

24-26 September 2024 Loughborough, UK

# A photogrammetric approach for automated measurements of large accelerators



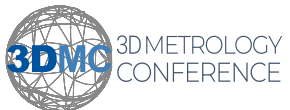
P. Bestmann CERN BE-GM/ASG

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# Outline



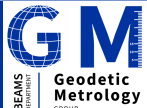
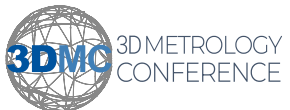
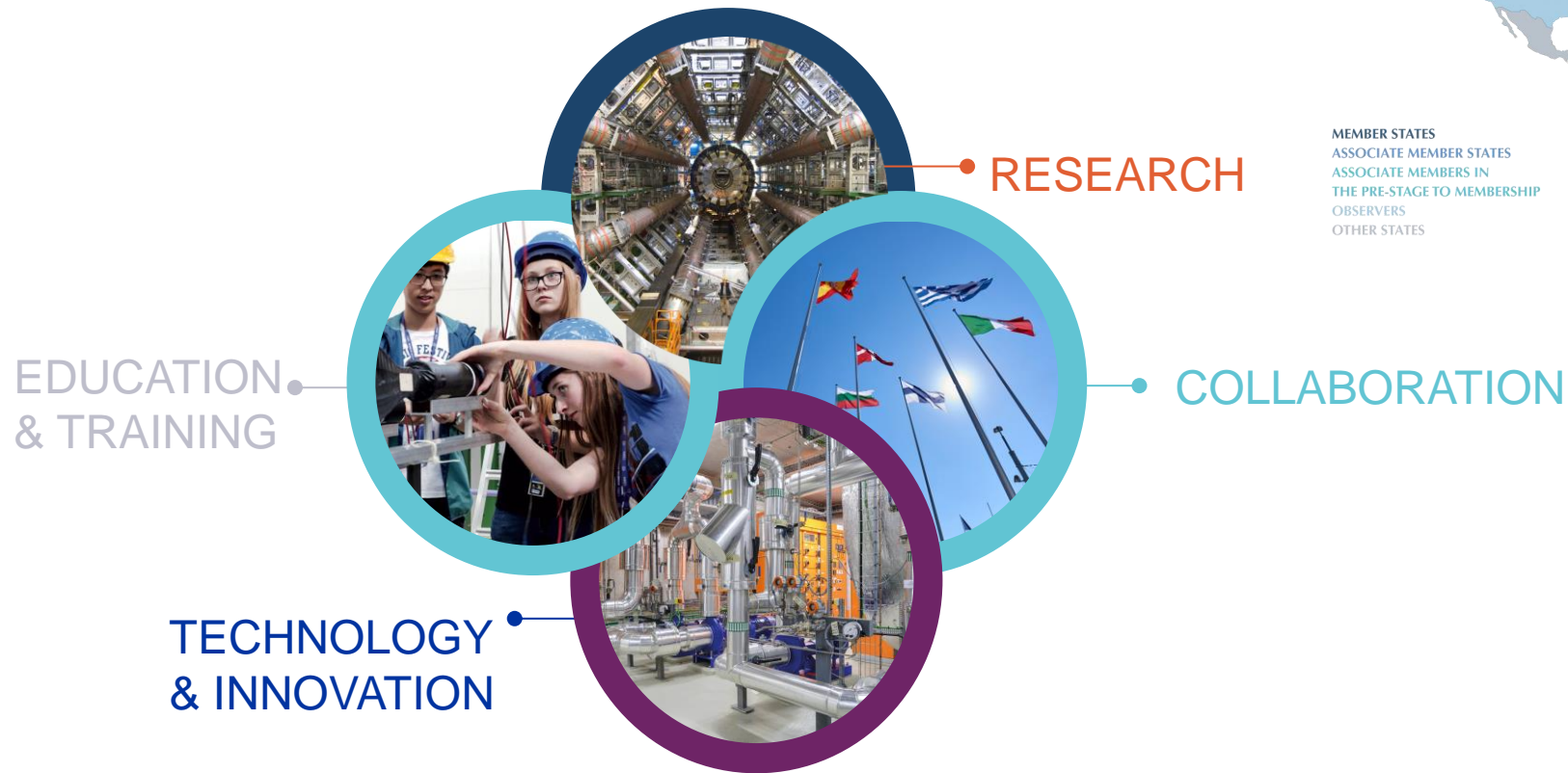
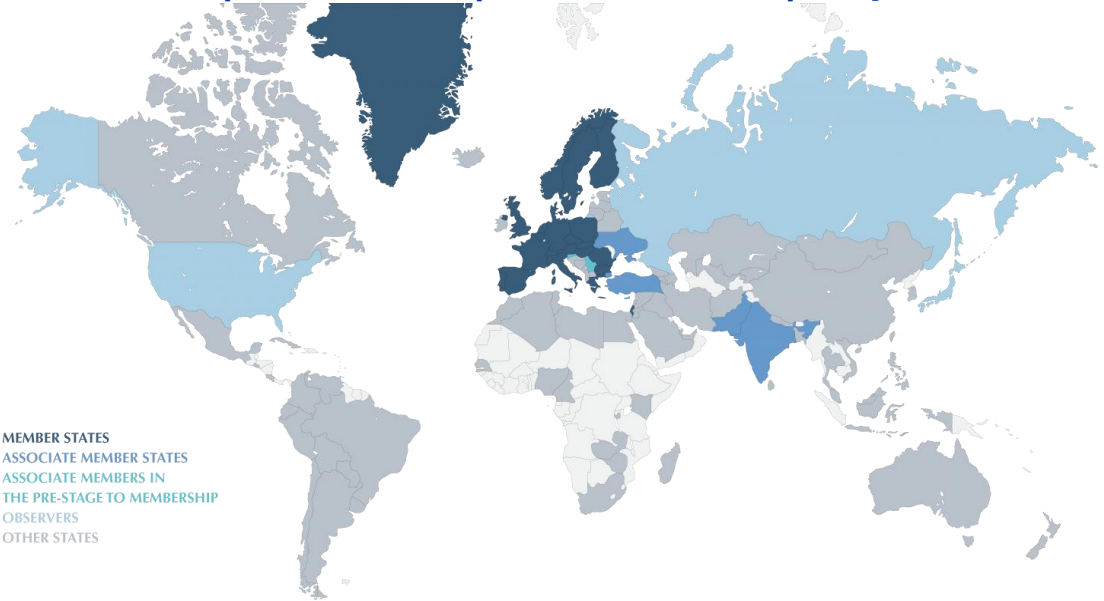
- **Introduction**
  - CERN in general
  - BE-GM Group and the accelerator complex
- **Accelerator alignment & future projects**
  - How accelerators are aligned, today & tomorrow
  - Future projects and upcoming constraints
- **Measurement automation**
  - What are the new requirements
  - Wire offset by Photogrammetry
  - Development projects



# CERN

Founded in 1954 as Conseil Européen pour la Recherche Nucléaire

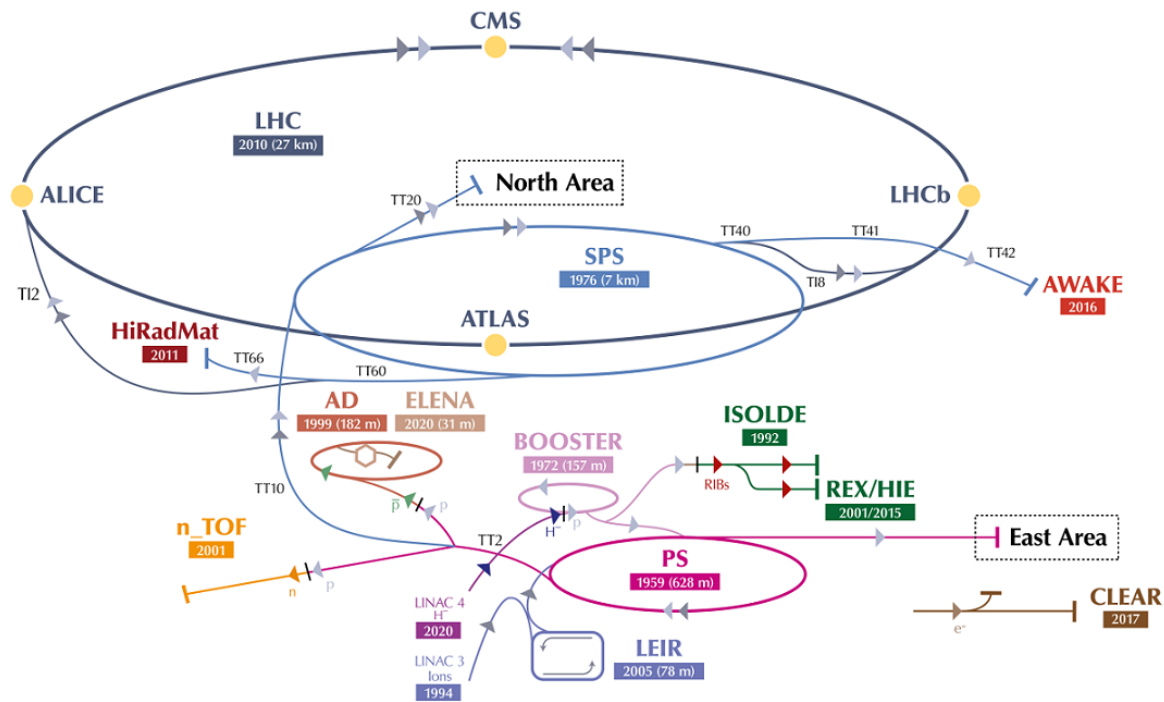
Research | Innovation | Collaboration | Inspiration



# CERN

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

- We are doing fundamental 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.





# BE-GM Group

**GM**  
Geodetic Metrology  
GL: H. Mainaud Durand  
DGL: J-C. Gayde

**ASG**  
Accelerator Survey &  
Geodetic measurements  
SL: J-F. Fuchs

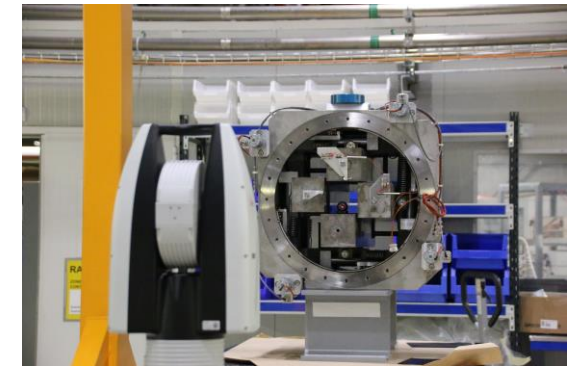
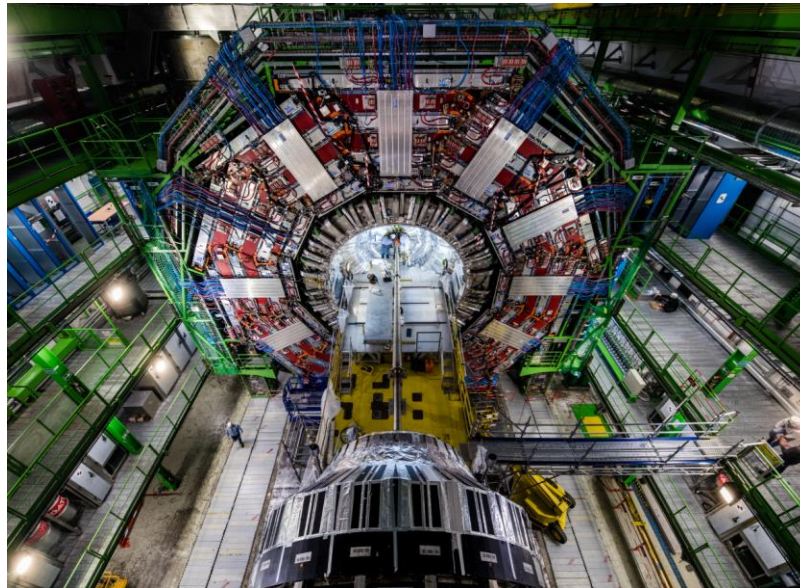
**ESA**  
Experimental Survey &  
Alignment  
SL: J-C. Gayde

**HPA**  
High Precision  
Alignment Technol.  
SL: M. Sosin

**APC**  
Acquisition Processing  
& Data Control Software  
SL: F. Klumb

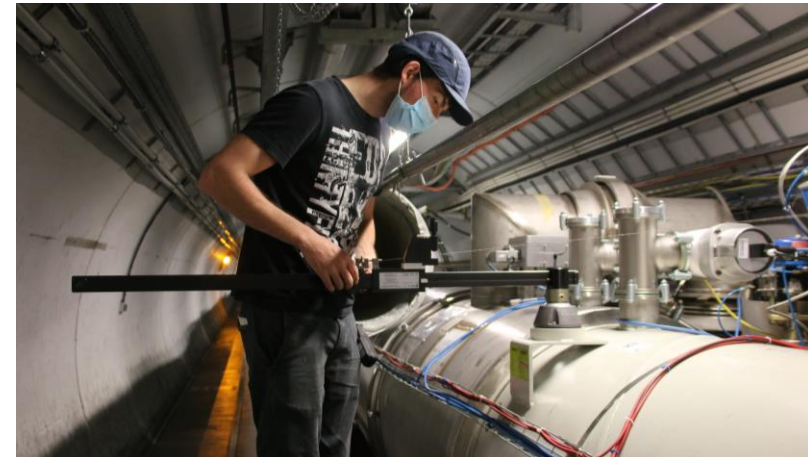
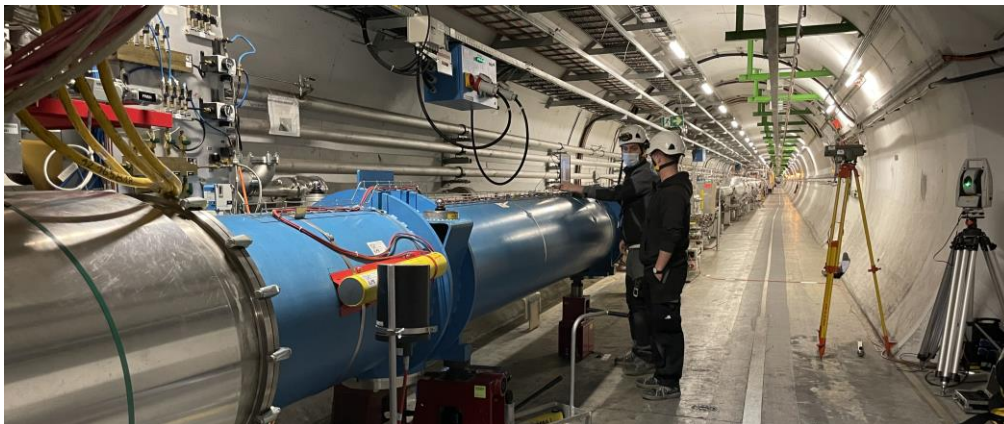
We provide metrology and alignment for components installed in the accelerators, their beam transfer lines and physics experiments throughout the CERN.

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



# Accelerator alignment

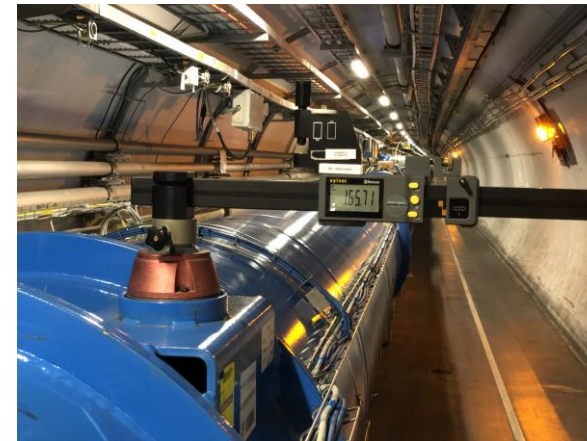
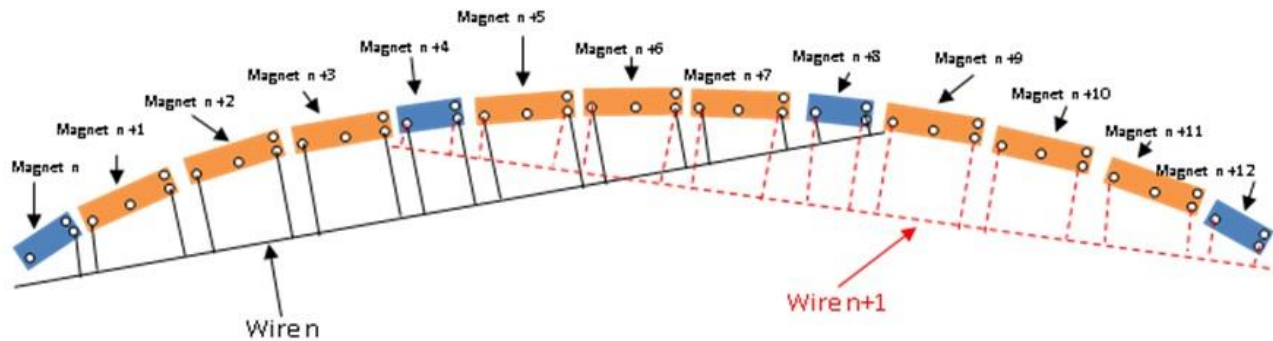
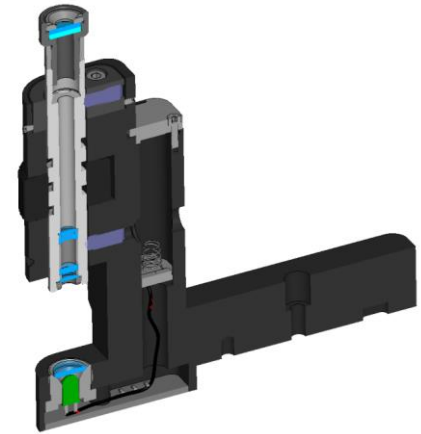
- **Basis is the underground geodetic Network**
  - GNSS, TotalStations, Levels, Gyro-Theodolites, Laser Tracker.....
- **Once the machine is installed and initially aligned, “only” a smoothing is performed**
  - The absolute position and overall form is not longer important
  - Long range deviations are acceptable, short wavelengths and singularities are critical
  - Laser Tracker, Levels, wire offset measurements





# Wire offset measurements

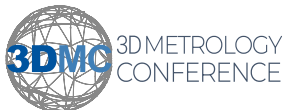
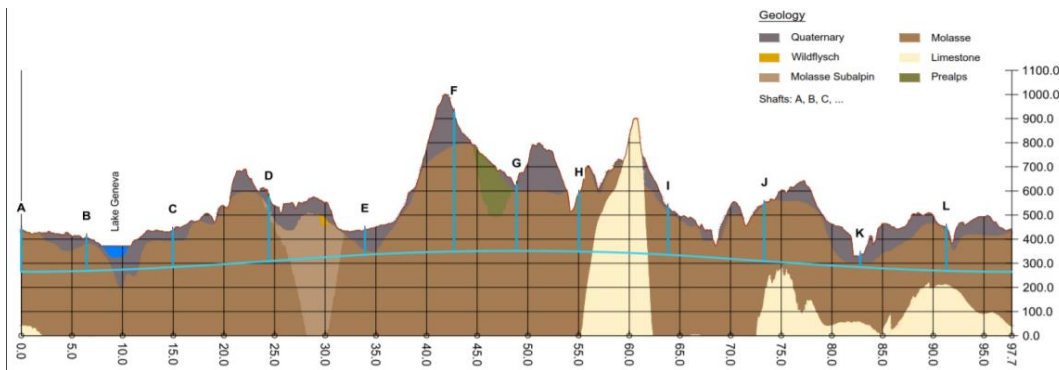
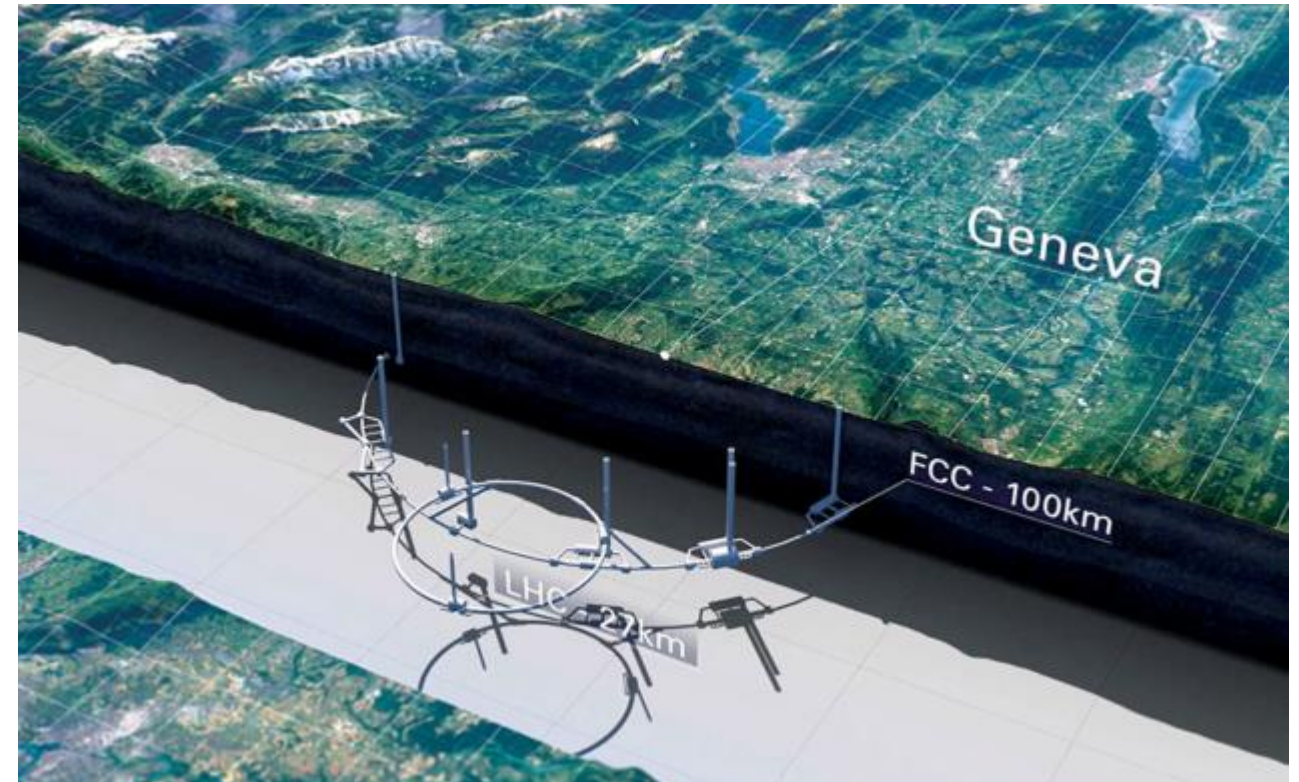
- **Wire offset measurements are still the standard in large accelerators**
  - It stabilizes the whole radial geometry over long distances (140m wire)
  - No superior replacement has been found so far (40 $\mu$ m / wire)
  - Quite time consuming and delicate measurements (8 wires per day / team)



# New projects



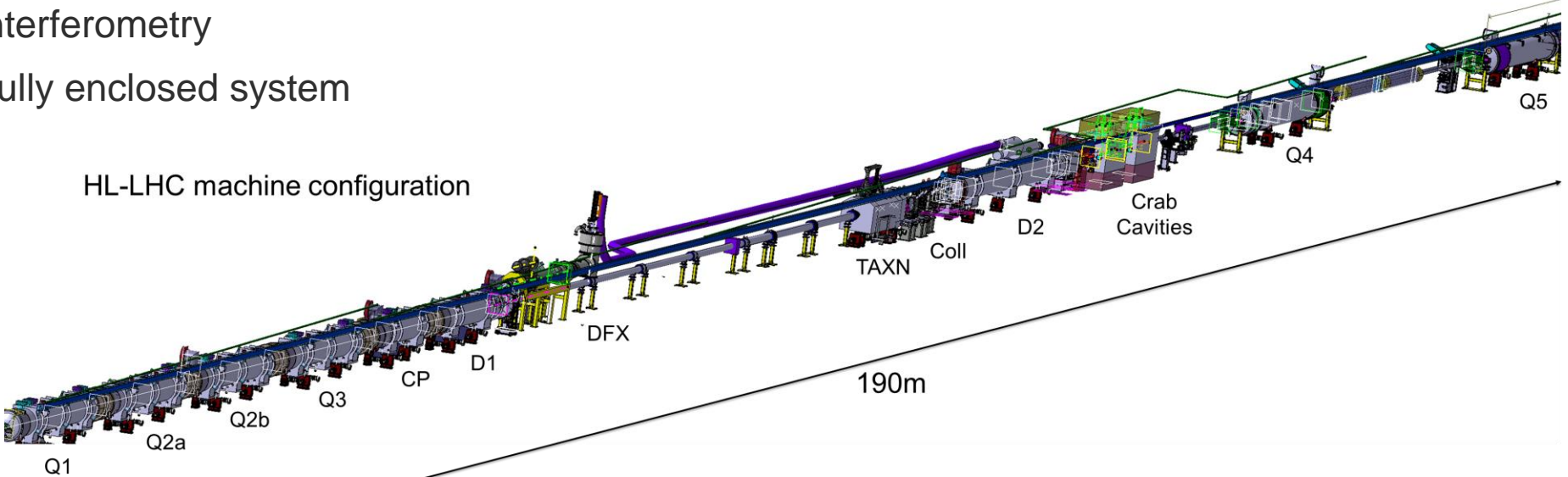
- **The Future Circular Collider FCC**
  - Almost 100km ring
  - No time for conventional measurements
- **Full alignment concept to develop**
  - Geodesy
  - Surface & underground network
  - Measurement & alignment concept



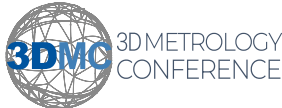


# HL-LHC Project

- **The HL-LHC Project is a major machine upgrade to increase the luminosity**
  - 1.2 km of machine will be replaced with new upgraded equipment
  - A Full Remote Alignment System will be deployed in those areas
    - Allowing real time remote measurements and alignments in these zones
    - Based on capacitive Wire Position Sensors, Hydrostatic Levelling Systems, Frequency Scanning Interferometry
    - Fully enclosed system

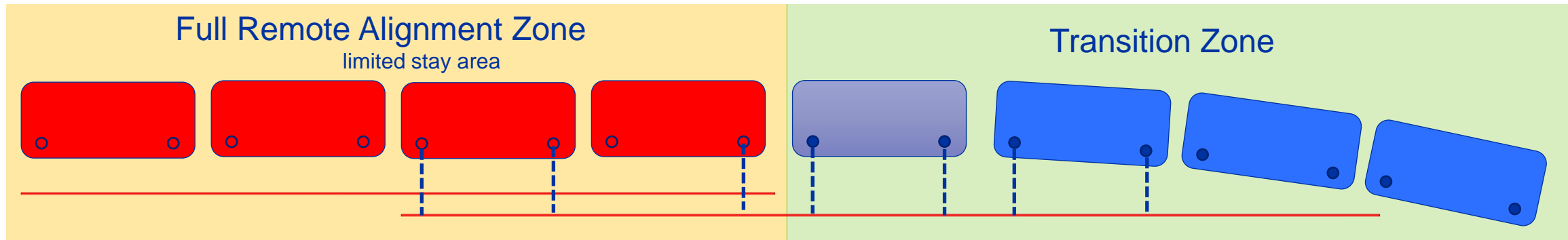
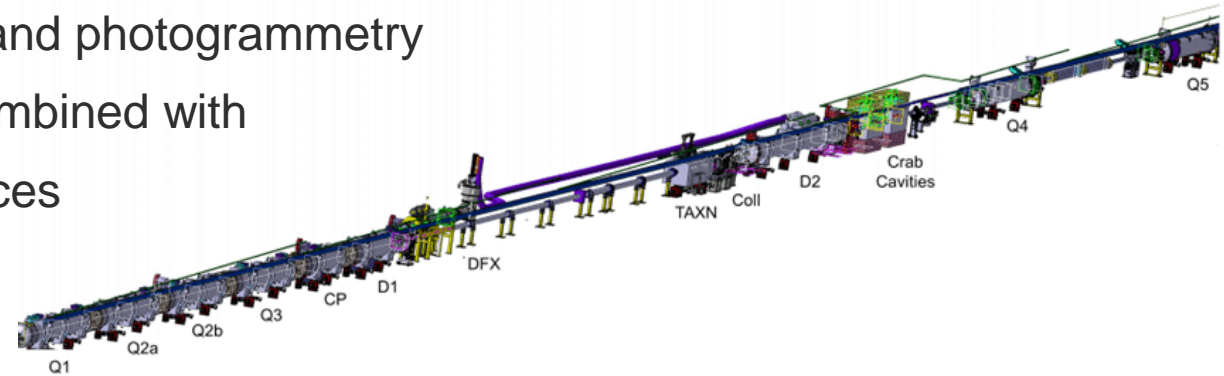


How do we connect this to the rest of the machine?



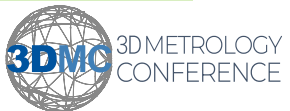
# Survey Train Development

- **Extending the Full Remote Alignment Zone**
  - Radial offset measurements only
  - Using a combination of stretched wire reference and photogrammetry
  - Highly precise and non-contact measurement combined with
  - Excellent straightness reference over long distances



Permanent monitoring wire

Train extension wire







# Train concept

- **Gravity link**
  - Four inclination sensors in pairs on the frame
  - Calibration against known target field (gravity)
  - Calibration against plumb lines
    - Very interesting topic



# Train concept

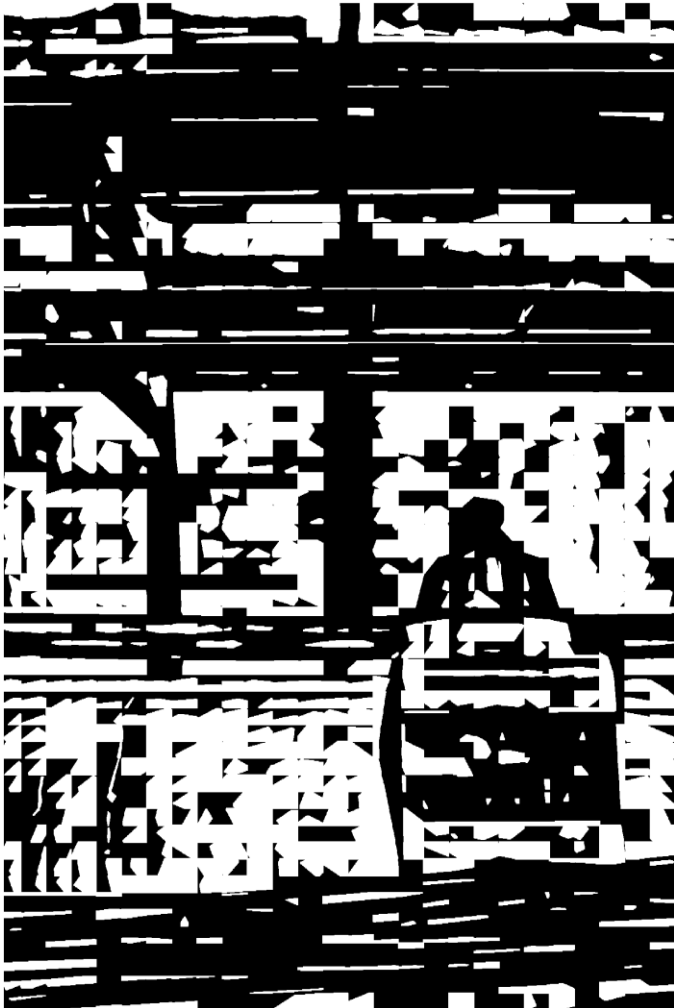
- **Process automation**
  - The most challenging part
    - Variable background and light conditions
    - The detection of the real wire is the key point
  - Need to determine **THE** wire inside the images
    - Reliable and failsafe
    - Certain parameters are known
    - Many iterations for the processing methods



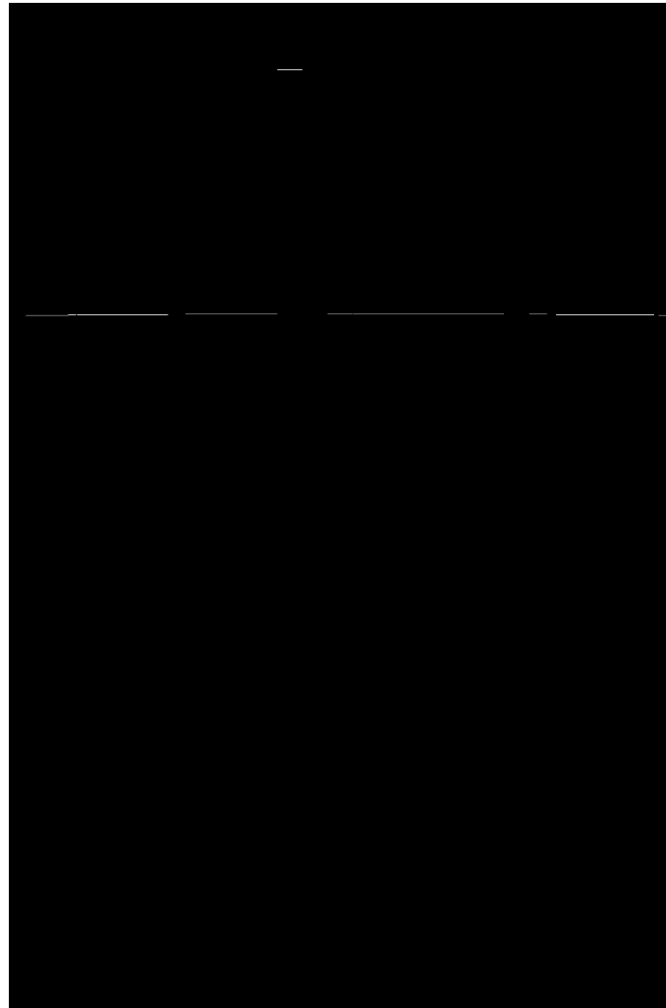
Original Image

# Processing

Patched Otsu



Identified wire



Final Detected Wire & Target





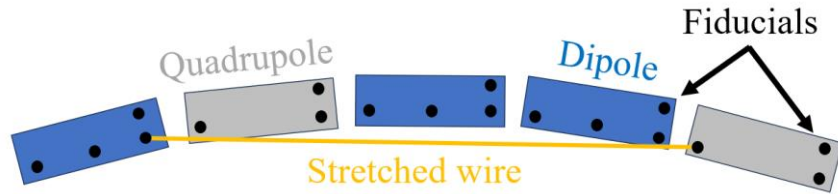
# Train concept

- **Keeping the wire as straightness reference**
  - Full photogrammetric wire measurement
    - Direct wire and target detection
    - Calculation of offset
    - Decomposing in vertical and horizontal direction
- **Validation of measurement equipment and processing**
  - Against full featured FRAS monitoring setup
- **Train platform and robotics part will follow at a second stage**
  - Based on the Monorail Inspection Train already used for the previous train



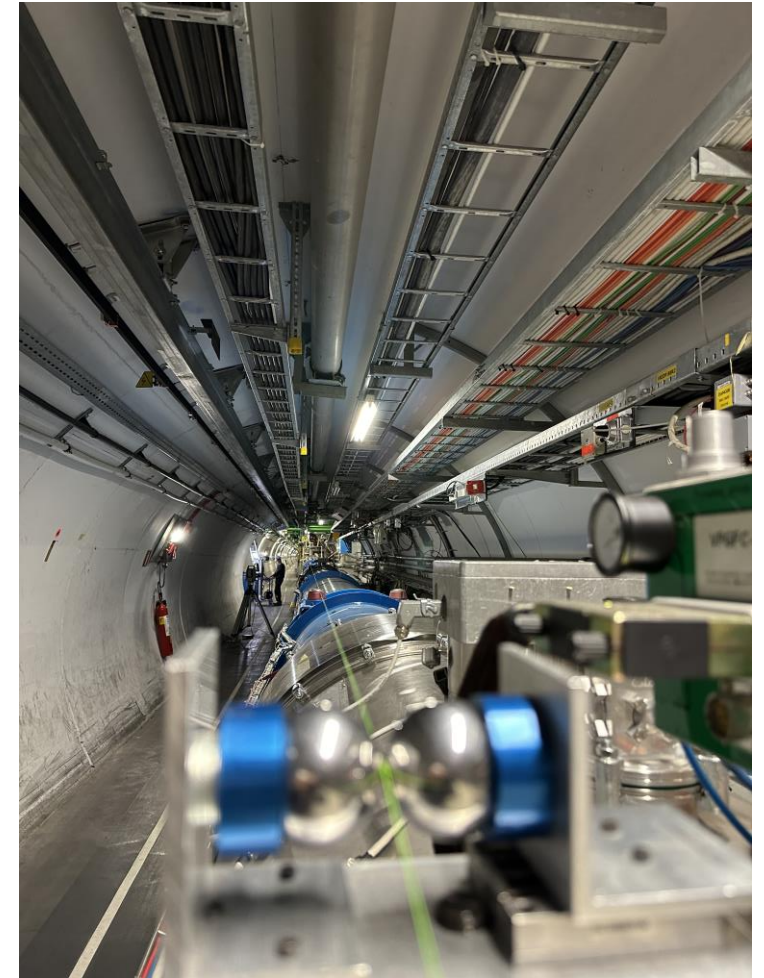
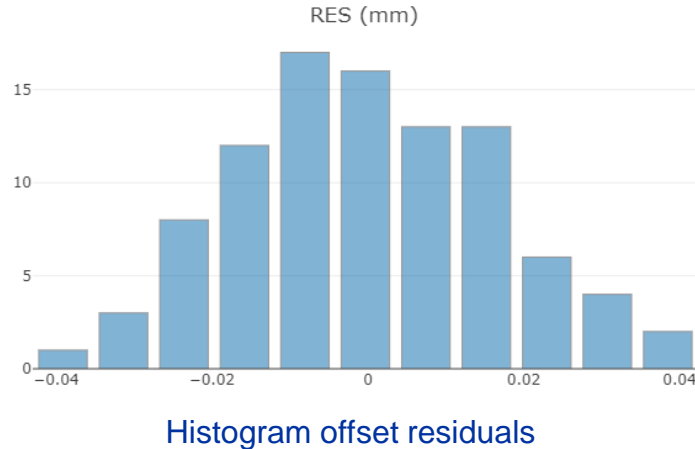
# First Results

Tested on a short section in the LHC



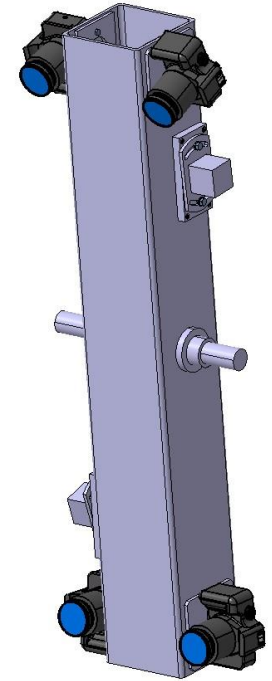
Standard deviation of 20 $\mu$ m reached already with prototype

Comparison to Laser Tracker is showing 40 $\mu$ m offset



# Next steps

- **Switching to carbon fiber frame**
- **Finalising software process**
- **Qualification test on monitoring setup**
- **Further developments for the LHC arc geometry**
  - Offset variations of 80cm
  - Inclination sensor update

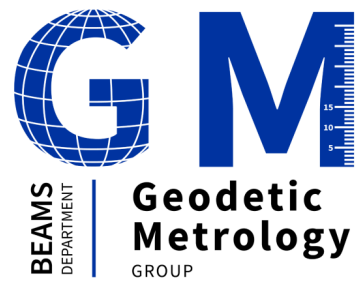


Carbon fiber camera Frame



# Further informations

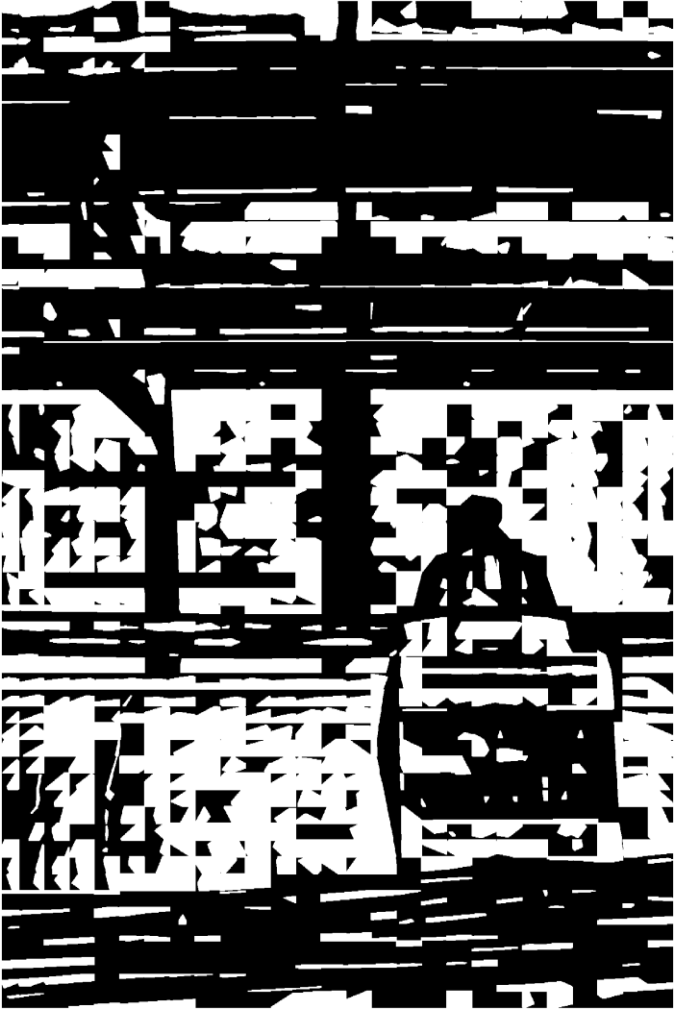
- **Two more detailed papers on the subject in preparation for IWAA 2024**
  - [A next generation survey train for future accelerators](#)
  - [Direct Wire Offset Measurements by Photogrammetry Including Gravity Link](#)
- **Previous studies and publications**
  - [Stretched wire photogrammetry \(IWAA 2016 ESRF\)](#)
  - [The LHC Collimator survey train \(IWAA 2010 DESY\)](#)



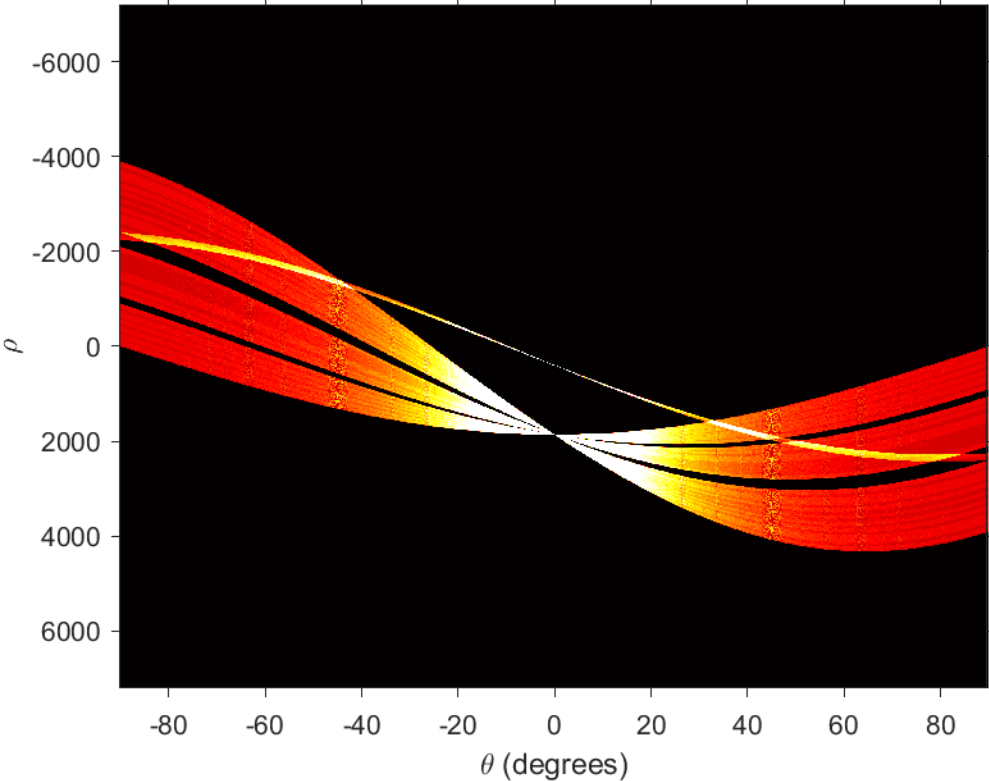
[home.cern](http://home.cern)

# Processing

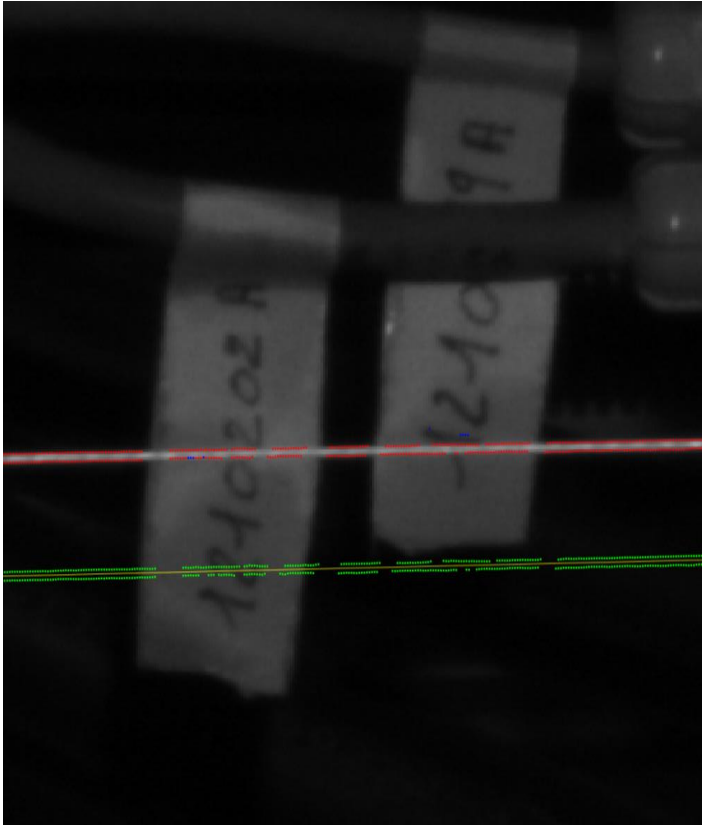
Patch Threshold



Hough Transform



Edge detection



# Collimator Survey Train from 2010





# Extending permanent wire

- The permanent system is monitoring precisely the position of the magnets between the Q1 and Q6
- The wire is not visible and not measurable directly, the WPS sensors act as magnet references
  - They are known in the magnet coordinate system
  - And we can measure them by photogrammetry
  - Novel laser engraved targets directly on the sensors

