

16-18 September 2025 Aachen, DE

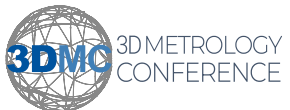
From millimetres to microns: ensuring alignment readiness in HL-LHC with robotic tracing



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Outline

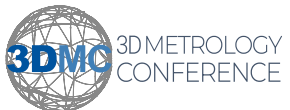
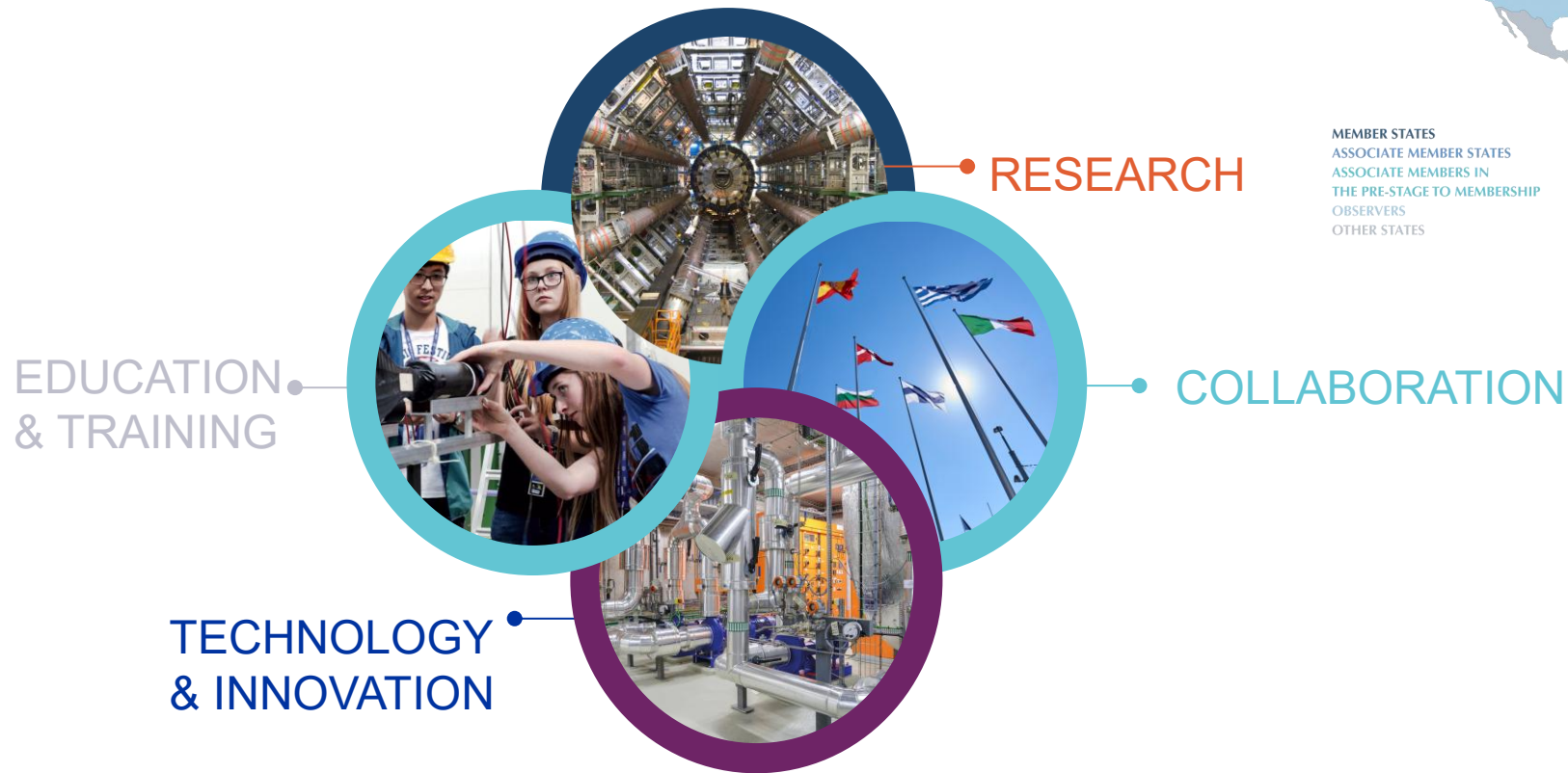
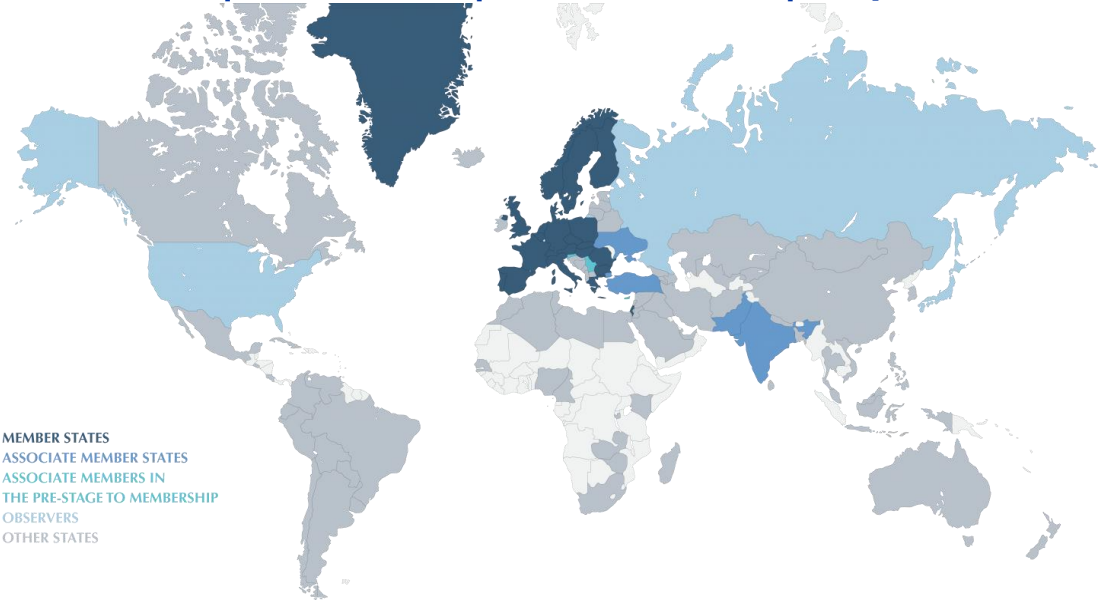
- **Introduction**
 - CERN
 - BE-GM Group and the accelerator complex
 - HL-LHC Project
- **Tracing**
 - Importance of the tracing stage
 - Installation and alignment strategy
 - Current process and its challenges
- **Robotization**
 - Proposed solution and its challenges
 - Evaluation
 - Conclusion and outlook



CERN

Founded in 1954 as Conseil Européen pour la Recherche Nucléaire

Research | Innovation | Collaboration | Inspiration



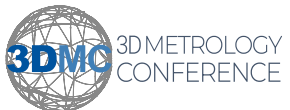
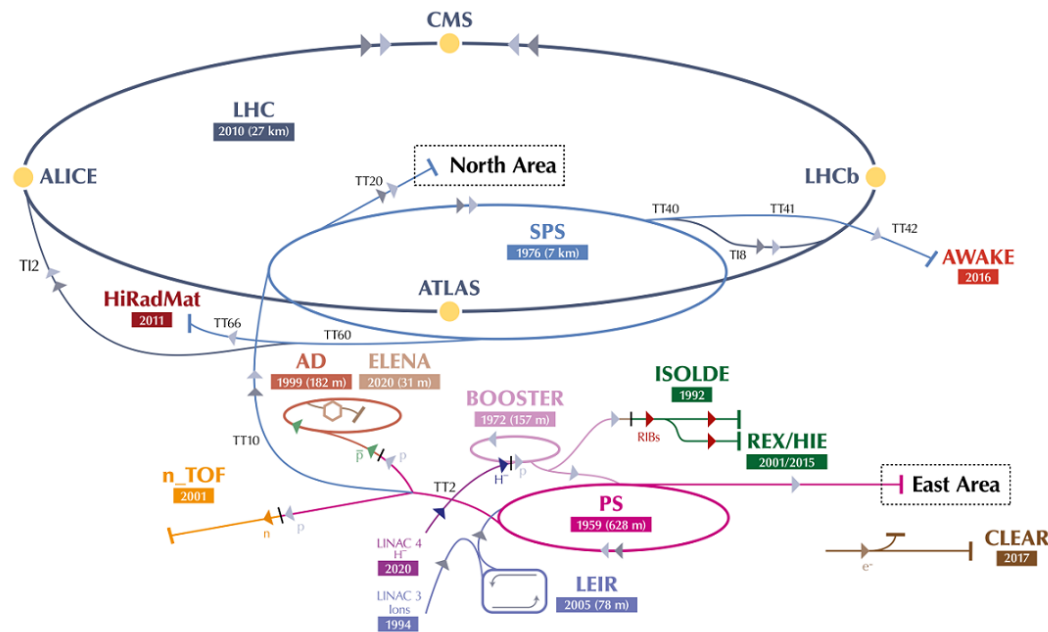
18 Sep 2025

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CERN

- **CERN is the world's largest particle physics laboratory**

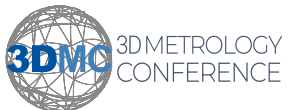
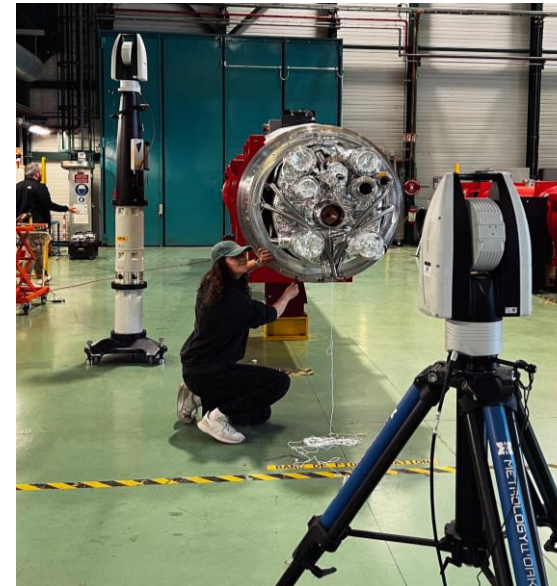
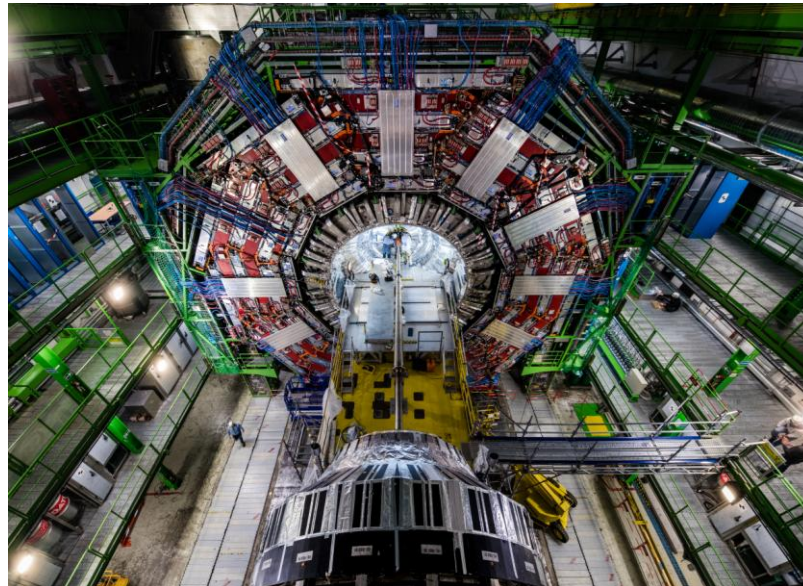
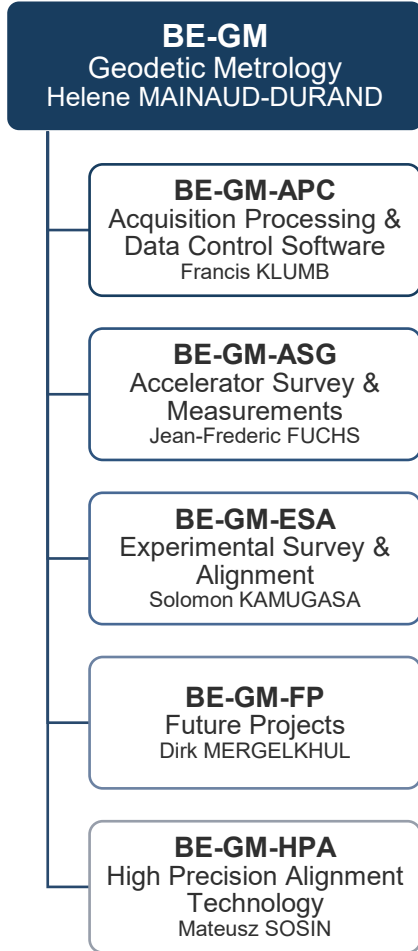
- CERN provides state-of-the-art accelerator facilities for high-energy physics research to uncover what the universe is made of and how it works.
- Providing a unique range of particle accelerator facilities to researchers, to advance the boundaries of human knowledge thanks to 3 pillars : accelerators, detectors, and computing



BE-GM Group

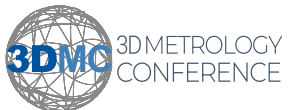
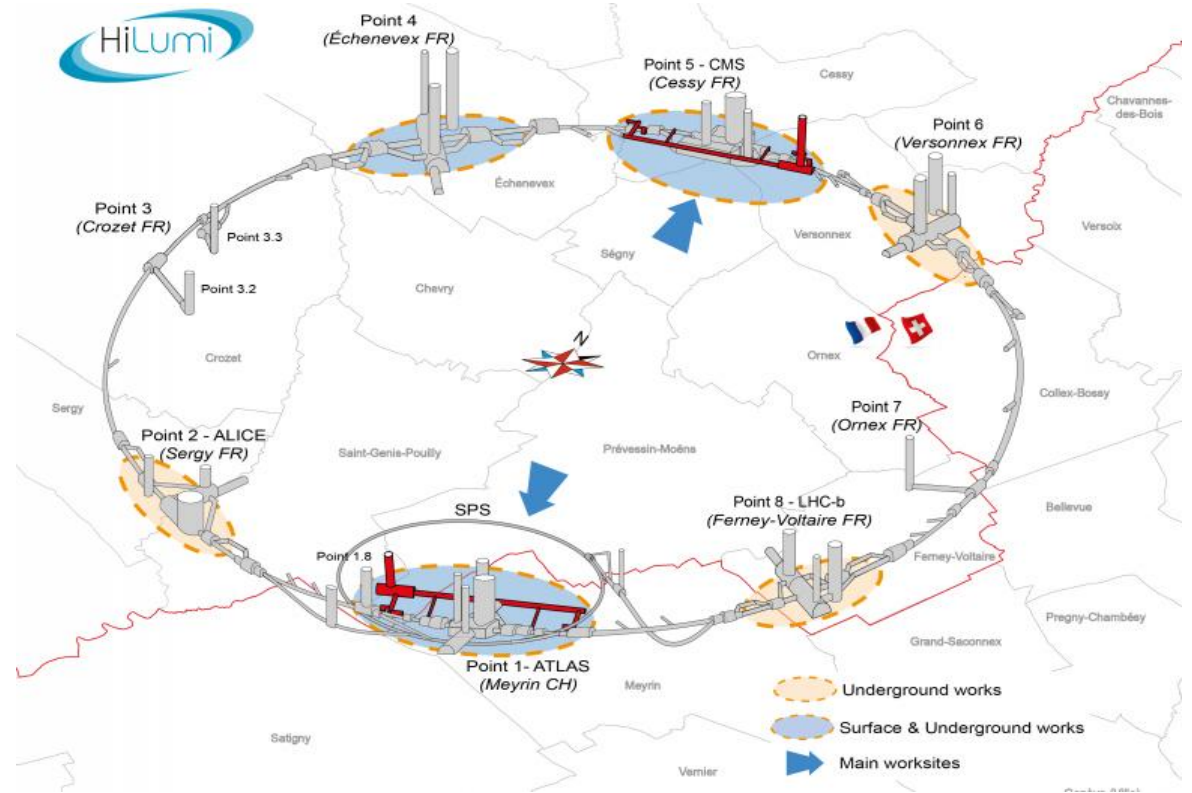
We provide metrology and alignment for components installed in the accelerators, their beam transfer lines and physics experiments throughout CERN.

Using standard tools, adapt them where needed and develop where necessary....



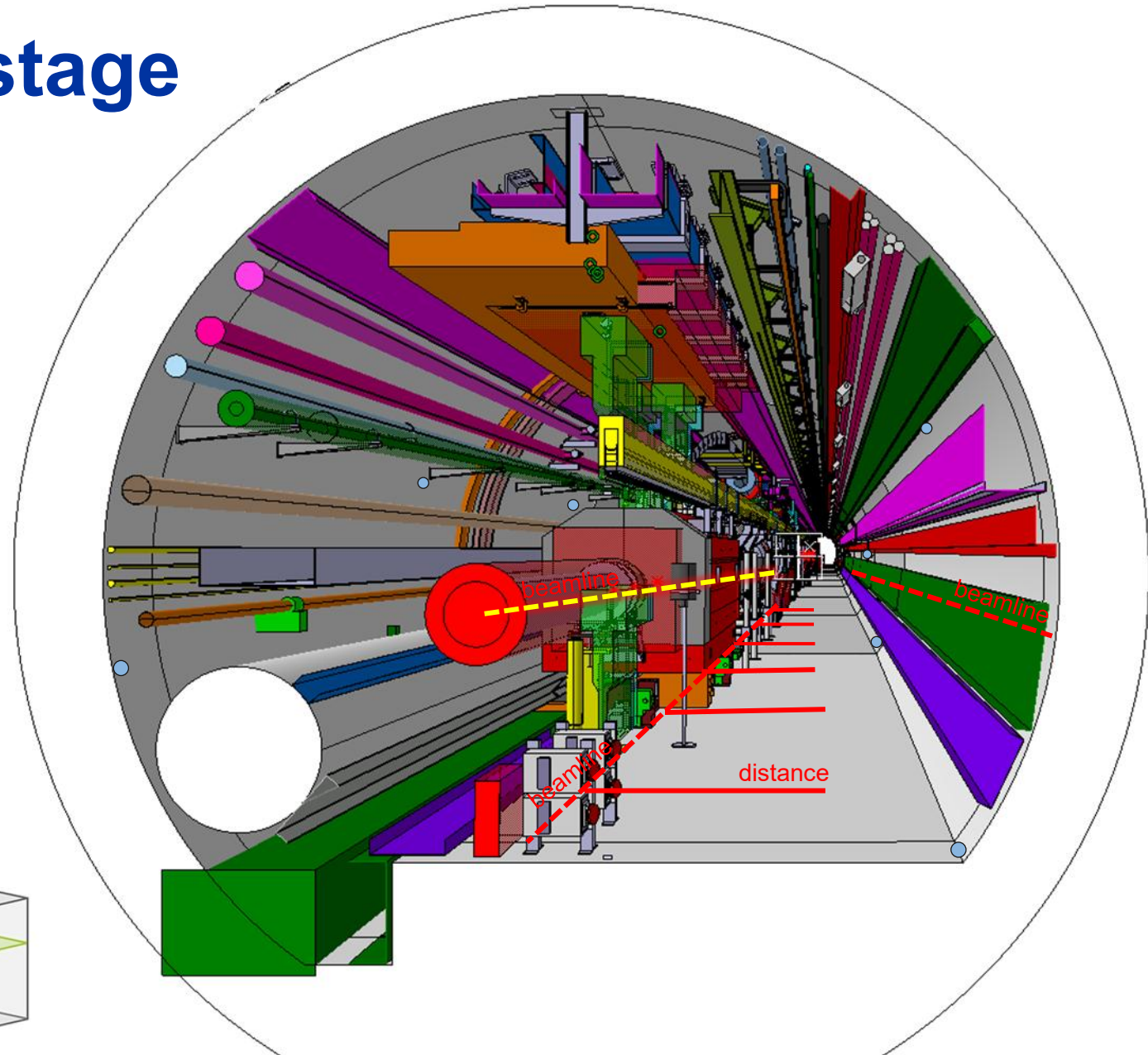
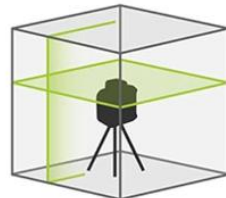
HL-LHC Project

- The HL-LHC Project is a major machine upgrade to increase the luminosity
 - Out of 27 km accelerator - 1.2 km of machine will be replaced with new upgraded equipment
 - A Full Remote Alignment System will be deployed in those areas
 - More: [Vincent Barbarroux poster 2024](#)



Importance of tracing stage

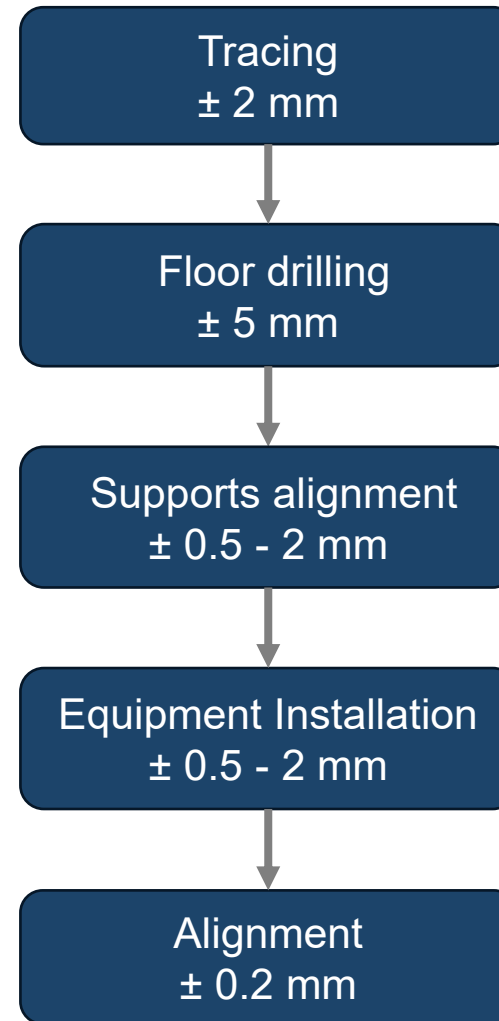
- After deinstallation of current LHC parts – the tunnel will be completely empty
- The installation teams need to know where are they and where to position the equipment
- Theoretical beamline as a general reference
- Common reference:
 - Beamline projections
 - Cumulative distance
- Additional points – supports – beampoints
- Installation using 3D axis laser



Installation and alignment strategy

- Tracing on the floor is only the first step
- Each step carries its own risk
- Each step can be compensated by mechanical design directly during installation:
 - Hole clearance
 - Adjustment systems
- Floor marking is the only step that cannot be compensated directly

It is extremely important to have all the adjustment systems in their middle range during the installation to assure lifetime alignment capabilities to be able to compensate the future misalignments



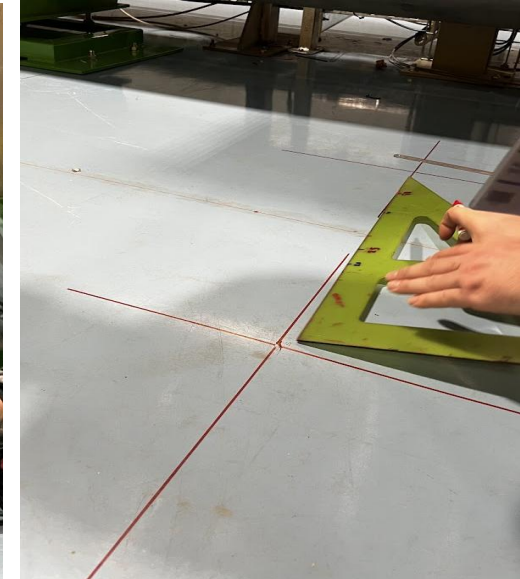
HL-LHC magnet support alignment

Equipment Assembly
Manufacturing tolerances

Challenges in manual tracing

- For the past 25 years the process was manual (27 km of the LHC was manually marked on the ground!)
- TDA5005 → AT40x
- Current process assuring accuracy of ± 2 mm
- Strain on the operator's health over long period
- Time consuming 50m/day
- Human error prone

Continuous features proving challenging for manual tracing



Solution – robotic tracing

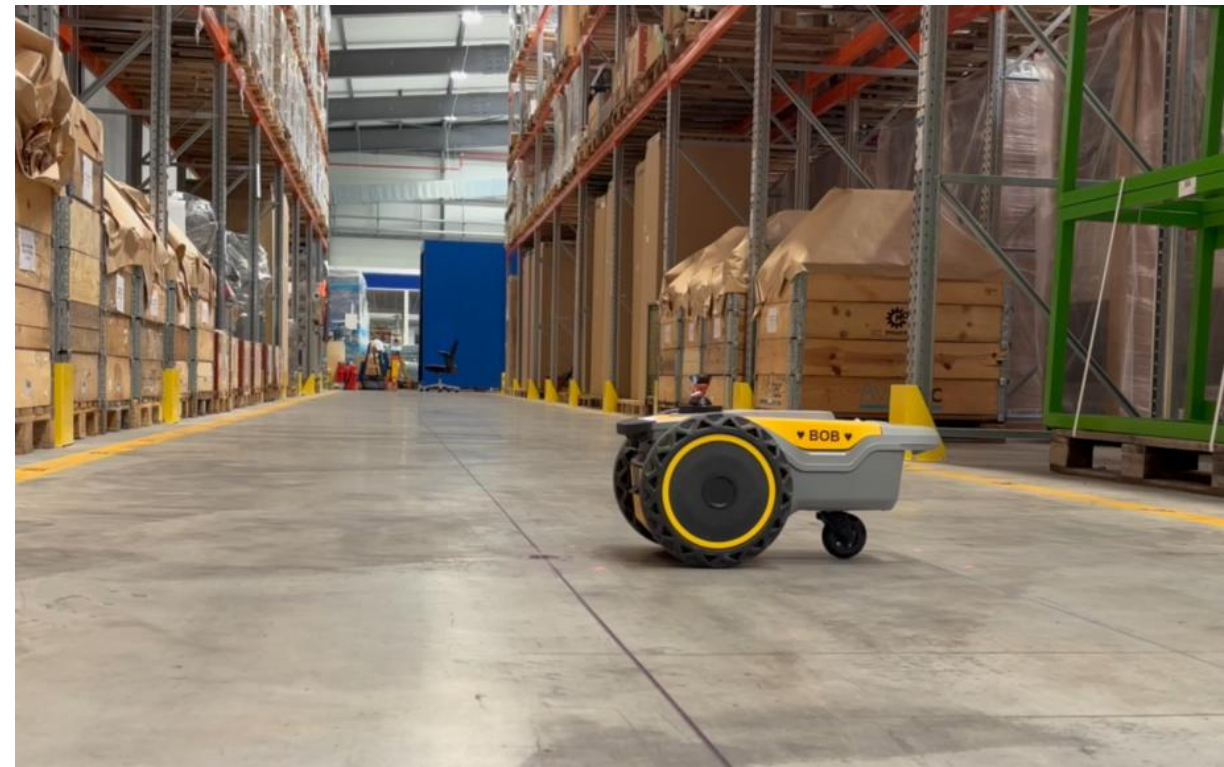
HP SitePrint

- Robot for layout marking
- Time reduction
- No. marked elements increased
- Floor height measurement
- Multiple inks available
- Precision close to the required

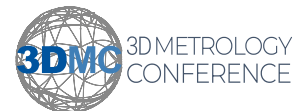
HP SitePrint Datasheet:

Print Accuracy Tolerance 1/8 in (3 mm)³

Floor Level Accuracy Tolerance 3/32 in (2 mm)⁵

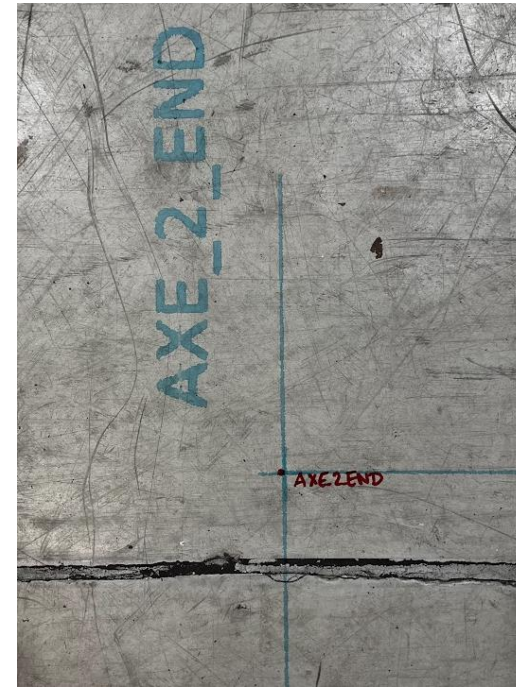


HP SitePrint



Challenges – robotic tracing

- Pushing accuracy to the limits
- Accuracy linked mostly to the instrument used – Absolute Trackers not compatible now
- Segment coherency and continuity
- A new BE-GM workflow had to be defined to handle the HP data flow

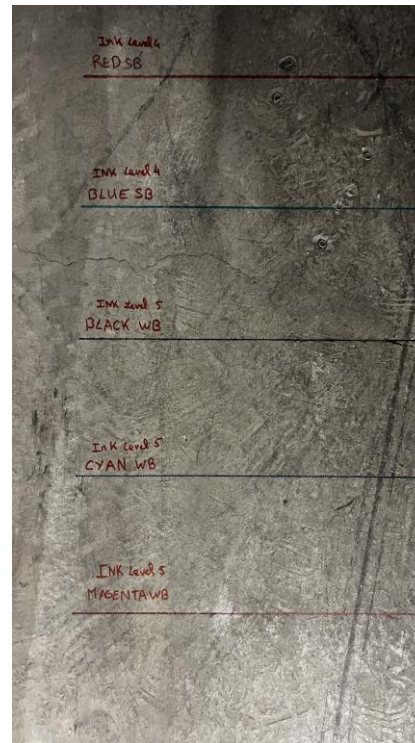
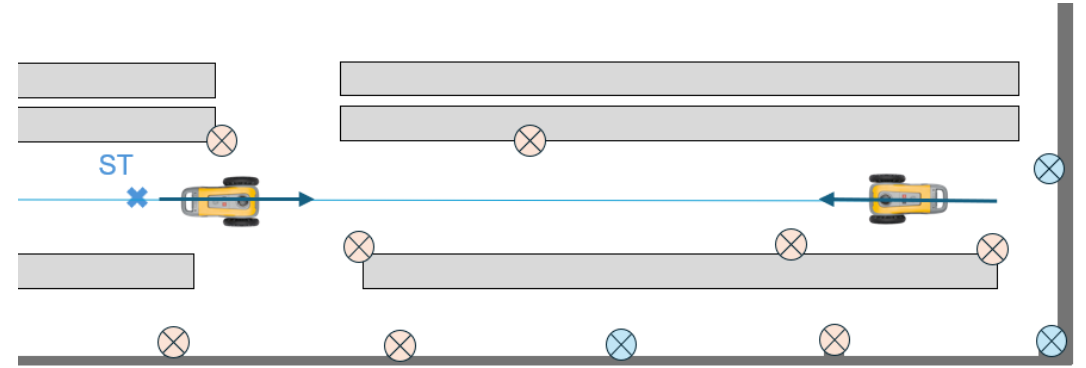


Evaluation

Main issues studied:

- “Absolute” accuracy
- Deviation over long continuous traces
- Line convergence from multiple setups
- Influence of the 360° prism
- Calibration process before tracing
- Ink visibility and durability

“Best practices” developed to utilise the robot in the most accurate way



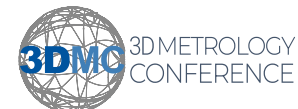
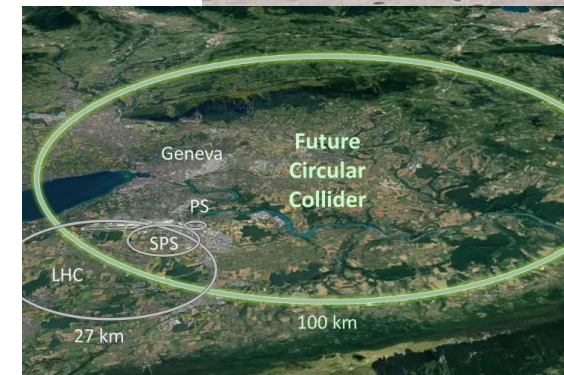
Calibration Distance (m)	6	30
Averaged Apparent Deviation (mm)	1.84	0.56

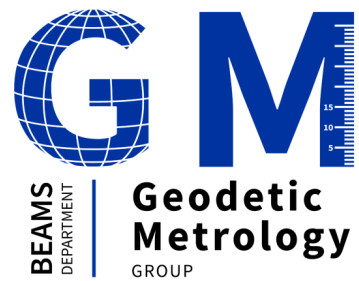


	Averaged Apparent Deviation (mm)
Tracing single points	1.51
Tracing two crosses	3.54
Tracing a perpendicular cross	2.27

Conclusion and outlook

- Robotic tracing meets HL-LHC requirements efficiency and will be further improved in accuracy
- “Best practises” developed to mitigate current issues
- Constant cooperation with HP
- Further tests with new HP solutions should improve the results
- New workflow to be validated and implemented
- **Crucial step to secure installation serve growing number of demand**
- **HP SitePrint to be implemented in other CERN projects for marking**
- **With FCC (Future Circular Collider) reaching 100km – manual tracing is not an option anymore**





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