion

- A lot of work has been done in 2 years
- To maintain the quality is always a challenge
- The standardization of the methods has revealed its efficiency.
- It is a team effort.