Large Volume Metrology challenges in particle accelerators

Hélène Mainaud Durand

LUMINAR workshop
18-19 May 2016

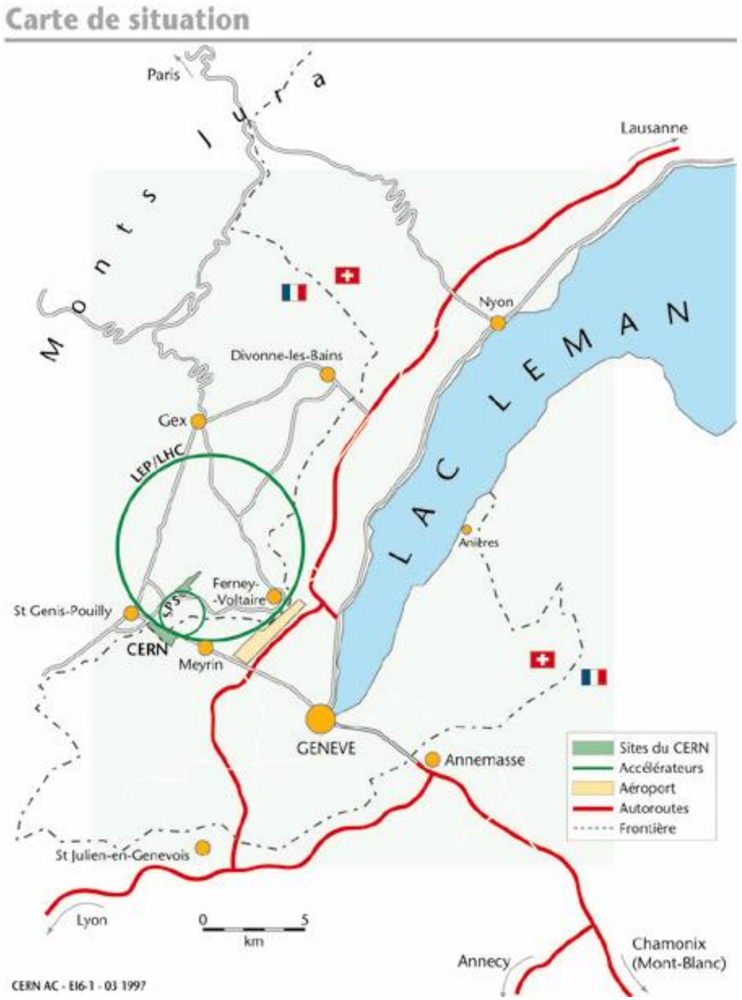
Outline:
- Large scale metrology section at CERN
- Challenges on current projects
- Challenges on future projects

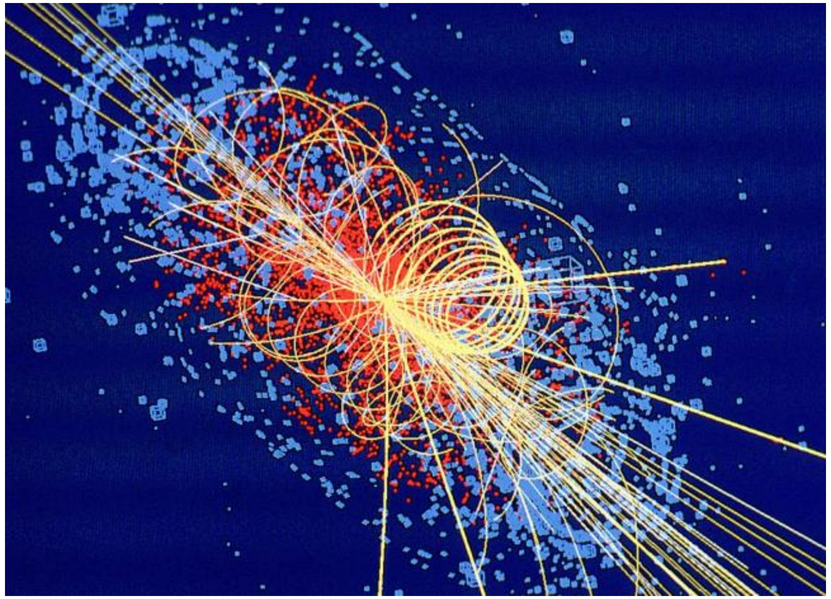
CERN

21 member states

2 500 staff members

12 000 visiting scientists

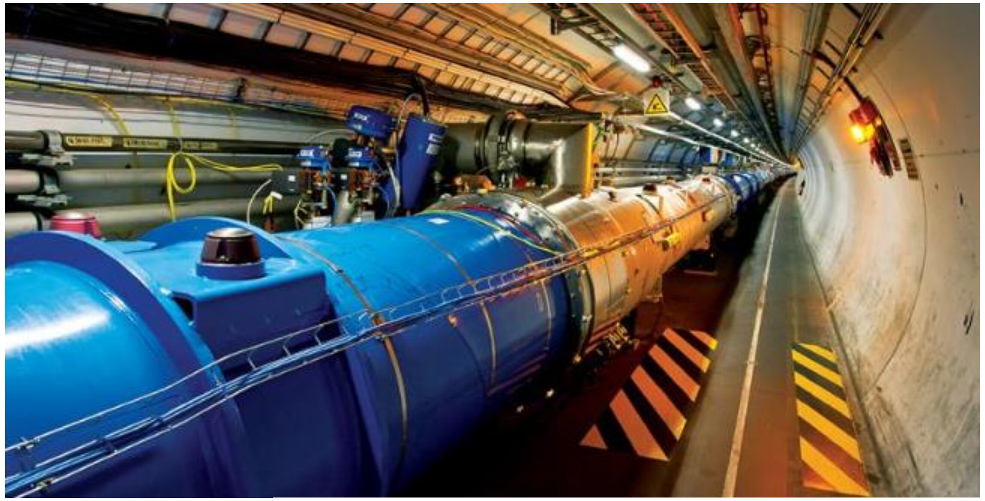


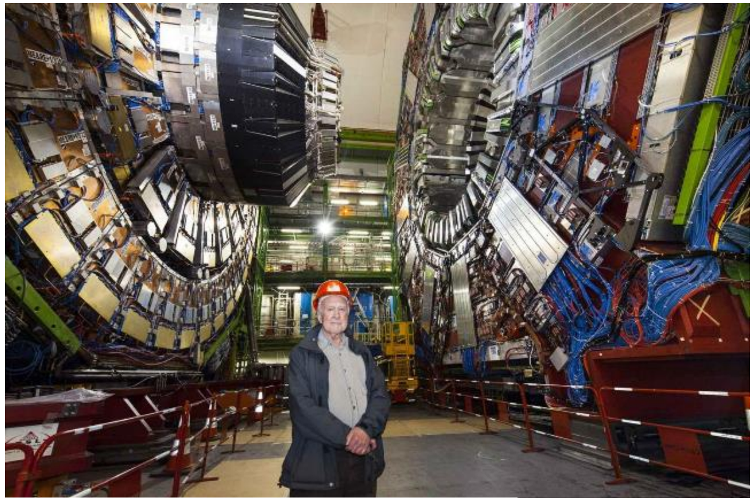


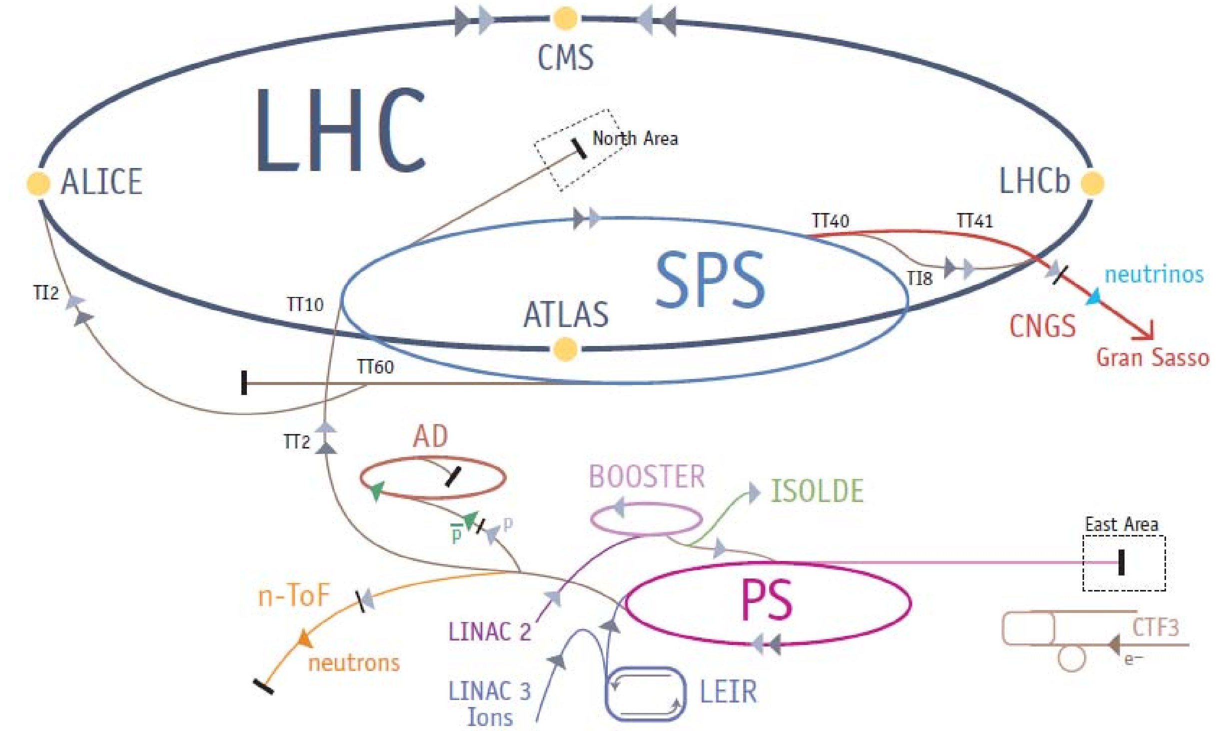
ASACUSA weighs antimatter to one part in a billion

In a paper published today in the journal *Nature*, the Japanese-European ASACUSA experiment at CERN reported a new measurement of the antiproton's mass accurate to about one part in a billion. Precision measurements of the antiproton mass provide an important way to investigate nature's apparent preference for matter over antimatter.

CERN






CMS
LHC
North Area
ALICE
LHCb
TT40
TT41
SPS
TI8
neutrinos
TI2
TT10
ATLAS
CNGS
Gran Sasso
TT60
TT2
AD
BOOSTER
ISOLDE
East Area
p̄
p
n-ToF
PS
LINAC 2
CTF3
e⁻
neutrons
LINAC 3
Ions
LEIR

Large scale metrology at CERN

Large scale metrology

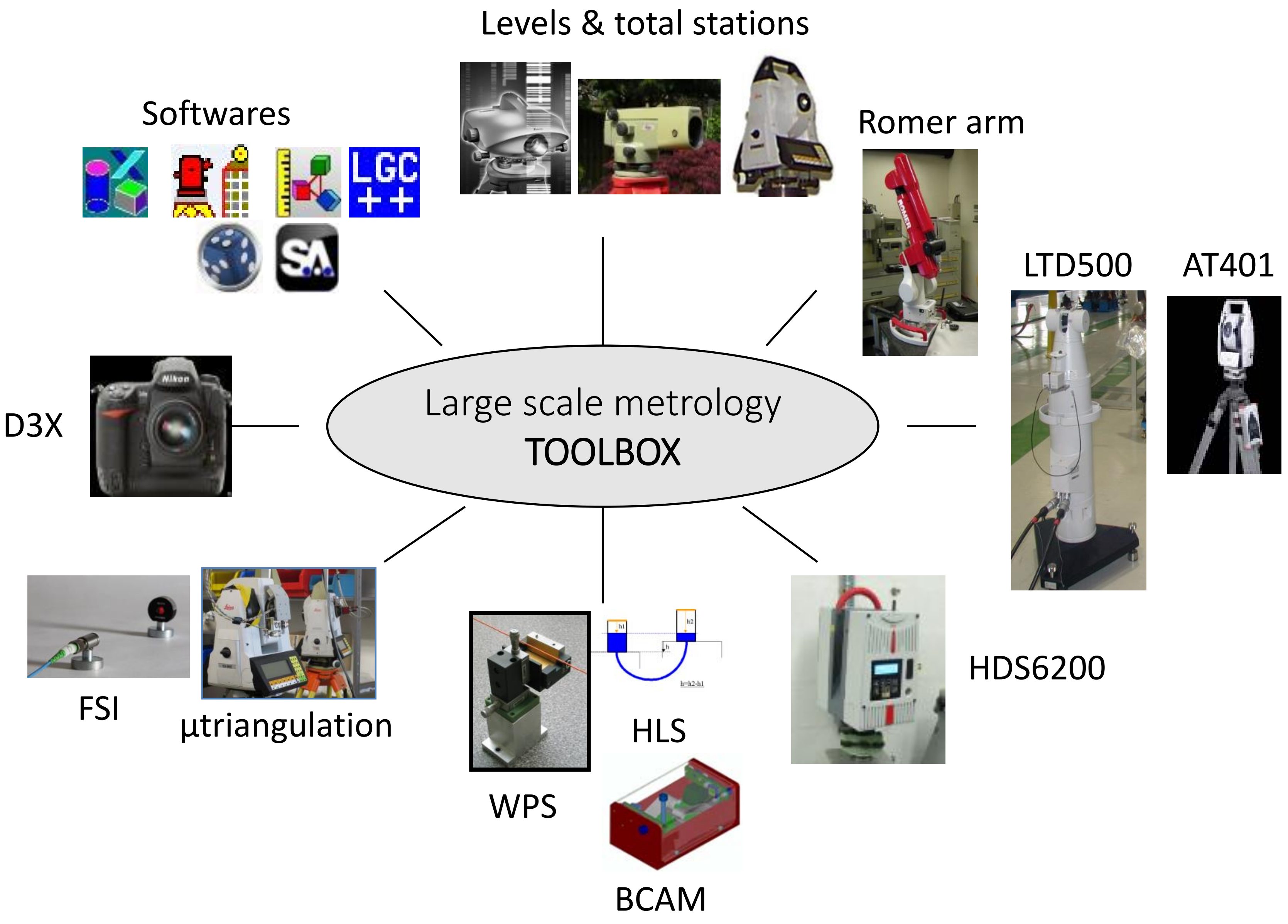
Leader: Dominique Missiaen
Deputy: Hélène Mainaud Durand

- **Geodesy & computing** — Mark Jones
- **Micro Technology & Instrumentation** — Hélène Mainaud Durand
- **Accelerator & computing** — Jean-Frédéric Fuchs
- **Experiment metrology** — Jean-Christophe Gayde

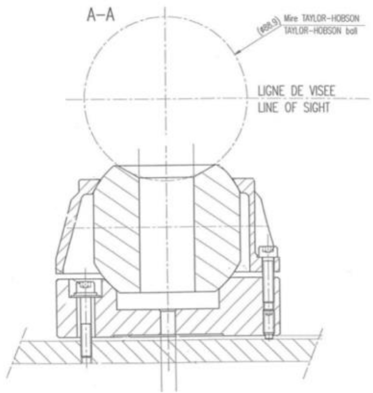
SU Section mandate :

- Geodetic aspects
- Dimensional metrology of accelerators and of experiments
- Positioning and alignment on beam lines
- Quality controls (infrastructure, installations, components)
- The R&D related to these tasks

Toolbox

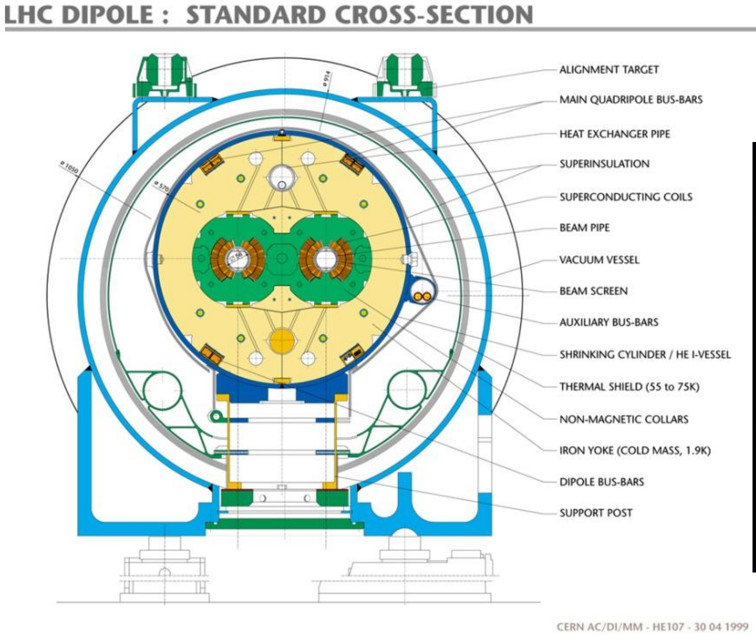

Levels & total stations
Softwares
LGC ++
SA
Romer arm
LTD500
AT401
D3X
Large scale metrology
TOOLBOX
FSI
µtriangulation
WPS
HLS
BCAM
HDS6200

Specific instrumentation



Fiducial Ø 88.9 mm

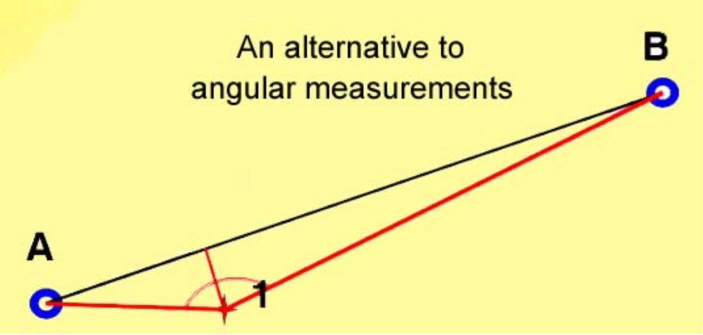
Specific interface

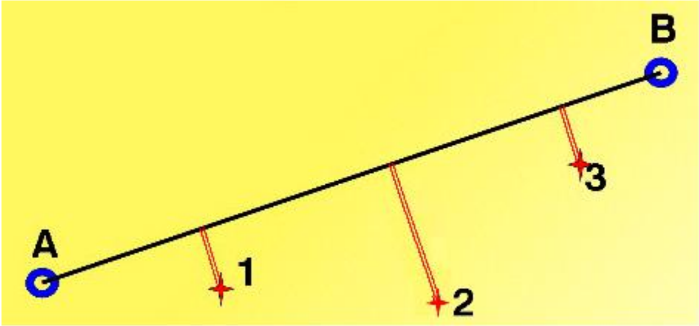


Wire ecartometer

Specific station

Specific instrumentation

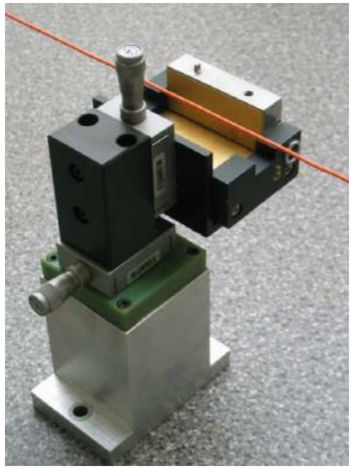


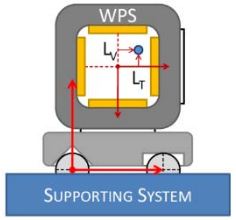


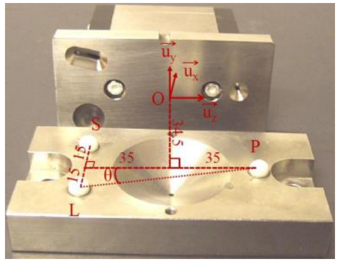
- Wire as straight alignment reference
- Radial measurements
- Wire to be protected from air currents
- Uncertainty of measurement < 0.1 mm

Specific instrumentation

Wire Positioning System (WPS)



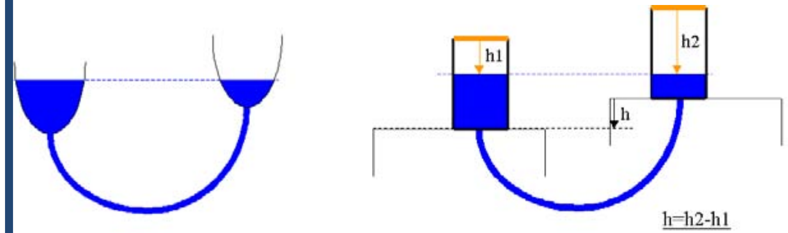


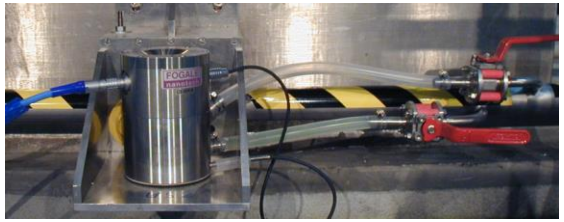


Main characteristics:

- ✓ Biaxial measurements
- ✓ Range : ± 5 mm
- ✓ Resolution < 0.2 µm
- ✓ Repeatability < 1 µm
- ✓ Accuracy < 5 µm over the whole range

Hydrostatic Levelling System (HLS)





Main characteristics:

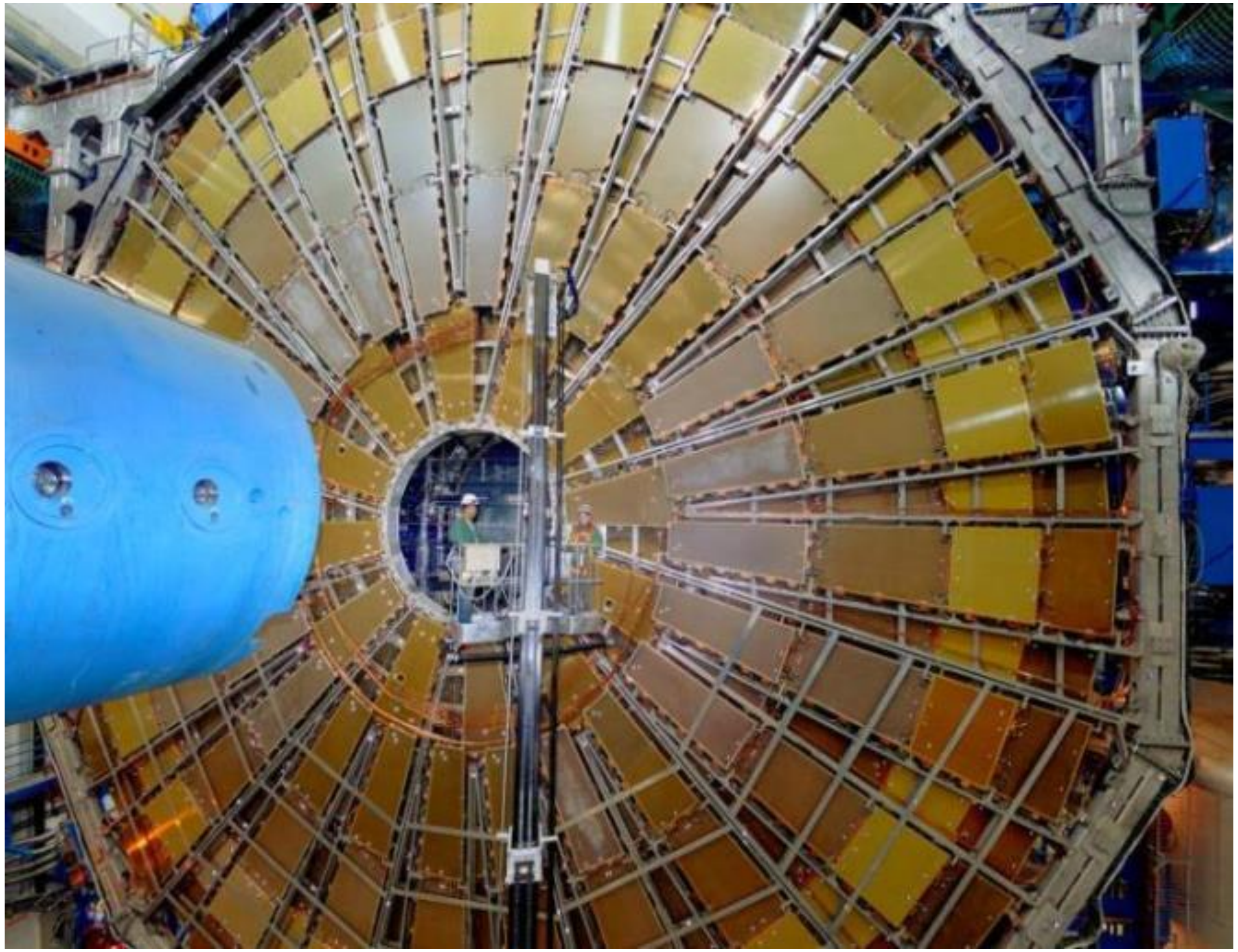
- ✓ Vertical measurements
- ✓ Range : 5 mm
- ✓ Resolution < 0.2 µm
- ✓ Repeatability < 1 µm

Challenges in current projects

Every day challenges

Challenges in current projects

size, length, etc.

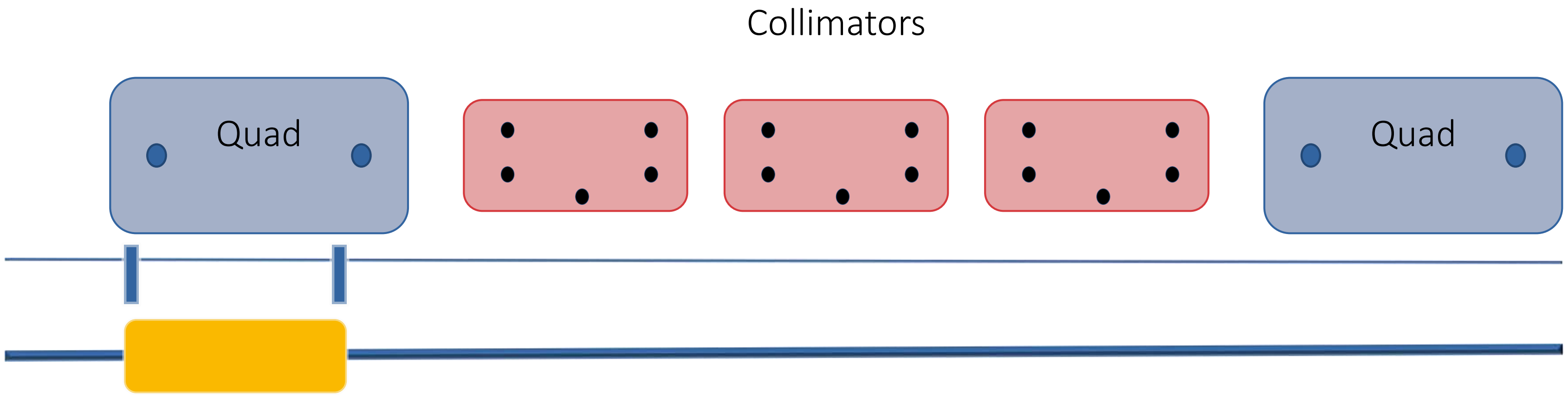


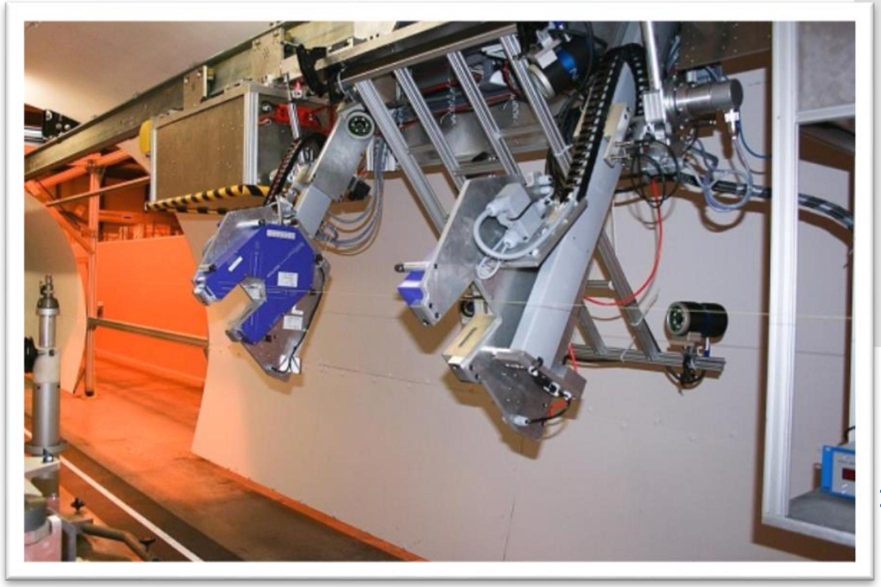
Challenges in current projects

Remote measurements

Determine remotely the position of collimators :

- w.r.t the two adjacent quadrupoles: ± 0.2 mm



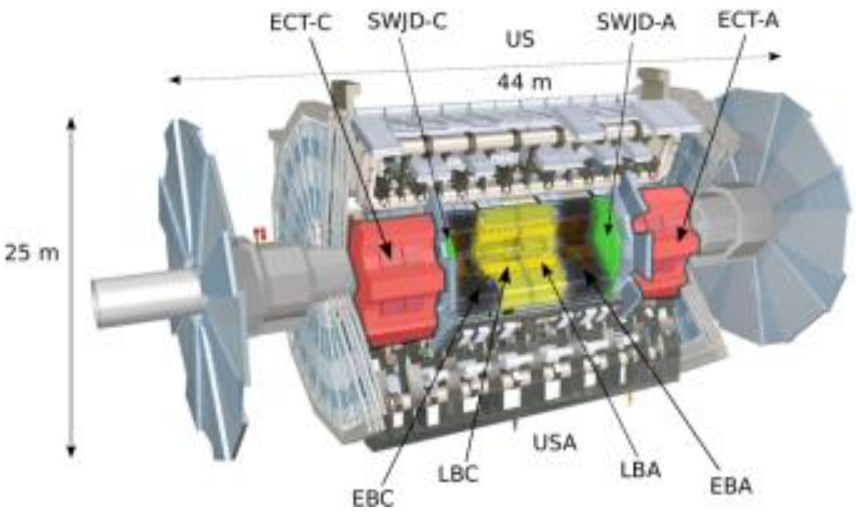


Challenges in current projects

Monitoring

- to gain time,
- accuracy
- no access needed

ADEPO Project

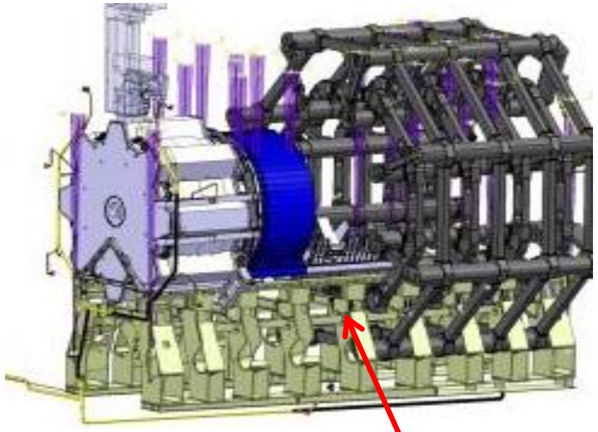


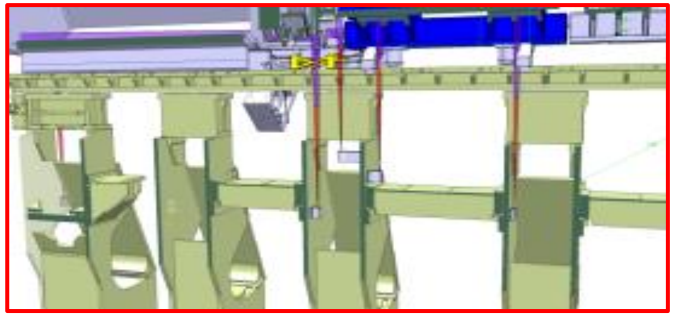
Requirements:

- Monitor and speed up closure
- Gain in precision for re-positioning
  - Relative repositioning at 0.3 mm (1 sigma)
  - Movement follow-up at 0.1 mm
- Cover 6 DOF per moving detector
- Cycle < 30 sec.
- Resist to 1 Tesla magnetic field
- Radiation dose of 2 Gy for lifetime

System is based on:

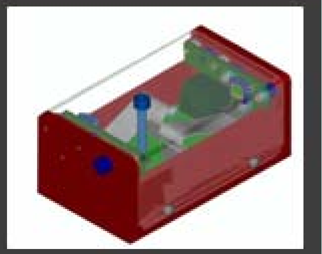
- 28 BCAMs on feet/rails system
- 44 passive targets (prisms)

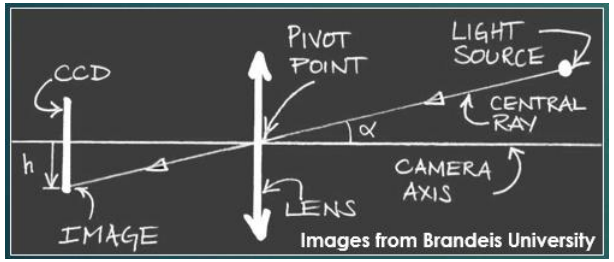




BCAM:

✓ Viewing window = 30×40 mrad;
✓ Precision = 5 µrad;
✓ Non-magnetic;
✓ Accept a total of 400 Gray.

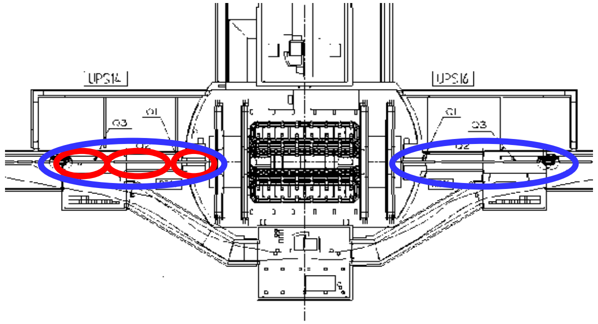


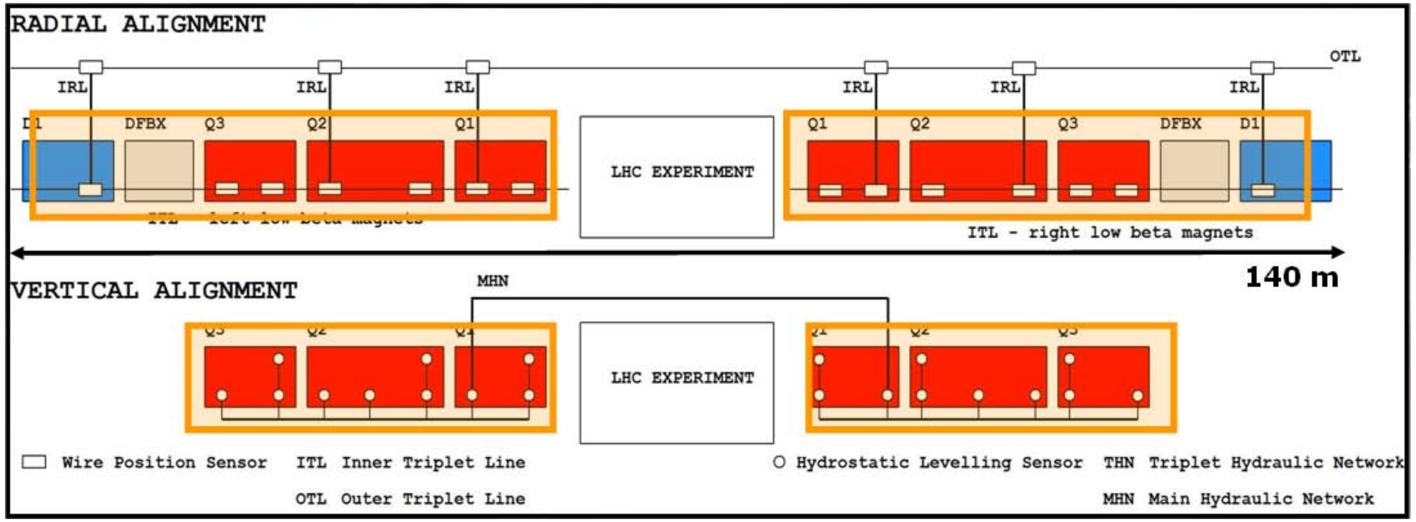


Challenges in current projects

Monitoring

- to gain time,
- accuracy
- no access needed





Alignment requirements:

- Positioning of one inner triplet w.r.t the other: ± 0.1 mm
- Stability of the positioning of one quadrupole inside its triplet: a few microns

Monitoring

to gain time,
accuracy
no access needed

Upgrade of the triplets (HL-LHC project in 2024):

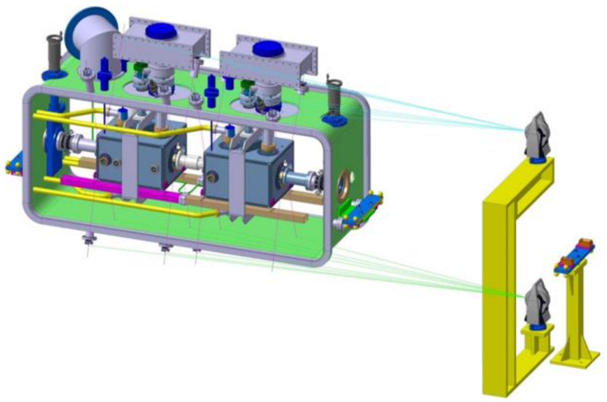
- Trying to find an alternative to stretched wire solutions (laser based solution…)
- Monitoring of the position of components at cold temperature (2 K)!

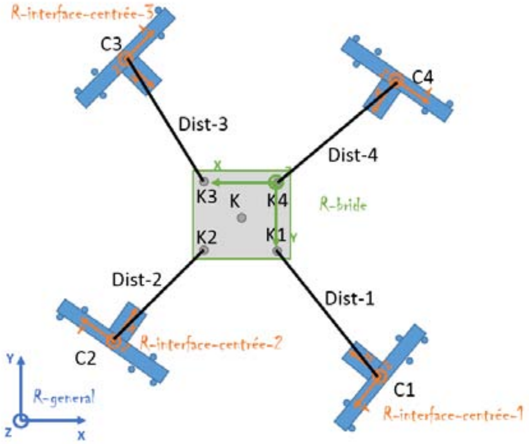
Challenges of the future projects

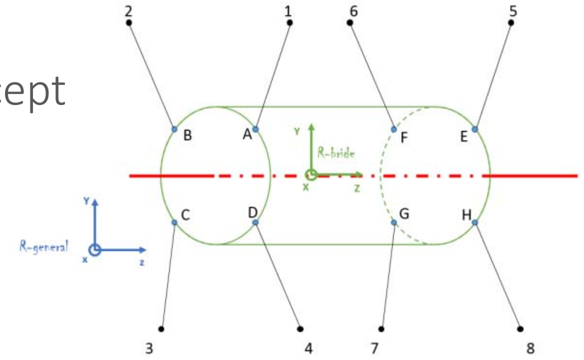
Monitoring of the position of cold components using FSI system

- **Objective:** propose, integrate & validate an alignment system to monitor the position of two crab cavities inside a cryostat (T°<3K, high level of radiation: > 1 MGy, technical vacuum)
- **Baseline:** Frequency Scanning Interferometry (FSI), validated through cross-check measurements by AT401 and BCAM
- **Strategy:**
  - Validation of the FSI itself for such environment:
    - Simulations & validation of the concept ✓
    - Irradiation tests ✓
    - Cold tests (cryolab)
    - Design & validation of a feedthrough
  - Comparison with AT401 & BCAM:
    - In the calibration base: validation of the concept
    - During the assembly (vacuum & cold T°)
    - In an accelerator environment (SPS)

➔ conclusion and extrapolation for the LHC







Challenges for future projects

CLIC

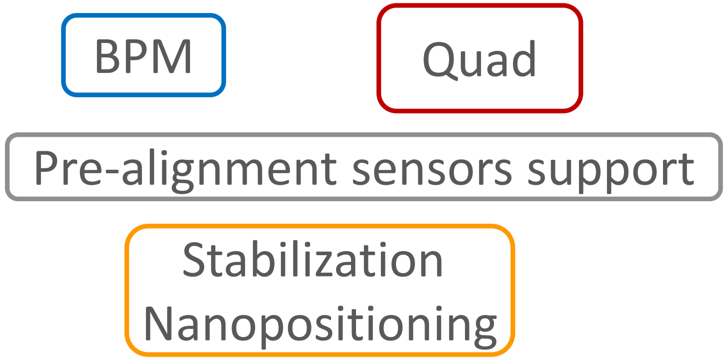
CLIC e+ e- collider under study at CERN for the post LHC area

What matters is the number of collisions :

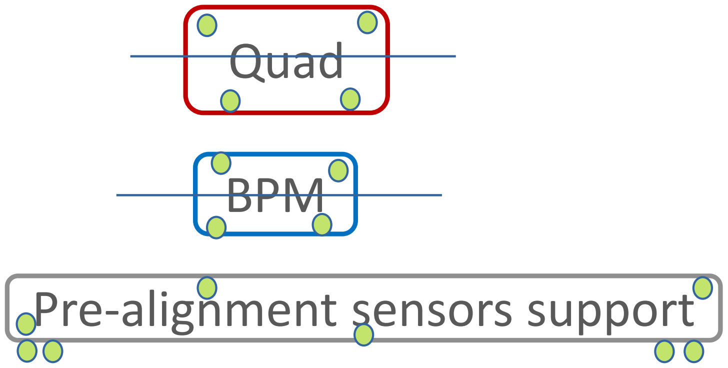
➔ Beam size very small at the collision point: 1 nm in vertical!

➔ Very tight requirements concerning the pre-alignment of the components before the 1^{st} beam is injected. Total budget of error: ± 14 µm at 1 σ.

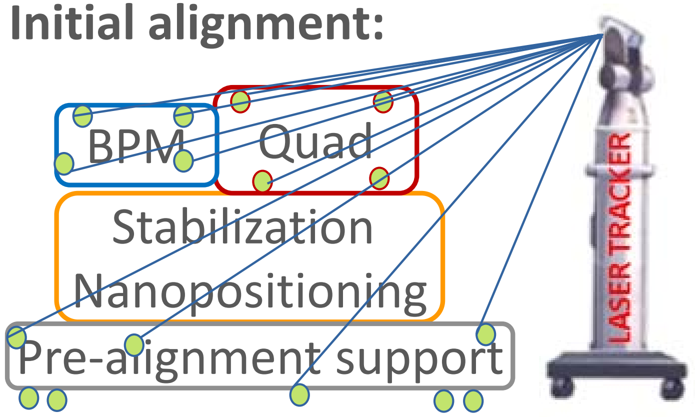
CLIC pre-alignment strategy



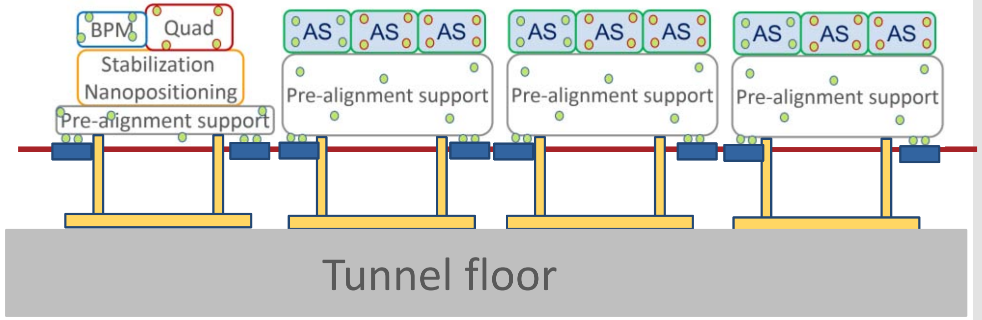
Fiducialisation:



Initial alignment:



Transfer in tunnel & alignment



- Strategy proposed for CDR in 2012. More than 20 000 assemblies!
- Accuracy achieved at that time: better than 15 µm over 140 m (mechanical reference axis) ➔ PACMAN project aims at improving that !

PACMAN project

PACMAN = a study on Particle Accelerator Components' Metrology and Alignment to the Nanometre scale
It is an Innovative Doctoral Program, hosted by CERN, providing training to 10 Early Stage Researchers.

Web site: http://pacman.web.cern.ch/

8 academic partners
8 industrial partners
Duration : 4 years
Start date: 1/09/2013

PACMAN NETWORK

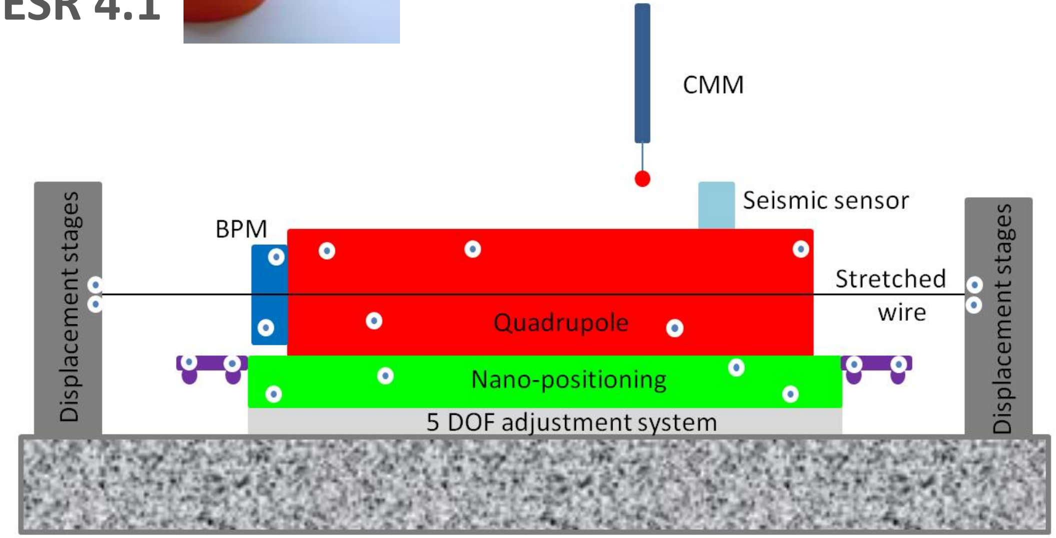
CERN, CH
Cranfield University, UK
Delft University of Technology, NL
ETH Zürich, CH
IFIC,ES
LAPP, FR
University of Sannio, IT
SYMME, FR
University of Pisa, IT
DMP, ES
ELTOS, IT
ETALON, DE
Hexagon Metrology, DE
METROLAB, CH
National Instruments, HU
SIGMAPHI, FR
TNO, NL

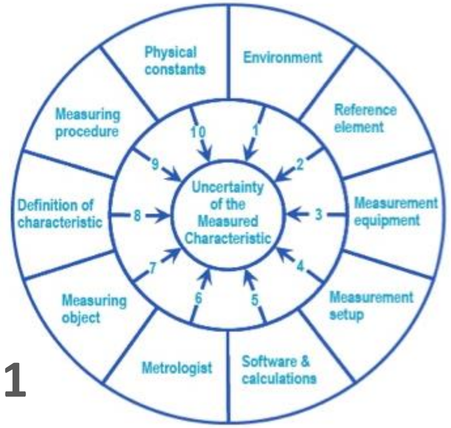
ESR 3.3

ESR 4.1

ESR 3.2

ESR 1.1



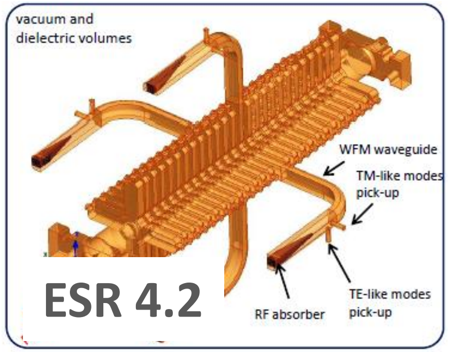


ESR 3.1

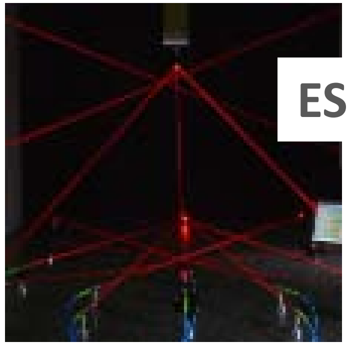
ESR 1.3

ESR 2.1

ESR 2.2



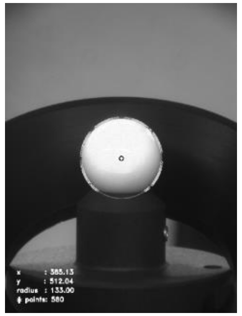
ESR 4.2

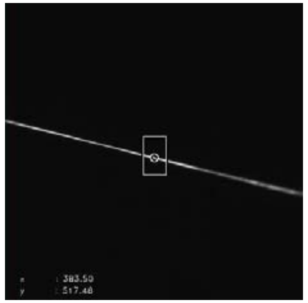


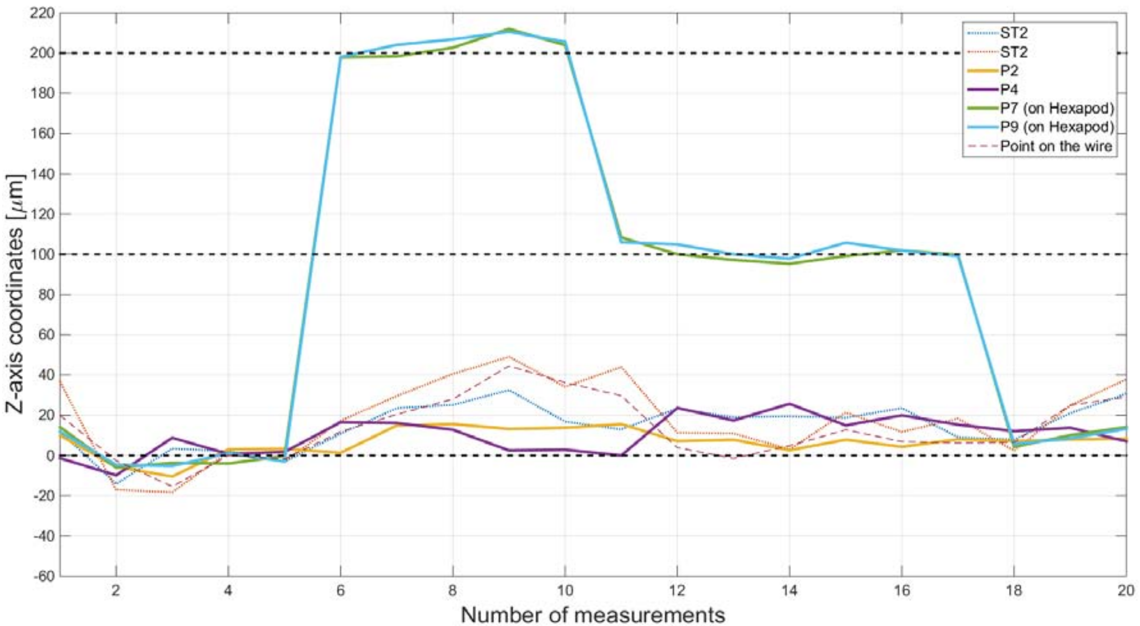
ESR 1.2

First results & preparation tests

Determination of the wire position (µtriangulation)







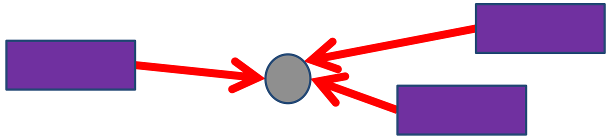
First results show a very good coherence between hexapod displacements & micro-triangulation measurements.

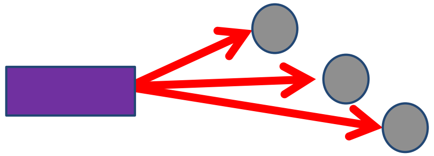
Scale factor to be integrated.

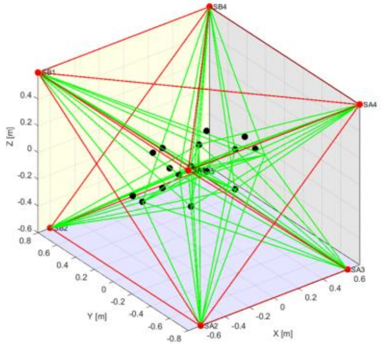
Objective: perform multilateration measurements

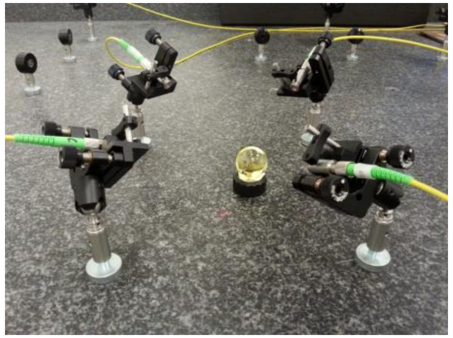
First results & preparation tests

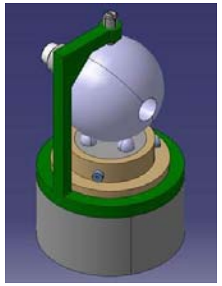
Determination of the wire position (FSI)

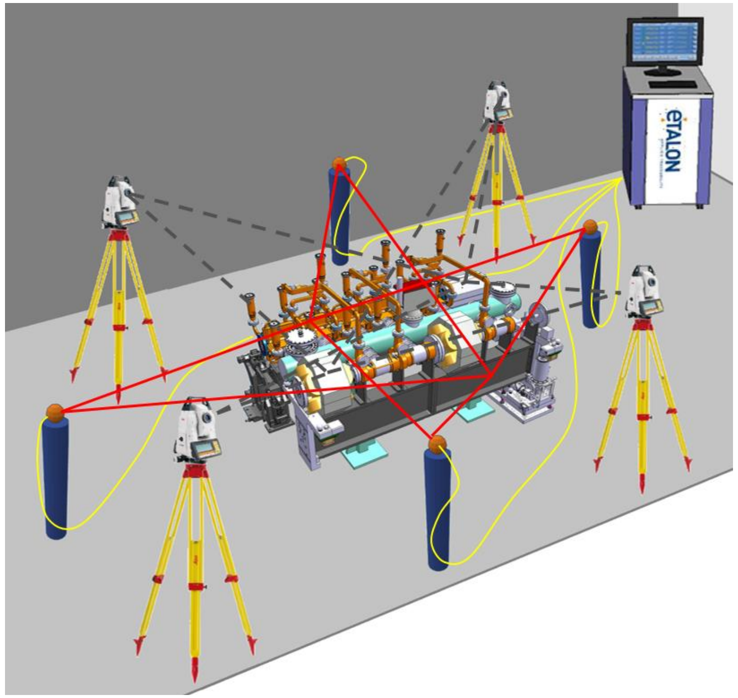












Combine µtriangulation & FSI

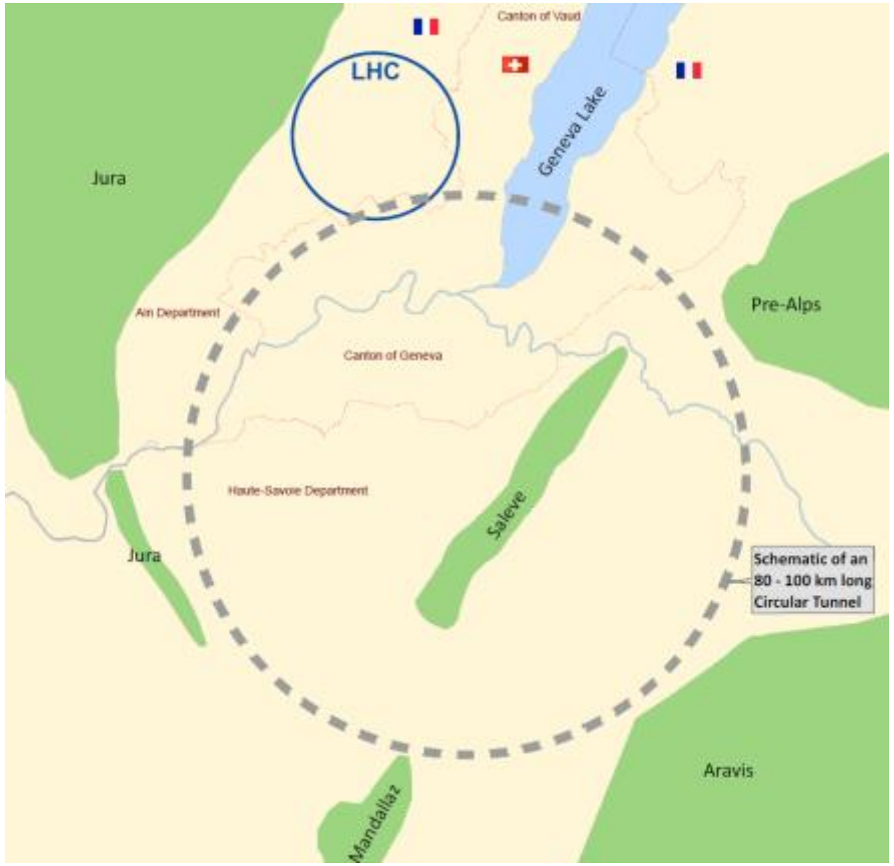
Portable & accurate solution

Measurements carried out after the transport of components in the tunnel

FCC

Future Circular Collider

- 80 – 100 km accelerator rings under study
- 5 year study
- Constraints
  - CERN area
  - Connected to SPS / LHC
  - Collision Energy
  - Geology
- Conceptual Design Report by 2018



Summary

- Challenges of Large Volume Metrology are numerous in the accelerators world, considering:
    - Size
    - Number of components to be aligned
    - Variety
    - Environment (radiations, magnetic fields, cold temperature)
    - Configuration (long straight sections or curved sections)
    - Accuracy (up to a few microns!)
- R&D to improve our toolbox:
    - Development of our own instrumentation (fiducials, wire ecartometre & stretched wire)
    - Upgrade of sensors to our needs (micrometric accuracy, radiation hard)
    - Development of the associated methods of measurements and analysis

Any questions?

LUMINAR workshop
18-19 May 2016